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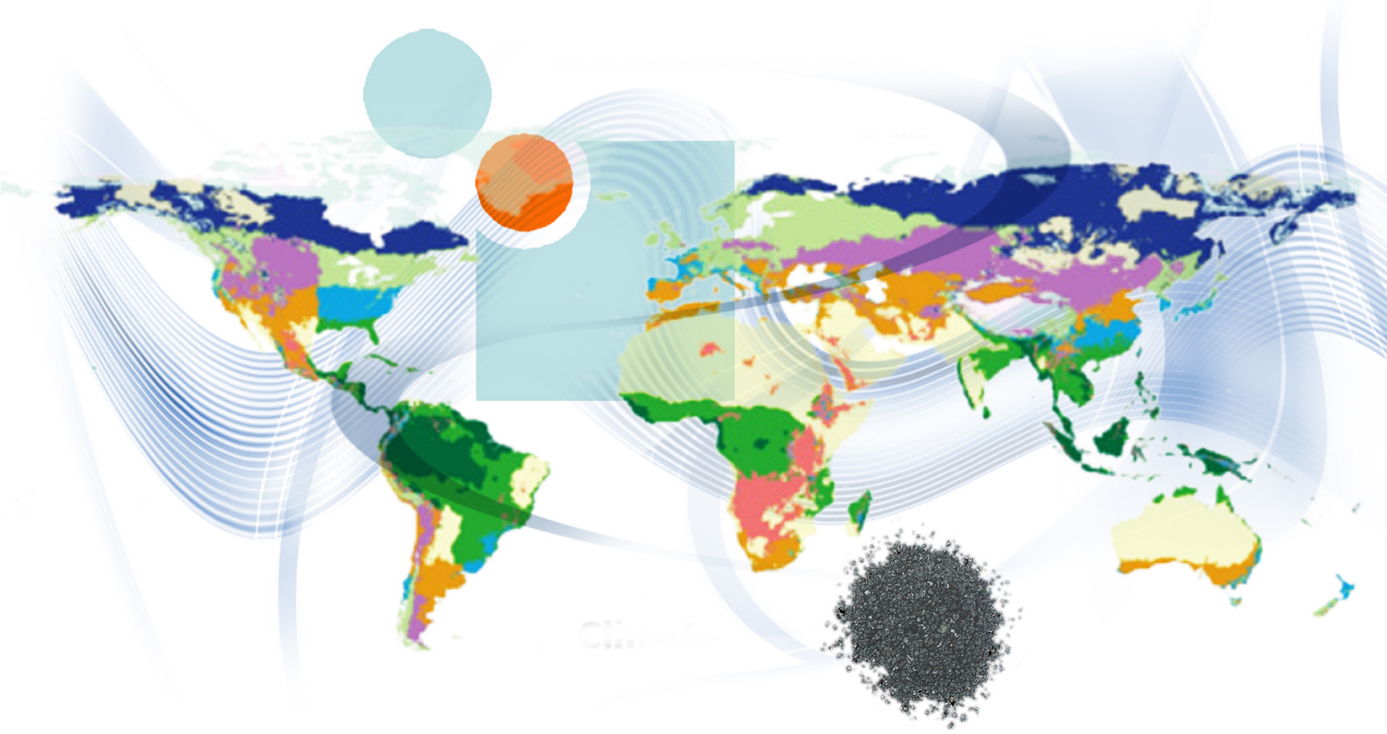
Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme

Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Florence Carré, Roland Hiederer, Viorel Blujdea, Renate Koeble

Sept. 2010



EUROPEAN COMMISSION

Institute for Environment and Sustainability

EUR 24573 EN

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PUBSY: JRC61098

EUR 24573 EN
ISBN 978-92-79-17455-1
ISSN 1018-5593
doi 10.2788/34463

Luxembourg: Publications Office of the European Union

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Printed in Italy

This document may be cited as follows:

F. Carré., R. Hiederer, R., Blujdea, V. and Koeble, R. (2010) Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. EUR 24573 EN. Luxembourg: Office for Official Publications of the European Communities. 109pp.

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Document prepared as part of

Administrative Arrangement

No.: TREN/D1/464-2009-SI2.539303

for providing

Technical assistance in evaluation of GHG emissions for biomass and biofuel pathways in the EU and 3rd countries and preparation of carbon stock guidelines

EXECUTIVE SUMMARY

The Directive on Renewable Energy (Directive 2009/28/EC, RED) sets ambitious targets for all Member States. Under the RED the EU should reach by 2020 a 20% share of energy from renewable sources and a 10% share of renewable energy specifically in the transport sector. Renewable energy from biofuels, including those imported into the EU, should come from sustainable sources and deliver high greenhouse gas (GHG) savings, at least 35% when compared to fossil fuels. In growing biofuels land use changes can lead to changes in carbon stocks in soils and biomass and subsequent changes in GHG emissions, which forms an important factor in the sustainability assessment. To encourage industry, governments and NGOs to set up voluntary certification schemes for all types of biofuels a new scheme was adopted by the European Commission as Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C(2010) 3751).

This *Guide for Calculation of Carbon Stock Changes in Soil and Above and Below Ground Vegetation due to Land Use Conversion* was prepared in support of the Decision. It covers the all data sources and processing steps performed to establish the rules for the calculation of land carbon stock changes due to land conversion for biofuel production. The standard methodology and the carbon stock coefficients together with the data layers will enable economic operators to determine what changes in land carbon stocks might arise from the conversion of land for biofuels production. This report has substantially contributed to the new EU system established to ensure that European biofuels and bioliquids come from sustainable sources and meet the highest environmental standards.

The methodology put forward for estimating changes in GHG emissions in soil and biomass resulting from land use changes is based on the Tier 1 approach as developed under the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. It is based on the definition of default values of carbon stocks for a set of soil, land cover and climate conditions. The default carbon stocks are modified according to changes in land use, management practices and inputs, which form a management system.

For soils the method distinguishes between mineral from organic soils. For mineral soils default values for carbon stocks are specified and coefficients of divergence from the default values are defined according to land use and land cover. For organic soils using a method based on emissions instead of stock changes is put forward. Default values for biomass carbon stocks are separated into those for above-ground vegetation and for below-ground vegetation.

To be used as a method for estimating GHG emissions from biofuel production the IPCC Tier 1 approach had to be adopted to the specifications of the scheme and modified in a number of key areas. One of the main changes is the use of spatial data layers to represent the parameters defining the default values and the changes in carbon stocks. This change required the creation of a harmonized database of all parameters and the definition of an analytical framework to evaluate the feasibility of the methodology.

Generating the reference layers form basic data and to common spatial characteristics improves consistency for data integration and greatly reduces problems of data variation. For estimating stocks in soil organic carbon according to the default values new spatial data defining the climatic regions and the distribution of soil types had to be produced. The soil layer was generated from the most recent global data (Harmonized World Soil Database, March, 2009). The map of climatic regions is presented in the IPCC guidelines, but could not be obtained. For consistency with other climate data and the distribution of climatic regions a specific climate layer was generated from historic global weather data (WorldClim). This task also included computations of potential evapo-transpiration using two different methods. A land cover layer according to the RED classes was generated by adapting and merging several land cover maps (GlobCover and McGill University M3 Cropland).

As an important departure from the IPCC approach the Guide provides directly carbon stock values for climate and land use types. The values were defined following a review of the literature to provide values for all combinations. Since savannahs (and wooded savannahs) are not characterized in the IPCC guidelines they were treated as grasslands in the tropical moist IPCC climate region. Degraded lands are also not targeted in the IPCC guidelines except for grasslands (moderately and severely degraded). Thus, the same reduction percentages (or increase percentages) were applied on the management coefficients per climate zone for forests and croplands. A particular problem is presented by organic soils when estimating changes in GHG emissions as compared to mineral soils. For organic soils, such as peatlands, the method based on a default value of carbon stocks to estimate changes in soil carbon is not applicable. Organic soils cannot be assessed in terms of carbon stock changes because changes occur on the overall peat soil profile (not only on the first 30 cm). Drainage of organic soils have direct consequences not only on the amount of CO_2 emissions but also on emissions of CH_4 and N_2O. Tables of coefficients of conversions are then proposed according to climate zone and continental boundaries for soil carbon stock changes and for above and below ground carbon stock changes in biomass in a Technical Annex.

This Guide should support economic operators to calculate the impact of land conversion on GHG emissions by using use actual values for the carbon stocks associated with the reference land use and the land use after conversion. While they should be able to use standard values for standard conditions, the Guide does not provide values for improbable combinations of climate and soil type, nor for the conversion of organic soils from undrained peatland, which is not allowed according to Directive 2009/28/EC for the purposes of sustainable biofuels and bioliquids production.

NOTE:

This report has been prepared to serve as a scientific basis for the Commission's Decision on guidelines for the calculation of carbon stocks for the purpose of Annex V of Directive 2009/28/EC.

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List of Acronyms

ACRONYM	TEXT
AI	Aridity Index
C	Carbon
DM	Dry matter
EEA	European Environment Agency
ESA	European Space Agency
ETRS89	European Terrestrial Reference System 1989
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographic Information System
GISCO	Geographic Information System for the Commission (Eurostat)
GRID	Global Resource Information Database
HAC	High-activity soils (IPCC)
HWSD	Harmonized World Soil Database
IFA	International Fertilizer Association
IGBP	International Geosphere-Biosphere Programme
IIASA	International Institute for Applied Systems Analyses
IPCC	Intergovernmental Panel on Climate Change
ISRIC	International Soil Reference and Information Centre
ISS-CAS	Institute of Soil Science, Chinese Academy of Sciences
JRC	European Commission Joint Research Centre
LAC	Low-activity soils (IPCC)
LADA	FAO Land Degradation Assessment in Drylands
LCCS	FAO Land Cover Classification System
LUC	Land use and cover
LULUCF	Land Use, Land Use Change and Forestry
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized-Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Center
PET	Potential evapo-transpiration
SOC	Soil organic carbon
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WRB	World Reference Base

1 INTRODUCTION

The implementation of certain provisions of the Directive 2009/28/EC on the Promotion of the use of energy from renewable sources (hereafter referred to as the *Directive*) involves the conversion of lands for biofuel production in Europe and in other countries. Changes in land use frequently result in changes in vegetation which greatly impact on above- and below-ground carbon stocks (Guo & Gifford, 2002). The objective of this report is to establish a guide for the calculation of changes in land carbon stock as a consequence of a conversion of land cover or management practices and in view of growing biofuel.

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 4* (IPCC, 2006) provide a methodological framework on how to calculate land carbon stocks for different types of land use conversions. This framework is considered as a reference at the global level and forms the basis for this Guide.

This Guide covers the specific conditions stipulated by the *Directive* which are as follows:

- Areas excluded from conversion are wetlands, forests above 30% canopy cover and undrained peatland. These areas are defined in terms of delineating features, i.e. where to draw the line between a land use for which conversion is forbidden and one for which conversion is reported in the methodology.
- Areas potentially available for the conversion of non-cropland to cropland concern the following categories:
    - Grassland (including degraded pasture)
    - Forest (less than 30% canopy cover)
    - Savannah/Wooded savannah
    - Degraded land

  "Cropland" in this context includes any system for producing biofuels, which may also be forest plantations or perennial crops.
- Land carbon stock changes are stratified according to land use conversion, different types of soil (especially organic and mineral soils) and climatic zones across the world. Soil C-stock changes are expressed insofar as possible as the total changes in C stock, or the closest possible approximation, in particular for drained peatland.
- The Guide specifies coefficients for changes in carbon between land uses which can be applied by economic operators to determine the GHG impact of land conversion per major soil type and climatic zone.

- For soil carbon stock calculation, links are nade to national and regional data on land C stock (particularly in soils) in the EU and in third countries.
- Where possible, the Guide draws on the *2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 4*. Additional scientific sources are used to complement the information provided therein.

After presenting the technical requirements for assessing land C-stock changes resulting from land use conversion, the Guide describes the common methodology to be used for this specific purpose where soil and above- and below-ground vegetation are differentiated. The methodology is then followed by a description of existing tools and datasets.

2 TECHNICAL CONSIDERATIONS FOR CALCULATING LAND CARBON STOCK CHANGES

The calculation of land carbon stock changes requires data inputs which should be available as spatial layers in order to cover all natural combinations. In the following section the factors determining land carbon stock are discussed.

2.1 Factors Determining Land Carbon Stock

As explained in IPCC (2006), land carbon stock depends on climate, soil type, land cover (vegetation type) and land management (mineral fertilizers and manures). In order to assess the actual situation of land carbon stock, these four defining factors need to be considered in combination. To cover the numerous combinations possible, a Geographical Information System (GIS) was used to generate and analyse data to suitably represent the factors in the spatial domain. The results of applying various scenarios of land use conversions give an overview of local land carbon stocks and are directly available in form of maps.

Tables for calculating land carbon stock changes according to modelled changes in land use and land management are available from IPCC (2006) and IPCC (2003). The parameters used in the tables are not fully compatible with the stipulations of the *Directive* and had to be amended. In particular for a spatial analysis, the layers representing the various defining factors had to be generated from basic data.

2.2 Spatial Representation of Factors Defining Land Carbon Stock under the IPCC and Directive 2009/28/EC

The first task to be performed in order to assess global land carbon stock changes due to land use conversion is to generate layers that represent the defining factors as spatial data layers. The preparation of one or more spatial data layer(s) for each factor is explained below. Problems of resolution and uncertainties are discussed in a second section.

2.2.1 Technical Specifications for Spatial Data Layers

The methodology used by the IPCC for estimating changes in land carbon stocks can be conveniently applied in a GIS by using raster layers and overlay functions. To simplify the procedure and to avoid incomplete results, all spatial layers should have the same extent and grid resolution. The technical specifications of the spatial data layers are given in Table 1.

Table 1: Technical Specifications of Spatial Data Layers

Feature	Value
Data type	16-bit integer or real
File type	Binary
No. of columns	4320
No. of rows	2160
Reference system	ETRS89
Reference units	Deg
Min. X-coordinate	-180.00
Max. X-coordinate	180.00
Min. Y-coordinate	-90.00
Max. Y-coordinate	90.00

As regards extent, full global coverage was considered necessary. The grid resolution was set to a regular size of 5 arc minutes (0.083333 deg). This grid spacing corresponds to approx. 10km at the equator. The grid size was chosen as a consequence of the spatial characteristics of the various spatial layers to be integrated and processing considerations. One of the most prominent factors for the analysis is soil data. Although global soil data are now distributed with a nominal resolution of 1km (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009), the spatial layer is derived from a scale 1:5mil. for large parts with mapping units spreading over larger areas a working resolution of 5 arc-minutes appeared to be justified. The data are arranged in geographic coordinates following the ETRS89 specifications (Annoni, *et al*., 2001).

To avoid arbitrary results in coastal areas, all spatial layers were adjusted to a standard land/sea mask. The mask was generated from the global GISCO (Geographic Information System of the European Commission) country coverage at a scale of 1:1mil. Coastal areas in the thematic data layers were revised using a distance function to allocate layer attributes to the common mask.

2.2.2 Climatic Zone Layer

The coefficients for changes in carbon stock of the *IPCC Guidelines for National Greenhouse Gas Inventories* distinguish between 12 climatic zones. The zones are defined by a set of rules based on

- annual mean daily temperature,
- total annual precipitation,
- total annual potential evapo-transpiration (PET) and
- elevation.

The rules defining the climatic zones are not compatible with the commonly used climate classification from Köppen-Geiger (Peel *et al*., 2007), largely due to the conditions set using PET. The rules defined by the IPCC are more suited to estimating SOC than one based on temperature and precipitation alone because it provides an indication of soil moisture conditions.

A graphical version of the IPCC classification scheme modified to better present the sequence of rules is given in Figure 1.

The classification presented as "*Figure 3A.5.1 Delineation of major climate zones, updated from the 1996 IPCC Guidelines*" (IPCC, 2006) could not be accessed in electronic form as a spatial layer so alternative sources of the data had to be used. The classification scheme applied by the IPCC resembles the delineation of life zones developed by Holdridge (1947). A dataset of the life zones was compiled by the International Institute for Applied Systems Analyses (IIASA) in Laxenburg, Austria (Leemans, 1990) and is available as, for example, the GNV5 dataset through the UNEP GRID (Global Resource Information Database) web-site[1] or the NOAA Global Ecosystem Database (Global Ecosystems Database Project, 2000)[2]. The version where the original classes were aggregated with Olson's ecosystem classes appears to be most similar to the IPCC classification. By visual comparison, the data from the Global Ecosystems Database Project and GNV5 data do not completely correspond in all details. A further inconvenience of using any of those datasets is the lower spatial resolution, generally 30 arc min.

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[1] http://www.grid.unep.ch/data/summary.php?dataid=GNV5&category=biosphere&dataurl=http://www.grid.unep.ch/data/download/gnv005.zip&browsen=http://www.grid.unep.ch/data/download/gnv005-1.gif#preview

[2] http://www.ngdc.noaa.gov/ecosys/cdroms/ged_iia/datasets/a06/lh.htm

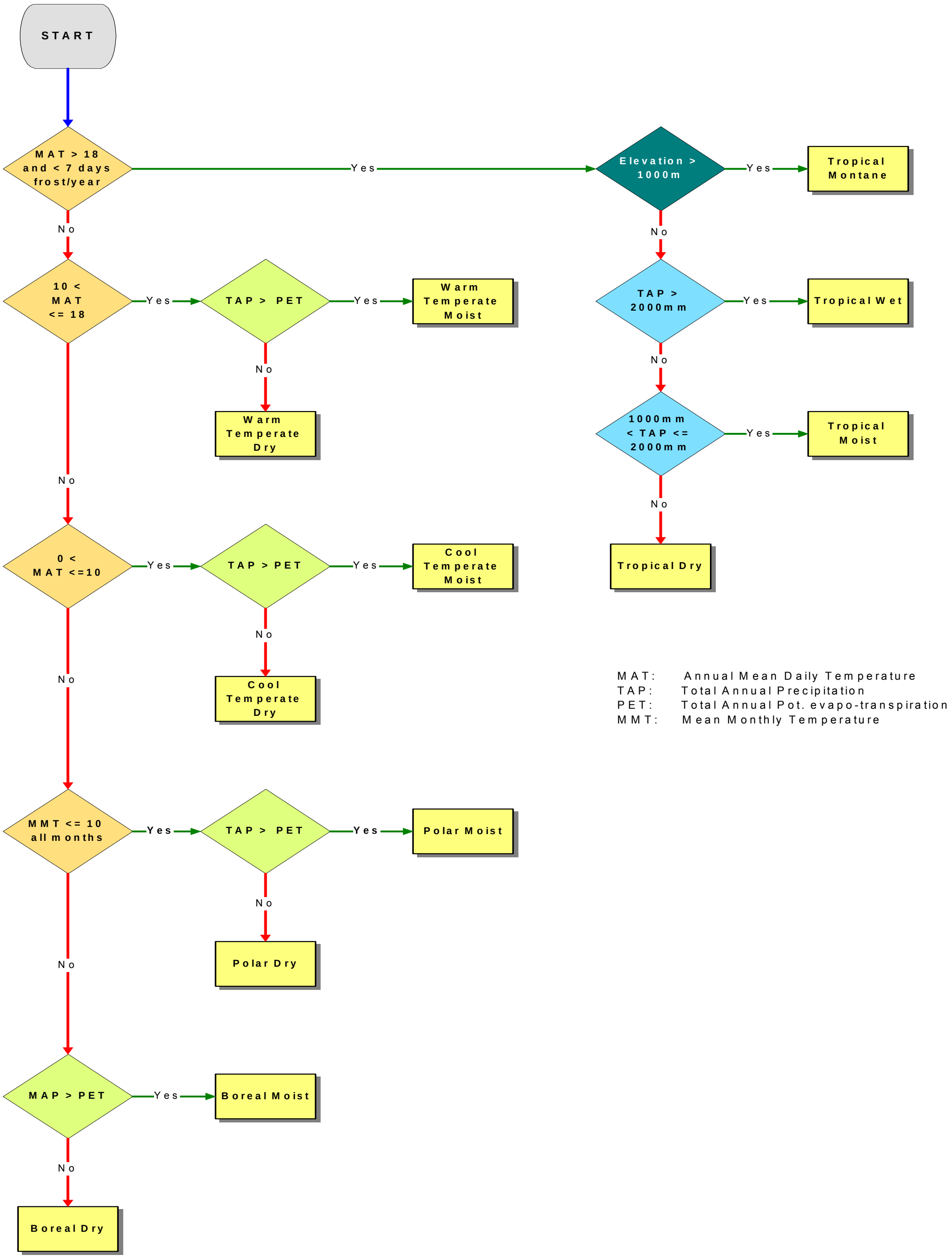

Figure 1: IPCC Classification Scheme for Default Climatic Regions (modified from IPCC, 2006)

One of the main disadvantages of using an existing dataset is the lack of access to the base data to which the classification scheme was applied. This will inevitably lead to inconsistencies when integrating the data in modelling tasks. The IPCC classification scheme was therefore applied to an independently developed set of base data layers. Climatic information on temperature and precipitation was provided by the 5 arc min. dataset Version 1.4[3] from the WorldClim project (Hijmans *et al.*, 2005). The data summarize climatic conditions for the period 1950 - 2000. In the absence of a monthly mean temperature, the parameter was computed from the minimum and maximum temperatures. The elevation data was taken from the same source for reasons of consistency with the climate parameters. PET was computed according to the temperature-based formula investigated by Oudin *et al.* (2005) and used by Kay and Davis (2008) as

$$PE_T = \frac{R_e(T_a + 5)}{\lambda \rho_w \times 100} \text{ m day}^{-1} \text{ for } T_a + 5 > 0$$

where

R_e extraterrestrial radiation (J m^{-2} s^{-1})
T_a mean daily air temperature (°C)
λ latent heat flux (MJ kg^{-1})
ρ_w density of water (kg m^{-3})

The computation of extraterrestrial radiation was based on Duffie & Beckman (1991) and Allen *et al*. (1994). The formulas were supplemented by the information provided by the “Solar Radiation Basis” webpage of the University of Oregon[4].

The IPCC classification scheme applied to the data was only modified to manage the first rule “<7 days of frost”. The rule could not be fully implemented because daily data were not available, only monthly averages. Therefore, the rule was adjusted to exclude any areas where the mean temperature was less than 0°C. The result of the re-calculation of the IPCC Climatic Regions compared to the map published in the IPCC 2006 report, Figure 3A.5.1, is presented in Figure 2.

