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proforbiomed
Promotion of residual forestry biomass in the Mediterranean basin

With the patronage of
REGIONE LAZIO

RAPPORTI

Short rotation forestry and methods for carbon accounting. A case study of black locust *(Robinia pseudoacacia* L.*)* plantation in central Italy

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SUMMARY FOR POLICYMAKERS

The call for strategies to fight global warming is one of the main drivers of a new interest and global attention in biomass-based energy production and specifically in ad hoc energy plantations. In fact these plantations offer double positive input to mitigate greenhouse gas (GHG) emissions: providing feed-stocks for bioenergy to displace fossil fuel use and storing carbon in biomass and soil. In fact, there is a key difference between energy production from fossil fuels and from biomass. The combustion of fossil fuels releases into the atmosphere the CO_2 that has been locked for millions of years into underground geological formations. By contrast, the combustion of biomass from new plantations returns to the atmosphere the CO_2 absorbed by plants in recent times, and—supposed that no indirect land-use change occurs, the production cycle and the use of the resources are maintained over time—this does not cause an overall increase of CO_2.

This report firstly describes the concepts beyond the role that woody energy plantations may have on reducing GHG emission. Subsequently it presents the methods to estimate GHG emissions used in existing accounting systems and their application to bioenergy systems, in particular to the establishment and management of short rotation forestry plantations. In particular the study examines methodologies from the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry and the current IPCC Guidelines for National Greenhouse Gas Inventories. The survey also presents some of the recent discussions about limits and gaps of current accounting methods for bioenergy systems.

Finally we present a specific case of a short rotation forestry plantations of black locust on a former abandoned cropland, for assessing the carbon sequestration in forest biomass, soils and products.

ABBREVIATIONS AND ACRONYMS

2006 IPCC GL	2006 IPCC Guidelines for National Greenhouse Gas Inventories
A/R	Afforestation and reforestation
ABCS	Aboveground and belowground biomass carbon stock
AFOLU	Agriculture, forestry and other land use
CAI	Current Annual Increment (m^3 ha^{-1} $year^{-1}$)
CAP	Common agricultural policy
CLC	Corine Land Cover
D	Wood density
d.m.	Dry matter
dLUC	Direct land use change
DOM	Dead organic matter
DW_{LSOC}	Dead wood, litter and soil organic carbon—the three carbon pools of non-living biomass in an ecosystem
EC	European Commission
EEA	European Environment Agency
EU RED	Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
FAO	Food and Agriculture Organization of the United Nations
GHG (s)	greenhouse gas (s)
GIS	geographic information system
GS	growing stock
HWP	Harvested wood products
IEA	International Energy Agency
iLUC	Indirect land use change

INFC	Inventario Nazionale delle Foreste e del Carbonio (National Inventory of Forests and Carbon)
IPCC	Intergovernmental Panel on Climate Change
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
LCA	Life cycle assessment
LUC	Land use change
MAI	Mean Annual Increment (m^3 ha^{-1} $year^{-1}$)
Mtoe	Million tonnes of oil equivalent
n.a.	not available
NAI	Net Annual Increment
NBP	Net Biome Production
NPP	Net Primary Production
OWL	Other Wooded Land
PHL	Potential Harvesting Level
POUR	Point of uptake and release accounting approach
R/S	Root-to-shoot ratio
RS	Remote Sensing
SFM	Sustainable Forest Management
SOC	Soil organic carbon
SOM	Soil Organic Matter
SRC (s)	Short Rotation Coppice (s)
SRF	Short Rotation Forestry
SRP (s)	Short Rotation Plantation (s)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

UNITS OF MEASURE AND CONVERSION FACTORS

Cubic meter	m^3
Hectare	ha
Megatonne (10^6 tonnes)	Mt
Meter (s)	m
Million (s)	M
Ton (s)	t
Year	yr
1 Gg biomass (oven-dry)	18.6 TJ
1 m^3 wood (oven-dry)	8.714 GJ
1 toe	41.87 GJ

GLOSSARY

BELOWGROUND BIOMASS	All living biomass of live roots. Fine roots of less than 2 mm diameter are normally excluded (as they often cannot be distinguished empirically from soil organic matter or litter).
BIOFUEL	Fuel produced from dry organic matter or combustible oils from plants, such as alcohol from fermented sugar or maize, and oils derived from oil palm, rapeseed or soybeans.
BIOMASS	Organic material both aboveground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above - and below - ground biomass. When used in reference to renewable energy, biomass is any biological (plant or animal) matter that can be converted to electricity or fuel. Woody biomass refers to biomass material specifically from trees and shrubs. It is most often transformed to usable energy by direct combustion, either alone or co-fired with coal; however, efforts are underway to develop methods to cost effectively convert woody material to liquid fuels.
BIOMASS ACCUMULATION RATES	Net build up of biomass, i.e., all increments minus all losses. When carbon accumulation rate is used, only one further conversion step is applied: i.e., the use of 50% carbon content in dry matter (IPCC default value).
BIOMASS EXPANSION FACTOR	A multiplication factor that expands growing stock, or commercial round-wood harvest volume, or growing stock volume increment data, to account for non-merchantable biomass components such as branches, foliage, and non-commercial trees.
CANOPY	The topmost layer of foliage and branches in a woodland, tree or group of trees.
CANOPY COVER	The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants. Same as crown cover.
CARBON DEBT	The excess of GHG emissions from the burning of a source of bioenergy over that from the reference energy source, usually fossil fuel (net emissions over fossil). There is a time delay before the emissions from exploiting bioenergy systems will have reached a breakeven point relative to the fossil fuel systems.

We recognise that this definition simplifies the GHG debt incurred by the burning of bioenergy (eg by neglecting the effect of black carbon and aerosol particles). An alternative definition of 'carbon debt' refers to all the CO_2 released from the combustion of biomass (absolute emissions). However, this definition is less frequently adopted and it is therefore not used in this report.

