LIFE
Climate Change Mitigation

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Deliverable Action A2:

Adjustment of the LULUCF methodology for a better accounting of mitigation cultural practices of agro-ecosystem

LIFE CLIMATREE

(LIFE14 CCM/GR/ 000635)

"A novel approach for accounting and monitoring carbon sequestration of tree crops and their potential as carbon sink areas"

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April, 2016

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Summary

This report summarizes current methodology for monitoring and accounting of GHG emissions for the AFOLU sector with a focus on tree crops which are included in Cropland category. Key documents were: the Decision 529/2013 of the European Commission, and the technical Guidelines for National Greenhouse Gas Inventories issued during 2006 by the Intergovernmental Panel on Climate Change (IPCC) and the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* issued in the 2014.

In places, a red text highlights possible improvements/adjustments of current methodology with the aim to shed the light on potential of tree crops category to serve as carbon sink. Particularly, the following points are suggested:

- to consider the perennial tree crops as key category rather than sub-category of the Crop Management one;
- preliminarily identification of additional criteria for a higher resolution of the emissions/removals tailored on tree crops such as evergreen/deciduous, irrigated/not-irrigated, climatic zones;
- improvement of default biomass factors to be used under Tier 1 estimation that possibly help to discriminate for different IPCC ecoregions;
- field periodic measurements for above-ground biomass monitoring.
- Higher Tier methodology is proposed, based on the use of easy implementable models for carbon turnover in soil.

Annexed to the report a summary[1] of a manuscript titled "***Carbon budget in a Mediterranean peach orchard under different management practices***" The manuscript provides annual data on gain-loss carbon fluxes along with data on carbon sequestration in above- below-ground biomass during orchard lifetime. This paper would be a supporting documents showing the potential of tree crops to serve as carbon sink.

[1] The paper has submitted to a Journal, now it is under revision, the full paper will be annexed as soon as i twill be published.

1. Introduction

The European Union (EU), as a party to the United Nations Framework Convention on Climate Change (UNFCCC), must submit annually the greenhouse gas (GHG) inventories for emissions and removals within the area covered by its Member States (MS) (i.e. domestic emissions taking place within its territory). The inventories must cover emissions and removals from the following sectors: Energy, Industrial Processes and Product Use, Agriculture, Land-Use Land-Use Change and Forestry (LULUCF), Other. In general, estimations of GHGs must follow the typical reporting principles of transparency, accuracy, consistency, completeness and comparability (TACCC).

Since 1998, the Parties to the UNFCCC have agreed to use the Guidelines provided by the Intergovernmental Panel on Climate Change (IPCC) for estimating greenhouse gas emissions and removals. In that context, reporting of LULUCF covers the following categories: forest land, cropland, grassland, wetland, settlements and other lands. According to the IPCC definition, fruit tree orchards which are the subject of the LIFE14 CLIMATREE Project, are included in cropland:

*"**Cropland includes** all annual and **perennial crops** as well as temporary fallow land (i.e., land set at rest for one or several years before being cultivated again). Annual crops include cereals, oils seeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g., agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas, except where these lands meet the criteria for categorisation as Forest Land. Arable land which is normally used for cultivation of annual crops but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation (mixed system) is included under cropland."*

The Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) (thereafter *2006 IPCC Guidelines*) are aware about the evidence that "*perennial woody vegetation in orchards, vineyards, and agroforestry systems can store significant carbon in long-lived biomass, the amount depending on species type, density, growth rates, and harvesting and pruning practices. Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with most management practices, including crop type and rotation, tillage, drainage, residue management and organic amendments*.". However, this is not reflected in available data on GHG inventories. Based on the latest annual EU GHG inventory (1990–2013) and inventory report (EEA, 2015) the sector LULUCF is a net carbon (C) sink (higher removals by sinks than emissions from sources) only because of the CO_2 sink capacity of the Forest land category (Fig. 1).

Tree crops ecosystems have a significant potential to be a net sink for atmospheric carbon as discussed in the attached Annex. Hence it appears that although a rigorous accounting of the C fluxes of the current LULUCF sector is of high significance the standard accounting methods fail to approximate the relevant characteristics of fruit tree orchards to be a net sink too (Montanaro et al., 2012; Zanotelli, et al., 2014). Although the recent revision of the IPCC methods and good practice guidance arising from the Kyoto Protocol (IPCC, 2014), certain aspects of orchards and vineyards cultivation relevant to climate change mitigation and adaptation strategy (e.g. carbon removal and storage in soil and woody biomass) are rarely reported in the literature under UNFCCC accounting protocols (Huffman et al., 2015). This is likely because orchards do not conform to the forest definition causing in most cases orchard category to be listed under others (e.g. croplands, grasslands) and in turn C stored in trees biomass (or orchard soil) not accounted (Arets et al., 2014). Similarly, variations of C pools (e.g. soil organic carbon and crop biomass) as result of land use change or differentiated management are often not accounted for assessing product life cycle greenhouse gas emissions due to limited information existing and to ill accounting procedures (PAS 2050, 2008; Goglio et al., 2015).

The GHG reporting and accounting exercises have been amended by the Kyoto Protocol for the first (2008-2012) and second (2013-2020) commitment period, and in turn the EC built up a more robust common accounting, monitoring and reporting rules (see Decision 529/2013) (EC, 2013). The present report, developed within the A2 Action of the LIFE14 CLIMATREE "*Adjustment of the LULUCF methodology for a better accounting of mitigation cultural practices of agro-ecosystem*" after a view of the current LULUCF legislation package will preliminary provide possible proposals for its improvement. Suggestions will be based also on implementation foreseen within the LIFE14 CLIMATREE toward an improved reporting (and accounting)[2] of fruit tree orchards contribution within the LULUCF to offset GHGs. This would be pivotal for the potential inclusion of the LULUCF sector in the EU GHG emission reduction targets by 2020

[2] **Reporting** relates to the inclusion of GHG estimates in a GHG inventory; **Accounting** refers to the use of the reported data within a processes determining the contribution of a specific sector to the achievements of a specific target, for example in terms of CO_2eq emissions.

accounting period, providing supporting information for monitoring and reporting emissions and removals associated with tree crops.

In addition, we preliminarily provide some integrative measures that can be implemented with the aim to contribute to the adjustment of the LULUCF GHG accounting methodologies.

Organic soils (>12-20% soil organic carbon) are not considered in this report.

2. View of the current LULUCF legislation and reporting options

In order to encounter the targeted reduction of GHG emissions (i.e. 20% below the 1990 emissions by 2020), the EU issued the Decision 529/2013 (EC, 2013) aimed at formally include the activities of the LULUCF sector within the accounting GHG emissions for all member states (MS), modifying the criteria of accounting from being area-based to activity-based.