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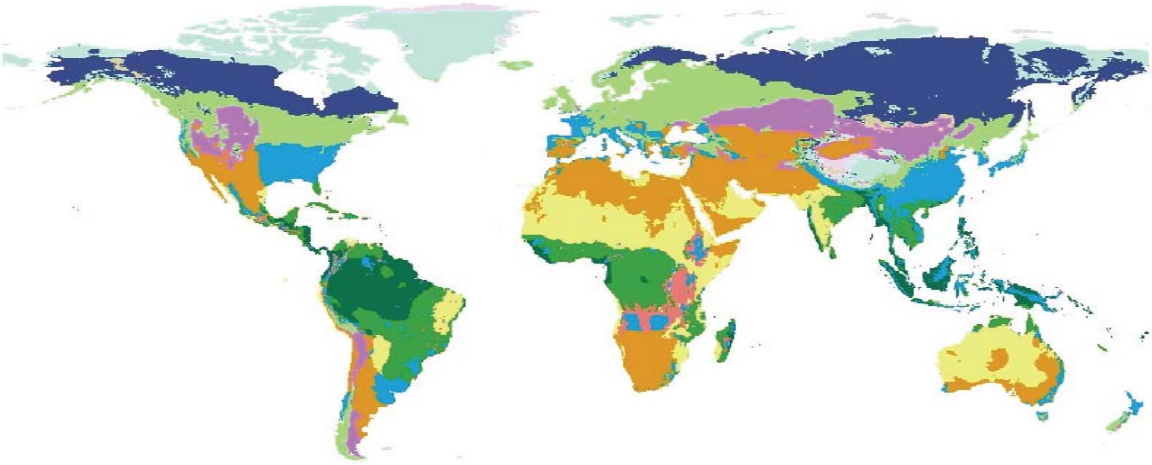
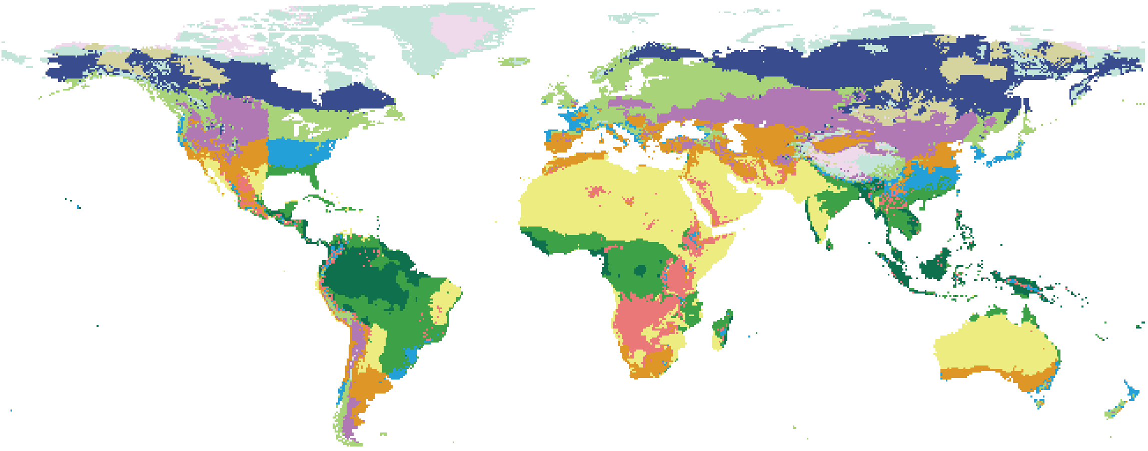
[3] http://www.worldclim.org/current

[4] http://solardat.uoregon.edu/SolarRadiationBasics.html



a) IPCC Default Climatic Regions, Figure 3A.5.1 (IPCC, 2006)



b) IPCC Default Climatic Regions, re-computed by the JRC

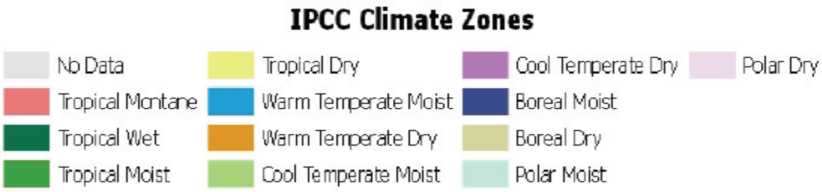


Figure 2: IPCC Default Climatic Zones from the IPCC Report and the JRC Re-calculation

The figure shows a general correspondence between the zones, in particular for the American continent. Differences occur mainly in the delineation of the "*Tropical Dry*" zone from the "*Warm Temperate Dry*" zone in the Sahara and the separation of the "*Boreal Moist*" from the "*Boreal Dry*" zone. The latter is almost non-existent in the IPCC map. However, the zone does appear in approximately the same areas in the aggregated Holdrige life zone data presented by the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC[5]) and the UNEP Division of Early Warning and Assessment / Global Resource Information Database (DEWA/GRID-Europe) website[6].

One reason for the difference in the boreal zone could be that the formula for PET is only applicable for conditions where $T_a + 5 > 0$ or where PE_T is set to 0. Under this constraint, and with the parameters set as given, PE_T does not become negative. It was found that this condition did not change the delineation except for central Greenland, where the "*Polar Dry*" zone could have been classified as "*Polar Moist*". The source of the discrepancy in the delineation of the boreal zones could not be established and the re-computed layer was used in further analyses.

2.2.3 Land Use / Cover Layer

Three sets of global land use / cover data were considered as sources from which the default land cover layer could be generated:

- The Global Land Cover 2000 product[7] (GLC2000) vs1.1 (Global Land Cover 2000 Database, 2003) with the nominal spatial resolution of 1km at the Equator.
- The GlobCover project[8] (Bicheron *et al.*, 2008), an initiative of the ESA and a result of the JRC/EEA/FAO/UNEP/GOFC-GOLD/IGBP partnership. The images used in the project were acquired from December 2004 to June 2006 and the spatial resolution is 300m.
- The M3-Cropland and M3-Pasture data[9] from McGill University (Ramankutty *et al.*, 2008) with a 5 arc min. resolution.

GlobCover Version 2.2 (released 10.12.2008) is the most recent product and the one with the highest spatial resolution (300m). Because of the dates on which its images were acquired it was used as the basis for generating the layers of land cover type. The legend used is the Level 1 classification scheme (applied to the global map product) for which the categories are largely compatible with the FAO Land Cover Classification System (LCCS, di Greggio & Jansen, 2000). However, the legend does not correspond to the legends of the *Directive*.

The land cover classes which could be converted to grow biofuels are:

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[5] http://daac.ornl.gov/NPP/html_docs/hold2_npp.html
[6] http://www.grid.unep.ch/data/download/gnv005-1.gif#preview
[7] http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php
[8] ftp://us-ext-nas.eo.esa.int/global
[9] http://www.geog.mcgill.ca/landuse/pub/Data/Agland2000/

- Grassland, including degraded pastures
- Forest with <30% canopy cover
- Savannah and wooded savannah
- Degraded land

The 22 categories of the GlobCover Level 1 legend had to be aligned to correspond to these land use and cover (LUC) types of potential biofuel areas. The legend contains a combination of distinct and mixed land cover types. For distinct classes, an assignment to one of the LUC classes of the *Directive* is possible without particular difficulty (except for ‘degraded land’ which is assessed using a different dataset). Assigning land cover types to the mixed classes is less obvious and to some degree problematic. The main obstruction in aligning the LUC types of the image data were the classes containing a mixture of LUC types for biofuel production. These mixed classes represent a typical mosaic of several distinct LUC types, which could not be separated in the images. Although a proportion of a single class within the mosaic is indicated, this proportion at times refers to a group of LUC types without further differentiation. The solution adopted was to proportionally repartition the LUC types of the mixed classes to the biofuel LUC types.

A particular problem is generated by the *Directive* threshold of using the criteria of 30% forest cover to distinguish between areas which could be converted to grow biofuels and forest, which cannot be converted to this purpose. The GlobCover legend and the LCCS use thresholds of 15% and 40% to classify forests in open or closed forestland. According to the LCCS conversion table for GlobCover[10], all classes with >15% forest cover are defined as forest. This does not lead to identifying a class of open forest with <30% cover. The extent of the convertible forest was therefore estimated by repartitioning the GlobCover forest classes. The process of repartitioning was supported by data from the Global Land Cover 2000 product (GLC2000) of the JRC. For that purpose, the GLC2000 global product Version 1.1 from 26.01.2004 with a nominal spatial resolution of 1km at the Equator was adjusted to the spatial properties of the biofuel layers by re-sampling the resolution first to 3 arc min. and then aggregating the data to 5 arc min. As with the GlobCover product, a single 5 arc min. thematic overlay containing the original legend categories was generated by sampling only the central pixels.

As a practical and conservative solution to the problem of identifying areas with <30% forest cover it was decided to allocate 60% of the open forest classes to forest with <30% cover and 40% to forest with >=30% cover. A category of shrubland not including herbaceous vegetation was included as the separate category “savannah and wooded savannah” in the LUC dataset. Wetland areas were also identified as a distinct category because they are treated separately when growing biofuel. The potential changes in organic carbon on wetlands following a transformation of land cover or use are treated by the IPCC using separate conversion factors, for example for changes in

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[10] ftp://uranus.esrin.esa.int/pub/globcover_v2/global/GLOBCOVER_Products_Description_Validation_Report_I2.1.pdf

soil organic carbon. These variations could only be considered by allowing a specific treatment of wetlands.

The proportions assigned to the GlobCover Level 1 legend to generate the LUC classes for the biofuel project are given in Table 2. It was possible to assign some classes of the GlobCover classification scheme completely to classes defined for this project, e.g. Class 11 (*Post-flooding or irrigated croplands*), Class 150 (*Sparse vegetation*). For GlobCover classes covering two or more biofuel classes the areas were distributed according to the defined weighting factors. A factor of 0.7 was used to estimate the area of open forest with a tree cover of 15-30% from a class with 15-40% tree cover. For the complex land cover patterns of the mosaics, a repartition to biofuel classes according to the proportions given in the GlobCover legend was applied. For example, Class 120 (*Mosaic grassland (50-70%) / forest or shrubland (20-50%)*) was assigned to grassland (60%) with the remainder split equally between forest (20%) and shrubland (20%).

To ensure compatibility with other applications, such as deposition, substituting the categories “Cropland” and “Grassland” with data from M3-Cropland and M3-Pasture datasets[11] produced by the Department of Geography, McGill University (Ramankutty *et al.*, 2008) was investigated. The data were taken from the land cover products of Boston University (Friedel *et al.*, 2002) and the GLC2000 dataset. The distribution of the cropland and pastures of 159 countries were adjusted to the national statistics as available from FAOSTAT[12].

The data largely correspond to the spatial characteristics of the biofuel dataset and were only adjusted to the land/sea overlay. However, the data relate to conditions of the year 2000 rather than to those of 2006. This difference in time was considered acceptable because no extensive changes in the occurrence of cropland or pastures over the period of 6 years were expected.

The global area under McGill M3-Cropland extracted from the spatial layer is 15.1 mil. km^2. The area extracted from the re-classified GlobCover data is 17.4 mil. km^2. The 15% difference is just outside the range given for the McGill M3 data for a 90% confidence level (17.1 mil. km^2). This difference could probably be accepted if one takes into consideration that users’ accuracy (percentage of land classified as a category that actually belongs to that category) for the 3 categories of croplands of the GlobCover data ranges from 60.9 to 84.4%[13]. However, the differences may be unevenly distributed and thus could lead to significantly conflicting identification of areas which could be converted to grow biofuel crops.

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[11] http://www.geog.mcgill.ca/landuse/pub/Data/Agland2000/

[12] http://faostat.fao.org

[13] This figure for accuracy is derived for the category containing a single LUC type. When taking categories with mixed LUC types into account to compute the overall accuracy for a single LUC category the figure has to be adjusted. For example, from Table 8 in the GlobCover report for the combined categories of croplands (Categories 10+11+14) the users’ accuracy is computed as 84.9% and the producers’ accuracy (percentage of land of a category classified as that category) as 44.2%. Category 10 (Cultivated and managed areas) does not occur in the spatial layer. It appears to have been included in Category 14 (Rainfed croplands).

Table 2: Weighting Factors for Converting GlobCover Level 1 Legend to Biofuel LUC Categories

Class	**Label**	**Forest <30%**	**Forest >30%**	**Cropland**	**Grassland**	**Shrub**	**Sparse**	**Wetlands**	**Settlements**	**Other Land**
11	Post-flooding, or irrigated croplands (or aquatic)			1.00						
14	Rainfed croplands			1.00						
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	0.10	0.10	0.60	0.10	0.10				
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	0.10	0.10	0.40	0.20	0.20				
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)		1.00							
50	Closed (>40%) broadleaved deciduous forest (>5m)		1.00							
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	0.70	0.30							
70	Closed (>40%) needleleaved evergreen forest (>5m)		1.00							
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	0.70	0.30							
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	0.30	0.70							
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	0.10	0.20		0.40	0.30				
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	0.10	0.10		0.60	0.20				
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)					1.00				
140	Closed to open (>15%) herbaceous vegetation (grassland, savannahs or lichens/mosses)				1.00					
150	Sparse (<15%) vegetation						1.00			
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water							1.00		
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water							1.00		
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water							1.00		
190	Artificial surfaces and associated areas (Urban areas >50%)								1.00	
200	Bare areas									1.00
210	*Water bodies*									1.00
220	Permanent snow and ice									1.00

The difference in the proportion attributed to croplands using the McGill M3 data and the corresponding category of the re-classified GlobCover data has been calculated for the spatial layers and is shown in Figure 3.

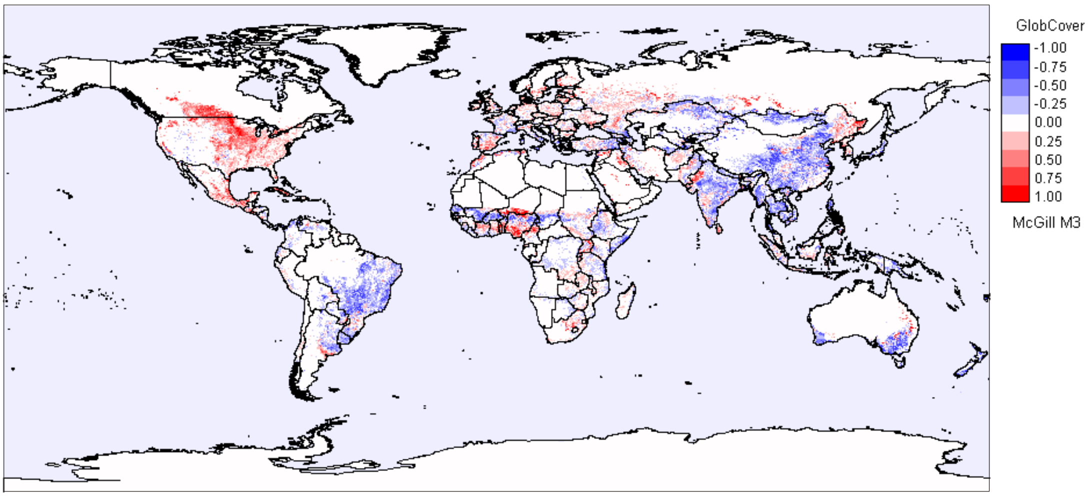

Figure 3: Difference in Proportion by Grid Cell for Croplands in M3 and Re-Classified GlobCover Data

Contrary to the differences in the occurrence of forest types between the re-classified GlobCover and GLC2000 datasets, the differences in the relative occurrence of croplands in a 5 arc min. grid cell between the McGill M3 and the GlobCover data show some distinct regional trends. The GlobCover data assigns larger portions of croplands mainly in eastern parts of South America, South-East Asia and southern Australia. The McGill M3 data shows more cropland in northern America and Europe. In Africa the differences are pronounced in sub-Sahelian regions, albeit more localized. The results are to some degree unexpected because the McGill M3 classification is based on the GlobCover data.

A similar evaluation was performed for the ‘pasture’ LUC type. The differences in the relative proportions assigned to the McGill M3 and the re-classified GlobCover data are presented in Figure 4.

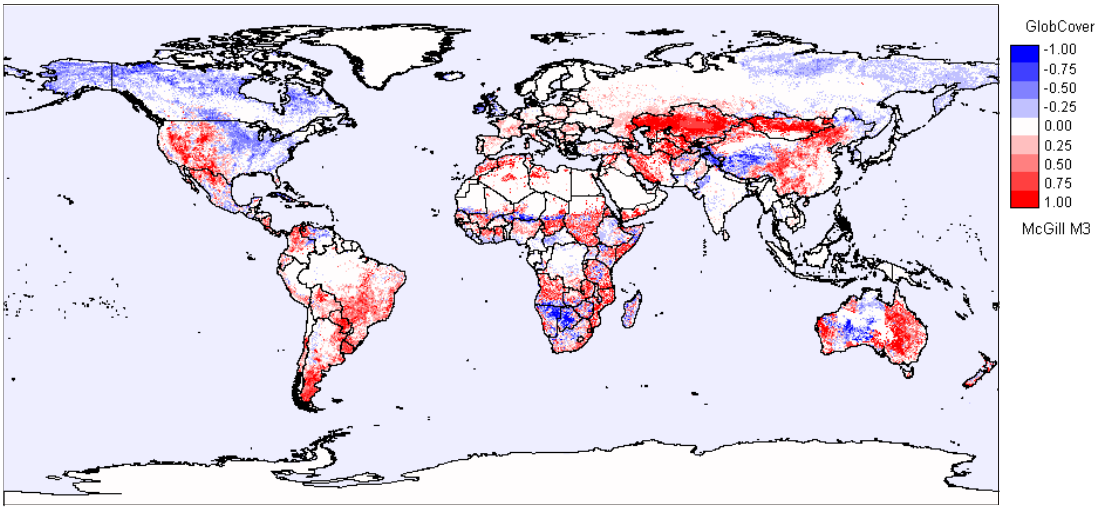

Figure 4: Difference in Proportion by Grid Cell for Pasture in M3 and Re-Classified GlobCover Data

The disparity in the allocation of pastures between the two datasets is even more pronounced than for cropland. To ensure that the disparity was not caused by the re-classification procedure of the GlobCover data, the category containing only herbaceous vegetation (Class 140) was also compared to the M3-Pasture layer. For these data the regional differences were as prevalent as for the re-classified data.

An inverse trend in the identification in the GlobCover data by region is notable when comparing the distribution of the differences for cropland to those for grassland. Grassland in North America is defined as cropland in the McGill M3 data while for South America the inverse is found. A similar trend can be seen for East Asia. Another condition leading to the differences is the uncertainty in the separation of pastures from shrubland. This confusion dominates the disparity in eastern parts of North America and Africa. The herbaceous vegetation in central Asia and Australia is generally classified as sparse vegetation in the GlobCover data. The characteristics separating one category from the other also fluctuate for this LUC type.

The difference in the distribution of croplands and the likely confusion of cropland with pastures or shrubland poses a problem to the identification of potential areas for growing biofuel. Extensive areas in North America and Europe are classified as grassland in the GlobCover data, but according to the McGill M3 data they are confused with croplands. Reverse conditions dominate in South America, East Asia and southern Australia, with a more mixed situation in Africa.

The evaluation of the distribution of LUC types in the GlobCover and GLC2000 data with the McGill M3 data suggested using the McGill M3 data for cropland and merging the layer with the GlobCover data for all other LUC types. The advantage of using the M3-Cropland data is that this maintains a level of compatibility with FAO statistical data on the distribution of crops at national level. The reliability of the spatial distribution of crops at sub-national level is less evident. When comparing the M3-

Cropland layer with GlobCover and GLC2000 data, the differences are largely due to different intensities of cropland rather than their presence.

A substantially different situation was found for the distribution of the M3-Pasture data. Variations to the GlobCover and GLC2000 data were marked by spatially divergent occurrences in the remote sensing data of pastures as compared to the classification of grassland. Areas covered up to 100% by pastures are indicated in desert areas (e.g. Sahara, Karoo) as well as in arid areas in North America and Australia. From the distribution of the data it appears that the delineation of pastures includes areas of sparse vegetation in the land cover data. This conjecture is supported by a map of the Aridity Index (AI) (UNEP, 1997) computed from the climatic data. The occurrence of pastures in hyper arid and arid areas is not supported by the climatic data. The option of re-classifying the M3-Pasture data to sparse vegetation where the AI indicates an arid climate (< 0.2) was not applied, as the layer would no longer correspond to the FAO statistical data and the result would have been insensitive to irrigated areas. Rather than over-interpreting the available data, the approach taken was to use the grassland derived from satellite data. With respect to identifying areas which could be converted to produce biofuels, the GlobCover data has the advantage over the GLC2000 data as it uses specific classes for open forests, albeit with an upper limit of 40% cover. Using a general ratio for separating GLC2000 forest classes into open and closed fractions has not yielded results comparable to those of the GlobCover data. The classes of the latter indicate that the proportion of open forest in the total forest area is spatially variable.

2.2.4 Degraded Lands

In the *Directive,* severely degraded lands refer to soil which are:

- highly saline, and/or
- low in organic matter content and severely eroded

The spatial identification of soils affected by secondary salinization (as a consequence of irrigation), and/or severe erosion is quite difficult, particularly at the global level. These soils can be identified locally using a long-term monitoring network.

For the calculation, the severe degradation of lands is not mentioned (only ‘degraded lands’ in general). In the context of this Guide, land degradation was considered as being a long-term decline in ecosystem function and productivity. This definition is based on the LADA Project[14]. It has been assessed by using long-term, remotely sensed normalized-difference vegetation index (NDVI) data and rain-use efficiency calculated from the 23-year *Global Inventory Modelling and Mapping Studies* (GIMMS) NDVI satellite data (Bai *et al*., 2008). This proxy is an indicator for assessing not only how and where soil degradation affects the net primary production of biomass, but also how and where climate change affects it. Biofuel production is also a matter of net primary production of biomass, which is why we consider this proxy to be appropriate. Figure 5

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[14] http://www.fao.org/nr/lada/index.php?/Overview.html

presents the map of location and intensity of land degradation (0.5 deg. map in the WGS84 coordinate system).

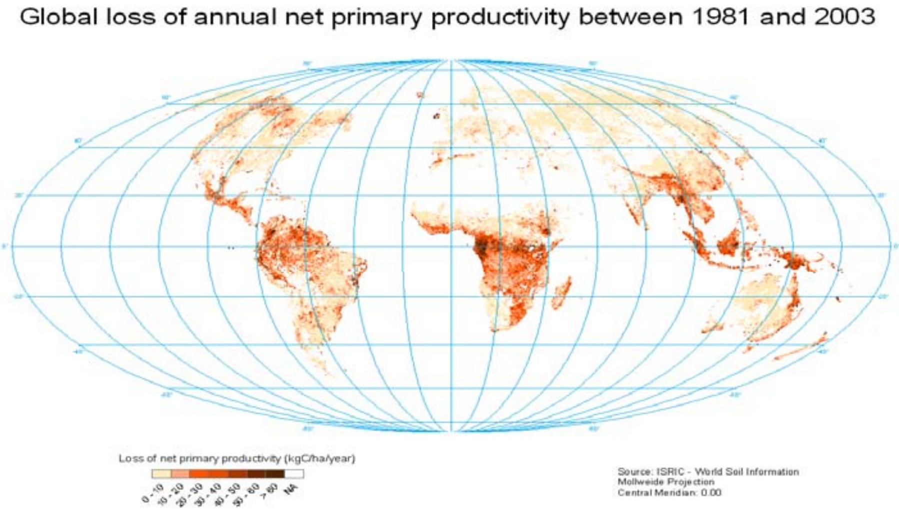

Figure 5: Land Degradation Proxy (from Bai et al., 2008)

Areas which are affected by land degradation are found mainly in Africa, south of the equator, South-East Asia and South China, north-central Australia, the Pampas and swaths of the Siberian and North American taiga. 1.5 billion people live in these areas.