CARBON LEAKAGE

The term refers to emissions from biomass produced within one geopolitical/national unit which have been displaced beyond the boundaries of this area (geographical understanding). In another sense, the term refers to a concealed breach of the boundaries of the accounting framework, as in the case of indirect land use change (climate policy understanding). Another example of the latter aspect is 'leakage' defined in the principles of the Clean Development Mechanism as the prohibited displacement of emissions beyond the project boundaries. A 'project' in this policy context is not a geographic realisation of a mitigation activity but an accounting framework for such an activity. Both aspects of the term are of relevance in understanding the effects of bioenergy use

CARBON SINK

Any process, activity or mechanism which removes a greenhouse gas (or an aerosol) from the atmosphere (UNFCCC, 1992). The sink function of a forest can best be described in terms of change in the growing forest carbon stock. This occurs for example when a forest is growing (quite naturally or in response to arrangement) and reverses in the case of dieback, decay and fire. The sink function of a newly created woodland is typically high because the stock is in a steep growth curve and the rate of carbon absorption from the atmosphere through photosynthesis is high, whilst the sink function of a mature forest is approaching zero. The accumulation of carbon by terrestrial biomass is reversible since greenhouse gas emissions can be returned to the atmosphere through natural disturbances or premature harvest. Carbon sinks are sometimes mistakenly equated with carbon stocks under the assumption that eg. mature forest holds more carbon from the atmosphere than a newly created woodland. Such misapplication of the term can significantly distort life cycle assessments of the impacts of biomass use.

CARBON STOCK

Pools of carbon, i.e. the overall carbon content accumulated in ecosystems. These pools include carbon in living biomass (above and below ground), dead organic matter (eg deadwood and litter) and soil organic carbon (UNFCCC, 1992). Carbon is accumulated by a forest only up to a point when a steady state is reached so the carbon stock of a given forest stand is finite.

CARBON STOCK CHANGE — The carbon stock in a pool can change due to the difference between additions of carbon and losses of carbon. When the losses are larger than the additions, the carbon stock becomes smaller, and thus the pool acts as a source to the atmosphere; when the losses are smaller than the additions, the pools acts as a sink to the atmosphere.

CO_2 EQUIVALENT — A measure used to compare different greenhouse gases based on their global warming potentials (GWPs). The GWPs are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme CO_2 (carbon dioxide) over a period of time (usually 100 years).

COPPICE — A growth of small trees that are repeatedly cut down at short intervals; the new shoots are produced by the old stumps. Coppicing represents a traditional method of woodland management and wood production, in which shoots are allowed to grow up from the base of a felled tree. Trees are felled in a rotation. Rotation lengths of coppices depend on the desired size and quality of poles and are typically 10-30 years depending on species and site. A coppice may be large, in which case trees, usually oak (*Quercus*), ash (*Fraxinus*) or hornbeam (*Ostrya*), are cut, leaving a massive stool from which up to 10 trunks arise; or small, in which case trees, usually hazel (*Corylus*) or willow (*Salix*), are cut to leave small, underground stools producing many short stems. The system provides a continuous supply of timber for fuel, fencing, etc., but not structural timber.

CROPLAND — Category of land-use that includes arable and tillage land, and agro-forestry systems where vegetation falls below the threshold used for the forest land category, consistent with the selection of national definitions.

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 any other diameter used by the country.

DRY MATTER — Dry matter (d.m.) refers to biomass that has been dried to an oven-dry state, often at 70 °C. Dry matter includes all non-living woody biomass not contained

	in the litter, either standing, lying on the ground, or in the soil.
FELLING CYCLE	The planned period, in years, within which all parts of a forest zoned for wood production and being managed under a selection silvicultural system should be selectively cut for logs. The term is synonymous with Cutting Cycle.
FOLIAGE	The live leaves or needles of the tree; the plant part primarily responsible for photosynthesis.
FOREST	In Italy, according to the National Inventory of Forests and Carbon (INFC, 2005), forest is a land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Forest may consist either of closed forest stands where trees of various storeys and undergrowth cover a high proportion of the ground; or of open where forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Forest can be open forest or closed forest. Young forest stand, even if derived from planting, or areas that are temporarily unstocked due forest management practice or natural disturbances, and which are expected to be regenerated within a short period of time, are considered forest. Forest also includes forest nurseries and seed orchards that constitute an integral part of the forest; forest roads, cleared tracts, firebreaks and other small open areas within the forest; forest in national parks, nature reserves and other protected areas such as those of special environmental, scientific, historical, cultural or spiritual interest; windbreaks and shelterbelts of trees with an area of more than 0.5 ha and a width of more than 20 m. Plantations and cork oak stands are included.
FOREST INVENTORY	System for measuring the extent, quantity and condition of a forest, usually by sampling.
FOREST MANAGEMENT	A system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.
FOREST RESIDUES	Residues resulting from tree harvesting (thinnings or regeneration fellings), e.g. those parts of the tree that are not removed in the roundwood extraction (stem top and stump, branches, foliage and roots). In this study the assessment of biomass potentials from forest residues is limited to stem tops and branches.

GHG EMISSION INTENSITY	The GHG emissions emitted as a result of combustion per unit of energy use at a point in time. This concept is frequently referred to as the GHG emission intensity of energy use as a form of shorthand. It is important to note, however, that the greenhouse gas emissions associated with land use activities for the production of bioenergy feedstocks include not only carbon dioxide (CO_2) but also other gases such as reactive compounds of nitrogen, methane, aerosol particles, eg black carbon, etc.1 Its value will depend on many bio-physical, environmental, climatic and agronomic or silvicultural factors affecting the nature of carbon stocks in the particular forest or agricultural ecosystem at a particular place and point in time when the biomass in question is harvested. We recognise that this term is not based on a scientific definition underpinned by an IPCC global assessment, but we use it in this report because it is commonly utilised in the life cycle assessments developed in the energy sector, typically at national level.
GHG EMISSIONS BALANCE	The overall atmospheric balance of life cycle greenhouse gases over a stated period of time for a given level of energy use. It is determined by the balance between emissions (from human activities and natural systems) and removals of gases from the atmosphere (by conversion to a different chemical compound) (IPCC, 2007). The long term EU targets are expressed as a reduction of the overall GHG emission balance by 80 to 95 per cent by 2050 in comparison with 1990.
GLOBAL WARMING IMPACT	The net global warming impact over a stated period of time for a given level of energy use.
GRASSLAND	Category of land-use which includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and is not expected to exceed, without human intervention, the thresholds used in the forest land category. This category also includes all grassland from wild lands to recreational areas as well as agricultural and silvo-pastural systems, subdivided into managed and unmanaged, consistent with national definitions.
GROWING STOCK	The living tree component of the standing volume (measured in m^3 overbark).
LAND COVER	The type of vegetation covering the earth's surface.