Each MS shall prepare and maintain accounts related to all emissions and removals resulting from the activities on their territory falling within the following categories:

(a) afforestation;

(b) reforestation;

(c) deforestation;

(d) forest management.

The Decision 529/2013 (EC, 2013) also focuses the second commitment period (2013-2020) under the Kyoto Protocol and establishes as mandatory a series of new land activities. That is, for the accounting periods beginning on 1 January 2021, and thereafter (see Art. 3, Decision 529/2013) *"Member States shall prepare and maintain annual accounts that accurately reflect all emissions and removals resulting from the activities on their territory falling within the following categories:*

(a) cropland management;

(b) *grazing land management;".*

To encourage MS toward the inclusion of such new categories, from 2016 to 2018, MS shall report (*i*) on the systems in place and being developed to estimate emissions and removals from cropland management (CM) and (*ii*) on how these systems are in accordance with IPCC methodologies (see below).

According to the definitions reported in the Decision 529/2013 (EC, 2013), "'***cropland management' means any activity resulting from a system of practices applicable to land on which agricultural crops are grown…***" which is relevant for fruit tree crops when they do not meet the definition of forest[3]. However, The *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (KP Supplement) (IPCC, 2014) states that croplands such as vineyards and orchards that meet the definition of forest can be included under CM. The definition of CM is similar to the Cropland definition reported in in *2006 IPCC Guidelines* which "*includes all annual and perennial crops as well as temporary fallow land"* (see Chapter 5, Volume 4).

Apart of certain tree crops whose plantations may conform to forest (e.g. old olive groves) and therefore are accountable under CM or Forestry Management categories, the cropland category is a relatively wide group of activities that do not allow to separately account for perennial crops. In that respect, considering that sustainable agricultural ecosystems (including orchards) have the potential to sequester carbon in various carbon pools (biomass, dead organic matter, soil) at rates similar or even higher than that of forests (Wu et al., 2012; Zanotelli et al., 2013; Montanaro et al., in revision), the significance of tree crops in terms of contribution to GHG emissions/removals should be revised. Hence it could be suggested to consider the perennial tree crops as *key category* as for forestry management. Having tree crops as key category (rather than sub-category of the CM one) may boost MS to implement their accounting procedures toward a better definition of the contribution of tree crops to national GHG inventories.

Within the widening of categories established by the Decision 529/2013 (EC, 2013), the Project CLIMATREE will support the definition of emissions and removals resulting from the activities falling within the tree crops

[3] From Decision 529/2013, FOREST means an area of land defined by the minimum values for area size (0.01-0.5 ha), tree crown cover (10-30%), and potential tree height at maturity (2-5 m), as specified for each Member State in Annex V; 'crown cover' means the proportion (%) of a fixed area that is covered by the vertical projection of the perimeter of tree crowns.

which are accountable under cropland management categories. Hopefully this would be useful for the introduction of a specific key category dedicated to tree crops.

Urban trees category

According to the Art. 3(3) of Decision 529/2013 (EC, 2013), MS could account on a voluntary base for **Revegetation (RV)** activity. **Revegetation is defined as any direct human-induced activity intended to increase the carbon stock of any site that covers a minimum area of 0.05 hectares**, through the proliferation of vegetation, where that activity does not constitute afforestation or reforestation. The option to account for RV could be relevant for fruit tree crops in case MS choose cropland management definition that leave out some of the management systems or sub-categories of land-uses with woody biomass, such as coppices, orchards, Christmas tree plantations, tree nurseries and define them as RV (Weiss et al 2015).

Interestingly, MS could account for CO_2 removals in living and dead biomass inferred from increment of **growing C stock in urban areas where overgrown roadsides, urban trees, green areas, park and other green infrastructures serve as CO_2 sink.** In that case**,** in settlements-remaining-settlements sub-category. Despite its potential relevance for the LULUCF sector, reporting and accounting for such urban trees is behind the scope of LIFE14 CLIMATREE and therefore not considered in the A2 Action and in the present report.

3. Stepwise methodology for estimating emissions and removals from Cropland management (CM) category

According with the Decision 529/2013 (EC, 2013) and with guidance provided in Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006 and 2014), MS should prepare and maintain their emissions and removals inventories from the LULUCF ensuring transparency, accuracy, consistency, completeness and comparability of information.

The IPCC has recently reviewed the methods for estimation, measurement, monitoring and reporting of emissions and removals for the various categories including CM, see Chapter 2, § 2.9 in *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC, 2014). In this section of the present report we summarise the steps suggested by IPCC as *good practice* to apply for estimating emissions and removals from CM category.

3.1. STEP 1 - CM definition

The definition of CM is of course of basic relevance, this will be used consistently over time. As regard perennial tree crops such as vineyards, orchards, olive groves and other plantations, are included in CM category. In cases tree crops meet the forest definition (see above) they can be included under CM as well, however it is recommended to avoid double counting of these tree crops under both CM and forestry management categories (IPCC, 2014).

3.2. STEP 2 - Land identification

Chapter 3, Vol. 4 of the *2006 IPCC Guidelines* (IPCC, 2006) provides guidance on using various types of data to be collected for the representation of land-use categories (and their changes) based on the evidence that countries use various methods to obtain data, including annual census, periodic surveys and remote sensing. Countries may use a mix of Approaches for different regions over time, these approaches briefly are:

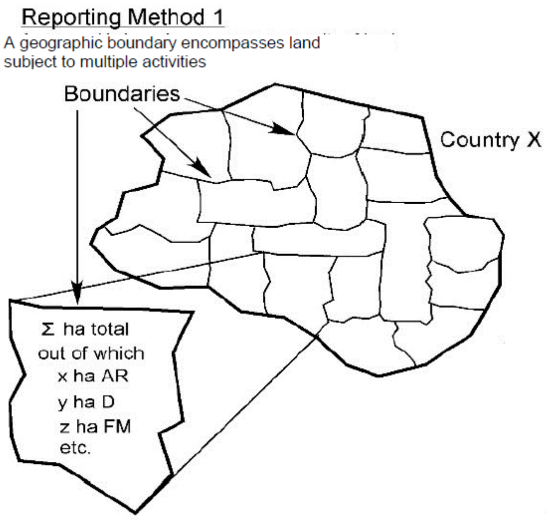
Approach 1 *identifies the total area for each individual land-use category within a country, but does not provide detailed information on the nature of conversions between land uses.* See 2.2.4.1 section of IPCC (2014) for further details.

Approach 2 *introduces tracking of conversions between land-use categories, but is not spatially explicit therefore does not allow to track conversions over time for individual lands.* See 2.2.4.2 section of IPCC (2014) for further details.

Approach 3 *extends the information available in Approach 2, it is characterized by spatially-explicit observations of land-use categories and land-use conversions and thus enables tracking of conversions over time of individual lands.* See 2.2.4.3 section of IPCC (2014) for further details.