2.2.5 Soil Classification and Default Reference Values for Soil Organic Carbon in Mineral Soils

To arrive at nominal values for the amount of organic carbon in soil, the IPCC guidelines apply default values of soil densities for the topsoil layer (0-30 cm) based on a matrix of soil type and climate zone. Soil types are grouped according to the World Reference Base (WRB) soil types. The scheme for translating soil types into IPCC classes is presented in Figure 6.

In the absence of an existing spatial layer of the default soil classes, the layer was generated from a suitable soil database. For global spatial layers on soil parameters, the most recent and complete dataset is available as the Harmonized World Soil Database (HWSD)[15] (Fisher *et al.*, 2008) from IIASA and the FAO.

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[15] http://www.iiasa.ac.at/Research/LUC/luc07/External-World-soil-database/HTML/index.html?sb=1

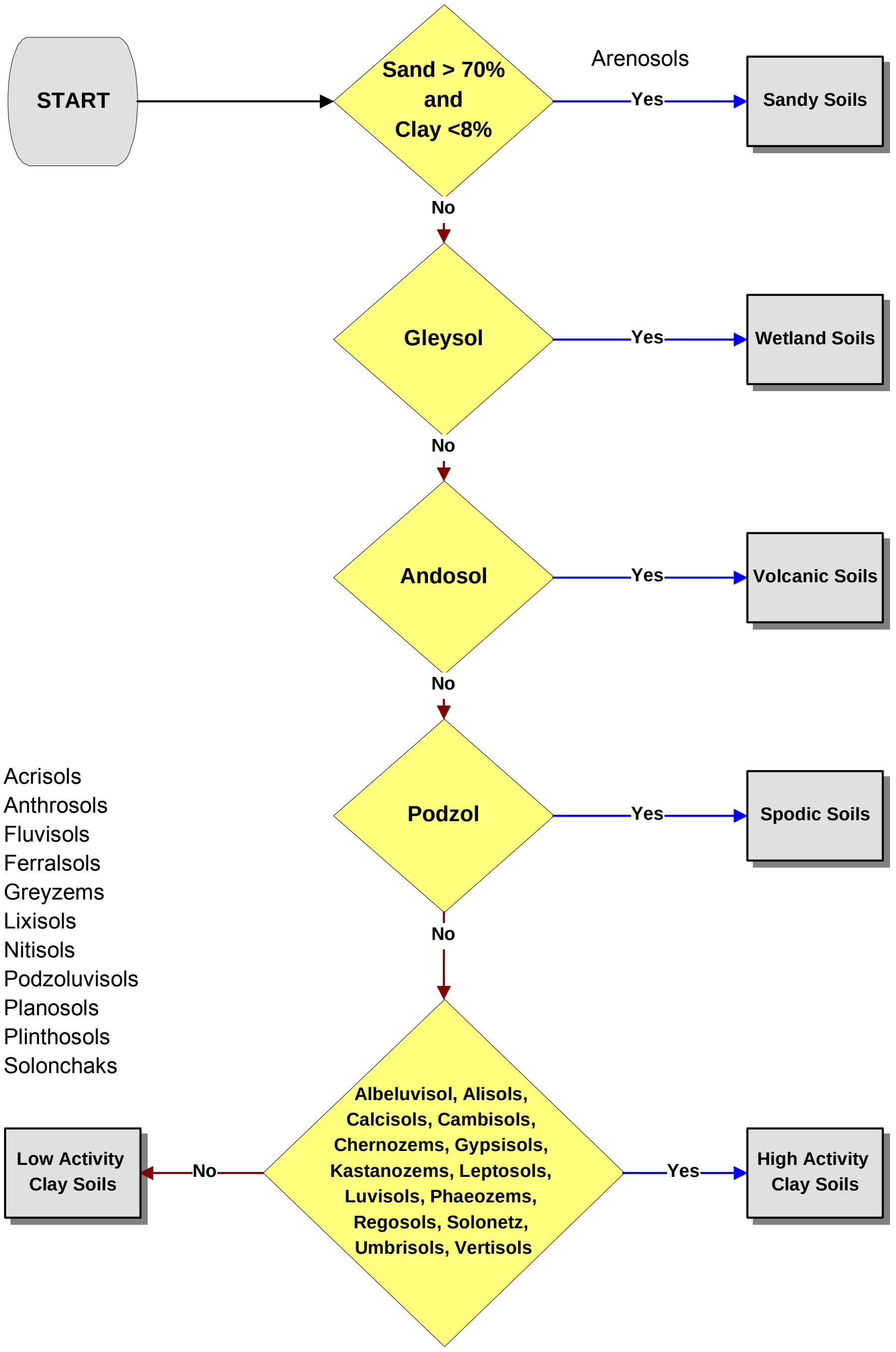

Figure 6: Classification of WRB Soil Types into IPCC Default Soil Classes

The IPCC Soil Classification presented in Figure 6 has been applied to the soil mapping units of the HWSD. Figure 7 presents the resulting spatial distribution of the IPCC soil classes.

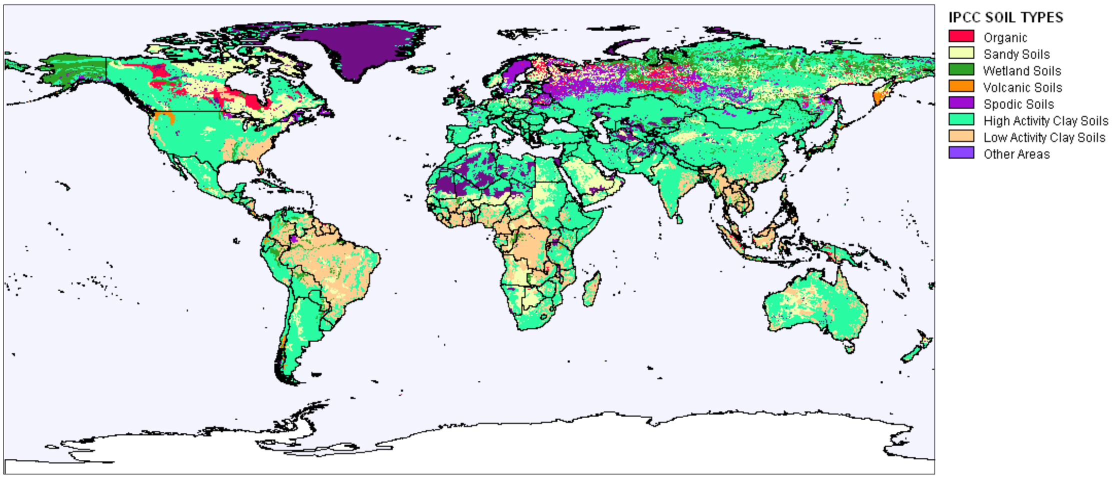

Figure 7: ***IPCC Soil Classification applied to Soil Type of Principal Mapping Unit of HWSD***

The matrix of soil class and climate zone defining the default values of SOC under native vegetation is presented in Table 3.

Table 3: ***Default Reference (under native vegetation) Soil Organic Carbon Stocks (SOCREF) for Mineral Soils (C t ha-1 in 0-30 cm depth)***

Climate Region	**HAC Soils** *C t ha^{-1}*	**LAC Soils** *C t ha^{-1}*	**Sandy Soils** *C t ha^{-1}*	**Spodic Soils** *C t ha^{-1}*	**Volcanic Soils** *C t ha^{-1}*	**Wetland Soils** *C t ha^{-1}*
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	87
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	88
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	86
Tropical, wet	44	60	66	NA	130#	86
Tropical montane	88*	63*	34*	NA	80*	86

Note: Data are derived from soil databases described by Jobbagy & Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown.

# Indicates where no data were available and default values from 1996 IPCC Guidelines were retained.

* Data were not available to directly estimate reference Carbon stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.

Some combinations of soil type and climate zone are highly unlikely to occur so no default values are provided. The application of the default values to the soil class and climate zone spatial layers produces the spatial data layer depicted in Figure 8.

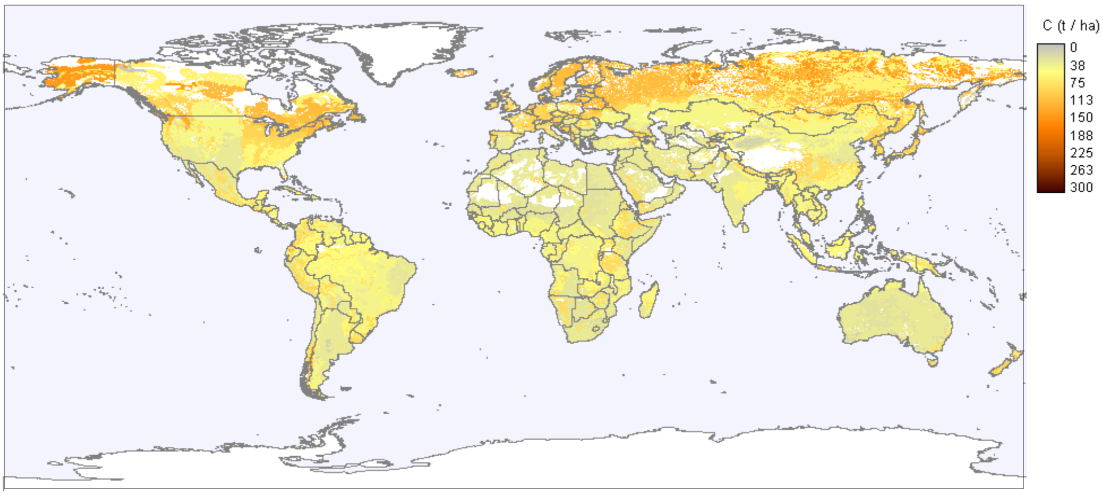

Figure 8: ***Mapping Default Reference Values for Soil Organic Carbon Stock for Mineral Soils***

In the interpretation of the data it should be considered that default values are only provided for mineral soils, under native vegetation and for the topsoil layer of 0-30 cm. To better evaluate the default values with actual conditions, a layer of SOC densities for the same characteristics was calculated from HWSD data. The difference between the HWSD map of topsoil stock densities and the IPCC map of default reference values is presented in Figure 9.

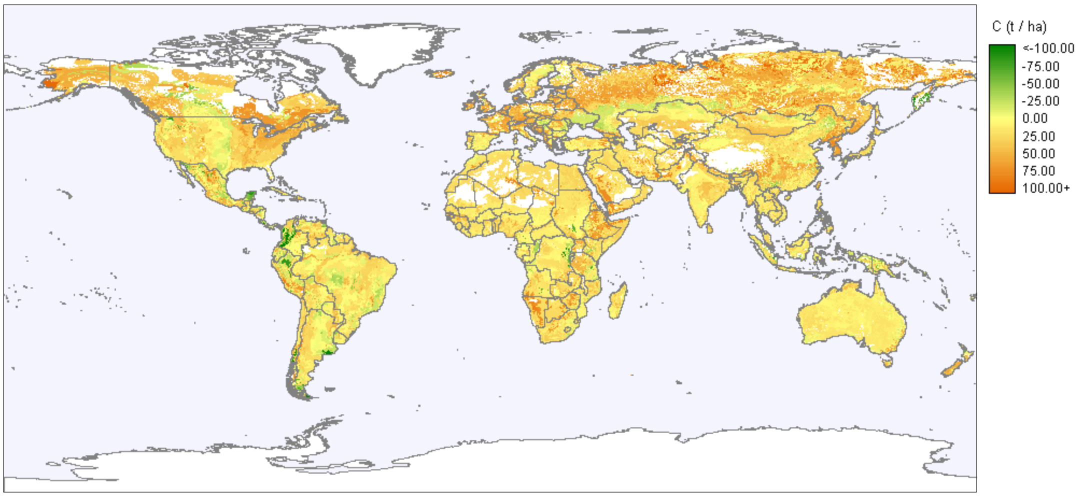

Figure 9: Difference between Topsoil Organic Carbon Density of the HWSD and IPCC Default Reference Values for Mineral Soils

The difference graph shows that the densities given by the HWSD layer are generally higher than those given by the mapped IPCC default reference values. This is not unexpected, because the IPCC values assume native vegetation, i.e. grassland or forest, where soils tend to have higher OC densities than when used as croplands. However, there are also some areas where the default reference values are below the data indicated by the HWSD. One reason for the difference could be the definition of climatic regions, as suggested by the changes on the North American continent. This explanation is less convincing when evaluating the differences for areas in South America and Central Asia.

The topsoil densities for OC were extracted from the processed HWSD data according to the specifications for climate regions and soil type. Native vegetation was calculated by including only areas with a minimum coverage of 75% forest, grassland, shrub or other vegetation. This selection does not necessarily exclude areas of managed land, but was considered sufficient to approximate conditions of native land cover. A test with a threshold of 95% for these land cover types did not result in a significant difference. The values obtained are presented in Table 4.

Table 4: Topsoil Carbon Densities for IPCC Climate and Soil Classes Extracted from Processed HWSD Data for Native Vegetation

Climate Region	**HAC Soils**	**LAC Soils**	**Sandy Soils**	**Spodic Soils**	**Volcanic Soils**	**Wetland Soils**
	C t ha^{-1}	*C t ha^{-1}*	*C t ha^{-1}*	*C t ha^{-1}*	*C t ha^{-1}*	*C t ha^{-1}*
Boreal, moist	46	81	26	77	97	79
Boreal, dry	51	55	24	67	116	81
Boreal	48	81	25	77	103	80
Cold temperate, dry	35	46	21	63	66	54
Cold temperate, moist	48	50	40	76	98	65
Warm temperate, dry	26	36	19	60	96	50
Warm temperate, moist	53	46	46	69	121	66
Tropical, dry	22	32	20	56	-	51
Tropical, moist	43	39	30	76	95	60
Tropical, wet	53	48	41	88	104	61
Tropical montane	33	45	19	94	112	56

One difference in the mean values of topsoil OC density between the IPCC default reference values and those extracted from the processed spatial data is that most fields of the matrix are now filled. Although the areas concerned are small, providing data for all combinations in the data avoids increasing the regions of missing information. The only exception is the combination of *Volcanic soils* x *Tropical, dry*, which is not present in the spatial data either. For *Boreal* regions, mean values were computed for the moist and dry variants. For reasons of comparability with the IPCC data, area-weighted means for a combined region are also included in the table.

Quantitative differences in carbon density in *t ha*$^{-1}$ are presented in Figure 10.

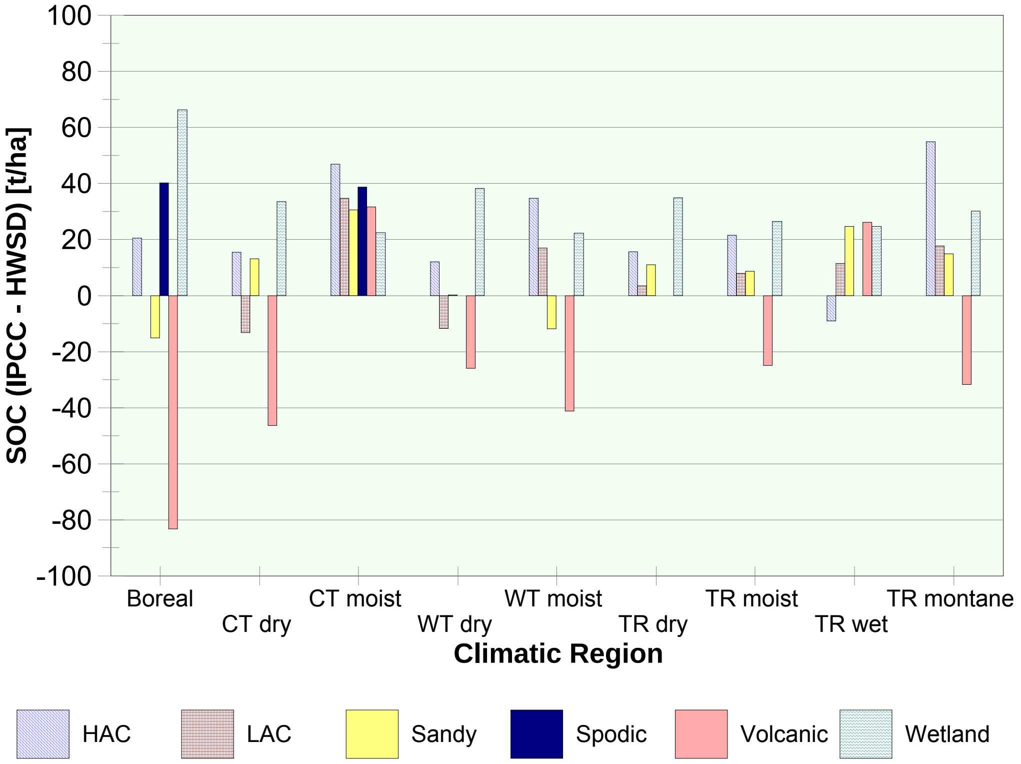

Figure 10: Difference between IPCC Default Reference values for Topsoil C-Densities and Mean C-Densities from HWSD for Native Vegetation

The graph shows that, in general, the IPCC default values for native vegetation are higher than those found in the spatial data. On the whole the values computed from the spatial data are one third lower than the IPCC default reference values. Overall the IPCC default reference values amount to a global average of 66.5 t ha^{-1}, while the average OC density in the topsoil derived from the spatial data is 43.8 t ha^{-1}. For *Boreal* regions the SOC density in *Wetlands* is 45% lower in the spatial data than in the IPCC table. This can be attributed to the definition of wetlands in the soil layer, which excludes areas of organic soils. With peatlands being part of wetlands, the separation made by IPCC in this field is not fully consistent with the standard definition.

Notable exceptions in the correlation of SOC densities were found for *Volcanic soils*. The differences found are due not so much a difference in the range of values for OC density, but rather to a disparate combination of soil type and climatic zone between the IPCC and the spatial data. Mean topsoil SOC densities from the spatial data are also somewhat higher for sandy soils in *Boreal* and *Warm temperate, moist* regions, for LAC soils in *Cool temperate, dry* and *Warm temperate, dry* regions and for LAC soils in *Tropical, wet* regions. For *Volcanic soils,* the IPCC default reference values were not directly based on profile data but on inference from other data. For soils under a *Tropical montane* climate the default reference values were derived from the *Warm temperate, moist* region. As a consequence, the IPCC default reference values may be replaced by the values from the spatial data when integrating the spatial soil, climate and land cover data.

A nominal error estimate of 2 standard deviations is assumed for the IPCC default reference values. Without quoting the standard error of the mean or the standard deviation and the sample size, the range that the default reference estimates cover cannot be determined. An indicator for the range of values obtained as a result of relating SOC with climate and soil texture is given in the paper on which the IPCC default reference values are based. The coefficient of determination (r^2) for a correlation of SOC with mean annual temperature, mean annual precipitation, clay or sand content for the upper 0-40cm ranges from -0.28 to +0.33. In other words, less than one third of the variation found in SOC is explained by the climate or texture parameters[16].

The overall effect is still a significantly higher global SOC stock for the IPCC default reference map than for the spatial data, as given below:

- Spatial: 473 *Pg*
- IPCC: 697 *Pg*

The figures refer only to mineral soils and the climatic regions covered by IPCC default reference values. Batjes (1996) estimated the total amount of SOC in the upper 0-30cm of the soil layer globally to be 684 – 724 *Pg*. This figure includes carbon in peat.

Incidentally, the spatial data for a soil interval of 0-100 cm for all soil types provides a global SOC stock estimate of 1,208 *Pg*. This compares with the estimated global SOC stock quoted by the IPCC of 1,500 *Pg*. The latter estimate is based on Jobbágy & Jackson (2000). The global amount of OC in the soil layer from 0-100cm was estimated from profile samples to be 1,502 *Pg*, a figure now widely used. The confidence interval for this estimated mean is ±320 *Pg* (1 STD), meaning that one can be 68% confident that the mean of the population lies within the range of 1,182 – 1,822 *Pg*. Therefore, the estimates derived from the spatial data are within their range. The profile estimates were used to define the IPCC default reference values and, in a first approximation, similar ranges can be applied to those values.

2.2.6 Peatlands

Peatlands are areas with organic soils or *histosols* formed from decaying organic matter. The definition of what constitutes peatland is not uniform between countries and international conventions. To define organic soils, the FAO uses the thickness of the layer, the organic carbon and clay content, the underlying material and the time of saturation with water (FAO, 1998). National definitions for organic soils are presented by Joost & Clarke, 2002.

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[16] The values for r^2 given by Jobbágy & Jackson (2000) are sometimes negative. For linear correlations, the coefficient of determination should be the square of the sample correlation coefficient r, i.e. it is always ≥ 0. It can, however, be negative when a model-fitting procedure is used and data employed for the predictions differ from the data used to define the model.

As a consequence of the complexity of defining peatlands, the area covered by peatlands varies depending on the data source. The global figure for peatland is approximately 4.0 mil. km^2, or approx. 3% of the total land surface, and contains about 550 Pg of Carbon (Parish *et al.*, 2008). Figures on peat areas from the FAO fluctuate, giving 3.27 to 3.75 mil. km^2 (FAO, 2006/7). The majority of peatlands are located in arctic and boreal areas, which are unsuited to growing crops. Peatlands in tropical areas are estimated to cover 0.3 to 0.45 mil. km^2 (10-12% of global peatland area), but may contain over 30% of the global carbon stored in peat (Rieley, 2007). Other sources report the total amount of 496 Gt for a depth of 0–100 cm of carbon in permafrost-affected soil (Jones *et al.*, 2010) These values indicate that the organic carbon in soils of the northern permafrost region account for approximately 50% of the global soil organic carbon.

The distribution of peatland areas in the spatial data is presented in Figure 11.

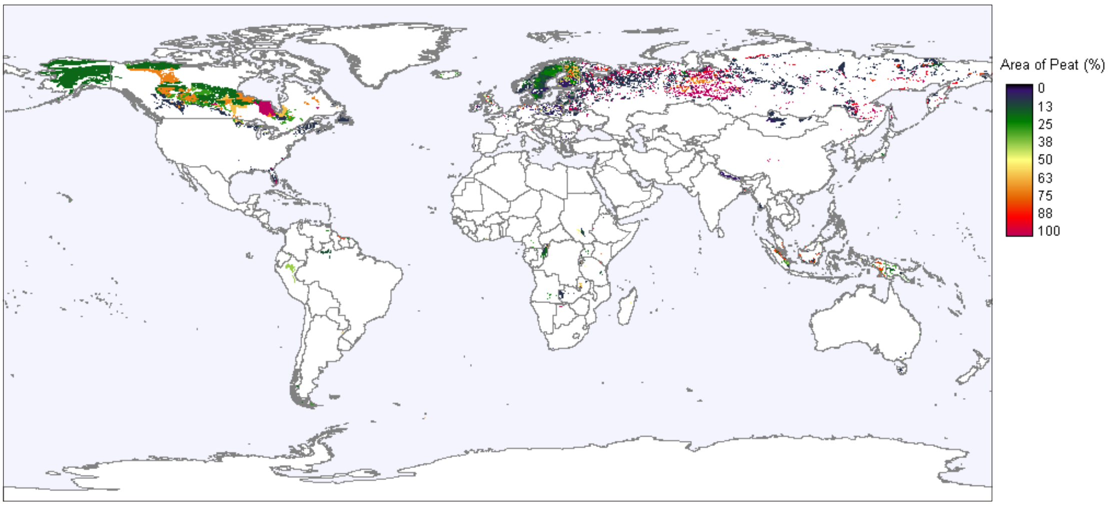

Figure 11: Distribution of Peatlands in Spatial Data Layer

The global area of peatlands according to the soil data is estimated to be 3.3 mil. km^2. This figure compares well with other estimates.