[1] Aerosols may have either a cooling effect on the climate by reflecting incoming solar radiation or a warming effect, by directly absorbing heat radiation and indirectly by changing surface albedo (eg, black carbon soot from biomass combustion) (IPCC, 2007; IPCC, 2011).

LAND USE	The type of activity being carried out on a unit of land.
LITTER	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included in litter where they cannot be distinguished from it empirically.
NET ANNUAL INCREMENT	Average annual volume over the given reference period of gross increment minus natural mortality, of all trees to a specified minimum diameter at breast height.
OTHER WOODED LAND	Land with either: (i) a tree- crown cover (or equivalent stocking level) of 5–10 % of trees which can reach a height of 5 m at maturity; or (ii) a crown cover (or equivalent stocking level) of more than 10 % of trees which can reach a height of 5 m at maturity (e.g. dwarf or stunted trees) and shrub or bush cover.
PASTURE	Grassland managed for grazing.
PAYBACK TIME	The time it takes to ‘pay off’ the carbon debt, i.e. the time it takes for biomass to grow and absorb CO_2 so that the excess emissions that resulted from the combustion of the biomass over the comparable use of fossil fuel are sequestered. Achieving this balance may take decades or even centuries in the case of forest biomass and greenhouse gases will therefore reside in the atmosphere for a long time.
POOL/CARBON POOL	A system which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, soils and the atmosphere. The units are mass.
PRIMARY ENERGY CONSUMPTION	Indicates how much energy is directly available for use in the country (such as electricity imported or produced by hydroelectric power plants), or indirectly available after having been converted into products to be sent to the end market (such as crude oil, which goes to refineries to be transformed into petrol or diesel oil) or having been transformed into electricity (for example, fossil fuels utilised by thermoelectric power plants to produce electricity).
RELATIVE GHG SAVINGS	The reduction of emissions relative to the fossil fuel alternative for a specific biomass use. As an indicator, it does not distinguish between different bioenergy pathways and biomass uses.
REMOVALS	Removals are a subset of fellings (the commercial part destined for processing).

ROTATION	The planned number of years between the establishment of a crop (by planting or regeneration) and final felling. The term is applied where forest is managed under a monocylic silvicultural system.
SHORT ROTATION FORESTRY	Short rotation forestry (SRF) is a practice of cultivating fast-growing trees that reach their economically optimum size between few years, from 1 to 15 years, employing intensive cultural techniques such as fertilization, irrigation and weed control, and utilizing genetically superior planting material, relying on coppice regeneration. In literature many definitions have been used to identify SRF: short-rotation woody crops, short- rotation intensive culture, short rotation forestry, short-rotation coppice, intensive culture of forest crops, intensive plantation culture, biomass and/or bioenergy plantation culture. The concept has evolved over the years. Now it can be meant as a forest plantation at a tree density between 1,100 and 16,000 plants/ha and coppiced from 1 to 5 years, with a length inversely proportional to the planting density. The duration of the planting is provided up to a maximum of 15-20 years.
SINK	Any process, activity or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere. Notation in the final stages of reporting is the negative (-) sign.
SOIL ORGANIC MATTER	Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below- ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.
STANDING VOLUME	Volume of standing trees, living or dead, above stump measured overbark to a predefined top diameter. Includes all trees with diameter above a given diameter at breast height (dbh). The minimum dbh and the top diameter vary by country and are usually country defined.
SUSTAINABLE YIELD	The equilibrium level of production from the growth rate of trees comprising a forest, annually or periodically, in perpetuity. It means the continuous production with the aim of achieving an approximate balance between net growth of a forest and harvest.
WETLANDS	Category of land use which includes land covered or saturated by water for all or part of the year (e.g. peatland) and that does not fall into the forest land,

cropland, grassland or settlements categories. This category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

WOOD DENSITY	Ratio between oven dry mass and fresh stem-wood volume without bark. It allows the calculation of woody biomass in dry matter mass.
YIELD DETERMINATION	The calculation, by volume or by area (or a combination of both), of the amount of forest produce that may be harvested annually, or periodically, from a specific area of forest over a stated period, in accordance with the objects of management.
YIELD PLANNING	The allocation over time of land units within a productive forest for harvesting in a manner calculated to yield sustainable amounts of logs and other products, while ensuring the maintenance and regeneration of the forest's productive capacity which may be required to support that production.

SUMMARY

INTRODUCTION

Global climate change is one of the major environmental issue of current times (GEO-5, 2012). Evidence for global climate change is mounting up year after year and there is a growing consensus that the most important cause is humankind's interference in the natural cycle of greenhouse gases (GHGs[2]). Human activities have enhanced the natural green-house effect by adding carbon dioxide (CO_2) and other greenhouse gases (GHGs)—such as methane (CH_4), nitrous oxide (N_2O), CFC-12, CFC-11 and 10 minor halogenated gases of industrial origin—to the atmosphere. During the 10,000 years before the start of the industrial age, the amount of CO_2 in the atmosphere is estimated to have been stable at around 280 ppm. In 2012, according to the U.S. National Oceanic and Atmospheric Administration, the average annual concentration of atmospheric CO_2 reached 389.78 parts per million (ppm), about 23% higher since the 1958 start of precision CO_2 measurements in the atmosphere. For the past decade the average annual increase was 2.04 ppm per year.

Terrestrial biosphere has major role in the global carbon cycle and in climate change. This is because it stores large amount carbon in vegetation (550±100 10^9 tonnes) and soils (two to three times the amount carbon in vegetation in the top meter) and it exchanges massive amounts of CO_2 and other gases with the atmosphere trough natural processes (such as photosynthesis, respiration and decay) and biotic and abiotic disturbances (such as fires, windthrows, pest and disease damages, herbivory in unmanaged systems, deforestation and forest degradation, wood fellings and removals). Forests are particularly important as a carbon reservoir because trees hold much more carbon per unit area than other types of vegetation and they cover about 4 billion hectares, or about 30 percent of the world's land area (FAO, 2011).

The significance of both the emissions and removals and the potential of humans to alter both the magnitude of carbon stocks in terrestrial biosphere and the direction of carbon fluxes explain why the United Nations Framework Convention on Climate Change (UNFCCC) includes forestry and land-based activities in the international climate change agreement. These activities include conservation of existing C stocks (e.g., through reduced deforestation, devegetation, forest degradation, and land degradation); sequestration of carbon through enhancement of terrestrial C stocks; replacement for more fossil carbon-intensive products; decrease of emissions of non-CO_2 gases (e.g., from agriculture); supplying of renewable energy in substitution of fossil fuels.