To avoid double counting of land areas and ensure completeness in land identification and consistency in reporting, the two following reporting methods have been proposed by the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol:*

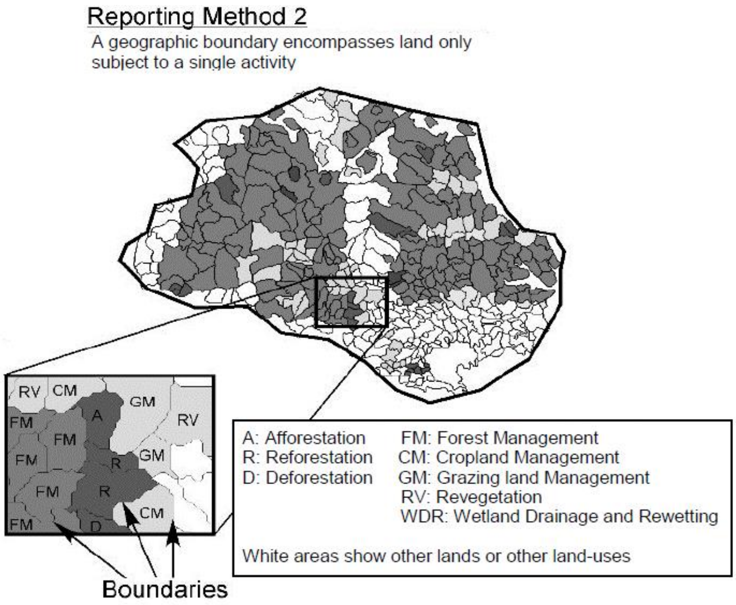
Method 1 *uses a spatially-referenced approach that delineates the geographic boundaries that contain multiple land units subject to various activities. The geographic boundaries can be defined using georeferenced legal, administrative, or ecosystem boundaries*.



Information about activities within these areas is derived from (grid-based or other) sampling techniques using remote sensing or ground-based data or from administrative statistics, although the location of each land unit within these geographic areas may not be known.

Method 2 is based on the spatially-explicit and complete geographical identification of all land units subject to the various categories.

The Table 1 (IPCC, 2014) describes the three land-identification Approaches and relations between Approaches and Reporting Methods



3.2.1 Identifying lands subjected to CM activities

The 2.9.3 section of the IPCC (2014) guidelines "*Choice of methods for identifying lands subject to Cropland Management activities*" provides general guidance on consistent representation of lands recalling information provided in Chapter 3 of the *2006 IPCC Guidelines* with additional guidance about identification of lands subject to CM. In general, it is suggested to continuously follow the management of land that is subject to CM by tracking land subject to CM from the base line year (1990) until the end of the commitment period(s). However, MS could develop statistical sampling techniques (see Annex 3A.3, Chapter 3, Vol. 4 of the *2006 IPCC Guidelines*). In this regard, it is recommended to identify criteria that could be used to set up a stratified sampling scheme. For tree crops, in addition to general stratification criteria (e.g. climate and soil type, management practices) the following criteria could be suggested:

- degree of soil disturbance (e.g. tillage frequency and intensity)

- level of input of crop biomass or organic amendment

- temporary use for livestock grazing

- evergreen/deciduous (accounting separately for evergreen such as olives, oranges and lemons and deciduous tree crops may help to collect more detailed data on removals/emissions because evergreen have a year round activity that may impact C fluxes (see Annex to this report).

- irrigated/not-irrigated. The water availability greatly impact gas exchanges of plants and in turn the potential of carbon sequestration. This may be relevant for certain tree crops (e.g. traditional olive groves) which are routinely rainfed. Hence a stratum that take into consideration this aspect would improve calculations.

- climate zones.

3.3. STEP 3 - Organic/mineral soils

At this stage two main subcategories are identified based on texture and SOC content namely in **mineral soils and organic soils**. Soils are classified in order to apply reference C stocks and stock change factors for estimation of soil C stock change, roughly a soil is considered organic when its SOC is higher than 12-20% by weight, for further details on soils classifications see Annex 3A.5, Chapter 3, Vol. 4 in IPCC (2006). Organic soils are usually found in wetlands or have been drained and converted to other land-use types (e.g., Forest Land, Cropland, Grassland, Settlements) (IPCC, 2006), thus under Mediterranean conditions organic soils are reasonably not common.

3.4. STEP 4 - Select Tier and methods

Within the Volume 4 of the of the IPCC guidelines for National GHG Inventories which devoted to Agriculture, Forestry and Other Land Use sector (AFOLU) (IPCC, 2006), the Chapter 5-Cropland provides a tiered methodology for estimating and reporting greenhouse gas emissions from croplands. The three hierarchical Tiers of methods range from default emission factors and simple equations to the use of country-specific data and models to accommodate national circumstances. The accuracy of these different methodologies varies, usually Tier 2 and 3 are referred as **"higher tier",** accuracy level could be visualised as follow:

According to IPCC (2006), if needed, a combination of Tiers can be used, e.g., Tier 2 can be used for biomass and Tier 1 for soil carbon. The following Box 1.1 reports the concepts of the three tiered approach suggested for the AFOLU sector (see Chapter 1, Vol. 4, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*). The IPCC (2014) provides a general decision tree for selecting the appropriate Tier to be adopted (Fig. 3), while specific decision tree related to CM and specific C pool are presented in forthcoming sections.

Box 1.1
Framework of tier structure for AFOLU methods

Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided in this volume. Country-specific activity data are needed, but for Tier 1 there are often globally available sources of activity data estimates (e.g., deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.), although these data are usually spatially coarse.

Tier 2 can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data, for the most important land-use or livestock categories. Country-defined emission factors are more appropriate for the climatic regions, land-use systems and livestock categories in that country. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use or livestock categories.

At **Tier 3**, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. These higher order methods provide estimates of greater certainty than lower tiers. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. Pieces of land where a land-use change occurs can usually be tracked over time, at least statistically. In most cases these systems have a climate dependency, and thus provide source estimates with interannual variability. Detailed disaggregation of livestock population according to animal type, age, body weight etc., can be used. Models should undergo quality checks, audits, and validations and be thoroughly documented.

BOX 1.1 – General description of the three Tiers of methods for accounting the emissions/removals of GHG in the Agriculture, Forestry and Other Land Use sector (AFOLU) sector. Redrawn from Chapter 1, Vol. 4, *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

4. Carbon pools: definitions and stock changes measurements

The Decision 529/2013 (EC, 2013) defined the ‘carbon pool’ as a biogeochemical feature or system of a MS territory within which carbon is stored. The relevant carbon pools for the cropland category are splitted as follow:

RELEVANT CARBON POOLS FOR CROPLAND

Biomass
1 Above-ground biomass
2 Below-ground biomass
Dead organic matter
3 Dead wood
4 Litter
5 Soils (soil organic matter)

Here below, we provide details on current IPCC accounting methodologies at the various tiers (Vol.4, Chapter 5, 2006 IPCC Guidelines) for the removals/emissions of GHG related to carbon changes of that aforementioned C pools.