The IPCC guidelines only apply the concept of defining default reference values and coefficients of change to minerals soils. This is in line with the method of using GHG emissions for peatlands rather than changes in stock for a given depth, which is not applicable to peat. The problematic issues related to peatlands when estimating changes in carbon stocks are discussed in detail in Chapter 3.2.3 Drained Peatland.

2.2.7 Fertilizer Input

The amount of mineral fertilizer and manure in soil are part of the information defining a land use system. Fertilizers are input factors that modify the amount of SOC on cropland and grassland. For croplands, the input factor represents the amount of crop residue and/or external organic amendments. On grassland the input factor represents the level of improvement over non-managed areas with an affect on primary productivity and carbon inputs to soil. Harmonized spatial data layers were generated for mineral fertilizer application rates (N-fertilizers) and for manure.

- **Mineral Fertilizer Input**

  A very detailed map giving the mineral fertilizer N input was compiled based on country fertilizer input for the year 2000 from the International Fertilizer Association (IFA, 2009) and crop- and country-specific fertilizer application given in IFA/IFDC/FAO (1999). The latter data source is much more detailed but only includes data prior to 1999. Thus we disaggregated country level data for the year 2000 from IFA (2009) with crop specific data from IFA/IFDC/FAO (1999), assuming that the relative shares of N input to the individual crops remained stable (e.g. if N fertilizer input per hectare of wheat is 20% higher than N input to rye in the year 1997 in a specific country it will also be 20% higher in the year 2000, but the input in absolute terms might change).

  The data sources allowed country specific fertilizer application rates to be calculated for 13 crops or crop groups for the year 2000, as presented in Table 5.

Table 5: Crops / Crop Groups Used to Disaggregate the Mineral Fertilizer Application

Crop Group(s)	Crop Group(s)
Cotton	Fruits and Vegetables
Grassland	Legumes
Maize	Other coarse grains
Other crops	Oil palm
Other Oilseeds	Rice
Soybean	Sugar crops
Wheat	

Figure 12 shows the spatial distribution of mineral fertilizer input as average values for an entire grid cell. The inputs for individual crops within this cell can be quite different.

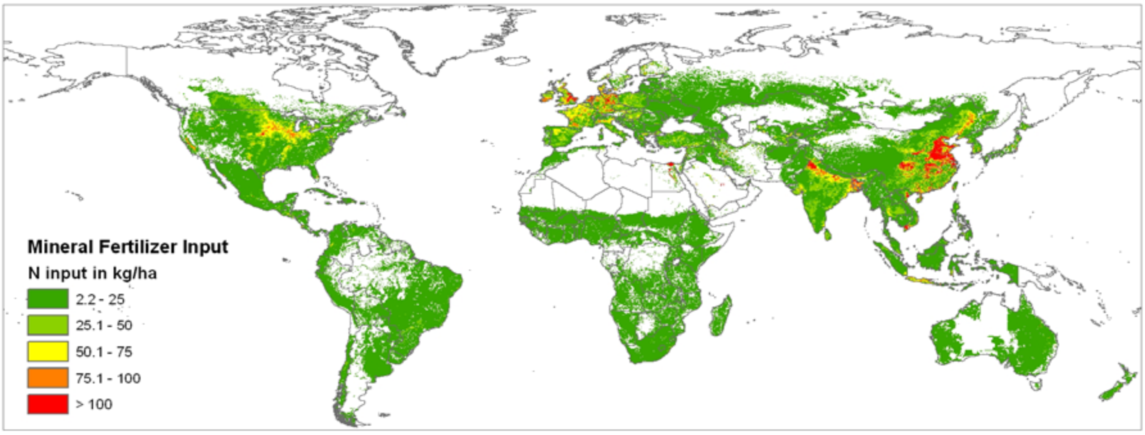

Figure 12: Mineral Fertilizer Application Rates (Mean Application Rates for Grid Cell)

- **Organic Fertilizer Input**

  Total N input from manure on agricultural land per country was available on a country level from the EDGAR database (JRC/PBL, 2009) for the year 2000. The N input from manure was distributed homogeneously over crop and grassland areas within each country. The spatial distribution is given in Figure 13.

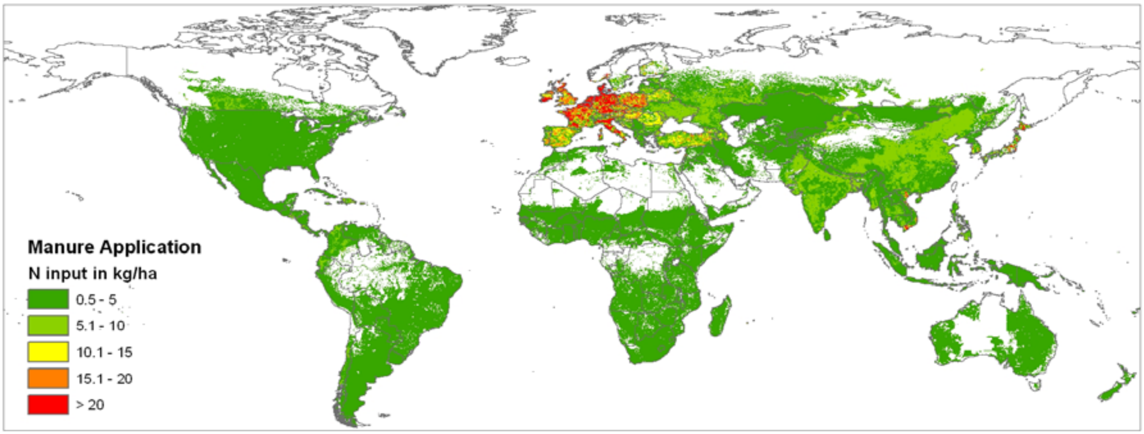

Figure 13: Manure Application Rates (Mean Application Rates for Grid Cell)

Nitrogen input from grazing animals based on FAO global animal density maps, animal specific excretion rates and considering different manure management systems was also available from the EDGAR database (JRC/PBL, 2009) on a 6 x 6 arc min. grid. The data was recalculated to fit with the grid size of 5 arc min. by 5 arc min.

Estimated N-deposits from grazing animals are given in Figure 14.

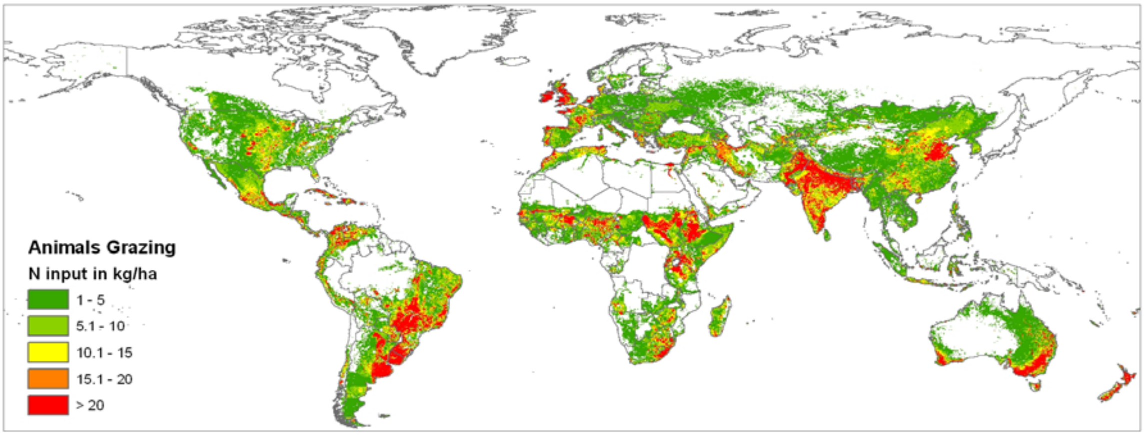

Figure 14: N-Deposits from Grazing Animals (Mean Application Rates for Grid Cell)

With fertilizer inputs being part of the system setup the effect depends on local application rates. These application rates may differ depending on whether a crop is grown for food or for biofuel The fertilizer input maps provide a guide on the amount of N-fertilizer presently used mainly for croplands under food production.

2.2.8 Geographic Stratification

For biomass estimates, the IPCC Guidelines use geographic stratification at continent (i.e. Africa; Asia) or sub-continental level (i.e. continental or insular Asia) in order to make better use of data availability and to improve the appropriateness of default data and parameters for an area. This geographic stratification has particular importance for biological pools (i.e. biomass, dead organic matter) which show large variation under prevailing natural and management conditions at such scales.

2.3 Problems of Uncertainties in Spatial Datasets

As already explained, when two or more spatial datasets are combined, discrepancies between spatial datasets become increasingly apparent. This means that, at the global level and for a regular grid size of 5 arc min., spatial datasets usually contain uncertainties. The users of the map should be aware of this problem before indiscriminately applying the specified methodology for calculating carbon stock changes.

In this Guide the default data provided for biomass and dead organic matter Carbon stocks are marked by inherent uncertainty. Original sources are often not detailed and precise enough when providing methodological information on collected data on biomass or dead organic mater. Additionally, while some data is spatially averaged (i.e. default IPCC, remote sensing), other information is strictly local (i.e. local studies/research/experiments). Recent assessment of the biomass Carbon stock in forests showed that the IPCC's spatially averaged data are within 1 SD (standard deviation) when compared with locally averaged values in a global synthesis of local data from major forest biomes (Keith *et al.*, 2009). This also applies for tropical and boreal forest biomes, while for temperate forests there are larger differences which are explained by human intervention and the rate of natural disturbances (but temperate forests are not of significant interest for biofuel crops).

Monte Carlo simulations can be applied to assess the uncertainties within the carbon-stock change calculation, by using the probability density functions of the input spatial layers. This provides an idea of the overall uncertainty in the calculation. Monte Carlo simulations can be implemented stepwise by modifying each spatial data layer (the others being considered as accurate, i.e. without uncertainty). This method allows for quantifying the impact of the spatial data layer uncertainties on the final output. Considering uncertainties in data and findings should be an important aspect of data modelling and be added to the methodology of spatial analysis.

3 METHODOLOGY FOR CALCULATING CHANGES IN LAND CARBON STOCK FROM LAND USE CONVERSION

In the methodology for calculating land carbon-stock changes following land use conversion, soil and above- and below-ground vegetation have been treated separately. The methodology focuses first on soil carbon and then on above- and below-ground vegetation.

3.1 *The IPCC Guide for Soil Carbon-Stock Changes*

For calculating carbon-stock changes, the IPCC guidelines (2006) propose different approaches according to the targeted scale and the number and accuracy of measurements. In this Guide, the Tier 1 approach is considered because the relevant spatial extent considered by the *Directive* is the global level and the demands for the input data are less stringent than for higher-tier methods. In the Tier 1 approach, only organic carbon stock changes are considered (inorganic carbon stock changes are considered to be 0).

The Tier 1 approach models soil carbon stock changes according to climate, soil type, land use conversion and management practices.

3.1.1 Soil Carbon Stock Changes in Mineral Soils

The following equation is used for calculating the annual change in organic carbon stocks in mineral soils:

$$\delta C_{\min eral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

where $SOC = \sum_{c,s,i} SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times F_{MG_{c,s,i}} \times F_{I_{c,s,i}} \times A_{c,s,i}$

where

$\delta C_{\min eral}$ annual change in carbon stocks in mineral soils (tonnes C yr^{-1})

SOC_0	soil organic carbon stock in the last year of an inventory time period (tonnes C)
$SOC_{(0-T)}$	soil organic carbon stock at the beginning of the inventory time period (tonnes C)
T	number of years in a single inventory time period
D	Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values (years). Commonly 20 years, but depends on assumptions made in computing the factors F_{LU}, F_{MG} and F_I. If T exceeds D, use the values for T to obtain an annual rate of change over the inventory time period (0-T years).
	c represents the climate zones, s the soil types, and i the set of management systems that are present in a country.
SOC_{REF}	the reference carbon stock (tonnes C ha^{-1})
F_{LU}	stock-change factor for land-use systems or subsystem for a particular land-use
F_{MG}	stock-change factor for management regime
F_I	stock-change factor for input of organic matter
A	land area of the stratum being estimated (ha)

All land in the stratum should have common biophysical conditions (i.e. climate and soil type) and management history over the inventory time period in order to be treated together for analytical purposes.

Inventory calculations are based on land areas that are stratified by climate regions (see Chapter *2.2.2* for the default classification of climate) and default soil types (see Chapter *2.2.5 Soil Classification and Default Reference Values for Soil Organic Carbon in Mineral Soils* for the default classification of soils). The stock-change factors are very broadly defined and include:

1) a land-use factor (F_{LU}) that reflects the carbon-stock changes associated with type of land use,
2) a management factor (F_{MG}) representing the principal management practice specific to the land-use sector (e.g. different tillage practices in croplands), and
3) an input factor (F_I) representing different levels of carbon input to soil.

On forest land F_{ND} is substituted for F_{LU} to account for the influence of natural disturbance regimes (see Chapter 4 for further discussion). The stock change factors are provided in the sections below. Each of these factors represents the change over a specified number of years (D), which can vary across sectors, but is typically invariant within sectors (e.g. 20 years for cropland systems). In some inventories, the time period (*T*) may exceed D. In those cases an annual rate of change in carbon stock may be obtained by dividing the product of [(SOC_0 – $SOC_{0\ -T}$) x A] by *T* instead of *D*. The default reference soil organic carbon stock (SOC_{ref}) for mineral soils are provided in Table 6 (Table 2.3 of the IPCC Guidelines).

3.1.2 Soil Carbon Stock Changes in Organic Soils

The *Directive* excludes undrained peatlands and wetlands for conversion to lands dedicated to biofuel production. For drained organic soils, the IPCC Guidelines do not provide any values because they use GHG emission factors instead of changes in carbon stock for peatland (see also Chapter 3.2.3 Drained Peatland).

3.2 Identifying the Gaps between the IPCC Guide and the Biofuel Guide Requirements for Soil Carbon Stock Changes

The Tier 1 approach of the IPCC Guidelines provides carbon-stock change coefficients for grassland, forest, savannah and wooded savannah which have been converted to croplands. These coefficients are listed in Chapter 3.3 of this Guide. The Tier 1 approach gives no indication about carbon-stock change coefficients for savannah and wooded savannah, for degraded lands and drained peatlands.

3.2.1 Savannah and Wooded Savannah

Kottek *et al*. (2006) defined savannah as being all sparse vegetations, grasslands, shrublands and open forests in the Equatorial climate zone with monthly summer and winter precipitation of less than 60 mm. According to the Köppen-Geiger climate classification, savannah is found in class *Aw* and *As* which correspond to the '*Tropical Moist*' climate zone of the IPCC Guidelines. The carbon-stock change coefficients of savannah and wooded savannah are then applied to the grassland and forest areas of the '*Tropical Moist*' IPCC Climate zone.

3.2.2 Degraded Land

The long-term decline in ecosystem function and productivity is not necessarily to the consequence of a decline in organic matter. It can be due to normal soil processes, to human activities such as secondary salinisation, soil erosion, soil compaction, landslides or even contamination of soil by heavy metals, or to natural hazards like heavy storms, rising temperatures and so on. The decline in organic matter plays a currently unquantified role in land degradation. It is therefore difficult to assess coefficients of carbon stock changes or even to adjust the default carbon stock values as a result of land degradation. Smith *et al*. (2007) defined annual mitigation potentials in each climate region for non-livestock mitigation options and considered the restoration of degraded lands. They applied a systematic average change in soil carbon stocks (CO_2) of 3.45 t CO_2 ha^{-1} yr^{-1} within each climate zone with a minimum value of -0.37 and a maximum value of 7.26. The authors were not able to differentiate changes in soil carbon stocks according to climate zone and soil type because of the number of uncertainties in the studies and the lack of literature on this topic. The average values are approximately those of the cool-moist, warm-dry and warm-moist climate zones. However, the conversion of degraded grasslands or degraded forests into croplands does not mean a restoration of the soil carbon stock. This really depends on the land use and the management practices which are carried out on the degraded lands. Several studies have shown that tree plantations with long rotation periods represent good practices for restoring degraded lands (Dawson and Smith, 2007). If managed with conventional tillage, agricultural and tropical crops tend to exacerbate land degradation (Follet, 2001; Dawson & Smith, 2007). Thus, Izaurralde *et al*. (2001) concluded that strongly and extremely degraded soils should be taken out of agricultural and pastoral land uses and planted with tree, shrub or grass species that can be used as biofuel. Furthermore, Arrouays *et al*. (2002) and Seguin *et al*. (2007) showed that carbon stock usually takes twice as long to accumulate than it takes organic carbon to decrease. Thuille & Schulze (2006) suggested that at least 80 years are required for initial stock levels to recover after afforestation in Thuringia and the Alps. In terms of potential carbon stock sequestration, Arrouays *et al*. (2006) showed that it is usually better to restore carbon stock where organic carbon content is not too low. It is then better to try to conserve soil carbon stock than to allow it to decrease significantly and try to restore it. Furthermore, conservation is better with perennial crops than with annual crops (Freibauer *et al*., 2004).

Considering the different points explained above, we assume that default carbon stock values remain the same for degraded land for a given climate and soil type because there are too many uncertainties regarding whether local degradation is due to a decline of organic matter. When the soil is degraded, the coefficients of carbon-stock changes (F_{LU}, F_{MG} and F_I) which are less than 1 (i.e. the coefficients which lead to a decrease in soil carbon stock) must be lower than their value under normal conditions of land use.. If however the coefficients are greater than 1, they do not necessarily lead to a change because soil restoration is very slow (in 20 years, there is no significant difference between an increase of carbon stock on non–degraded lands and an increase on degraded lands because the kinetics of soil carbon stock accumulation are slow for this length of time). Hence, for a moderately degraded grassland, the IPCC Guidelines (Table 6.2) provide an F_{MG} of 0.95 to 0.97, depending on climate zones (5 to 3% less than on a non-degraded grassland) and for a severely degraded grassland, the F_{MG} coefficient is 0.7 in all climatic zones (30% less then a non-degraded grassland). As,forest converted to cropland and grassland converted to cropland present the same rate of carbon decrease for 20 years after conversion, we apply the same percentage of decrease on F_{MG} for degraded forest according to climate zone. We do the same for degraded croplands. For degraded croplands, we consider tillage to have a real negative impact on soil organic carbon stocks. If the land is degraded and fully tilled we consider the F_{MG} to be 0.7 (as for severely degraded grassland) instead of 1, whatever the climatic zone. For degraded croplands which are not tilled, we do not change the coefficients of F_{MG} compared to non-degraded croplands. For reduced tillage, we decrease the coefficients by 5% in temperate/boreal climatic zones, by 4% in *Tropical montane* and by 3% in other *Tropical* zones (as for moderately degraded grasslands).

3.2.3 Drained Peatland

Peatlands are part of the wetland ecosystems, and about 60% of all wetlands are covered by peat. In peatlands, water, peat and the specific vegetation that grows in these ecosystems are strongly interconnected. If any one of these components is removed, or should the balance between them be significantly altered, the nature of the peatland fundamentally changes. There are many different variations of peatlands, depending on geographic region, altitude, terrain and vegetation. Peatlands may be naturally forested or naturally open and vegetated with mosses or sedges. A distinction can be made between peatlands where peat is currently being formed – known as mires – and areas which formerly had peat formation but in which, due to human interventions or climate change, peat is no longer developing (Parish *et al.*, 2008). As a result of their high water concentration, undrained peatlands are a source of CH_4 emissions and a sink of CO_2.

Globally, between 60 and 80% of the peatlands are estimated to be pristine (Parish *et al*., 2008), which means that about 30% have been or are being drained. The drainage of peat due to conversion of peat for arable lands, forest plantations or grasslands leads to a net increase in radiative forcing due to large fluxes of CO_2 and N_2O (due to the presence of water, the high mineralization of organic matter and fertilization), despite decreases in emissions of CH_4 (Kasimir- Klemedtsson *et al*., 1997). Once drained, most peat carbon above the drainage limit is released into the atmosphere over prolonged periods of time.

In order to use peatlands to grow crops, they are generally drained and frequently also limed. This combination of increasing aerobic conditions in the ground and raising the *pH* leads to oxidization of the organic material which has the effect of increasing CO_2 and N_2O emissions, but reducing emissions of CH_4.

There are therefore several reasons why using the methodology developed for mineral soils for estimating the changes in soil carbon stocks following conversions of land are not pertinent to peatlands:

- **Use of fixed layer depth**

  For mineral soils, the OC content in the upper 30cm is considered to be most affected by changes in land use / cover. At deeper levels, there is much less OC and it less affected by land use / cover (Hiederer, 2009). Furthermore, the concept of analysing OC in the topsoil is realistic, because changes in the amount of OC in this layer do not significantly change the volume of the soil section analysed. In contrast, when assessing the upper 30cm of peat, changes in organic carbon affect the depth of the layer. It is the material itself that is removed. It is therefore argued that, for peatlands, the use of a methodology of changes in carbon stocks should be applied to the total depth of peat rather than to a fixed layer. Otherwise, relatively small changes in carbon may be observed for an area where the organic material itself is being reduced because a different layer is actually being assessed with a reduction in total depth..

- **Proxy**

  Changes in SOC are used as an indicator, or proxy, for estimating CO_2 emissions from land use / cover changes in mineral soils. For peatlands, the changes in land use and management result in a variety of pathways for losses of carbon (dissolved, CH_4, CO_2) but also for emissions of N_2O. As a consequence, changes in carbon stocks are only vaguely related to the effect of changes in land use / cover on emissions from peatlands (Joosten, 2009).

- **Land Use / Cover vs. Re-Wetting**

  The effects of changes in land use / cover are considered to be marginal compared to the effect of draining peatlands. Carbon-stock losses from peatlands through drainage are estimated at 7 – 20 t C ha^{-1} $year^{-1}$. This change is smaller than the error in estimating carbon stocks in peatlands, which argues against a stock-based approach in general for peatlands (Joosten, 2009). By rewetting drained peatlands, the areas can be restored to their original function as carbon sinks. The amount of GHG emissions avoided is considered to outweigh any production of biomass on drained peatlands (Couwenberg, 2009).

The IPCC therefore assesses changes of carbon in peatlands in terms of GHG emissions rather than changes in carbon stock. The whole issue of assessing emissions from peatlands, either drained, pristine or excavated, is still very much under discussion (Barthelmes *et al*., 2009) and will likely develop in the future.

3.3 Tables of Coefficients for Soil Carbon Stock Changes

The coefficients for soil carbon stocks are separated into those relevant to define the default reference values and those modifying the default values as a consequence of land management practices.

3.3.1 Reference Default Soil Carbon Stock Values

Table 6 presents the values used by the IPCC Guidelines (2006) as the default reference values for organic carbon in mineral soils.