The call for strategies to fight global warming is one of the main drivers of a new interest and global attention in biomass-based energy production and specifically in ad hoc energy plantations. In fact these plantations offer double positive input to mitigate GHG emissions: providing feed-stocks for bioenergy to displace fossil fuel use and storing carbon in biomass and soil.

The scope of this report is to describe the concepts beyond the role that woody energy plantations may have on reducing GHG emissions and to point up existing methods to estimate GHG emissions linked to the bioenergy systems and in particular to the establishment and management of short rotation forestry plantations.

[2] GHGs get their name from their ability to trap the sun's heat in the earth's atmosphere and provoke the so-called greenhouse effect.

1. CARBON ACCUMULATION AND CARBON ACCOUNTING

From the atmosphere point of view there is a key difference between energy production from fossil fuels and from biomass. The combustion of fossil fuels releases into the atmosphere the CO_2 that has been locked for millions of years into underground geological formations. By contrast, the combustion of biomass returns to the atmosphere the CO_2 absorbed by plants in more recent times and —supposed that the production cycle and the use of the forest resources are maintained over time— the carbon released will be re-sequestered when the forest re-grows. This does not cause an overall increase of CO_2 (Figure 1). This cycle is possible because plants capture CO_2 from the atmosphere through photosynthesis, releasing oxygen and part of the CO_2 through respiration, and retaining a reservoir of carbon in organic matter. The capability of plants to re-capture the carbon released is at the basis of the carbon neutrality assumption, adopted by the accounting systems under the UNFCCC and Kyoto Protocol. According to this principle, the use of plant based products, including bioenergy do not cause an overall increase of CO_2 in the atmosphere.

If stocks of carbon are increased by planting new forest area or by increasing carbon stocks in croplands or forest stands through changes in management practices, additional CO_2 is removed from the atmosphere. For example, if an area of arable or pasture land is converted to forest, additional CO_2 will be removed from the atmosphere and stored in the tree biomass, provided that other land is not converted to arable or pasture land to compensate for the loss (indirect land use change). The carbon stock on that land increases, creating a *carbon sink* (Figure 1, points a to c). This is the case, for example, of afforestation/reforestation for conservation (establishing a forest cover for conservation purposes, i.e. without intent to harvest).

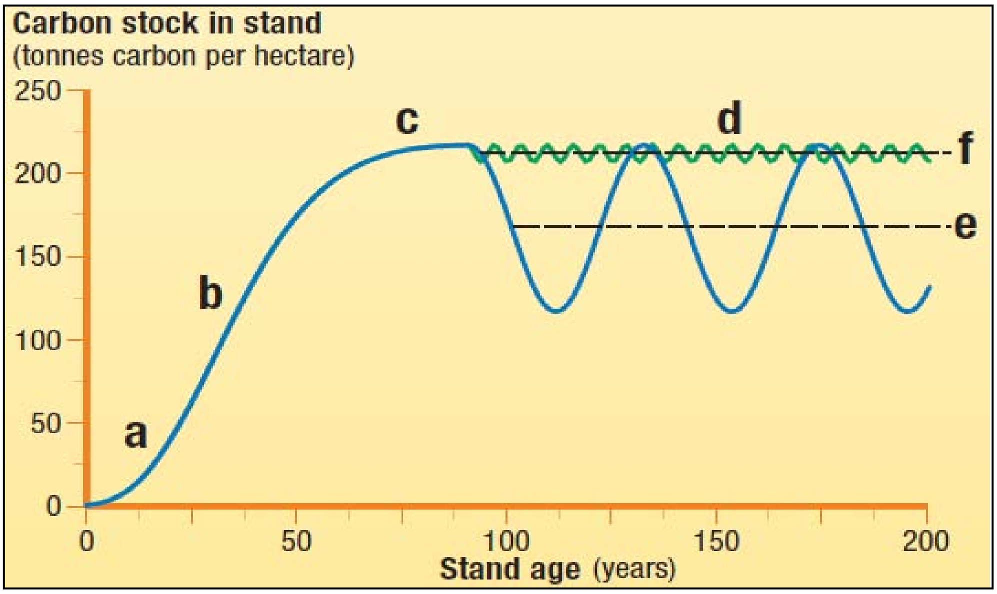

Figure 1 - *New forest stand managed for carbon sink (Source EEA, http://www.ieabioenergy-task38.org/publications/faq/)*

The newly created forest is a carbon sink only while the carbon stock continues to increase. Eventually an upper limit (*equilibrium* or steady state, line *f* or *e*) is reached where losses through respiration, death and disturbances such as fire, storms, pests or diseases, or due to harvesting and other forestry operations equal the carbon gain from photosynthesis (fluctuations after point *c*). Depending on the intensity of the disturbance, the average level of equilibrium can vary (level *e* or *f* in Figure 1). When a forest is managed, the harvested wood is partially converted into wood products. The carbon stored in the products will initially increase (thus acting as a sink) until the decay and destruction of old products matches the addition of new products. Thus a forest and the products derived from it have a finite capacity to remove CO_2 from the atmosphere, and do not act as a perpetual carbon sink.

By substituting for fossil fuels, however, land used for biomass and bioenergy production can potentially continue to provide emissions reductions indefinitely. This can happen in the case of a newly created forest stand for bioenergy production (Figure 2) with consecutive harvest. Periodically (every 50 years in the example reported in Figure 2, times are indicated by vertical arrows) the stand of trees is felled[3] to provide bioenergy, and the soil is replanted or the plantation let to re-grow, with a new stand which grows in place of the old one. In this simplified example, carbon is sequestered and released at harvest.