In the present report we focus the changes in carbon stocks in *Cropland Remaining Cropland* which are croplands that have not undergone any land use change for a period of at least 20 years as a default period. That changes in carbon stock are estimated using the following Equation 2.3 (Vol.4, Chapter 2, 2006 IPCC Guidelines):

EQUATION 2.3
ANNUAL CARBON STOCK CHANGES FOR A STRATUM OF A LAND-USE CATEGORY AS A SUM OF CHANGES IN ALL POOLS

$$\Delta C_{LU_i} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

ΔCLU_i = carbon stock changes for a stratum of a land-use category

Subscripts denote the following carbon pools:
AB = above-ground biomass
BB = below-ground biomass
DW = deadwood

LI = litter
SO = soils
HWP = harvested wood products

According to IPCC (2014), for perennial crops (e.g. trees, shelterbelts and orchards), carbon stock changes may not be estimated for all pools shown in Equation 2.3 but MS should provide verifiable information that these carbon stocks are not decreasing.

4.1. Biomass

According to 2006 IPCC Guidelines (Chapter, 5, vol. 4, section 5.2.1) changes in carbon in cropland remaining in the same land-use category (ΔC_B) may be estimated from either (a) annual rates of biomass **gain and loss (Chapter 2, Equation 2.7)** or (b) **carbon stocks at two points in time (Chapter 2, Equation 2.8)** depending also in Tier adopted. Figure 4 show the decision tree for the estimation of carbon changes in biomass.

Tier 1

The default method is to multiply the area of perennial woody cropland by a net estimate of biomass accumulation from growth and subtract losses (harvest, gathering or disturbance) (Eq. 2.7 in Chapter 2, Vol. 4, 2006 IPCC Guidelines):

EQUATION 2.7
ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS IN LAND REMAINING IN A PARTICULAR LAND-USE CATEGORY (GAIN-LOSS METHOD)

$$\Delta C_B = \Delta C_G - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass for each land sub-category, considering the total area, tonnes C yr-1

ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tonnes C yr-1

ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tonnes C yr-1

This Tier 1 method works under several assumptions, particularly it assumes that no below-ground biomass accumulation do occur, default values for below-ground biomass for agricultural systems are not available. Under Tier 1, default factors for biomass accumulation are reported in Table 2 redrawn from Chapter 5, Vol. 4 *2006 IPCC Guidelines* and are applied to nationally derived estimates of land areas. These default factors are very general as the wide error range shows (± 75%) and are based on Schroeder (1994) literature survey. The LIFE CLIMATREE Project will provide an update of default factors (possibly also for below-ground biomass) to be used under Tier 1 estimation through the experience of the research team and a deeper literature survey focussing of more recent published researches. In addition, CLIMATREE will make efforts to extend the availability of default emission factors that discriminate for different ecoregions currently listed in *2006 IPCC Guidelines* (i.e. Tab. 5.2, Chp.5, Vol. 4)

Tier 2

In addition to the **Gain-Loss Method** (see the abovementioned Eq. 2.7), a second method called the **Stock-Difference Method** could be used. This second method is based on the Eq. 2.8 (Chapter 2, Vol. 4 *2006 IPCC Guidelines*) and requires biomass carbon stock inventories for a given land-use area at two points in time:

EQUATION 2.8
ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS
IN LAND REMAINING IN THE SAME LAND-USE CATEGORY (STOCK-DIFFERENCE METHOD)

$$\Delta C_B = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \qquad \text{(a)}$$

ΔC_B = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass, tonnes C yr^{-1};

C_{t2} = total carbon in biomass for each land sub-category at time t2, tonnes C;

C_{t1} = total carbon in biomass for each land sub-category at time t1, tonnes C;

A Tier 2 estimate, in contrast, will generally develop estimates for the major woody crop types by climate zones, using where possible or country-specific estimates of carbon stocks at two points in time. The Tier 2 methods use country-specific carbon accumulation rates and stock losses for above- and below-ground biomass incorporating the effect of C accumulation drivers (e.g. management system). Where data are missing, default data may be used.

Estimating below-ground biomass accumulation is recommended for Tier 2 calculation (IPCC, 2006), however limited data is available for this specific issue hence empirically-derived root-to-shoot ratios specific to a region or vegetation type should be used (IPCC, 2006).

The LIFE CLIMATREE Project will deeply search for available data on above- and below-ground biomass of crop trees as affected by management(s) and climate to provide a dataset easily/freely accessible.

Tier 3

Adoption of a Tier 3 estimate highly disaggregated factors for biomass accumulation are needed. These may include categorisation of species, management effects (e.g. fertilization). Measurement of above-ground biomass, similar to forest inventory with periodic measurement of above-ground biomass accumulation, is necessary. General guidance on survey and sampling techniques for biomass inventories for Tier 3 is given in Chapter 3, Vol. 4, Annex 3A.3 *2006 IPCC Guidelines*.

The LIFE CLIMATREE Project will propose possible feasible set of field periodic measurements for above-ground biomass monitoring. Efforts will made to identify possible indexes able to predict biomass accumulation in tree crops.

4.2. Dead organic matter

The dead organic matter (DOM) is a carbon pool that includes litter and dead wood. The IPCC (2006) (Chapter 1, Vol. 4) defines these pools as:

Dead wood: "*Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country)".*

Litter: *"Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically."*

The *2006 IPCC Guidelines* reports that cropland will have little or no DOM with the exception of agroforestry. However, based on literature and own research experience (see Annex to this report) the LIFE CLIMATREE Project will focus on the relevance of this carbon pool as affected by certain management practices (e.g. adoption of cover crops, retain of pruning residuals).

The decision tree reported in Figure 5 provide assistance in the choice of correct Tier for DOM estimations.

Tier 1

This method assumes that there is no DOM or it is in equilibrium (gain=loss) hence there is no need to account for it.

Tier 2 and 3

Similarly to the calculation of the biomass carbon pool, two methods could be adopted for DOM carbon calculations: the Gain-Loss Method (see the Eq. 2.18, Chapter 2, Vol. 4 *2006 IPCC Guidelines*), and the Stock-Difference Method (see the Eq. 2.19, Chapter 2, Vol. 4 *2006 IPCC Guidelines*).

Gain-Loss Method: should be used in case the management practices consider annual transfer into and out of dead wood and litter stocks. This method requires information on the quantity of biomass transferred into dead wood and litter stocks under i) different climate or cropland types; ii) management regime.