Table 6: Default Reference (under native vegetation) Soil Organic Carbon Stocks (SOC_{REF}) for mineral soils (0-30 cm depth)

Climate Region	**HAC Soils** *C t ha^{-1}*	**LAC Soils** *C t ha^{-1}*	**Sandy Soils** *C t ha^{-1}*	**Spodic Soils** *C t ha^{-1}*	**Volcanic Soils** *C t ha^{-1}*	**Wetland Soils** *C t ha^{-1}*
Boreal	68	NA	10	117	20	146
Cold temperate, dry	50	33	34	NA	20	87
Cold temperate, moist	95	85	71	115	130	87
Warm temperate, dry	38	24	19	NA	70	88
Warm temperate, moist	88	63	34	NA	80	88
Tropical, dry	38	35	31	NA	50	86
Tropical, moist	65	47	39	NA	70	86
Tropical, wet	44	60	66	NA	130	86
Tropical montane	88	63	34	NA	80	86

NA: no default available because of improbable combination of soil and climate

The default reference values from the IPCC Guidelines (2006) were not modified. For some combinations of soil type and climate default reference values occurring in the HWSD – Climate Zone layers, additional values could be defined for areas which are not covered by the IPCC table after more in-depth analysis of the conditions and possibly the use of measured soil profile data.

3.3.2 Coefficients of Soil Carbon Stock Changes according to Land Use Management Practices and Inputs

The tables describing the coefficients of soil carbon-stock changes according to land use, management practices and inputs are described in the Technical Annex according to each type of conversion.

Note that the relative uncertainties of the final product coefficient (which is the product of the F_{LU}, F_{MG} and F_I coefficients) correspond to the sum of the relative uncertainties of F_{LU}, F_{MG} and F_I.

- Coefficients for Conversion **from Grassland and Savannah to Croplands** – see Table 1 of the Technical Annex
- Coefficients for Conversion from **Degraded Grassland to Degraded Croplands**– see Table 2 of the Technical Annex
- Coefficients for Conversion from **Forest and Wooded Savannah to Croplands**– see Table 3 of the Technical Annex
- Coefficients for Conversion from **Degraded Forest and Wooded Savannah to Croplands**– see Table 4 of the Technical Annex

3.4 IPCC Guide for Above- and Below-Ground Carbon Stock Changes

This *Guide* describes the methodological principles, gives the step-by-step procedure, and provides the default data and factors necessary for the estimation of carbon emissions and removals as a result of land use conversions to biofuel crops. As such, it follows the “one stop shop” concept. It represents a low complexity approach, corresponding to IPCC methodological Tier 1, as it is based on the IPCC’s guidelines regarding Land use, Land Use Change and Forestry: the IPCC’s 2003 Good Practice Guidelines for Land Use, Land Use Change and Forestry and 2006 Guidelines for National Greenhouse Gas Inventories. A Tier 1 methodological approach has been used by several authors to assess the emissions arising as a result of changing land use to biofuel production (Wicke *et al.*, 2008; Ruesch & Gibbs, 2008; Miles *et al.*, 2008).

The Guide facilitates the estimation of carbon-stock changes (increases and decreases) in biomass and dead organic matter, i.e. the emissions/removal of CO_2 from soils as a result of land conversion to cropland for biofuels. The estimation methodology is built on the mass balance principle, with the estimation of carbon-stock changes in relevant pools over an adequate period of time. The methodology, default carbon-stock data and factors provided in the Guide cover the conversions of land use categories (i.e. grassland, forestland, etc.) and strata (i.e. annual or perennial crops) to biofuel crops, while seeking to fit into various IPCC stratifications (climatic and ecological zones, geography, etc.).

It should be noted that the Guide allows for the estimation of "potential" CO_2 emissions and removals as a result of land conversions. This means that the total CO_2 emissions and removals are accurately estimated (under given default data uncertainty) over the land conversion period, but their precise occurrence in time is not given. Emissions as a result of carbon-stock changes in biomass are not at all steady or constant in time in land use conversion, given that "actual" emissions of CO_2 occur mostly at the beginning of the period (i.e. from biomass removal). Consequently, large uncertainties are associated with the linear annualisation of biomass emissions. On the other hand, actual emissions resulting from land use conversions may be underestimated insofar as non-CO_2 emissions (i.e. N_2O and CH_4 from soil disturbance, biomass burning, fertilization of crops, etc.) are not covered by this Guide[17].

The Guide promotes the principle of "conservativeness" in order to avoid the risk of underestimating CO_2 emissions (Grassi *et al.*, 2008), while observing accuracy with current data

The methodology allows the estimation of the carbon stock changes for the relevant carbon pools per unit area (1 ha), the so-called *Carbon stock-change factor* (*EF)*. For the estimation of emissions from a specific area, the *EF* should be applied to the land area on which conversion takes place (called *activity data* or *AD*). Carbon stock may increase or decrease as a result of land use conversion. From the perspective of CO_2 exchange with the atmosphere, there could be the removal of CO_2 by sinks (when CO_2 is removed from atmosphere, conventionally indicated by "-") or the emission of CO_2 by sources (when CO_2 is emitted into the atmosphere, conventionally indicated by "+").

- **Total Carbon Stock Change Computation**

  The general formula for estimating carbon stock change as a result of land use conversion is:

$$\Delta C_{LUC} = (C_{AFTER} - C_{BEFORE}) * A_{TO}$$

where:

ΔC_{LUC}	carbon stock changes as a result of conversion from a generic land-use category to cropland (t C ha^{-1}). If ΔC_{LUC} is negative there is a decrease of C-stock in "after" compared to "before" land use, indicating emissions of CO_2 to the atmosphere.
C_{BEFORE}	carbon stock on land before the conversion (t C ha^{-1})
C_{AFTER}	carbon stock on land after conversion (t C ha^{-1})

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[17] The administrative arrangement between the JRC and EC/DG TREN calls for, in this stage, a Tier 1 estimation of carbon stock changes, not the estimation of all non-CO_2 GHG involved.

A_{TO}	area of land use converted to another land use in a given year (ha yr^{-1}). By default, using this methodology A_{TO} = 1 ha.

The appropriate method to compute carbon stocks (either before or after conversion) depends on availability of data:

$$\mathbf{C_{STOCK} = C_{BIOMASS} + C_{DOM} = (C_{AGB} + C_{BGB}) + (C_{LI} + C_{DW})}$$

where:

$\mathbf{C_{STOCK}}$	total carbon stock ($_{AFTER,\ BEFORE}$) in relevant pools (t C ha^{-1})
$\mathbf{C_{BIOMASS}}$	carbon stock in biomass on land (t C ha^{-1})
$\mathbf{C_{DOM}}$	carbon stock in dead organic matter on land (t C ha^{-1})
and/or,	
$\mathbf{C_{AGB}}$	carbon stock in above-ground biomass on land (t C ha^{-1})
$\mathbf{C_{BGB}}$	carbon stock in below-ground biomass on land (t C ha^{-1})
$\mathbf{C_{LI}}$	carbon stock in litter on land (t C ha^{-1})
$\mathbf{C_{DW}}$	carbon stock in dead wood on land (t C ha^{-1})

- **Computation of C-Stock in Biomass**

When biomass data (before and/or after conversion) is available, the following formula is used to compute the associated carbon stock using dry matter (DM):

$$\mathbf{C_{BIOMASS} = B_{AGB}\,(1+R)^{*}\ CF = (B_{AGB} + B_{BGB}) * CF}$$

where:

$\mathbf{C_{BIOMASS}}$	total carbon stock in biomass on land (t C ha^{-1})
$\mathbf{B_{AGB}}$	above-ground biomass on land (t DM ha^{-1})
$\mathbf{B_{BGB}}$	below-ground biomass on land (t DM ha^{-1}) Alternatively, the ratio of root-to-shoot is used:
R	ratio of below-ground to above-ground biomass
CF	carbon fraction of DM (t C /t DM). The default IPCC 2006 value is 0.47 t C/t DM.

- **Computation of C-Stock in Dead Organic Matter**

  When dead organic matter data (before and/or after conversion) is available the following formula is used:

$$C_{DOM} = C_{LI} + C_{DW} = (DOM_{LI} * CF_{LI}) + (DOM_{DW} * CF_{DW})$$

where

C_{DOM}	total carbon stock in the dead organic matter pool on land (t C ha^{-1})
C_{LI}	carbon stock in the litter pool on land (t C ha^{-1})
C_{DW}	carbon stock in the dead wood pool on land (t C ha^{-1})

and/or alternatively,

DOM_{LI}	mass of litter on land (t DM ha^{-1})
DOM_{DW}	mass of dead wood on land (t DM ha^{-1})

$CF_{LI/WD}$ - carbon fraction of dry matter. The default IPCC 2006 values are 0.50 t C/t dm for dead wood and 0.40 t C/t dm for litter.

However, dead organic matter is of low significance in the land use conversion related to the establishment of biofuel crops.

3.5 Identifying Gaps between the IPCC and the Biofuel Guide Requirements for Biomass and Dead Organic Matter C-Stock Changes

The Guide provides the methodology and data for the computation of the carbon stock changes in land use conversion to biofuel crops. There are differences between the IPCC Guidelines and this Guide in the requirements for the stratification of land categories and the availability of biomass default data.

3.5.1 Biofuel Crops and their Global Distribution

For the Tier 1 estimation of carbon stocks and carbon stock changes in conversion of land to biofuel crops, more explicit data on cropland categories and a breakdown on crop types are needed. For that purpose the crop types are categorized as

a) annual and

b) perennial.

Perennials are further categorized as B.1) perennial non-woody and B.2) perennial woody, each of which is further stratified by biofuel crop relevant species. Such detailed stratification is consistent with the IPCC's categorisation (climate and ecological zones, geographical regions, etc.) and allows for quick estimation of carbon stock changes. Global stratification of relevant biofuel crops is listed in Table 7 (note that this data is not relevant from the point of view of suitability for production).

Table 7: Geographical Distribution of Biofuel Crops within Climatic and Ecological Zones

Species	Crop	Crop group (FAO classes)	Annual/ Perennial	Herbaceous/ Shrub/Tree	Europe	North America	Central and South America	Asia (continental, insular)	Africa	Australia
Barley, Cassava, Cotton, Maize, Rapeseed, Rye, Safflower, Sorghum, Soybean, Sugar beet, Sunflower, Triticale, Wheat	Various	cereals, roots & tubers, fibre, oil crops, sugar crops	annual	herbaceous	Annual C stock "near zero"(i.e. annual net CO_2 removal is nil)					
Coconut	Coconut fruits	oil crops	perennial	tree			TAr TAWa TAWb	TAr TBSh TAWb TAWa SCf	TAr TAWa TAWb TBSh	
Oil palm	Oil palm fruits	oil crops	perennial	tree			TAr TAWa	TAr TAWa TAWb	TAr TAWa TBSh	
Sugar cane	Sugar cane biomass	sugar crops	perennial	herbaceous		SCf SBSh	TAr TAWa SCf	TAr TBSh TAWb	TAr TAWa	TAWb SCf
Jatropha	Jatropha fruits	bio fuels	perennial	shrub			TAr TAWa TAWb SCf SCs SBSh	TAr TAWb TAWa TBSh SCf TeDo TeDc TeBSk	TAr TBSh TAWb TAWa SCf SCs	TBSh SBSh SCs SCf TeDo

Legend (global ecological zones):

Tropical rain forest (Tar); Tropical moist deciduous forest (TAWa); Tropical dry forest (TAWb); Tropical shrubland (TBSh);
Tropical desert (TBWh); Tropical mountain systems (TM); Subtropical humid forest (SCf); Subtropical dry forest (SCs);
Subtropical steppe (SBSh); Subtropical desert (SBWh); Subtropical mountain system (SM); Temperate oceanic forest (TeDo);
Temperate continental forest (TeDc); Temperate steppe (TeBSk); Temperate desert (TeBWk); Temperate mountain system (TeM)

3.5.2 Land Use Conversion Matrix

The IPCC Guidelines define six broad land-use categories, namely: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. These definitions may incorporate land cover type, land use, or a combination of the two, depending on data availability. The broad land-use categories may be further stratified by climate or ecological zone, soil and vegetation type, biomass stock, etc.

“Before conversion” land categories are strictly defined by the Directive as the most probable sources of land for biofuel crop establishment. Nevertheless, other land use categories are considered in terms of the boundary of the system where emissions may occur directly and/or indirectly (i.e. “leakage”). On lands “after conversion”, the biofuel crops have various biological characteristics which directly determine the amount and duration of the carbon stocks. A matrix of possible land conversions to biofuel crops is shown in Table 8.

Table 8: Land Conversion Matrix for Biofuel Crops (Y – possible land conversion)

	Land use / activity	**After conversion**		
		Cropland (biofuel crops)		
		Annual crops	Perennial crops	
			Non-woody	Woody
Before conversion	Grassland	Y [a]	Y	Y
	Forest (<30% canopy cover)	Y	Y	Y
	Savannah, wooded savannah and shrublands	Y	Y	Y
	Degraded land (degraded forest, degraded grassland, degraded/ marginal cropland)	Y	Y	Y
	Forest land[b]	Y	Y	Y
	Cropland[b]	Y	Y	Y

[a] Y - possible land conversion

[b] – these land use categories are considered in terms of boundary

Cropland and grassland are defined according to the IPCC Guidelines. Forest land (with <30% canopy cover) is defined above (i.e. woody vegetation height >5m). Savannah and wooded savannah are considered either as grassland communities with shrubs and trees (with max 10% coverage of area) in the ‘Tropical Moist’ IPCC climate zone (i.e.

the cerrado in South America and savannahs in Africa) or as shrubland. Forest plantations are either under forest or cropland, according to their characteristics.

Degraded land does not fall under a specific land use category in the IPCC land classification, as the process may affect all basic land use types. Degradation is characterized by a lower NDVI, less productivity and production or other features (such as physical disturbances leading to soil erosion) compared to sustainably managed lands. All these make classification of degraded lands and assessment of biomass difficult except under large uncertainty.

On the other hand, it should be kept in mind that often the land may have experienced *several successive uses or cover changes* before it is finally converted to a biofuel crop. In this case, the initial land use over a reference period should be considered (i.e. 20 years before the biofuel crop is established), but not the intermediary land uses.

3.5.3 Carbon Stock and Change Default Data

For their six broad land use categories, the IPCC Guidelines define default data for biomass and dead organic matter, which allow for a Tier 1 estimation of the carbon stock and carbon stock changes for lands which remain in the same category and those under conversion. Additionally, various default parameters are provided (i.e. root-to-shoot ratio; carbon fraction of matter in different pools).

According to the Biofuel Guide the estimation of carbon stock changes is made under the following conservative assumptions:

- for “before” conversion land it is assumed that all biomass and dead organic matter are cleared, thus “near zero” amounts of C remain in these pools and all CO_2 is emitted into atmosphere. In natural ecosystems (i.e. grassland, forest land) the biomass/C stocks are assumed to be more or less constant in time (i.e. steady state) reaching a maximum quantity under prevailing natural and management conditions. Dead organic matter is considered to be present only in forest land (i.e. closed forests).
- for “after” conversion land it is assumed that the net CO_2 removal from annual crops is nil, while in perennial crops there is a constant CO_2 removal proportional to the permanent C stock in biomass (time averaged C stock). It is also assumed that the dead organic matter pool in such lands is nil.

Insofar as possible, consistency of the IPCC Guidelines data was ensured with more recent references (datasets, publications).

A description of the default data for the estimation of carbon stock changes provided by this Guide for each type of land use/activity follows (the data is presented in tables in the Technical Annex).

- **Grassland**

  Default data of the IPCC 2006 Guidelines for biomass are used. The data are consistent with the latest available data (Lasco, 2004; Yichun *et al.*, 2009; Fargione *et al.*, 2008; Germer & Sauerborn, 2008).

- **Forest (more than 30% land cover)**

  Considered in terms of boundary. Default IPCC 2006 Guidelines data for biomass and dead organic matter, as well as root-to-shoot IPCC default parameters are used to obtain aggregated forest land data on climatic and ecological zones and geographic domains.

- **Forest (less than 30% cover)**

  The definition of forest is important as a country may or may not consider a conversion as deforestation according selected thresholds for tree cover. The FAO[18] defines a land as a forest if the tree cover is > 10% of the area, further split in ”open forest” if the tree cover is 10-40% or “closed forest” if it covers more than 40%. For the purpose of defining afforestation/reforestation in the CDM[19] of the Kyoto Protocol of UNFCCC[20], a “forest” is an area 0.05-1 ha with a minimum tree crown cover of 10–30%, with a ‘tree’ defined as a plant with the capability of growing to be >2–5m tall. So a non-Annex I Party that selected a high threshold for forest cover (i.e. 30%) may have more land available for conversion to cropland “without” carrying out deforestation, compared to a Party that selected a lower threshold for forest (i.e. 10%). Given the complex issue of harmonizing national definitions for forest, all lands with tree cover between 10-30% are considered to fall under this land category (as determined in Chapter 2.2.3).

  Biomass/carbon stock data for different types of tree cover are not readily available from the IPCC Guidelines or other sources. In order to quantify the carbon stock on such lands, the Biofuel Guide assumes that tree cover is directly proportional to standing biomass. Thus biomass/carbon stock equals 20% of IPCC default data for forest land biomass under climatic and ecological zoning. This is a conservative approach given that the real amount of biomass/carbon

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[18] Food and Agriculture Organization of the United Nations. Forest definition available at: ftp://ftp.fao.org/docrep/fao/008/A0400E/A0400E13.pdf

[19] Clean Development Mechanism, a flexible instrument of the Kyoto Protocol of the United Nations Framework Convention for Climate Change (UNFCCC)

[20] UNFCCC (2002). Report of the Conference of the Parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001 (FCCC/CP/2001/13/Add.1, UNFCCC, Marrakesh, Morocco, 2001). URL: http://unfccc.int/resource/docs/cop7/13a01.pdf

stock is likely to be less than in the case where carbon stock is directly proportional to tree cover.

- **Forest plantations**

  The above-ground biomass default data of the IPCC 2006 Guidelines is used to obtain time averaged carbon stocks in mature plantations (i.e. the value at half cycle), assuming that the land use is under successive cycles of forest plantations. IPCC default root-to-shoot parameters for forest land are used to compute below-ground biomass. Data is organized by main plantation species according to climatic and ecological zones and geographic domains.

- **Savannah and wooded savannah**

  The IPCC 2006 Guidelines default data for grassland is used. If more information is available on the regional particularities of the landscape concerned, *Shrubland* data may also be used for more conservative estimates of carbon stock changes.

- **Shrubland**

  An additional detailed table from the IPCC 2006 Guidelines regarding the carbon stock in shrublands across relevant climatic regions is provided and expanded to climatic and ecological zoning according to data from Ruesch and Gibbs (2008) and others (Goetz *et al.*, 2008; Germer and Sauerborn, 2008; Fargione *et al.*, 2008).

- **Cropland**

  The biomass/carbon stocks in this category are relevant both for “before” and “after” land conversions. Conservatively, the default biomass data of the IPCC 2006 Guidelines is used for perennial cropland “before” conversion (i.e. orchards, coffee/rubber plantations).

For “after conversion” this Guide provides default carbon stocks by crop type, ecological and climatic zone and geographical regions of the world. The Guide assumes that after the conversion the land use remains stable for several production cycles of the same biofuel crop.

Conservatively, it is assumed that there is no net carbon accumulation in the case of annual biofuel crops (i.e. cassava, cereals, soybean, etc.).

For non-woody perennial crops (sugar cane, miscanthus) only the carbon stock in the permanent compartment of biomass is considered (i.e. belowground: roots and rhizomes), as compiled from various sources (Benizoni, 1988; Ripoli *et al.*, 2000; Kahle *et al.*, 2001; Clifton-Brown *et al.*, 2004; Heaton *et al.*, 2004; Brijder *et al.*, 2005;

Boehmel *et al.*, 2008; Fargione *et al.*, 2008; Woltjer *et al.*, 2008; Atkinson, 2009; Balat & Balata, 2009; Burner *et al.*, 2009; Romjin, 2009). Root-to-shoot data is compiled from existing literature (Kahle *et al.*, 2001; Smith *et al.*, 2005).

In the case of woody perennial crops (oil palm, coconut, jatropha, jojoba), there is a gradual net accumulation of carbon in biomass followed by its sudden removal at the end of the cycle. Production cycle varies in accordance with species and local conditions: coconut (50 years); oil palm (25); jatropha (20); jojoba (20); miscanthus (15); sugarcane (15). Carbon stock is assumed to be the "average storage" as a time-integrated carbon accumulation in biomass occurs over the crop cycle (Schroeder, 1992). Thus, there is an overestimation of carbon stock in the first part of the production cycle and an underestimation for last half of the cycle, but a spatial-temporal compensation is expected under large areas with such crops. Biomass/carbon -stock data is compiled from the IPCC 2006 Guidelines and various other sources (Benizoni, 1988; Palm and Härdter, 2000; Lasco, 2002; Fairhurst & Härdter, 2003; Leigh, 2007; Jongschaap *et al.*, 2007; Patolia *et al.*, 2007; Wicke *et al.*, 2008; Miles *et al.*, 2008; Romjin, 2009).

When original data are reported as fresh matter, a humidity correction factor of 30% is applied in order to convert from air-dried fresh matter to dry matter.

- **Degraded land**

  Biomass data is essentially missing for degraded land even in the lower Tiers. From a methodological perspective there are two situations here:

  1) "before conversion" land falls under the cropland category (i.e. marginal or degraded) where it is expected that biofuel crop establishment would lead to an increase of the carbon stock in all pools. In the case of forest plantations established on such lands, it is conservatively assumed that the carbon stock equals to an amount corresponding to the time-averaged carbon stocks in mature plantations (i.e. value at the half cycle). Biomass data is derived from the IPCC 2006 Guidelines. Other pools are conservatively not considered. Where other non-woody biofuel crops are established on such lands, the default C stocks set for cropland should be used.
  2) low carbon status in biomass on land "before conversion" (i.e. either forest or grassland). Degraded land pools are poorer in carbon than normal land (i.e. sustainably managed or natural land). Estimating carbon stocks in degraded land is problematic insofar as "degraded land" is a generic definition which does not allow for quantitative inferences. Under various types of degradation (i.e. intensity, duration), degraded forest land shows long term degradation with 25-50% less carbon than normal. For grasslands, this figure reaches 60-90% (Mutinho & Schwartzman, 2005; Miles *et al.*, 2008; IPCC, 2000).

Thus, on degraded grassland (including pasture, grazing land, etc.), in order to estimate the carbon stocks in a way that is consistent with IPCC stratification, it is considered that 40% of the IPCC Guidelines default biomass is still present on such lands.

For the purpose of this Biofuel Guide requirements, under Tier 1 we assume that the forest crown cover is proportional to the standing biomass. The superior limit of the FAO's threshold forest cover range (between 10-30%) is selected as reflecting total C stock in the case of forest degradation. Thus we consider that 30% of default biomass is present on degraded forest lands, under a global stratification consistent with IPCC climatic, ecological and geographical zoning.

Uncertainty associated with carbon-stock data is allowed for in accordance with the source (IPCC Guidelines) or computed as 1 standard error relative to the average of available data.