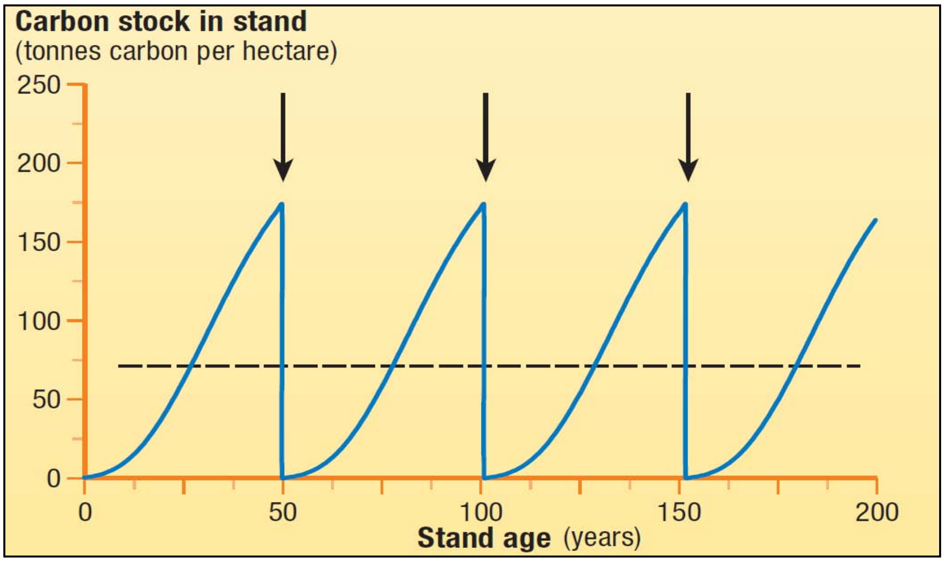

Figure 2 - *New forest stand for bioenergy production, with a felling cycle of 50 years*

Looking over several rotations, it is evident that—following an increase in carbon stocks on the ground due to the initial establishment of the stand—carbon stocks neither increase nor decrease because accumulation of carbon in growing trees is balanced by removals due to harvesting of products. In fact a forest usually consists of many stands like the one in the Figure 2, all established and harvested at different times. Averaged over a whole forest, therefore, the accumulation of carbon stocks is more likely to resemble the time-averaged projection shown as a dashed line in Figure 2. (Carbon dynamics in soil, litter and coarse woody debris are ignored. Impacts outside the forest, such a wood products and bioenergy are also excluded).

Of course fossil energy is usually spent in producing bioenergy: for tractors, for chainsaws, for the transport of plant material, and so on. Some researches consider that this amount of fossil energy is very low, only one unit consumed for roughly 25 to 50 units of energy produced; on the contrary others think this figure—especially for the production of ethanol and biodiesel—is much

[3] This harvesting should not be confused with deforestation. Deforestation implies a change in land cover from forest to non-forest land, whereas sustainable wood production involves cyclical harvesting and growing.

higher: one unit of fossil energy consumed for 4 or 5 produced, but still reduces fossil fuel consumption overall.

2. IS BIOENERGY CARBON NEUTRAL? THERE IS A DEBATE

The presumption (or simplified assumption) of 'carbon neutrality' for bioenergy has become conceptually the norm in several scientific and policy *milieux*, owing in part to GHG emissions from energy and land-based activities, namely agriculture and forestry, being reported separately in national inventories (IPCC, 2006). However, while the assumption can be coherent with the carbon fluxes in new dedicated bioenergy plantations, it is problematic when extended to all bioenergy sources, both in terms of misrepresenting the heterogeneity of existing sources and intensity of use. The main reason for this misconception is perhaps the incomplete implementation of international accounting rules and the misapplied use of the accounting frameworks and life cycle metrics for greenhouse gas emissions from bioenergy which typically address only a part of the actual emissions that occur in the physical world.

More recently, many authors (Searchinger et al., 2009; Pingoud et al., 2010) and agencies, including the European Environment Agency (EEA, 2011), have reconsidered the assumption that bioenergy is carbon neutral, questioning the acclaimed benefits of bioenergy strategies for combating the greenhouse effect and conflicts between bioenergy and food security, sustainable land use, proper management of water, forests, air quality. The opinion of the EEA points the finger at the premise - also received by the EU Directive 2009/28/EC on renewable energy growth (EC, 2009) - for which the combustion of biomass is carbon neutral, regardless of its origin. According to the Scientific Committee of the EEA, biomass burning, when biomass removal is accompanied by a reduction of the stock of carbon in biomass and soil or when the removal puts at risk the potential of an ecosystem to act as a carbon sink (positive net balance between carbon absorbed and emitted), produces accumulation of carbon into the atmosphere. Just like oil, coal and natural gas. Thus, the assumption of 'carbon neutrality' is misleading because it conceals the fact that often the absorption of carbon by plants would occur (fully or partly) even in the absence of bioenergy production. It is only the difference in the overall level of carbon absorption (arising from the deliberate use of bioenergy) that can be reasonably credited to offset the emissions arising from diverting biomass into energy supply. These limits emerge when the term of comparison, or baseline, is a parallel and alternative system that does not include bioenergy (see "Baselines" section). This is a much more demanding test of the contribution of bioenergy use to climate change than assuming that carbon neutrality is inherent. Thus, bioenergy is not a single entity, but encompasses an assortment of very diverse feedstocks and conversion technologies which can be utilised to offset the use of different fossil fuels in various circumstances. Supply chains exhibit great variety in terms of climate impact.

For instance, significant bioenergy development could come at the expense of natural ecosystems, including forests, either directly through conversion to non-forestland, or indirectly, through competition between land uses. In fact bioenergy development may increase the demand for agricultural land; if such land is taken from forests or other natural forms of land use, the net carbon balance would be highly negative (EEA, 2013). In this debate there is a second important factor to take into account. The emissions and removals of carbon by living organisms do not occur in the same time period. Consequently, any claim of carbon neutrality may in effect borrow from, and presume, future emission savings from future growth of plants that has yet to occur and may not take place as envisaged. In effect, an implicit claim is being made on the land where the future absorption could supposedly occur. The importance of the temporal question is much greater for forest biomass (which takes years to re-grow) than, for example, for the waste sector.

Moreover, unlike other renewable sources of energy, a new biomass combustion facility requires a continued supply of biomass resources to feed it over a period of years, not necessarily from the same source. Consequently, its climate impact is not static over time and may be subject to considerable variation. Thus, assumptions about future supply patterns need to be made when evaluating the merits of a new (or an existing) scheme. In addition, the overall pathway chosen to derive useful energy from bioenergy, including the origins of the feedstock used, determines the GHG emission intensity of the various forms of bioenergy. The final conversion technologies in the supply chain are only one component. Finally, utilisation for energy represents only one potential use of diverse biomass materials within society and one means of achieving greenhouse gas emission reductions from the material. In a variety of situations other uses will be preferable purely in terms of climate impact, and irrespective of other considerations. Consequently, maximising the potential carbon benefit from the use of bioenergy will require an appropriately balanced and effective policy framework that is sensitive to the choices and trade-offs.