Stock-Difference Method: involves estimating the area of cropland and the dead wood and litter stocks at two periods of time, t1 and t2. This method is feasible for countries which have periodic inventories and when adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors and national data gained through permanent sample plots for their croplands and/or models.

Section 5.2.2.4, Chapter 5, Vol. 4 of the *2006 IPCC Guidelines* summarizes steps for estimating change in DOM carbon stocks.

4.3. Soil carbon

Generally, IPCC (2014) recommend to use Tier 2 or Tier 3 methods for reporting carbon stock changes from mineral soils if CM is a key category and mineral soils are a significant subcategory under CM.

Tier 1

The default Tier 1 methodology provided by IPCC guidelines (2006) for the accounting of soil carbon change in the AFOLU sector (Eq. 2.25 Chapter 2, Vol. 4 2006 IPCC *Guidelines*) is based on the reference carbon stock (SOCref, t C ha^{-1}) and on three relative stock change factors: F_{LU} related to land use (long term cultivated, paddy rice, perennial/tree crop, set aside), F_{MG} related to management (e.g. tillage regime full, reduced, no-tillage) and F_I related to carbon input level (low, medium, high):

$$SOC = SOCref \times F_{LU} \times F_{MG} \times F_I$$

The SOCref value should be selected according to soil type (HAC[4], LAC[5], Sandy, Spodic, Volcanic, Wetland) and nine climate regions (boreal, cold temperate dry, cold temperate moist, warm temperate dry, warm temperate moist, tropical dry, tropical moist, tropical wet, tropical montane) see Table 3 for SOCref values and Table 4, Table 5, Table 6 for land-use (perennial crops) (F_{LU}), management (F_{MG}), input level (F_I) stock change factors, respectively.

Applying that equation at two point in time allow to calculate the soil organic carbon content before change (SOCinitial) and after change (SOCfinal). Then, the difference between the final stock (new equilibrium, SOCfinal) and the initial one (old equilibrium, SOCinitial), gives the soil carbon stock change (ΔSOC) calculated for the 30 cm topsoil, in a time period of 20 years, expressed as tons of carbon per hectare;

$$\Delta SOC = (SOCfinal – SOCinitial)/T \qquad (t\ C\ year\text{-}1)$$

Where

T = default time period for transition between equilibrium SOC values, 20 years

At regional and sub-regional level, Tier 1 level methods are not always sufficiently accurate to account for geographical variability of GHG emissions caused by different soil, climate or management practices. In fact the qualitative

[4] HCA, High Activity Clay.

[5] LCA, Low Activity Clay.

stock change factors are characterized by wide error ranges (between ±5% and ±50%) and is often difficult to select the right factors based on the qualitative description provided in IPCC guidelines (2006).

Thus, according to IPCC (2014), an affordable higher Tier methodology is proposed, based on the use of easy implementable models for carbon turnover in soil, as Roth C (Coleman, 1999) or Century (Parton, 1992), integrated with the 2010 baseline of organic carbon stock in European agricultural soils provided by the EU Joint Research Center (Lugato, 2014), and validated against measurements. This more accurate methodology requires as input data the soil texture, monthly climate data (temperatures, rainfall and evapotranspiration) and the estimate of the amount of carbon input to soil. These data are often available to local and regional authorities so that the proposed methodology can be considered of “medium effort” against the Tier, which is “low effort”, but does not ensure a good accuracy of results.

Data regarding the amount of organic material added to soil at landscape level could be retrieved through statistical surveys of tree crop management practices, integrated with literature data and sampling activity about crop residues amounts, for each crop species and each climate region. The simulations performed to include SOC change from tree crop management modifications into National GHG accounting, should be verified against systematic SOC measurement performed every 5 years, for each “Soil Climate Unit”, which is the land unit defined in Lugato (2014); these measurements would be useful to update regularly the EU SOC map for agricultural soils.

Tier 2

Application of a Tier 2 A Tier 2 approach requires country-specific values of stock change factors and SOCref. According to IPCC (2006), derivation of input (F_I) and management factors (F_{MG}) should be based on comparisons to medium input and intensive tillage, respectively. For the implementation of a Tier 2 method for soil carbon changes estimation, a higher resolution classification of management, climate and soil types among more disaggregated sub-categories are required.

Tier 3

A Tier 3 approach should provide a more detailed estimation of emissions/removals, hence a variable rates of carbon stock change that more accurately capture land-use and management effects is desirable.

5. Conclusions

The present report has provided the current stepwise methodology for measuring of emissions/removals of GHG focussing the Cropland category which includes perennial tree crops. In several places the document provide a preliminary identification of possible improvements/adjustments of current methodology with the aim to shed the light on potential of tree crops category to serve as carbon sink.

Thus, according to IPCC (2014), an affordable higher Tier methodology is proposed for the estimation of SOC changes, based on the use of easy implementable models for carbon turnover in soil. This more accurate methodology requires as input data the soil texture, monthly climate data (temperatures, rainfall and evapotranspiration) and the estimate of the amount of carbon input to soil which are often available to local and regional authorities. It could be anticipated that this proposed methodology can be considered of “medium effort” against the Tier, which is “low effort”, but does not ensure a good accuracy of results.

Annexed to the report a summary (now under revision stage of the publication process) of a manuscript titled “***Carbon budget in a Mediterranean peach orchard under different management practices***” The manuscript provides annual data on gain-loss carbon fluxes along with data on carbon sequestration in above- below-ground biomass during orchard lifetime. This paper would be a supporting document showing the potential of tree crops to serve as carbon sink.

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7. Annex

"Carbon budget in a Mediterranean peach orchard under different management practices"[6] developed within LIFE14 CLIMATREE.

Abstract

Soil organic carbon (SOC) contents in many Mediterranean soils is rather low (~1%) hampering both economic and ecological functions. Environmental conditions of the Mediterranean area (i.e. low annual precipitation, warm and dry summer) as combined with agricultural management options may have specific impact on the carbon (C) cycle. To improve knowledge of C fluxes in Mediterranean agro-ecosystems this paper examined the effect of 7-year of sustainable management practices (S_{mng}) (no-till, weed mowing, retention of aboveground residues, import of organic amendment) on soil and biome C budget against locally conventional managed orchard (C_{mng}) (tillage, removal of pruning residuals, mineral fertilisers). Through field measurements of soil respiration (Li-6400, LI-COR, USA) and above- and belowground biomass sampling the annual net ecosystem production (NEP) was determined. The mean annual NEP was close 474 and 320 g C m^{-2} yr^{-1} at the S_{mng} and C_{mng} plot, respectively. As managed ecosystems, anthropogenic C imports/exports and related changes of soil C pool were then accounted through the net ecosystem C balance (NECB). The NECB approximated 730 g C m^{-2} yr^{-1} (S_{mng}) and 90 g C m^{-2} yr^{-1} (C_{mng}) highlighting the role of appropriate management of the variable components (e.g. pruning residuals, supply of external organic material, adoption of cover crops) to sustain ecosystem resilience. During the studied period soil C stock (SOC and litter) increased at a mean rate of 156 g C m^{-2} yr^{-1} at the S_{mng} plot while it was 4 g C m^{-2} yr^{-1}. Through excavations of trees it was measured the C sequestered in whole tree standing biomass during the orchard lifespan that was close to 25 t C ha^{-1}. This paper provides information on C stocks variation (soil + biome) and on annual net C removal (NEP) in cultivated peach orchard under Mediterranean environmental conditions, identifying potential issues able to strength C capture capability and in turn support new environmental policy release.