3.6 Table of Coefficients for Above- and Below-Ground Carbon Stock Changes

Carbon stock data calculated according to climatic, ecological and geographic zoning are given in Tables 9 to 17 of the Technical Annexes according to each type of land use. For the computation of the C-stock change in land conversion, appropriate values from tables should be extracted; the value of "before" carbon stock value should subtracted from the "after" value, according to 3.4.1. In order to estimate the emissions as a result of carbon stock changes, the result should be multiplied by -1 (a negative result indicates the removal of CO_2, a positive result indicates emissions of CO_2).

- Data for conversion **from Grassland** – see Table 5 of the Technical Annex
- Data for conversion **from Forestland (less than 30 % cover)** – see Table 6 of the Technical Annex
- Data for conversion **from Forestland (more than 30 % cover)** – see Table 7 of the Technical Annex
- Data for conversion **from Shrubland** – see Table 8 of the Technical Annex
- Data for conversion **from Perennial crops** – see Table 9 of the Technical Annex
- Data for conversion **from/to Forest plantations** - see Table 10 of the Technical Annex
- Data for conversion **from Degraded Grassland** – see Table 11 of the Technical Annex
- Data for conversion **from Degraded Forest** – see Table 12 of the Technical Annex
- Data for conversion **to Cropland on biofuel crops type** - see Table 13 of the Technical Annex

4 EXISTING TOOLS AND DATA SUPPORT

In this section, we present the tools and data that an economic operator can use for calculating carbon stock changes.

4.1 Existing Tools for Soil Carbon Stock Changes

As part of the "*Good Practice Guidance for Land Use, Land-Use Change and Forestry*" software called "*Tools for Estimation of Changes in Soil Carbon Stocks associated with management Changes in Croplands and Grazing Lands based on IPCC Default Data*"[21] is provided under Annex 4A.1. This tool is a database implementation which combines the default reference values with the change coefficients by country.

The data tables of the tool and the accompanying help files also contain information on the classification of the input maps. The information on the classification of the soil and climate layer shows some differences with the procedures documented in the main text:

- Climate zones are defined for 9 classes instead of 12. The reduction is achieved by merging the classes of *Polar* regions with those of *Boreal* regions. Not included is the class of *Tropical Montane*.
- The *Warm Temperate*, dry region was defined as having a mean annual precipitation of < 600mm instead of a positive difference between mean annual precipitation and potential evapo-transpiration.
- The temperature range for the *Tropical* zones was set at 20°C instead of the 18°C specified in the IPCC classification scheme.
- *Sandy Soils* were defined as *Arenosols* in the WRB classification instead of according to the texture-based rule (Sand > 70% AND Clay < 8%).

No differences were found in the default values or the coefficients between the tool’s data tables and the information provided under the help functionality.

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[21] http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/annex4a1.html

4.2 Spatial Data for the Calculation of Carbon-Stock Changes

All the spatial data which are useful for the calculation of soil carbon-stock changes according to land use conversion and which are presentation in this Guide will be available from the SOIL Action website of the JRC at: http://eusoils.jrc.ec.europa.eu/.

Acknowledgements

The authors would like to thank Paul Hodson and Ewout Deurwaarder (DG ENER) for giving guidance where specific details of the Directive were concerned and providing invaluable comments on the presentation in this Guide. Further thanks go to Luisa Marelli (JRC-IE) for her initiative and enthusiasm to launch the work to this Guide. The authors and any reader are further indebted to Grainne Mulhern (JRC-IES) for her patience in going through all corners of the text and making this Guide so much more accessible to a wider audience.

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ANNEX to

Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 9: Coefficients for Conversion from Grasslands and Savannahs

Table 9a- Coefficients for conversion from grasslands and savannahs (DC: Default Carbon Value)

Fraction Land use (F_{LU}) = 1

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
Temperate/Boreal	Dry	Grassland	Non degraded	Medium	DC*1*1*1	NA
				High	DC*1*1*1.11	NA
			Improved	Medium	DC*1*1.14*1	NA
				High	DC*1*1.14*1.11	NA
	Moist/wet	Grassland	Non degraded	Medium	DC*1*1*1	NA
				High	DC*1*1*1.11	NA
			Improved	Medium	DC*1*1.14*1	NA
				High	DC*1*1.14*1.11	NA
Tropical	Dry	Grassland	Non degraded	Medium	DC*1*1*1	NA
				High	DC*1*1*1.11	NA
			Improved	Medium	DC*1*1.17*1	NA
				High	DC*1*1.17*1.11	NA
	Moist/wet	Savannah	Non degraded	Medium	DC*1*1*1	NA
				High	DC*1*1*1.11	NA
			Improved	Medium	DC*1*1.17*1	NA
				High	DC*1*1.17*1.11	NA
Tropical Montane	Dry	Grassland	Non degraded	Medium	DC*1*1*1	NA
				High	DC*1*1*1.11	NA
			Improved	Medium	DC*1*1.16*1	NA
				High	DC*1*1.16*1.11	NA

Table 9b- Coefficients for conversion to croplands (DC: Default Carbon Value)

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
Temperate/Boreal	Dry	Long-term cultivated	Full-tillage	Low	DC*0.8*1*0.95	NA
				Medium	DC*0.8*1*1	NA
				High with manure	DC*0.8*1*1.37	NA
				High without manure	DC*0.8*1*1.04	NA
			Reduced tillage	Low	DC*0.8*1.02*0.95	28%
				Medium	DC*0.8*1.02*1	NA
				High with manure	DC*0.8*1.02*1.37	27%
				High without manure	DC*0.8*1.02*1.04	28%
			No till	Low	DC*0.8*1.1*0.95	27%
				Medium	DC*0.8*1.1*1	NA
				High with manure	DC*0.8*1.1*1.37	26%
				High without manure	DC*0.8*1.1*1.04	27%
	Moist/wet	Long-term cultivated	Full-tillage	Low	Dc*0.69*1*0.92	NA
				Medium	Dc*0.69*1*1	NA
				High with manure	Dc*0.69*1*1.44	NA
				High without manure	Dc*0.69*1*1.11	NA
			Reduced tillage	Low	Dc*0.69*1.08*0.92	31%
				Medium	Dc*0.69*1.08*1	NA
				High with manure	Dc*0.69*1.08*1.44	30%
				High without manure	Dc*0.69*1.08*1.11	27%
			No till	Low	Dc*0.69*1.15*0.92	30%
				Medium	Dc*0.69*1.15*1	NA
				High with manure	Dc*0.69*1.15*1.44	29%
				High without manure	Dc*0.69*1.15*1.11	26%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
Tropical	Dry	Long-term cultivated	Full-tillage	Low	DC*0.58*1*0.95	NA
				Medium	DC*0.58*1*1	NA
				High with manure	DC*0.58*1*1.37	NA
				High without manure	DC*0.58*1*1.04	NA
			Reduced tillage	Low	DC*0.58*1.09*0.95	83%
				Medium	DC*0.58*1.09*1	NA
				High with manure	DC*0.58*1.09*1.37	82%
				High without manure	DC*0.58*1.09*1.04	83%
			No till	Low	DC*0.58*1.17*0.95	82%
				Medium	DC*0.58*1.17*1	NA
				High with manure	DC*0.58*1.17*1.37	81%
				High without manure	DC*0.58*1.17*1.04	82%
	Moist/wet	Long-term cultivated	Full-tillage	Low	DC*0.48*1*0.92	NA
				Medium	DC*0.48*1*1	NA
				High with manure	DC*0.48*1*1.44	NA
				High without manure	DC*0.48*1*1.11	NA
			Reduced tillage	Low	DC*0.48*1.15*0.92	68%
				Medium	DC*0.48*1.15*1	NA
				High with manure	DC*0.48*1.15*1.44	67%
				High without manure	DC*0.48*1.15*1.11	64%
			No till	Low	DC*0.48*1.22*0.92	68%
				Medium	DC*0.48*1.22*1	NA
				High with manure	DC*0.48*1.22*1.44	66%
				High without manure	DC*0.48*1.22*1.11	63%
Tropical Montane	n/a	Long-term cultivated	Full-tillage	Low	DC*0.64*1*0.94	NA
				Medium	DC*0.64*1*1	NA
				High with manure	DC*0.64*1*1.41	NA

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_I	$Dc*F_{LU}*F_{MG}*F_I$	Final Error
				High without manure	DC*0.64*1*1.08	NA
			Reduced tillage	Low	DC*0.64*1.09*0.94	150%
				Medium	DC*0.64*1.09*1	NA
				High with manure	DC*0.64*1.09*1.41	150%
				High without manure	DC*0.64*1.09*1.08	150%
			No till	Low	DC*0.64*1.16*0.94	150%
				Medium	DC*0.64*1.16*1	NA
				High with manure	DC*0.64*1.16*1.41	150%
				High without manure	DC*0.64*1.16*1.08	150%
Temperate/Boreal	Dry	Paddy rice	Full-tillage	Low	DC*1.1*1*0.95	NA
				Medium	DC*1.1*1*1	NA
				High with manure	DC*1.1*1*1.37	NA
				High without manure	DC*1.1*1*1.04	NA
			Reduced tillage	Low	DC*1.1*1.02*0.95	69%
				Medium	DC*1.1*1.02*1	NA
				High with manure	DC*1.1*1.02*1.37	68%
				High without manure	DC*1.1*1.02*1.04	59%
			No till	Low	DC*1.1*1.1*0.95	68%
				Medium	DC*1.1*1.1*1	NA
				High with manure	DC*1.1*1.1*1.37	67%
				High without manure	DC*1.1*1.1*1.04	68%
	Moist/wet	Paddy rice	Full-tillage	Low	DC*1.1*1*0.92	NA
				Medium	DC*1.1*1*1	NA
				High with manure	DC*1.1*1*1.44	NA
				High without manure	DC*1.1*1*1.11	NA
			Reduced tillage	Low	DC*1.1*1.08*0.92	70%
				Medium	DC*1.1*1.08*1	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
				High with manure	DC*1.1*1.08*1.44	69%
				High without manure	DC*1.1*1.08*1.11	66%
			No till	Low	DC*1.1*1.15*0.92	69%
				Medium	DC*1.1*1.15*1	NA
				High with manure	DC*1.1*1.15*1.44	68%
				High without manure	DC*1.1*1.15*1.11	65%
Tropical	Dry	Paddy rice	Full-tillage	Low	DC*1.1*1*0.95	NA
				Medium	DC*1.1*1*1	NA
				High with manure	DC*1.1*1*1.37	NA
				High without manure	DC*1.1*1*1.04	NA
			Reduced tillage	Low	DC*1.1*1.09*0.95	72%
				Medium	DC*1.1*1.09*1	NA
				High with manure	DC*1.1*1.09*1.37	71%
				High without manure	DC*1.1*1.09*1.04	72%
			No till	Low	DC*1.1*1.17*0.95	71%
				Medium	DC*1.1*1.17*1	NA
				High with manure	DC*1.1*1.17*1.37	70%
				High without manure	DC*1.1*1.17*1.04	71%
	Moist/wet	Paddy rice	Full-tillage	Low	DC*1.1*1*0.92	NA
				Medium	DC*1.1*1*1	NA
				High with manure	DC*1.1*1*1.44	NA
				High without manure	DC*1.1*1*1.11	NA
			Reduced tillage	Low	DC*1.1*1.15*0.92	72%
				Medium	DC*1.1*1.15*1	NA
				High with manure	DC*1.1*1.15*1.44	71%
				High without manure	DC*1.1*1.15*1.11	68%
			No till	Low	DC*1.1*1.22*0.92	71%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use F_{LU}**	**Management F_{MG}**	**Input F_I**	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
				Medium	DC*1.1*1.22*1	NA
				High with manure	DC*1.1*1.22*1.44	70%
				High without manure	DC*1.1*1.22*1.11	67%
Tropical Montane	n/a	Paddy rice	Full-tillage	Low	DC*1.1*1*0.94	NA
				Medium	DC*1.1*1*1	NA
				High with manure	DC*1.1*1*1.41	NA
				High without manure	DC*1.1*1*1.08	NA
			Reduced tillage	Low	DC*1.1*1.09*0.94	150%
				Medium	DC*1.1*1.09*1	NA
				High with manure	DC*1.1*1.09*1.41	150%
				High without manure	DC*1.1*1.09*1.08	150%
			No till	Low	DC*1.1*1.16*0.94	150%
				Medium	DC*1.1*1.16*1	150%
				High with manure	DC*1.1*1.16*1.41	150%
				High without manure	DC*1.1*1.16*1.08	150%
Temperate/Boreal	Dry	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.95	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.37	NA
				High without manure	DC*1*1*1.04	NA
			Reduced tillage	Low	DC*1*1.02*0.95	69%
				Medium	DC*1*1.02*1	NA
				High with manure	DC*1*1.02*1.37	68%
				High without manure	DC*1*1.02*1.04	69%
			No till	Low	DC*1*1.1*0.95	68%
				Medium	DC*1*1.1*1	NA
				High with manure	DC*1*1.1*1.37	67%
				High without manure	DC*1*1.1*1.04	68%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** **F_{LU}**	**Management** **F_{MG}**	**Input** **F_I**	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.92	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.44	NA
				High without manure	DC*1*1*1.11	NA
			Reduced tillage	Low	DC*1*1.08*0.92	69%
				Medium	DC*1*1.08*1	NA
				High with manure	DC*1*1.08*1.44	68%
				High without manure	DC*1*1.08*1.11	65%
			No till	Low	DC*1*1.15*0.92	68%
				Medium	DC*1*1.15*1	NA
				High with manure	DC*1*1.15*1.44	67%
				High without manure	DC*1*1.15*1.11	64%
Tropical	Dry	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.95	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.37	NA
				High without manure	DC*1*1*1.04	NA
			Reduced tillage	Low	DC*1*1.09*0.95	72%
				Medium	DC*1*1.09*1	NA
				High with manure	DC*1*1.09*1.37	71%
				High without manure	DC*1*1.09*1.04	72%
			No till	Low	DC*1*1.17*0.95	71%
				Medium	DC*1*1.17*1	NA
				High with manure	DC*1*1.17*1.37	70%
				High without manure	DC*1*1.171.04	71%
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.92	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.44	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use F_{LU}**	**Management F_{MG}**	**Input F_I**	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
				High without manure	DC*1*1*1.11	NA
			Reduced tillage	Low	DC*1*1.15*0.92	72%
				Medium	DC*1*1.15*1	NA
				High with manure	DC*1*1.15*1.44	71%
				High without manure	DC*1*1.15*1.11	68%
			No till	Low	DC*1*1.22*0.92	71%
				Medium	DC*1*1.22*1	NA
				High with manure	DC*1*1.22*1.44	70%
				High without manure	DC*1*1.22*1.11	67%
Tropical Montane	n/a	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.94	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.41	NA
				High without manure	DC*1*1*1.08	NA
			Reduced tillage	Low	DC*1*1.09*0.94	150%
				Medium	DC*1*1.09*1	150%
				High with manure	DC*1*1.09*1.41	150%
				High without manure	DC*1*1.09*1.08	150%
			No till	Low	DC*1*1.16*0.94	150%
				Medium	DC*1*1.16*1	NA
				High with manure	DC*1*1.16*1.41	150ù
				High without manure	DC*1*1.16*1.08	150%
Temperate/Boreal	Dry	Set aside (<20 yrs)	Full-tillage	Low	DC*0.93*1*0.95	NA
				Medium	DC*0.93*1*1	NA
				High with manure	DC*0.93*1*1.37	NA
				High without manure	DC*0.93*1*1.04	NA
			Reduced tillage	Low	DC*0.93*1.02*0.95	30%
				Medium	DC*0.93*1.02*1	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
				High with manure	DC*0.93*1.02*1.37	29%
				High without manure	DC*0.93*1.02*1.04	30%
			No till	Low	DC*0.93*1.1*0.95	28%
				Medium	DC*0.93*1.1*1	NA
				High with manure	DC*0.93*1.1*1.37	28%
				High without manure	DC*0.93*1.1*1.04	29%
	Moist/wet	Set aside (<20 yrs)	Full-tillage	Low	DC*0.82*1*0.92	NA
				Medium	DC*0.82*1*1	NA
				High with manure	DC*0.82*1*1.44	NA
				High without manure	DC*0.82*1*1.11	NA
			Reduced tillage	Low	DC*0.82*1.08*0.92	36%
				Medium	DC*0.82*1.08*1	NA
				High with manure	DC*0.82*1.08*1.44	35%
				High without manure	DC*0.82*1.08*1.11	32%
			No till	Low	DC*0.82*1.15*0.92	35%
				Medium	DC*0.82*1.15*1	NA
				High with manure	DC*0.82*1.15*1.44	34%
				High without manure	DC*0.82*1.15*1.11	31%
Tropical	Dry	Set aside (<20 yrs)	Full-tillage	Low	DC*0.93*1*0.95	NA
				Medium	DC*0.93*1*1	NA
				High with manure	DC*0.93*1*1.37	NA
				High without manure	DC*0.93*1*1.04	NA
			Reduced tillage	Low	DC*0.93*1.09*0.95	33%
				Medium	DC*0.93*1.09*1	NA
				High with manure	DC*0.93*1.09*1.37	32%
				High without manure	DC*0.93*1.09*1.04	33%
			No till	Low	DC*0.93*1.17*0.95	32%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** **F_{LU}**	**Management** **F_{MG}**	**Input** **F_{I}**	**$Dc*F_{LU}*F_{MG}*F_{I}$**	**Final Error**
				Medium	DC*0.93*1.17*1	NA
				High with manure	DC*0.93*1.17*1.37	31%
				High without manure	DC*0.93*1.17*1.04	32%
	Moist/wet	Set aside (<20 yrs)	Full-tillage	Low	DC*0.82*1*0.92	NA
				Medium	DC*0.82*1*1	NA
				High with manure	DC*0.82*1*1.44	NA
				High without manure	DC*0.82*1*1.11	NA
			Reduced tillage	Low	DC*0.82*1.15*0.92	39%
				Medium	DC*0.82*1.15*1	NA
				High with manure	DC*0.82*1.15*1.44	38%
				High without manure	DC*0.82*1.15*1.11	35%
			No till	Low	DC*0.82*1.22*0.92	38%
				Medium	DC*0.82*1.22*1	NA
				High with manure	DC*0.82*1.22*1.44	37%
				High without manure	DC*0.82*1.22*1.11	34%
Tropical Montane	n/a	Set aside (<20 yrs)	Full-tillage	Low	DC*0.88*1*0.94	NA
				Medium	DC*0.88*1*1	NA
				High with manure	DC*0.88*1*1.41	NA
				High without manure	DC*0.88*1*1.08	NA
			Reduced tillage	Low	DC*0.88*1.09*0.94	150%
				Medium	DC*0.88*1.09*1	NA
				High with manure	DC*0.88*1.09*1.41	150%
				High without manure	DC*0.88*1.09*1.08	150%
			No till	Low	DC*0.88*1.16*0.94	150%
				Medium	DC*0.88*1.16*1	NA
				High with manure	DC*0.88*1.16*1.41	150%
				High without manure	DC*0.88*1.16*1.08	150%

Table 10: Coefficients of Conversion from Degraded Grasslands

Table 10a- Coefficients of conversion from degraded grasslands (and savannahs) (DC: Default Carbon Value)

Fraction Land use (F_{LU}) = 1

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_I	$Dc*F_{LU}*F_{MG}*F_I$	Final Error
Temperate/Boreal	Dry	Grassland	Moderately degraded	Medium	DC*1*0.95*1	NA
				High	DC*1*0.95*1.11	NA
			Severely degraded	Medium	DC*1*0.7*1	NA
				High	DC*1*0.7*1.11	NA
	Moist/wet	Grassland	Moderately degraded	Medium	DC*1*0.95*1	NA
				High	DC*1*0.95*1.11	NA
			Severely degraded	Medium	DC*1*0.7*1	NA
				High	DC*1*0.7*1.11	NA
Tropical	Dry	Grassland	Moderately degraded	Medium	DC*1*0.97*1	NA
				High	DC*1*0.97*1.11	NA
			Severely degraded	Medium	DC*1*0.7*1	NA
				High	DC*1*0.7*1.11	NA
	Moist/wet	Savannah	Moderately degraded	Medium	DC*1*0.97*1	NA
				High	DC*1*0.97*1.11	NA
			Severely degraded	Medium	DC*1*0.7*1	NA
				High	DC*1*0.7*1.11	NA
Tropical Montane	n/a	Grassland	Moderately degraded	Medium	DC*1*0.96*1	NA
				High	DC*1*0.96*1.11	NA
			Severely degraded	Medium	DC*1*0.7*1	NA
				High	DC*1*0.7*1.11	NA

Table 10b - Coefficients of conversion to degraded croplands (DC: Default Carbon Value)