3. METHODS FOR CARBON ACCOUNTING

Under the current climate policy framework, defined methods are used to account for carbon in the land use sector ad from bioenergy. In this report, we will illustrate the accounting method developed by the IPCC and used under the Kyoto Protocol and the method implemented for the European Renewable Energy Directive. However, criticisms and alternative proposals for carbon accounting are emerging to close some of the accounting gaps existing in the current systems and revise how responsibility for emission reduction is shared globally (Haberl et al., 2012; Cherubini et al., 2009).

One of the foreseen changes concerns the type of baseline used, such as the proposal for using reference levels for forest management in the second commitment period of the Kyoto Protocol (Grassi et al., 2013). Referring to emissions reductions from bioenergy, the choice of baseline can strongly affect the results of the accounting. We will first describe two types of baseline, one adopted under the current accounting system and the second adopted in studies that apply a comparative approach between different energy systems and that are the basis of criticisms against the carbon neutrality assumption.

A further section analyses the specific case of a newly created forest stand on a former agricultural land. The basic assumption is that the biomass after conversion is used for bioenergy production. The analysis focuses on the differences in accounting of GHGs caused by changes in the carbon stock in the biomass. The analysis uses the CO_2FIX (Masera et al., 2003) and GORCAM2 (Marland and Schlamadinger, 1995; Schlamadinger and Marland, 1996) stand-based carbon models as a basis for the analysis, using site-specific or country-specific silvicultural and tree growth information, tree descriptions and geological and climatic data as inputs.

4. BASELINES

The assessment of a change always requires choosing a status to compare to. This choice is required also when we try to estimate an increase or decrease of GHG emissions. The comparison can be between:

- Present emissions to emissions at a certain point in the past
- Present measured emissions and emissions at the same point in time, but under a hypothetical scenario.

The first system has been used in the accounting systems designed for the UNFCCC and the Kyoto Protocol. The reference point, or "baseline", usually was a reference year in the past. For instance, the emission reduction targets were equal to a percentage reduction compared to emissions in 1990. This system has been applied also to the carbon sink or source in the forest and agricultural sector.

The second system is used when we want to establish which of two conditions produces less emission. It is the same principle applied when we compare the emissions from the production of a wood and an aluminium window frame. The two products have the same function, but they require different materials and different production processes. In the forest and agricultural sector, this type of analysis can be applied to evaluate the effects of alternative activities, such as an increase of harvest to produce more bioenergy compared to the current management and the use of fossil fuels (Figure 3).

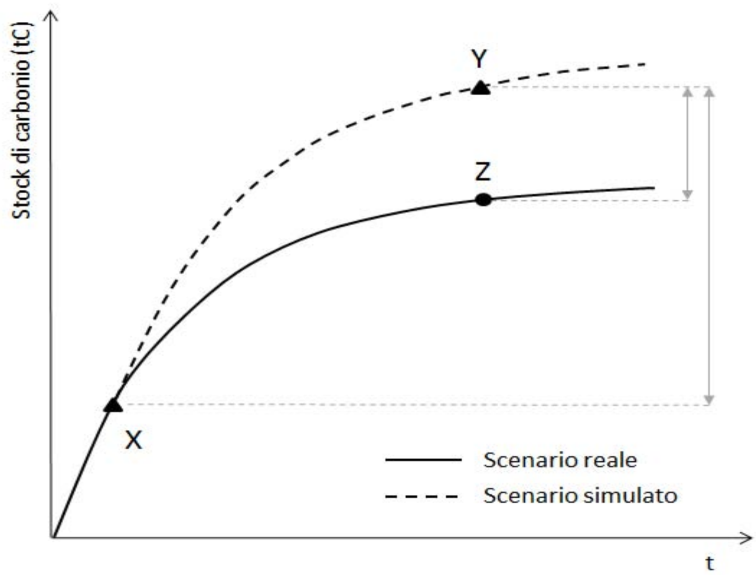

Figure 3 - *Assessment of the effects of an increase of harvest on the forest carbon stock by using different baselines. A) Past baseline (Z – X): it compares the carbon stock after the increase of harvest (Z) with the carbon stock in the same forest in the past (X). B) Baseline under an alternative scenario (Z-Y): it compares the carbon stock after the increase of harvest (Z) with the carbon stock theoretically present in the same forest if the increase of harvest would not occur (Y).*

The analysis can be based on the comparison of two existing situations in different locations. Or it can be based on comparing an existing situation with an alternative scenario simulated with models. Simulated scenarios can also be used to assess the future impact of two alternative activities.

The baseline we choose affects the results we obtain. In some cases, opposite results are obtained from accounting systems using different baselines. In the case depicted in Figure 3, the adoption of a past baseline result in a carbon stock increase in the forest, while the comparison with an alternative scenario, results in a loss of forest carbon stock.

5. HOW THE UNFCCC AND THE IPCC TREAT THE GHG EMISSIONS FROM THE CONSUMPTION OF BIOENERGY?

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) identifies the key role of land use, crop production, conversion of grasslands to croplands and biomass burning in the increase in atmospheric CO_2 concentrations (IPCC, 2007). The report identifies land use activities and biomass burning as key factors contributing to global warming alongside the burning of fossil fuels and deforestation.

The *United Nations Framework Convention for Climate Change* (UNFCCC, 1992) requires annual reporting by nations (IPCC, 1996; IPCC, 2006). One requirement is that all nations have to draw up national inventories of GHG emissions and must count up emissions from biomass use either within the energy sector or, alternatively, within the Land Use and Land Use Change and Forestry (LULUCF) sector. Land-use emissions are described by reporting changes in the carbon stocks of agricultural or forest ecosystems, including those that supply biomass feedstock for energy facilities. These carbon stock changes are calculated by using a past baseline, i.e. by comparing present carbon stocks with carbon stock in a reference year (usually 1990).

The UNFCCC thus provide the only structure which is valid at global and national levels and which includes all GHG emissions related to bioenergy production.