Key words: Carbon balance, standing biomass, carbon sequestration, *prunus*, NECB, sustainable, conventional, soil respiration

[6] As it is under revision at the deliverable deadline, only the abstract is annexed. As soon as the manuscript will be accepted for publication the deliverable will be integrated.

8. List of tables and figures

Tables

Table 1 - Three land-identification Approaches and relations between Approaches and Reporting Methods proposed by IPCC (2014). (Redrawn from Chapter 2, Vol. 4)

TABLE 2.2.1
RELATIONSHIP BETWEEN APPROACHES IN CHAPTER 3 OF *2006 IPCC GUIDELINES* AND REPORTING METHODS IN THIS REPORT

Chapter 3 Approaches	Reporting Method 1 (Broad area identification)	Reporting Method 2 (Complete identification)
Approach 1 Total land-use area, no data on conversions between land uses	Can only be used if additional spatial information is available by re-analysing existing inventories with reference to boundaries of geographic areas or from sampling programs.	Not applicable
Approach 2 Total land-use area, including changes between categories	Can only be used if additional information is available by re-analysing existing inventories with reference to boundaries of geographic areas or from sampling programs.	Not applicable
Approach 3 Spatially explicit land-use conversion data	This is *good practice* if spatial resolution is fine enough to represent minimum forest area. Involves aggregating data within the reported geographic boundaries.	This is *good practice* if spatial resolution is fine enough to represent minimum forest area.

Table 2 – Coefficients for woody biomass accumulated in cropland including tree crops. (redrawn from Chapter 5, Vol. 4 2006 IPCC Guidelines).

DEFAULT COEFFICIENTS FOR ABOVE-GROUND WOODY BIOMASS AND HARVEST CYCLES IN CROPPING SYSTEMS CONTAINING PERENNIAL SPECIES

Climate region	Above-ground biomass carbon stock at harvest (tonnes C ha^{-1})	Harvest /Maturity cycle (yr)	Biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Biomass carbon loss (L) (tonnes C ha^{-1} yr^{-1})	Error range[1]
Temperate (all moisture regimes)	63	30	2.1	63	± 75%
Tropical, dry	9	5	1.8	9	± 75%
Tropical, moist	21	8	2.6	21	± 75%
Tropical, wet	50	5	10.0	50	± 75%

Note: Values are derived from the literature survey and synthesis published by Schroeder (1994).
[1] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Table 3 – Values of default soil organic C stock (SOCref) for mineral soil in the top 30 cm soil layer. (Redrawn from Chapter 5, Vol. 4 2006 IPCC Guidelines).

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TABLE 2.3
DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS (SOC_{REF}) FOR MINERAL SOILS (TONNES C HA^{-1} IN 0-30 CM DEPTH)

Climate region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetland soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	
Tropical montane	88*	63*	34*	NA	80*	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

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

* Data were not available to directly estimate reference C 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.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

Table 4 - Land-use factor for perennial tree crops to be used in Tier 1 calculations for SOC change determinations (redrawn from Chapter 5, Vol. 4 2006 IPCC Guidelines).

TABLE 5.5
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temper-ature regime	Moist-ure regime[1]	IPCC defaults	Error[2,3]	Description
Land use (F_{LU})	Peren-nial/ Tree Crop	All	Dry and Moist/ Wet	1.00	± 50%	Long-term perennial tree crops such as fruit and nut trees, coffee and cacao.

Table 5 – Management factor in relation to temperature regime to be used in Tier 1 calculations for SOC change determinations (redrawn from Chapter 5, Vol. 4 2006 IPCC Guidelines).

TABLE 5.5
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temper -ature regime	Moist- ure regime[1]	IPCC defaults	Error[2,3]	Description
Tillage (F_{MG})	Full	All	Dry and Moist/ Wet	1.00	NA	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.
Tillage (F_{MG})	Re- duced	Tem- perate/ Boreal	Dry	1.02	± 6%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
			Moist	1.08	± 5%	
		Tropical	Dry	1.09	± 9%	
			Moist/ Wet	1.15	± 8%	
		Tropical montane[4]	n/a	1.09	± 50%	
Tillage (F_{MG})	No-till	Temperat e/ Boreal	Dry	1.10	± 5%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
			Moist	1.15	± 4%	
		Tropical	Dry	1.17	± 8%	
			Moist/ Wet	1.22	± 7%	
		Tropical montane[4]	n/a	1.16	± 50%	

Table 6 - Input factor in relation to temperature and moisture regime to be used in Tier 1 calculations for SOC change determinations (redrawn from Chapter 5, Vol. 4 2006 IPCC Guidelines).

TABLE 5.5
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temper-ature regime	Moist-ure regime[1]	IPCC defaults	Error[2,3]	Description
Input (F_I)	Low	Tem-perate/ Boreal	Dry	0.95	± 13%	Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e.g., vegetables, tobacco, cotton), no mineral fertilization or N-fixing crops.
			Moist	0.92	± 14%	
		Tropical	Dry	0.95	± 13%	
			Moist/ Wet	0.92	± 14%	
		Tropical montane[4]	n/a	0.94	± 50%	
Input (F_I)	Med-ium	All	Dry and Moist/ Wet	1.00	NA	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.
Input (F_I)	High with-out manure	Tem-perate/ Boreal and Tropical	Dry	1.04	± 13%	Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below).
			Moist/ Wet	1.11	± 10%	
		Tropical montane[4]	n/a	1.08	± 50%	
Input (F_I)	High – with manure	Tem-perate/ Boreal and Tropical	Dry	1.37	± 12%	Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.
			Moist/ Wet	1.44	± 13%	
		Tropical montane[4]	n/a	1.41	± 50%	