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
Temperate/Boreal	Dry	Long-term cultivated	Full-tillage	Low	DC*0.8*0.7*0.95	NA
				Medium	DC*0.8*0.7*1	NA
				High with manure	DC*0.8*0.7*1.37	NA
				High without manure	DC*0.8*0.7*1.04	NA
			Reduced tillage	Low	DC*0.8*1*0.95	28%
				Medium	DC*0.8*1*1	NA
				High with manure	DC*0.8*1*1.37	27%
				High without manure	DC*0.8*1*1.04	28%
			No till	Low	DC*0.8*1.1*0.95	27%
				Medium	DC*0.8*1.1*1	NA
				High with manure	DC*0.8*1.1*1.37	26%
				High without manure	DC*0.8*1.1*1.04	27%
	Moist/wet	Long-term cultivated	Full-tillage	Low	Dc*0.69*0.7*0.92	NA
				Medium	Dc*0.69*0.7*1	NA
				High with manure	Dc*0.69*0.7*1.44	NA
				High without manure	Dc*0.69*0.7*1.11	NA
			Reduced tillage	Low	Dc*0.69*1.03*0.92	31%
				Medium	Dc*0.69*1.03*1	NA
				High with manure	Dc*0.69*1.03*1.44	30%
				High without manure	Dc*0.69*1.03*1.11	27%
			No till	Low	Dc*0.69*1.15*0.92	30%
				Medium	Dc*0.69*1.15*1	NA
				High with manure	Dc*0.69*1.15*1.44	29%
				High without manure	Dc*0.69*1.15*1.11	26%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
Tropical	Dry	Long-term cultivated	Full-tillage	Low	DC*0.58*0.7*0.95	NA
				Medium	DC*0.58*0.7*1	NA
				High with manure	DC*0.58*0.7*1.37	NA
				High without manure	DC*0.58*0.7*1.04	NA
			Reduced tillage	Low	DC*0.58*1.06*0.95	83%
				Medium	DC*0.58*1.06*1	NA
				High with manure	DC*0.58*1.06*1.37	82%
				High without manure	DC*0.58*1.06*1.04	83%
			No till	Low	DC*0.58*1.17*0.95	82%
				Medium	DC*0.58*1.17*1	NA
				High with manure	DC*0.58*1.17*1.37	81%
				High without manure	DC*0.58*1.17*1.04	82%
	Moist/wet	Long-term cultivated	Full-tillage	Low	DC*0.48*0.7*0.92	NA
				Medium	DC*0.48*0.7*1	NA
				High with manure	DC*0.48*0.7*1.44	NA
				High without manure	DC*0.48*0.7*1.11	NA
			Reduced tillage	Low	DC*0.48*1.12*0.92	68%
				Medium	DC*0.48*1.12*1	NA
				High with manure	DC*0.48*1.12*1.44	67%
				High without manure	DC*0.48*1.12*1.11	64%
			No till	Low	DC*0.48*1.22*0.92	68%
				Medium	DC*0.48*1.22*1	NA
				High with manure	DC*0.48*1.22*1.44	66%
				High without manure	DC*0.48*1.22*1.11	63%
Tropical Montane	n/a	Long-term cultivated	Full-tillage	Low	DC*0.64*0.7*0.94	NA
				Medium	DC*0.64*0.7*1	NA
				High with manure	DC*0.64*0.7*1.41	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	$Dc*F_{LU}*F_{MG}*F_I$	**Final Error**
				High without manure	DC*0.64*0.7*1.08	NA
			Reduced tillage	Low	DC*0.64*1.05*0.94	150%
				Medium	DC*0.64*1.05*1	NA
				High with manure	DC*0.64*1.05*1.41	150%
				High without manure	DC*0.64*1.05*1.08	150%
			No till	Low	DC*0.64*1.16*0.94	150%
				Medium	DC*0.64*1.16*1	NA
				High with manure	DC*0.64*1.16*1.41	150%
				High without manure	DC*0.64*1.16*1.08	150%
Temperate/Boreal	Dry	Paddy rice	Full-tillage	Low	DC*1.1*0.7*0.95	NA
				Medium	DC*1.1*0.7*1	NA
				High with manure	DC*1.1*0.7*1.37	NA
				High without manure	DC*1.1*0.7*1.04	NA
			Reduced tillage	Low	DC*1.1*1*0.95	69%
				Medium	DC*1.1*1*1	NA
				High with manure	DC*1.1*1*1.37	68%
				High without manure	DC*1.1*1*1.04	59%
			No till	Low	DC*1.1*1.1*0.95	68%
				Medium	DC*1.1*1.1*1	NA
				High with manure	DC*1.1*1.1*1.37	67%
				High without manure	DC*1.1*1.1*1.04	68%
	Moist/wet	Paddy rice	Full-tillage	Low	DC*1.1*0.7*0.92	NA
				Medium	DC*1.1*0.7*1	NA
				High with manure	DC*1.1*0.7*1.44	NA
				High without manure	DC*1.1*0.7*1.11	NA
			Reduced tillage	Low	DC*1.1*1.03*0.92	70%
				Medium	DC*1.1*1.03*1	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
				High with manure	DC*1.1*1.03*1.44	69%
				High without manure	DC*1.1*1.03*1.11	66%
			No till	Low	DC*1.1*1.15*0.92	69%
				Medium	DC*1.1*1.15*1	NA
				High with manure	DC*1.1*1.15*1.44	68%
				High without manure	DC*1.1*1.15*1.11	65%
Tropical	Dry	Paddy rice	Full-tillage	Low	DC*1.1*0.7*0.95	NA
				Medium	DC*1.1*0.7*1	NA
				High with manure	DC*1.1*0.7*1.37	NA
				High without manure	DC*1.1*0.7*1.04	NA
			Reduced tillage	Low	DC*1.1*1.06*0.95	72%
				Medium	DC*1.1*1.06*1	NA
				High with manure	DC*1.1*1.06*1.37	71%
				High without manure	DC*1.1*1.06*1.04	72%
			No till	Low	DC*1.1*1.17*0.95	71%
				Medium	DC*1.1*1.17*1	NA
				High with manure	DC*1.1*1.17*1.37	70%
				High without manure	DC*1.1*1.17*1.04	71%
	Moist/wet	Paddy rice	Full-tillage	Low	DC*1.1*0.7*0.92	NA
				Medium	DC*1.1*0.7*1	NA
				High with manure	DC*1.1*0.7*1.44	NA
				High without manure	DC*1.1*0.7*1.11	NA
			Reduced tillage	Low	DC*1.1*1.12*0.92	72%
				Medium	DC*1.1*1.12*1	NA
				High with manure	DC*1.1*1.12*1.44	71%
				High without manure	DC*1.1*1.12*1.11	68%
			No till	Low	DC*1.1*1.22*0.92	71%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	$Dc*F_{LU}*F_{MG}*F_I$	**Final Error**
				Medium	DC*1.1*1.22*1	NA
				High with manure	DC*1.1*1.22*1.44	70%
				High without manure	DC*1.1*1.22*1.11	67%
Tropical Montane	n/a	Paddy rice	Full-tillage	Low	DC*1.1*0.7*0.94	NA
				Medium	DC*1.1*0.7*1	NA
				High with manure	DC*1.1*0.7*1.41	NA
				High without manure	DC*1.1*0.7*1.08	NA
			Reduced tillage	Low	DC*1.1*1.05*0.94	150%
				Medium	DC*1.1*1.05*1	NA
				High with manure	DC*1.1*1.05*1.41	150%
				High without manure	DC*1.1*1.05*1.08	150%
			No till	Low	DC*1.1*1.16*0.94	150%
				Medium	DC*1.1*1.16*1	150%
				High with manure	DC*1.1*1.16*1.41	150%
				High without manure	DC*1.1*1.16*1.08	150%
Temperate/Boreal	Dry	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.95	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.37	NA
				High without manure	DC*1*0.7*1.04	NA
			Reduced tillage	Low	DC*1*1*0.95	69%
				Medium	DC*1*1.*1	NA
				High with manure	DC*1*1*1.37	68%
				High without manure	DC*1*1*1.04	69%
			No till	Low	DC*1*1.1*0.95	68%
				Medium	DC*1*1.1*1	NA
				High with manure	DC*1*1.1*1.37	67%
				High without manure	DC*1*1.1*1.04	68%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.92	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.44	NA
				High without manure	DC*1*0.7*1.11	NA
			Reduced tillage	Low	DC*1*1.03*0.92	69%
				Medium	DC*1*1.03*1	NA
				High with manure	DC*1*1.03*1.44	68%
				High without manure	DC*1*1.03*1.11	65%
			No till	Low	DC*1*1.15*0.92	68%
				Medium	DC*1*1.15*1	NA
				High with manure	DC*1*1.15*1.44	67%
				High without manure	DC*1*1.15*1.11	64%
Tropical	Dry	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.95	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.37	NA
				High without manure	DC*1*0.7*1.04	NA
			Reduced tillage	Low	DC*1*1.06*0.95	72%
				Medium	DC*1*1.06*1	NA
				High with manure	DC*1*1.06*1.37	71%
				High without manure	DC*1*1.06*1.04	72%
			No till	Low	DC*1*1.17*0.95	71%
				Medium	DC*1*1.17*1	NA
				High with manure	DC*1*1.17*1.37	70%
				High without manure	DC*1*1.171.04	71%
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.92	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.44	NA

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_I	$Dc*F_{LU}*F_{MG}*F_I$	Final Error
				High without manure	DC*1*0.7*1.11	NA
			Reduced tillage	Low	DC*1*1.12*0.92	72%
				Medium	DC*1*1.12*1	NA
				High with manure	DC*1*1.12*1.44	71%
				High without manure	DC*1*1.12*1.11	68%
			No till	Low	DC*1*1.22*0.92	71%
				Medium	DC*1*1.22*1	NA
				High with manure	DC*1*1.22*1.44	70%
				High without manure	DC*1*1.22*1.11	67%
Tropical Montane	n/a	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.94	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.41	NA
				High without manure	DC*1*0.7*1.08	NA
			Reduced tillage	Low	DC*1*1.05*0.94	150%
				Medium	DC*1*1.05*1	150%
				High with manure	DC*1*1.05*1.41	150%
				High without manure	DC*1*1.05*1.08	150%
			No till	Low	DC*1*1.16*0.94	150%
				Medium	DC*1*1.16*1	NA
				High with manure	DC*1*1.16*1.41	150%
				High without manure	DC*1*1.16*1.08	150%
Temperate/Boreal	Dry	Set aside (<20 yrs)	Full-tillage	Low	DC*0.93*0.7*0.95	NA
				Medium	DC*0.93*0.7*1	NA
				High with manure	DC*0.93*0.7*1.37	NA
				High without manure	DC*0.93*0.7*1.04	NA
			Reduced tillage	Low	DC*0.93*12*0.95	30%
				Medium	DC*0.93*1*1	NA

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_I	$Dc*F_{LU}*F_{MG}*F_I$	Final Error
				High with manure	DC*0.93*1*1.37	29%
				High without manure	DC*0.93*1*1.04	30%
			No till	Low	DC*0.93*1.1*0.95	28%
				Medium	DC*0.93*1.1*1	NA
				High with manure	DC*0.93*1.1*1.37	28%
				High without manure	DC*0.93*1.1*1.04	29%
	Moist/wet	Set aside (<20 yrs)	Full-tillage	Low	DC*0.82*0.7*0.92	NA
				Medium	DC*0.82*0.7*1	NA
				High with manure	DC*0.82*0.7*1.44	NA
				High without manure	DC*0.82*0.7*1.11	NA
			Reduced tillage	Low	DC*0.82*1.03*0.92	36%
				Medium	DC*0.82*1.03*1	NA
				High with manure	DC*0.82*1.03*1.44	35%
				High without manure	DC*0.82*1.03*1.11	32%
			No till	Low	DC*0.82*1.15*0.92	35%
				Medium	DC*0.82*1.15*1	NA
				High with manure	DC*0.82*1.15*1.44	34%
				High without manure	DC*0.82*1.15*1.11	31%
Tropical	Dry	Set aside (<20 yrs)	Full-tillage	Low	DC*0.93*0.7*0.95	NA
				Medium	DC*0.93*0.7*1	NA
				High with manure	DC*0.93*0.7*1.37	NA
				High without manure	DC*0.93*0.7*1.04	NA
			Reduced tillage	Low	DC*0.93*1.06*0.95	33%
				Medium	DC*0.93*1.06*1	NA
				High with manure	DC*0.93*1.06*1.37	32%
				High without manure	DC*0.93*1.06*1.04	33%
			No till	Low	DC*0.93*1.17*0.95	32%

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** **F_{LU}**	**Management** **F_{MG}**	**Input** **F_I**	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
				Medium	DC*0.93*1.17*1	NA
				High with manure	DC*0.93*1.17*1.37	31%
				High without manure	DC*0.93*1.17*1.04	32%
	Moist/wet	Set aside (<20 yrs)	Full-tillage	Low	DC*0.82*0.7*0.92	NA
				Medium	DC*0.82*0.7*1	NA
				High with manure	DC*0.82*0.7*1.44	NA
				High without manure	DC*0.82*0.7*1.11	NA
			Reduced tillage	Low	DC*0.82*1.12*0.92	39%
				Medium	DC*0.82*1.12*1	NA
				High with manure	DC*0.82*1.12*1.44	38%
				High without manure	DC*0.82*1.12*1.11	35%
			No till	Low	DC*0.82*1.22*0.92	38%
				Medium	DC*0.82*1.22*1	NA
				High with manure	DC*0.82*1.22*1.44	37%
				High without manure	DC*0.82*1.22*1.11	34%
Tropical Montane	n/a	Set aside (<20 yrs)	Full-tillage	Low	DC*0.88*0.7*0.94	NA
				Medium	DC*0.88*0.7*1	NA
				High with manure	DC*0.88*0.7*1.41	NA
				High without manure	DC*0.88*0.7*1.08	NA
			Reduced tillage	Low	DC*0.88*1.05*0.94	150%
				Medium	DC*0.88*1.05*1	NA
				High with manure	DC*0.88*1.05*1.41	150%
				High without manure	DC*0.88*1.05*1.08	150%
			No till	Low	DC*0.88*1.16*0.94	150%
				Medium	DC*0.88*1.16*1	NA
				High with manure	DC*0.88*1.16*1.41	150%
				High without manure	DC*0.88*1.16*1.08	150%

Table 11: Coefficients of Conversion from Forest and Wooded Savannah

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
Temperate/Boreal	Dry	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.95	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.37	NA
				High without manure	DC*1*1*1.04	NA
			Reduced tillage	Low	DC*1*1.02*0.95	69%
				Medium	DC*1*1.02*1	NA
				High with manure	DC*1*1.02*1.37	68%
				High without manure	DC*1*1.02*1.04	69%
			No till	Low	DC*1*1.1*0.95	68%
				Medium	DC*1*1.1*1	NA
				High with manure	DC*1*1.1*1.37	67%
				High without manure	DC*1*1.1*1.04	68%
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.92	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.44	NA
				High without manure	DC*1*1*1.11	NA
			Reduced tillage	Low	DC*1*1.08*0.92	69%
				Medium	DC*1*1.08*1	NA
				High with manure	DC*1*1.08*1.44	68%
				High without manure	DC*1*1.08*1.11	65%
			No till	Low	DC*1*1.15*0.92	68%
				Medium	DC*1*1.15*1	NA
				High with manure	DC*1*1.15*1.44	67%
				High without manure	DC*1*1.15*1.11	64%
Tropical	Dry	Perennial/	Full-tillage	Low	DC*1*1*0.95	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
		Tree crop		Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.37	NA
				High without manure	DC*1*1*1.04	NA
			Reduced tillage	Low	DC*1*1.09*0.95	72%
				Medium	DC*1*1.09*1	NA
				High with manure	DC*1*1.09*1.37	71%
				High without manure	DC*1*1.09*1.04	72%
			No till	Low	DC*1*1.17*0.95	71%
				Medium	DC*1*1.17*1	NA
				High with manure	DC*1*1.17*1.37	70%
				High without manure	DC*1*1.171.04	71%
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.92	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.44	NA
				High without manure	DC*1*1*1.11	NA
			Reduced tillage	Low	DC*1*1.15*0.92	72%
				Medium	DC*1*1.15*1	NA
				High with manure	DC*1*1.15*1.44	71%
				High without manure	DC*1*1.15*1.11	68%
			No till	Low	DC*1*1.22*0.92	71%
				Medium	DC*1*1.22*1	NA
				High with manure	DC*1*1.22*1.44	70%
				High without manure	DC*1*1.22*1.11	67%
Tropical Montane	n/a	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.94	NA
				Medium	DC*1*1*1	NA
				High with manure	DC*1*1*1.41	NA
				High without manure	DC*1*1*1.08	NA

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_I	$Dc*F_{LU}*F_{MG}*F_I$	Final Error
			Reduced tillage	Low	DC*1*1.09*0.94	150%
				Medium	DC*1*1.09*1	NA
				High with manure	DC*1*1.09*1.41	150%
				High without manure	DC*1*1.09*1.08	150%
			No till	Low	DC*1*1.16*0.94	150%
				Medium	DC*1*1.16*1	NA
				High with manure	DC*1*1.16*1.41	150%
				High without manure	DC*1*1.16*1.08	150%
All	All	Native Forest Or wooded savannah (non degraded)	n/a	n/a	DC*1*..*..*..	NA
All	All	Managed forest	All	All	DC*1*1*1*1	NA
Tropical	Moist/dry	Shifting cultivation- shortened fallow: clear native forest for 3 years and natural regrowth	n/a	n/a	DC*0.64*1*..*..	NA
	Moist/dry	Shifting cultivation- mature fallow: clear native forest for 3 years and natural regrowth	n/a	n/a	DC*0.8*1*..*..	NA
Temperate/Boreal	Moist/dry	Shifting cultivation- shortened fallow: clear native forest for 3 years and natural regrowth	n/a	n/a	DC*1*1*..*..	NA

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_{I}	$Dc*F_{LU}*F_{MG}*F_{I}$	Final Error
	Moist/dry	Shifting cultivation- mature fallow: clear native forest for 3 years and natural regrowth	n/a	n/a	DC*1*1*..*..	NA

Table 12: Coefficients of Conversion from Degraded Forest and Wooded Savannah

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** **F_{LU}**	**Management** **F_{MG}**	**Input** **F_I**	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
Temperate/Boreal	Dry	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.95	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.37	NA
				High without manure	DC*1*0.7*1.04	NA
			Reduced tillage	Low	DC*1*1*0.95	69%
				Medium	DC*1*1.*1	NA
				High with manure	DC*1*1*1.37	68%
				High without manure	DC*1*1*1.04	69%
			No till	Low	DC*1*1.1*0.95	68%
				Medium	DC*1*1.1*1	NA
				High with manure	DC*1*1.1*1.37	67%
				High without manure	DC*1*1.1*1.04	68%
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.92	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.44	NA
				High without manure	DC*1*0.7*1.11	NA
			Reduced tillage	Low	DC*1*1.03*0.92	69%
				Medium	DC*1*1.03*1	NA
				High with manure	DC*1*1.03*1.44	68%
				High without manure	DC*1*1.03*1.11	65%
			No till	Low	DC*1*1.15*0.92	68%
				Medium	DC*1*1.15*1	NA
				High with manure	DC*1*1.15*1.44	67%
				High without manure	DC*1*1.15*1.11	64%
Tropical	Dry	Perennial/	Full-tillage	Low	DC*1*0.7*0.95	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** F_{LU}	**Management** F_{MG}	**Input** F_I	**Dc*F_{LU}*F_{MG}*F_I**	**Final Error**
		Tree crop		Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.37	NA
				High without manure	DC*1*0.7*1.04	NA
			Reduced tillage	Low	DC*1*1.06*0.95	72%
				Medium	DC*1*1.06*1	NA
				High with manure	DC*1*1.06*1.37	71%
				High without manure	DC*1*1.06*1.04	72%
			No till	Low	DC*1*1.17*0.95	71%
				Medium	DC*1*1.17*1	NA
				High with manure	DC*1*1.17*1.37	70%
				High without manure	DC*1*1.17*1.04	71%
	Moist/wet	Perennial/ Tree crop	Full-tillage	Low	DC*1*0.7*0.92	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.44	NA
				High without manure	DC*1*0.7*1.11	NA
			Reduced tillage	Low	DC*1*1.12*0.92	72%
				Medium	DC*1*1.12*1	NA
				High with manure	DC*1*1.12*1.44	71%
				High without manure	DC*1*1.12*1.11	68%
			No till	Low	DC*1*1.22*0.92	71%
				Medium	DC*1*1.22*1	NA
				High with manure	DC*1*1.22*1.44	70%
				High without manure	DC*1*1.22*1.11	67%
Tropical Montane	n/a	Perennial/ Tree crop	Full-tillage	Low	DC*1*1*0.94	NA
				Medium	DC*1*0.7*1	NA
				High with manure	DC*1*0.7*1.41	NA
				High without manure	DC*1*0.7*1.08	NA

Climate Zone Temperate Regime	Moisture Regime	Land Use F_{LU}	Management F_{MG}	Input F_I	$Dc*F_{LU}*F_{MG}*F_I$	Final Error
			Reduced tillage	Low	DC*1*1.05*0.94	150%
				Medium	DC*1*1.05*1	NA
				High with manure	DC*1*1.05*1.41	150%
				High without manure	DC*1*1.05*1.08	150%
			No till	Low	DC*1*1.16*0.94	150%
				Medium	DC*1*1.16*1	NA
				High with manure	DC*1*1.16*1.41	150%
				High without manure	DC*1*1.16*1.08	150%
All	All	Native Forest or wooded savannah (non degraded)	n/a	n/a	DC*1*..*..*..	NA
All	All	Managed Forest	All	All	DC*1*1*1*1	NA
Tropical	Moist/dry	Shifting cultivation-shortened fallow: clear native forest for 3 years and natural regrowth	n/a	n/a	DC*0.64*1*..*..	NA
		Shifting cultivation-mature fallow: clear native forest for 3-5 years and natural regrowth	n/a	n/a	DC*0.8*1*..*..	NA
Temperate/Boreal	Moist/dry	Shifting cultivation-shortened fallow: clear native forest for 3-5 years and natural regrowth	n/a	n/a	DC*1*1*..*..	NA

Climate Zone **Temperate Regime**	**Moisture Regime**	**Land Use** **F_{LU}**	**Management** **F_{MG}**	**Input** **F_I**	**$Dc*F_{LU}*F_{MG}*F_I$**	**Final Error**
		Shifting cultivation-mature fallow: clear native forest for 3-5 years and natural regrowth	n/a	n/a	DC*1*1*..*..	NA

Table 13: Data for Conversion from Grassland

Climate Region	**Total C stock in non-woody biomass (above- and below-ground) (IPCC default)**	**Uncertainty (IPCC default)**
	t C ha^{-1}	**%**
Boreal – Dry & Wet	4.3	± 75%
Cool Temperate – Dry	3.3	± 75%
Cool Temperate –Wet	6.8	± 75%
Warm Temperate – Dry	3.1	± 75%
Warm Temperate –Wet	6.8	± 75%
Tropical – Dry	4.4	± 75%
Tropical - Moist & Wet	8.1	± 75%

Table 14: Data for Conversion from Forest (less than 30 % cover)

Formula: = 0.2*B*(1+R)*CF

Domain	Ecological zone	Continent	Total C stock in biomass (above- and below-ground)	Range of total carbon stock	Factor B: Forest Average above-ground biomass (IPCC default)	Factor R: Root-to-shoot ratio (IPCC default)
			t C ha^{-1}	*t C ha^{-1}*	*t dm ha^{-1}*	
Tropical	Tropical rain forest	Africa	40	17 - 66	310	0.37
		North and South America	39	15 - 52	300	0.37
		Asia (continental)	36	15 - 88	280	0.37
		Asia (insular)	45	36 - 67	350	0.37
	Tropical moist deciduous forest	Africa	30	19 - 50	260	0.24
		North and South America	26	24 - 33	220	0.24
		Asia (continental)	21	1 - 65	180	0.24
		Asia (insular)	34		290	0.24
	Tropical dry forest	Africa	14	14 - 16	120	0.28
		North and South America	25	24 - 49	210	0.28
		Asia (continental)	16	12 - 19	130	0.28
		Asia (insular)	19		160	0.28
	Tropical mountain systems	Africa	13	5 - 22	115	0.24
		North and South America	17	7 - 27	145	0.24
		Asia (continental)	16	6 - 26	135	0.24
		Asia (insular)	26	6 - 43	220	0.28
Subtropical	Subtropical humid forest	North and South America	26	25 - 34	220	0.28
		Asia (continental)	22	1 - 67	180	0.28

Domain	**Ecological zone**	**Continent**	**Total C stock in biomass (above- and below-ground)** *t C ha^{-1}*	**Range of total carbon stock** *t C ha^{-1}*	**Factor B: Forest Average above-ground biomass (IPCC default)** *t dm ha^{-1}*	**Factor R: Root-to-shoot ratio (IPCC default)**
		Asia (insular)	35		290	0.28
	Subtropical dry forest	Africa	17		140	0.28
		North and South America	26	25 - 51	210	0.32
		Asia (continental)	16	12 - 20	130	0.32
		Asia (insular)	20		160	0.32
	Subtropical steppe	Africa	9	2 - 25	70	0.32
		North and South America	10	5 - 11	80	0.32
		Asia (continental)	7		60	0.32
		Asia (insular)	9		70	0.32
Temperate	Temperate oceanic forest	Europe	14		120	0.27
		North America	79	10 - 143	660	0.27
		New Zealand	43	25 - 51	360	0.27
		South America	21	11 - 37	180	0.27
	Temperate continental forest	Asia, Europe (≤20 y)	2		20	0.27
		Asia, Europe (>20 y)	14	2 - 38	120	0.27
		North and South America (≤20 y)	7	1 - 16	60	0.27
		North and South America (>20 y)	16	6 - 24	130	0.27
	Temperate mountain systems	Asia, Europe (≤20 y)	12	2 - 21	100	0.27
		Asia, Europe (>20 y)	16	2 - 72	130	0.27
		North and South America (≤20 y)	6	2 - 13	50	0.27