The accounting framework for LULUCF under the first commitment period of the Kyoto Protocol has to be interpreted against the backdrop of its objective, which is to ensure that overall GHG emissions do not exceed the emission limitation and reduction commitments assigned to industrialised countries listed in Protocol's Annex I (which includes all EU countries) with a view to reducing overall GHG emissions by at least 5,2 per cent below 1990 levels in the commitment period 2008–2012 (Article 3). It allows for bioenergy emissions being ignored within the energy sector on the condition that they are counted within the LULUCF sector in the same framework. The accounting framework is correct and consistent in its objective, although the consequence—which is a shift of the reporting of GHG emissions from bioenergy combustion into the LULUCF sector—is to some extent inconsistent with the structure of the national inventories under the UNFCCC reporting process. More importantly, the implementation of the LULUCF requirements under the Kyoto Protocol is very inadequate at this point, because only selected Land-Use activities are eligible as mitigation options. The result is that that only a part of the land-use sector is included in the accounting and GHG emissions from bioenergy consumption are not accounted systematically anywhere in the progress toward the GHG reduction targets.

6. DESCRIPTION OF EXISTING ACCOUNTING METHODOLOGIES

This report examines methodologies from:

- the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF; IPCC 2003) and the current IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006);
- Directive 2009/28/EC of the European Parliament and of the Council (EU Renewable Energy Directive; European Union, 2009).

6.1 IPCC methodology

In 1991 the IPCC begun the National Greenhouse Gas Inventories Programme (IPCC NGGIP), with the aim to elaborate and develop a methodology and a related software for periodic assessing and reporting of GHG emissions and removals. Since then the IPCC-NGGIP maintains a data base of emission factors and other parameters, complemented by documents and technical and scientific references (http://www.IPCC-nggip.iges.or.jp/EFDB/main.php) The IPCC Guidelines provide a general framework for the different GHG emission sectors, such energy, industry, waste, and agriculture and forestry. Within each sector, nations provide inventories that reduce as much as possible uncertainties and that are produced in good faith, allowed to use different tiers, different for quality and precision.
Currently the 2006 IPCC Guidelines (IPCC, 2006) are the most update guidelines for preparing the national GHG inventories.

6.1.1 Treatment of bioenergy

A very important aspect of the IPCC methodology is its treatment of emissions from the use of biomass for bioenergy[4]. Both 1996 and 2006 editions of the IPCC guidelines for GHG accounting (IPCC, 1996; IPCC, 2006) consider bioenergy to have zero CO_2 emissions in the energy sector only, but not zero emissions overall. In fact CO_2 and non CO_2 gas emissions from the combustion of biomass for energy are included as a change in levels of carbon stocks in the land use sector.

Bioenergy was allocated zero CO_2 emissions in the energy sector because:

1. 'the net release of carbon should be evident in the calculation of CO_2 emissions described in the Land Use Change and Forestry chapter' (IPCC, 1996);
2. 'of the sustainable nature of biofuels' (IPCC, 1996);
3. 'the accounting system should be as simple as possible, but not simpler';
4. net emissions or removals of CO_2 are estimated in the AFOLU sector and take account of these emissions' (IPCC, 2006);
5. biomass data are generally more uncertain than other data in national energy statistics'(IPCC, 2006);
6. 'a large fraction of the biomass, used for energy, may be part of the informal economy, and the it may be not registered in the official statistics and thus in the national GHG balances' (IPCC, 2006);
7. it avoids any double counting' (IPCC, 2006).

[4] The IPCC guidelines are designed to estimate emissions and removals of GHGs from different sectors, including land-based activities, such as agriculture and forestry, for the compilation of a national inventory. However, the IPCC methodologies can be extended in assessing the climate change mitigation potential of project activities, including sustainable forest-based bioenergy.

This approach to allocate GHG emissions is correct and provides what all countries are reporting. However, as Searchinger et al. (2008) and Pingoud et al. (2010) point out, it contravenes the principle of completeness over space as some countries are not participating in the Kyoto Protocol (like USA and several developing countries). in addition, in countries that are participating, some parts of the AFOLU sector are not included because only reporting carbon stock changes from afforestation, deforestation and reforestation is mandatory under the Kyoto Protocol (article 3.3), while other land-based activities are optional (article 3.4). Hence reductions in carbon stock in a forest that remain forest, due to diverse forest management regime, may not be included. Thus, as not all emissions from the AFOLU sector are included, the assumption of zero CO_2 emissions from bioenergy in the energy sector is not valid, and the GHG emission benefits from bioenergy are overestimated.

The current accounting system may have two perverse consequences. First, nations with GHG limitations have an incentive to source biomass from nations that do not. Therefore, neither the carbon stock changes nor the GHG emissions at the point of combustion are accounted for—even if the biomass is used in nations that do have obligations under the Kyoto Protocol. Second, since the Kyoto Protocol accounting system relieves energy producers of all responsibility for CO_2 emissions from bioenergy, the system provides a powerful incentive for them to use bioenergy even where its use may lead to increases in CO_2 emissions.

6.1.2 Framework for bioenergy assessment of GHG emissions

In this paragraph we describe the IPCC framework that nations or regions can use in calculating their GHG emissions.

The IPCC methodology for carbon accounting uses a generic framework combined with a 3-tiered approach to data quality and complexity (see paragraph 5.1.2). The generic framework estimates the carbon stock changes in 5 pools, on an annual basis across the following 6 land use categories: forestland, cropland, grassland, wetlands, settlements, and other land (like desert and rocks). The 5 pools for each land use category are: aboveground biomass, belowground biomass, dead wood, litter and soil. In addition, a 6th pool, harvested wood products (HWP), should be reported at the national level.

Therefore, carbon stock changes from land use are generally calculated on an yearly basis by the following formula:

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{S} + \Delta C_{OL} + \Delta CH_{WP} \qquad (1)$$

where:

ΔC_{AFOLU} carbon stock change from AFOLU, tC yr^{-1}
ΔC_{FL} carbon stock change on forestland, tC yr^{-1}
ΔC_{CL} carbon stock change on cropland, tC yr^{-1}
ΔC_{GL} carbon stock change on grassland, tC yr^{-1}
ΔC_{WL} carbon stock change on wetlands, tC yr^{-1}
ΔC_{S} carbon stock change on settlements, tC yr^{-1}
ΔC_{OL} carbon stock change on other lands, tC yr^{-1}
ΔCH_{WP} carbon stock change in harvested wood products, tC yr^{-1}

For each land use, the carbon stock changes in each pool have to be estimated and summed. Therefore:

$$\Delta CLUi = \Delta CAB + \Delta CBB + \Delta CDW + \Delta CLI + \Delta CSO \qquad (2)$$

where:

ΔC_{LUi} carbon stock change in land use, i tC yr^{-1}
ΔC_{AB} carbon stock change in aboveground living biomass, tC yr^{-1}
ΔC_{BB} carbon stock change in belowground living biomass, tC yr^{-1}
ΔC_{DW} carbon stock change in dead wood, tC/yr ΔCLI carbon stock change in litter, tC yr^{-1}
ΔC_{SO} carbon stock change in soils, tC yr^{-1}

6.1.2.1 Tier structure

The IPCC inventory system uses the concept of 'key category' to identify sectors and items that have a significant influence on a country's total inventory of GHGs. The significance can be in terms of: the absolute level of, trend in, or uncertainty in GHG emissions and removals. Generally, if an item is considered a key category, then it is accounted for using a more detailed and accurate method or level of complexity (tier).