Figures

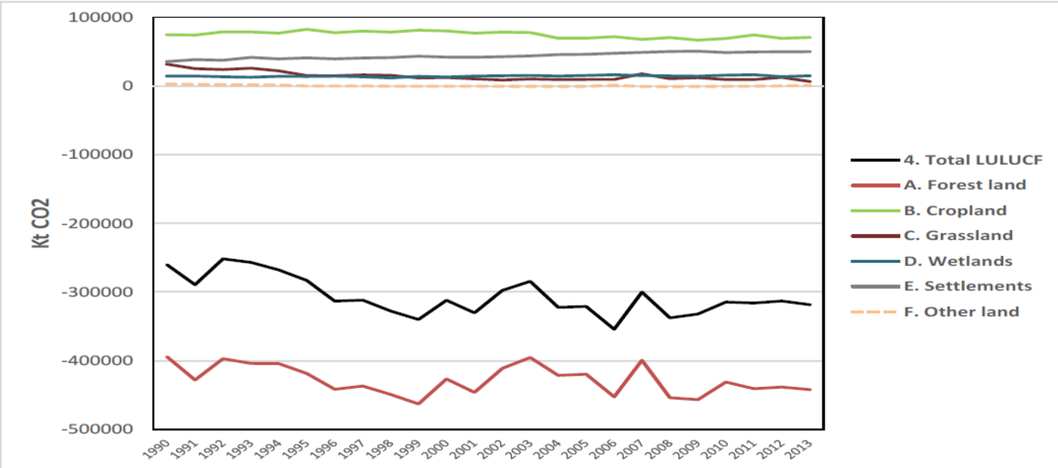


Figure 1 – Trend of the EU GHG net emissions in CO2 eq. (kt) (+) / removals (-) for 1990–2013, within the LULUCF sector for all land use categories. (redrawn from EEA, 2015 Fig 6.17).

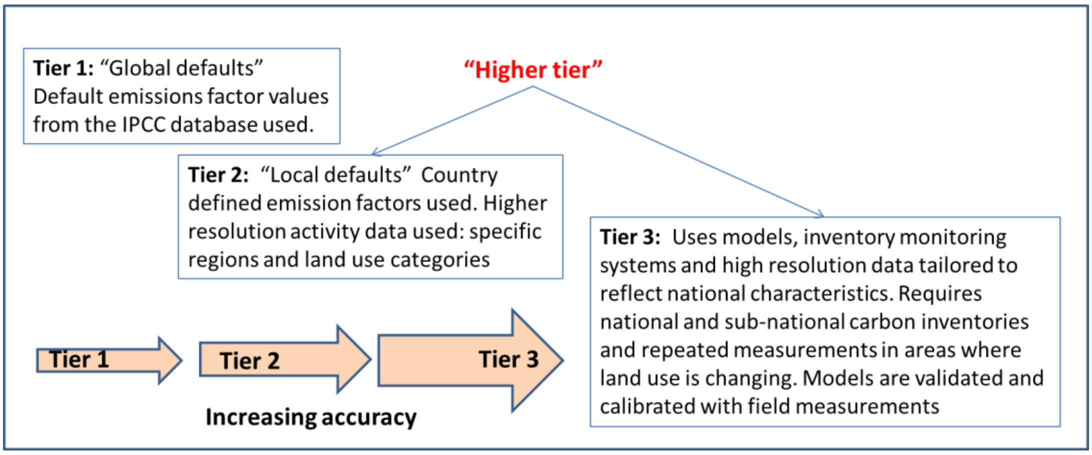


Figure 2 – Schematic representation of the three Tiers for determination of emissions/removals of GHG within the IPCC accounting GHG framework IPCC framework.

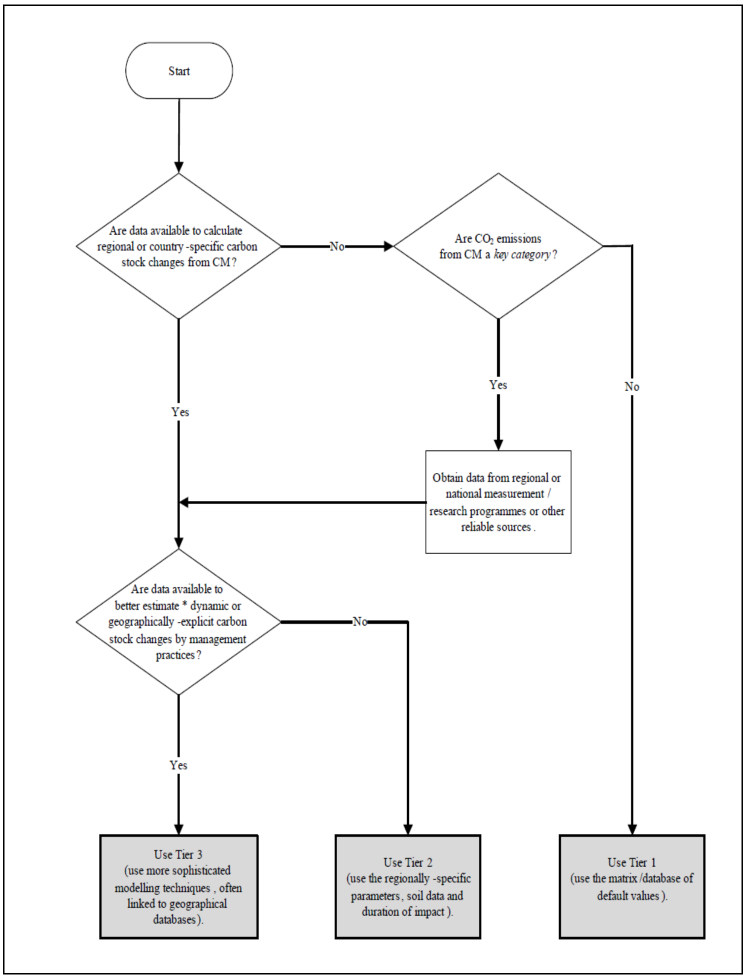
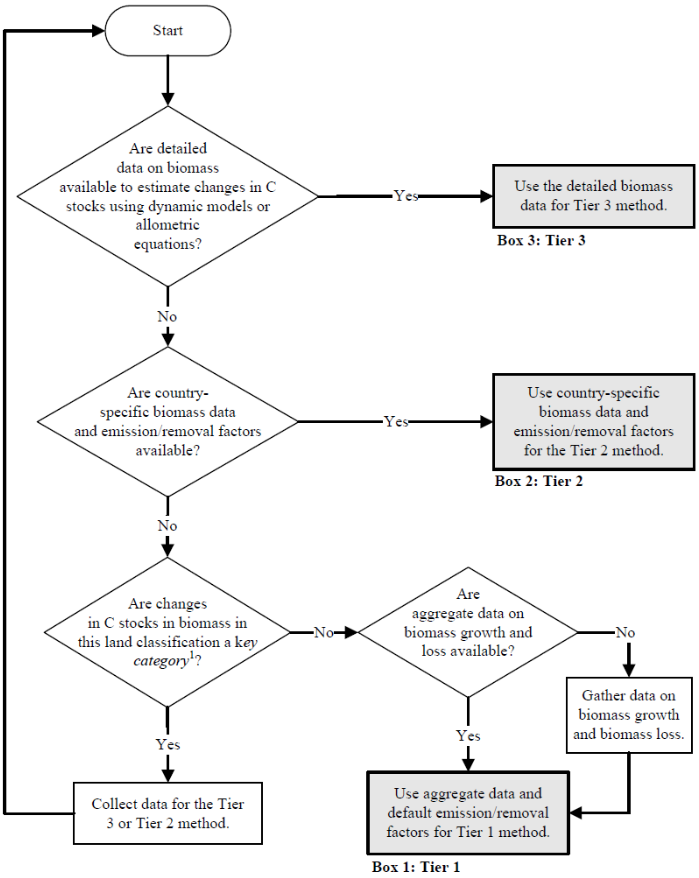


Figure 3 - Decision tree for selecting the appropriate tier for estimating emissions and removals in the carbon pools under CM for KP reporting; * a better estimate improves consistency, comparability, completeness, accuracy and transparency (redrawn from Chapter 2, *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol*).