Domain	Ecological zone	Continent	Total C stock in biomass (above- and below-ground)	Range of total carbon stock	Factor B: Forest Average above-ground biomass (IPCC default)	Factor R: Root-to-shoot ratio (IPCC default)
			t C ha^{-1}	*t C ha^{-1}*	*t dm ha^{-1}*	
		North and South America (>20 y)	6	5 - 33	50	0.27
Boreal	Boreal coniferous forest	Asia, Europe, North America	12	1 - 10	100	0.24
	Boreal tundra woodland	Asia, Europe, North America (≤20 y)	0		4	0.24
		Asia, Europe, North America (>20 y)	2		15	0.24
	Boreal mountain systems	Asia, Europe, North America (≤20 y)	2	1 - 2	15	0.24
		Asia, Europe, North America (>20 y)	6	5 - 6	50	0.24

Table 15: Data for Conversion from Forest (more than 30 % cover)

Domain	**Ecological Zone**	**Continent**	**Total C stock in biomass (above- and below-ground) and dead organic matter (IPCC default)**	**Range of total carbon stock**
			t C ha^{-1}	*t C ha^{-1}*
Tropical	Tropical rain forest	Africa	204	94 - 355
		North and South America	198	87 - 279
		Asia (continental)	185	87 - 471
		Asia (insular)	230	197 - 361
	Tropical moist deciduous forest	Africa	156	104 - 272
		North and South America	133	135 - 179
		Asia (continental)	110	11 - 352
		Asia (insular)	174	186 - 186
	Tropical dry forest	Africa	77	82 - 88
		North and South America	131	133 - 268
		Asia (continental)	83	69 - 108
		Asia (insular)	101	108 - 109
	Tropical mountain systems	Africa	77	31 - 127
		North and South America	94	43 - 153
		Asia (continental)	88	37 - 145
		Asia (insular)	130	37 - 234
Subtropical	Subtropical humid forest	North and South America	132	134 - 178
		Asia (continental)	109	10 - 351
		Asia (insular)	173	184 - 184
	Subtropical dry forest	Africa	88	94 - 94

Domain	Ecological Zone	Continent	Total C stock in biomass (above- and below-ground) and dead organic matter (IPCC default) *t C ha^{-1}*	Range of total carbon stock *t C ha^{-1}*
		North and South America	130	132 - 267
		Asia (continental)	82	68 - 107
		Asia (insular)	100	107 - 108
	Subtropical steppe	Africa	46	17 - 132
		North and South America	53	31 - 64
		Asia (continental)	41	44 - 44
		Asia (insular)	47	50 - 50
Temperate	Temperate oceanic forest	Europe	84	90 - 90
		North America	406	64 - 775
		New Zealand	227	146 - 286
		South America	120	70 - 210
	Temperate continental forest	Asia, Europe (≤20 y)	27	29 - 30
		Asia, Europe (>20 y)	87	29 - 219
		North and South America (≤20 y)	51	22 - 99
		North and South America (>20 y)	93	48 - 143
	Temperate mountain systems	Asia, Europe (≤20 y)	75	29 - 130
		Asia, Europe (>20 y)	93	29 - 397
		North and South America (≤20 y)	45	29 - 86
		North and South America (>20 y)	93	41 - 194
Boreal	Boreal coniferous forest	Asia, Europe, North America	53	31 - 82
	Boreal tundra woodland	Asia, Europe, North America (≤20 y)	26	27 - 27

Domain	**Ecological Zone**	**Continent**	**Total C stock in biomass (above- and below-ground) and dead organic matter (IPCC default)** *t C ha^{-1}*	**Range of total carbon stock** *t C ha^{-1}*
		Asia, Europe, North America (>20 y)	35	34 - 37
	Boreal mountain systems	Asia, Europe, North America (≤20 y)	32	32 - 34
		Asia, Europe, North America (>20 y)	53	50 - 56

Table 16: Data for Conversion from Shrubland

Domain	**Continent**	**Total C stock in biomass**	**Uncertainty**
		t C ha^{-1}	*%*
Tropical	Africa	46	± 60 %
	North and South America	53	± 60 %
	Asia (continental)	39	± 60 %
	Asia (insular)	46	± 60 %
	Australia	46	± 60 %
Subtropical	Africa	43	± 60 %
	North and South America	50	± 60 %
	Asia (continental)	37	± 60 %
	Europe	37	± 60 %
	Asia (insular)	43	± 60 %
Temperate	Global	7.4	± 60 %

Table 17: Data for Conversion from Cropland (perennial crops)

Climate Region	**Total C stock in biomass above- and bellow-ground (0.5 x IPCC default)**[22]	**Uncertainty (IPCC default)**
	t C ha^{-1}	**%**
Temperate (all moisture regimes)	43.2	± 75%
Tropical, dry	6.2	± 75%
Tropical, moist	14.4	± 75%
Tropical, wet	34.3	± 75%

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[22] IPCC figures apply to mature woody crops, figures in table are 0.5 x IPCC default values..

Table 18: Data for Conversion from/to Forest Plantations

Formula: = B*(1+R)*CF

Domain	Ecological Zone	Continent	Total C stock in biomass (above- and below-ground) *t C ha^{-1}*	Factor B: Above-ground biomass (IPCC default) *t dm ha^{-1}*	Factor R: Root-to-shoot ratio (IPCC default)
Tropical	Tropical rain forest	Africa broadleaf > 20 y	87	300	0.24
		Africa broadleaf ≤ 20 y	29	100	0.24
		Africa Pinus sp. > 20 y	58	200	0.24
		Africa Pinus sp. ≤ 20 y	17	60	0.24
		Americas Eucalyptus sp.	58	200	0.24
		Americas Pinus sp.	87	300	0.24
		Americas Tectona grandis	70	240	0.24
		Americas other broadleaf	44	150	0.24
		Asia broadleaf	64	220	0.24
		Asia other	38	130	0.24
	Tropical moist deciduous forest	Africa broadleaf > 20 y	44	150	0.24
		Africa broadleaf ≤ 20 y	23	80	0.24
		Africa Pinus sp. > 20 y	35	120	0.24
		Africa Pinus sp. ≤ 20 y	12	40	0.24
		Americas Eucalyptus sp.	26	90	0.24
		Americas Pinus sp.	79	270	0.24
		Americas Tectona grandis	35	120	0.24
		Americas other broadleaf	29	100	0.24
		Asia broadleaf	52	180	0.24
		Asia other	29	100	0.24
	Tropical dry forest	Africa broadleaf > 20 y	21	70	0.28
		Africa broadleaf ≤ 20 y	9	30	0.28
		Africa Pinus sp. > 20 y	18	60	0.28

Domain	Ecological Zone	Continent	Total C stock in biomass (above- and below-ground) *t C ha⁻¹*	Factor B: Above-ground biomass (IPCC default) *t dm ha⁻¹*	Factor R: Root-to-shoot ratio (IPCC default)
		Africa Pinus sp. ≤ 20 y	6	20	0.28
		Americas Eucalyptus sp.	27	90	0.28
		Americas Pinus sp.	33	110	0.28
		Americas Tectona grandis	27	90	0.28
		Americas other broadleaf	18	60	0.28
		Asia broadleaf	27	90	0.28
		Asia other	18	60	0.28
	Tropical shrubland	Africa broadleaf	6	20	0.27
		Africa Pinus sp. > 20 y	6	20	0.27
		Africa Pinus sp. ≤ 20 y	4	15	0.27
		Americas Eucalyptus sp.	18	60	0.27
		Americas Pinus sp.	18	60	0.27
		Americas Tectona grandis	15	50	0.27
		Americas other broadleaf	9	30	0.27
		Asia broadleaf	12	40	0.27
		Asia other	9	30	0.27
	Tropical mountain systems	Africa broadleaf > 20 y	31	60-150	0.24
		Africa broadleaf ≤ 20 y	20	40-100	0.24
		Africa Pinus sp. > 20 y	19	30-100	0.24
		Africa Pinus sp. ≤ 20 y	7	10-40	0.24
		Americas Eucalyptus sp.	22	30-120	0.24
		Americas Pinus sp.	29	60-170	0.24
		Americas Tectona grandis	23	30-130	0.24
		Americas other broadleaf	16	30-80	0.24
		Asia broadleaf	28	40-150	0.24
		Asia other	15	25-80	0.24

Domain	**Ecological Zone**	**Continent**	**Total C stock in biomass (above- and below-ground)** *t C ha⁻¹*	**Factor B: Above-ground biomass (IPCC default)** *t dm ha⁻¹*	**Factor R: Root-to-shoot ratio (IPCC default)**
Subtropical	Subtropical humid forest	Americas Eucalyptus sp.	42	140	0.28
		Americas Pinus sp.	81	270	0.28
		Americas Tectona grandis	36	120	0.28
		Americas other broadleaf	30	100	0.28
		Asia broadleaf	54	180	0.28
		Asia other	30	100	0.28
	Subtropical dry forest	Africa broadleaf > 20 y	21	70	0.28
		Africa broadleaf ≤ 20 y	9	30	0.32
		Africa Pinus sp. > 20 y	19	60	0.32
		Africa Pinus sp. ≤ 20 y	6	20	0.32
		Americas Eucalyptus sp.	34	110	0.32
		Americas Pinus sp.	34	110	0.32
		Americas Tectona grandis	28	90	0.32
		Americas other broadleaf	19	60	0.32
		Asia broadleaf	28	90	0.32
		Asia other	19	60	0.32
	Subtropical steppe	Africa broadleaf	6	20	0.32
		Africa Pinus sp. > 20 y	6	20	0.32
		Africa Pinus sp. ≤ 20 y	5	15	0.32
		Americas Eucalyptus sp.	19	60	0.32
		Americas Pinus sp.	19	60	0.32
		Americas Tectona grandis	16	50	0.32
		Americas other broadleaf	9	30	0.32
		Asia broadleaf > 20 y	25	80	0.32
		Asia broadleaf ≤ 20 y	3	10	0.32
		Asia coniferous > 20 y	6	20	0.32

Domain	Ecological Zone	Continent	Total C stock in biomass (above- and below-ground) *t C ha^{-1}*	Factor B: Above-ground biomass (IPCC default) *t dm ha^{-1}*	Factor R: Root-to-shoot ratio (IPCC default)
		Asia coniferous ≤ 20 y	34	100-120	0.32
	Subtropical mountain systems	Africa broadleaf > 20 y	31	60-150	0.24
		Africa broadleaf ≤ 20 y	20	40-100	0.24
		Africa Pinus sp. > 20 y	19	30-100	0.24
		Africa Pinus sp. ≤ 20 y	7	10-40	0.24
		Americas Eucalyptus sp.	22	30-120	0.24
		Americas Pinus sp.	34	60-170	0.24
		Americas Tectona grandis	23	30-130	0.24
		Americas other broadleaf	16	30-80	0.24
		Asia broadleaf	28	40-150	0.24
		Asia other	15	25-80	0.24
Temperate	Temperate oceanic forest	Asia, Europe, broadleaf > 20 y	60	200	0.27
		Asia, Europe, broadleaf ≤ 20 y	9	30	0.27
		Asia, Europe, coniferous > 20 y	60	150-250	0.27
		Asia, Europe, coniferous ≤ 20 y	12	40	0.27
		North America	52	50-300	0.27
		New Zealand	75	150-350	0.27
		South America	31	90-120	0.27
	Temperate continental forest and mountain systems	Asia, Europe, broadleaf > 20 y	60	200	0.27
		Asia, Europe, broadleaf ≤ 20 y	4	15	0.27
		Asia, Europe, coniferous > 20 y	52	150-200	0.27
		Asia, Europe, coniferous ≤ 20 y	7	25-30	0.27
		North America	52	50-300	0.27
		South America	31	90-120	0.27
Boreal	Boreal coniferous forest and mountain systems	Asia, Europe > 20 y	12	40	0.24

Domain	Ecological Zone	Continent	Total C stock in biomass (above- and below-ground) t C ha^{-1}	Factor B: Above-ground biomass (IPCC default) t dm ha^{-1}	Factor R: Root-to-shoot ratio (IPCC default)
		Asia, Europe ≤ 20 y	1	5	0.24
		North America	13	40-50	0.24
	Boreal tundra woodland	Asia, Europe > 20 y	7	25	0.24
		Asia, Europe ≤ 20 y	1	5	0.24
		North America	7	25	0.24

Table 19: Data for Conversion from Degraded Grassland

Formula: = 0.4*B*CF

Climate region	Total C stock in non-woody biomass (above- and below-ground) *t C ha^{-1}*	Factor B: Total C stock in non-woody biomass (above- and below-ground) (IPCC default) *t C ha^{-1}*	Uncertainty %
Boreal – Dry & Wet	1.7	4.3	± 100%
Cool Temperate – Dry	1.3	3.3	± 100%
Cool Temperate –Wet	2.7	6.8	± 100%
Warm Temperate – Dry	1.2	3.1	± 100%
Warm Temperate –Wet	2.7	6.8	± 100%
Tropical – Dry	1.7	4.4	± 100%
Tropical - Moist & Wet	3.2	8.1	± 100%

Table 20: Data for Conversion from Degraded Forests

Formula: = 0.3*B*(1+R)*CF

Domain	Ecological zone	Continent	Total C stock in biomass (above- and below-ground) t C ha^{-1}	Factor B: Biomass (above-ground) (IPCC default) t d.m. ha^{-1}	Factor R: Root to shoot ratio (IPCC default)	Uncertainty %
Tropical	Tropical rain forest	Africa	60	310	0.37	± 100%
		North and South America	58	300	0.37	± 100%
		Asia (continental)	54	280	0.37	± 100%
		Asia (insular)	68	350	0.37	± 100%
	Tropical moist deciduous forest	Africa	45	260	0.24	± 100%
		North and South America	38	220	0.24	± 100%
		Asia (continental)	31	180	0.24	± 100%
		Asia (insular)	51	290	0.24	± 100%
	Tropical dry forest	Africa	22	120	0.28	± 100%
		North and South America	38	210	0.28	± 100%
		Asia (continental)	23	130	0.28	± 100%
		Asia (insular)	29	160	0.28	± 100%
	Tropical shrubland	Africa	21	70	0.27	± 100%
		North and South America	27	80	0.27	± 100%
		Asia (continental)	25	60	0.27	± 100%
		Asia (insular)	38	70	0.27	± 100%
Subtropical	Tropical mountain systems	Africa	38	115	0.24	± 100%
		North and South America	31	145	0.24	± 100%
		Asia (continental)	51	135	0.24	± 100%
		Asia (insular)	25	220	0.28	± 100%
	Subtropical humid forest	North and South America	38	220	0.28	± 100%

Domain	**Ecological zone**	**Continent**	**Total C stock in biomass (above- and below-ground)** *t C ha^{-1}*	**Factor B: Biomass (above-ground) (IPCC default)** *t d.m. ha^{-1}*	**Factor R: Root to shoot ratio (IPCC default)**	**Uncertainty** **%**
		Asia (continental)	23	180	0.28	± 100%
		Asia (insular)	29	290	0.28	± 100%
	Subtropical dry forest	Africa	13	140	0.28	± 100%
		North and South America	15	210	0.32	± 100%
		Asia (continental)	11	130	0.32	± 100%
		Asia (insular)	13	160	0.32	± 100%
	Subtropical steppe	Africa	9	70	0.32	± 100%
		North and South America	28	80	0.32	± 100%
		Asia (continental)	26	60	0.32	± 100%
		Asia (insular)	39	70	0.32	± 100%
Temperate	Temperate oceanic forest	Europe	21	120	0.27	± 100%
		North America	118	660	0.27	± 100%
		New Zealand	64	360	0.27	± 100%
		South America	32	180	0.27	± 100%
	Temperate continental forest	Asia, Europe (≤20 y)	4	20	0.27	± 100%
		Asia, Europe (>20 y)	21	120	0.27	± 100%
		North and South America (≤20 y)	11	60	0.27	± 100%
		North and South America (>20 y)	23	130	0.27	± 100%
	Temperate mountain systems	Asia, Europe (≤20 y)	18	100	0.27	± 100%
		Asia, Europe (>20 y)	23	130	0.27	± 100%
		North and South America (≤20 y)	9	50	0.27	± 100%
		North and South America (>20 y)	23	50	0.27	± 100%
Boreal	Boreal coniferous forest	Asia, Europe, North America	9	100	0.24	± 100%
	Boreal tundra woodland	Asia, Europe, North America (≤20 y)	1	4	0.24	± 100%
		Asia, Europe, North America (>20 y)	3	15	0.24	± 100%

Domain	**Ecological zone**	**Continent**	**Total C stock in biomass (above- and below-ground)** *t C ha^{-1}*	**Factor B: Biomass (above-ground) (IPCC default)** *t d.m. ha^{-1}*	**Factor R: Root to shoot ratio (IPCC default)**	**Uncertainty** **%**
	Boreal mountain systems	Asia, Europe, North America (≤20 y)	3	15	0.24	± 100%
		Asia, Europe, North America (>20 y)	9	50	0.24	± 100%

Table 21: Data for Conversion to Cropland Biofuel Crops

Domain	Climate Region	Ecological Zone	Continent	Biofuel Crop Type	Total C stock in total biomass	Uncertainties
					t C ha^{-1}	%
Tropical	Tropical dry	Tropical dry forest	Africa	Jatropha	17.5	± 75 %
			Africa	Oil palm	60	± 60 %
			Africa	Sugar cane	4.2	± 50 %
			Africa	Jojoba	2.4	NA
			Asia (continental, insular)	Oil palm	60	± 60 %
			Asia (continental, insular)	Coconuts	75	± 60 %
			Asia (continental, insular)	Sugar cane	4	± 50 %
			Asia (continental, insular)	Jojoba	2.4	NA
			Central and South America	Coconuts	75	± 60 %
			Central and South America	Jojoba	2.4	NA
		Tropical shrubland	Asia (continental, insular)	Sugar cane	4	± 50 %
			Asia (continental, insular)	Coconuts	75	± 60 %
			Asia (continental, insular)	Jatropha	17.5	± 75 %
			Australia	Coconuts	75	± 60 %
			Australia	Oil palm	60	± 60 %
			Australia	Jojoba	2.4	NA
			Central and South America	Jatropha	17.5	± 75 %
			Central and South America	Jojoba	2.4	NA
	Tropical moist	Tropical moist decidous forest	Africa	Coconuts	75	± 60 %
			Africa	Sugar cane	4.2	± 50 %
			Africa	Jatropha	17.5	± 75 %
			Africa	Oil palm	60	± 60 %
			Asia (continental, insular)	Oil palm	60	± 60 %
			Asia (continental, insular)	Jatropha	17.5	± 75 %
			Asia (continental, insular)	Coconuts	75	± 60 %
			Central and South America	Coconuts	75	± 60 %

Domain	Climate Region	Ecological Zone	Continent	Biofuel Crop Type	Total C stock in total biomass	Uncertainties
					t C ha^{-1}	%
			Central and South America	Oil palm	60	± 60 %
			Central and South America	Sugar cane	5	± 50 %
			Central and South America	Jatropha	17.5	± 75 %
	Tropical wet	Tropical rain forest	Africa	Jatropha	17.5	± 75 %
			Africa	Coconuts	75	± 60 %
			Asia (continental, insular)	Sugar cane	4	± 50 %
			Asia (continental, insular)	Coconuts	75	± 60 %
			Asia (continental, insular)	Oil palm	60	± 60 %
			Asia (continental, insular)	Jatropha	17.5	± 75 %
			Central and South America	Coconuts	75	± 60 %
			Central and South America	Oil palm	60	± 60 %
			Central and South America	Sugar cane	5	± 50 %
			Central and South America	Jatropha	17.5	± 75 %
Subtropical	Warm temperate dry	Subtropical dry forest	Africa	Jatropha	17.5	± 75 %
			Australia	Jatropha	17.5	± 75 %
			Central and South America	Jatropha	17.5	± 75 %
			Europe	Miscanthus	10	± 70 %
			North America	Miscanthus	14.9	± 70 %
		Subtropical steppe	Australia	Jatropha	17.5	± 75 %
			Australia	Jojoba	2.4	NA
			Central and South America	Jatropha	17.5	± 75 %
			Central and South America	Jojoba	2.4	NA
			North America	Sugar cane	4.8	± 50 %
			North America	Jojoba	2.4	NA
			North America	Miscanthus	14.9	± 70 %
	Warm temperate moist	Subtropical humid forest	Africa	Jatropha	17.5	± 75 %
			Asia (continental, insular)	Jatropha	17.5	± 75 %
			Asia (continental, insular)	Coconuts	75	± 60 %

Domain	Climate Region	Ecological Zone	Continent	Biofuel Crop Type	Total C stock in total biomass	Uncertainties
					t C ha^{-1}	%
			Australia	Jatropha	17.5	± 75 %
			Australia	Coconuts	75	± 60 %
			Central and South America	Sugar cane	5	± 50 %
			Central and South America	Jatropha	17.5	± 75 %
			North America	Sugar cane	4.8	± 50 %
Temperate	Cool temperate dry	Temperate steppe	Asia (continental, insular)	Jatropha	17.5	± 75 %
	Cool temperate moist	Temperate continental forest	Asia (continental, insular)	Jatropha	17.5	± 75 %
		Temperate oceanic forest	Asia (continental, insular)	Jatropha	17.5	± 75 %
			Australia	Oil palm	60	± 60 %

European Commission

EUR 24573 EN – Joint Research Centre
Institute for Environment and Sustainability

Title: **Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories**

Authors: Florence Carré, Roland Hiederer, Viorel Blujdea, Renate Koeble

Luxembourg: Publications Office of the European Union
2010 – 109 pp. – 21.0 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-17455-1
Catalogue number LB-NA-24573-EN-C
doi 10.2788/34463

Abstract

This Guide covers the calculation of carbon-stock changes in soil and above- and below-ground vegetation due to land use conversion in support of Directive 2009/28/EC on the promotion of the use of energy from renewable sources, particularly for assessing carbon-stock changes due to land conversion for biofuel production. The methodology put forward is based on the Tier 1 approach as developed under the IPCC Guidelines 2006. It is based on specifying default values for carbon stocks and using coefficients of divergence from the default values according to land use/cover. The methodological approach of the IPCC was adapted for use with spatial layers instead of data tables. The spatial layers of the factors influencing carbon-stock changes were generated with global coverage and thematically aligned to comply with stipulations made in the Directive. According to the types of land use/cover conversion, a review is made of the methodology of the IPCC (2006). Particular problems regarding peatlands are presented. Drained peatlands cannot be assessed in terms of carbon-stock changes because drainage occurs on the overall peat soil profile (not only on the first 30 cm). This has direct consequences not only on CO_2 emissions but also on CH_4 and N_2O. Tables of coefficients of conversions are then proposed according to climate zone and continental boundaries for soil carbon-stock changes and for above- and below-ground carbon stock changes in biomass in a Technical Annex.

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EUROPEAN COMMISSION

LB-NA-24573-EN-C

Publications Office

ISBN 978-92-79-17455-1