Figure 2.2 Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in biomass in a land-use category.



Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

Figure 4 – Decision tree for estimation of carbon changes in biomass. Redrawn from Chapter 2, Vol. 4, *2006 IPCC Guidelines*.

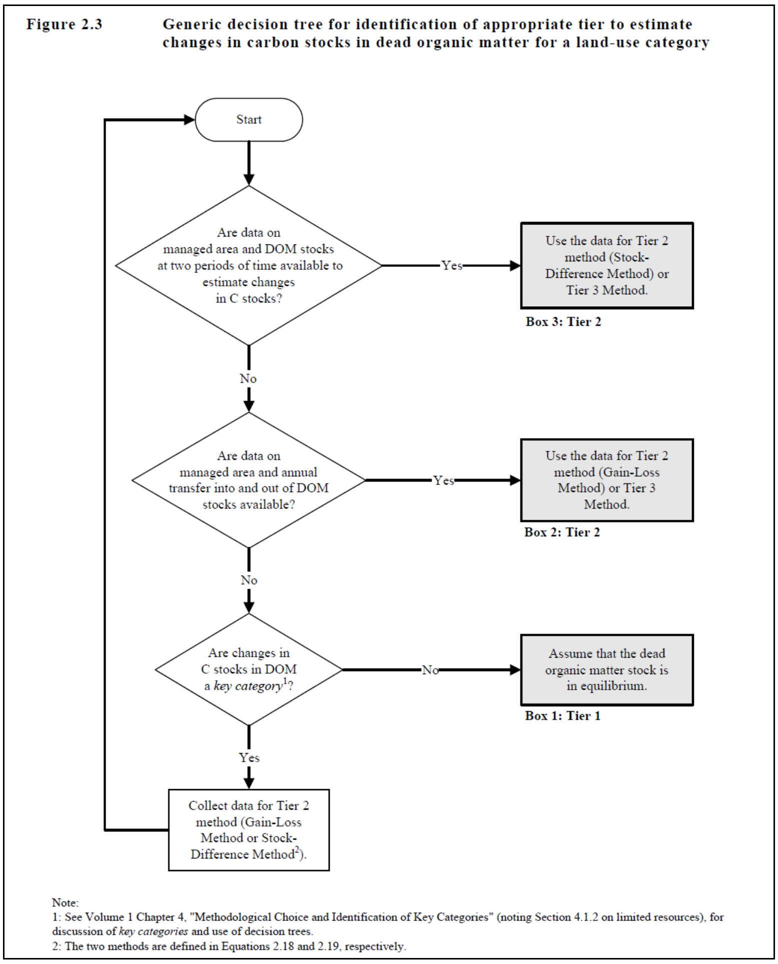


Figure 5- Redrawn from Fig. 2.3, Chapter 2, Vol. 4 2006 IPCC Guidelines.

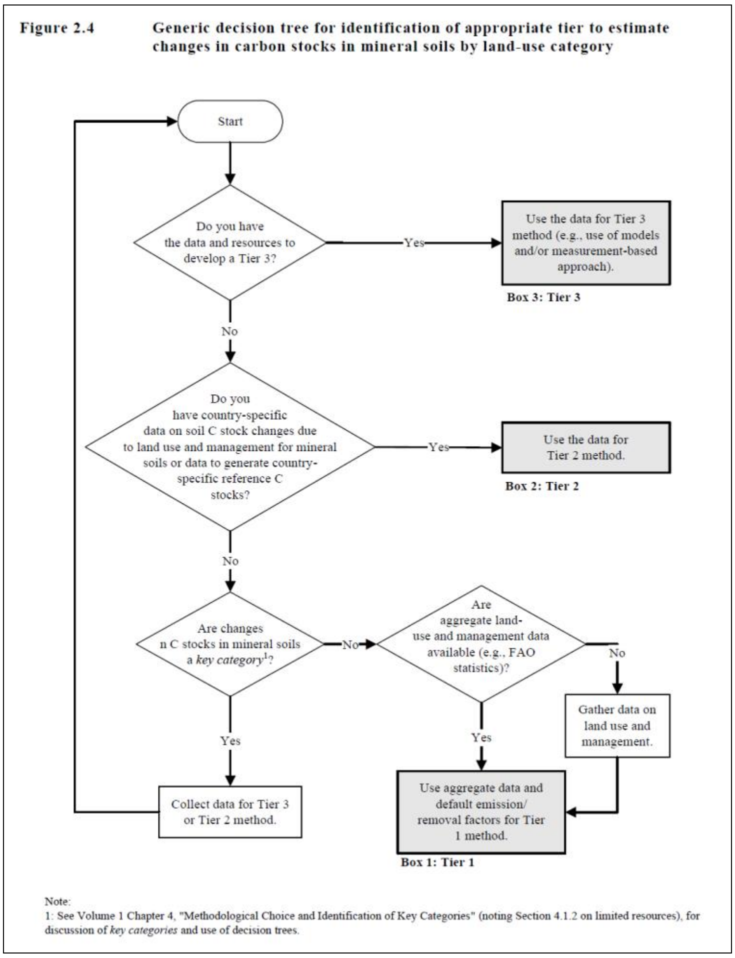


Figure 6- Decision tree for identification of appropriate Tier to estimate carbon stock changes in mineral soils (redrawn from Chapter 2, Vol. 4 2006 IPCC Guidelines).

The **LIFE CLIMATREE** project "A novel approach for accounting and monitoring carbon sequestration of tree crops and their potential as carbon sink areas" (LIFE14 CCM/GR/000635) is co-funded by the EU Environmental Funding Programme **LIFE Climate Change Mitigation**.

Implementation period: 16.7.2015 until 28.6.2019

Project budget: Total budget: 1,931,447 €

EU financial contribution: 1,158,868 €

Participating Beneficiaries:

University Research Institute
urban environment human resources Panteion Universtity, Athens

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