The tier structure relates to the availability of activity data and the quality of the estimate of the accounting. The higher the tier, the more comprehensive, accurate and complete is the carbon accounting, but more detailed data are required.

- Tier 1 is the simplest methodology to be used by countries. The 2006 IPCC GL provide equations and default parameter values. Country-specific activity data are needed, but in Tier 1 missing or unavailable activity data can be replaced by estimates based on globally available sources of data.
- Tier 2 uses the same methodological approach as Tier 1 but applies country- or region-specific parameters and activity data that are more appropriate for the climatic conditions and land use and agricultural systems in the country.
- Tier 3 applies models and inventory measurement systems specific to address national circumstances, repeated over time and driven by high-resolution activity data and disaggregated at sub-national level. Models and measurement systems must undergo quality checks, audits and validations and be thoroughly documented. In this paper, Tier 3 is equivalent to full carbon accounting and is estimated using the models described in the introduction.

Depending on country circumstances and the tier chosen, stock changes may not be estimated for all pools. For example, Tier 1 methods include the following simplifying assumptions:

- changes in belowground biomass carbon stocks are assumed to be zero;
- dead wood and litter pools are often grouped together as dead organic matter (DOM) and DOM stocks are assumed to be zero for non-forest land use categories;
- the average transfer rate into DOM is assumed to equal out the average transfer rate of DOM for land that remains in the same category, so that the net stock change is zero;
- for forestland converted to another land use, the net stock change is not zero, but default values for estimating DOM carbon stocks are provided.

Finally, countries can report different tiers for different pools and land use categories.

6.1.2.2 Accounting approaches

There are 2 fundamentally different approaches for estimating carbon stock changes:

1. the *process-based approach*, which estimates the net balance of additions to and removals from a carbon stock (*gain–loss method*); and
2. the *stock-based approach*, which estimates the difference in carbon stocks at 2 points in time (*stock-difference method*).

6.1.2.2.1. Gain–loss method

In the gain–loss method, yearly changes in carbon stocks are estimated by summing the differences between the gains and losses in a carbon pool. Gains occur due to growth (increase of above- and below-ground biomass) and due to transfers of carbon from another pool (e.g. transfer of carbon from the live biomass carbon pool to the DOM pool due to harvest or natural disturbances). Losses occur due to transfers of carbon from one pool to another (e.g. the carbon in the slash during a harvesting operation is a loss from the aboveground biomass pool) or other processes such as decay, burning or harvesting.

For each pool, the carbon stock change is calculated using the following equation:

$$\Delta C = \Delta C_G - \Delta C_L \qquad (3)$$

where:
ΔC annual change in carbon stocks in the pool, tC yr^{-1}
ΔC_G annual gain of carbon in the pool, tC yr^{-1}
ΔC_L annual loss of carbon from the pool, tC yr^{-1}

6.1.2.2.2. Stock-difference method

The stock-difference method can be used where carbon stocks in relevant pools are measured at 2 points in time to assess carbon stock changes. The following equation is applied:

$$\Delta C = \left((Ct2 - Ct1))/((t2 - t1) \right) \qquad (4)$$

where:
ΔC annual change in carbon stocks in the pool, tC yr^{-1}
C_{t1} carbon stocks in the pool at time t_1, tC
C_{t2} carbon stocks in the pool at time t_2, tC

Basically the two methods give the same result in terms of GHG emissions and removals, but differ in terms of effort. For example, the gain–loss method does not estimate the actual biomass stocks, which has advantages in certain situations. For example, it is nearly impossible to apply the stock-difference method to soil carbon in peatland, but relatively straightforward to implement the gain–loss approach.

6.1.2.3 Accounting gaps in the IPCC framework

To assess the potential of forest-based bioenergy for climate change mitigation, it is necessary to calculate the GHG emissions and removals against a reference system (baseline) and estimate any emissions that inadvertently occur outside the system boundary.

6.1.2.4 Baseline or reference system

The baseline or reference system is considered to be the emissions and land use that would otherwise occur in absence of the bioenergy activity or project. In the case of natural forest, such emissions may result from periodic natural disturbances such as fire or insect damage. In grasslands, the cause may be continued use as grazing land or perhaps slow natural regeneration of forest. Croplands could continue to be used for agricultural purposes, converted to grasslands or abandoned as degraded lands with slow natural regeneration of forest.

The baseline or reference system is project and site specific and there is no IPCC methodology for its incorporation. It is included below as part of the example presented.

6.1.2.5 Indirect land use change and leakage

Indirect land use change (iLUC) refers to land use change that occurs outside the system boundary because of the loss of a service that the land provided before the application of the bioenergy activity. A well-documented example of iLUC is the deforestation of Brazilian Amazon rainforest caused by the shift from corn production for animal feed to ethanol production in the United States (Fargione et al., 2008; Searchinger, 2008). This loss of animal feed (not corn) caused an increase in the production of soy in Brazil and resulted in large- scale deforestation.

In the CDM lexicon, GHG emissions resulting from iLUC are a type of leakage. iLUC is potentially the largest source of leakage for many bioenergy activities, but leakage should incorporate all emissions outside the project or system boundary that occur as a result of the activity.

To properly assess the potential of forest-based bioenergy for climate change mitigation, iLUC and leakage emissions should be considered.
The emissions caused by the iLUC appear in the emission inventory of the country in which the iLUC occurs (if it is reporting), regardless of whether the land use change occurs in that country.

6.1.2.6 Cyclic harvesting systems

Permanence, or the potential for the loss of carbon stocks, is a perennial issue in LULUCF projects. Of interest here is a method for assessing the carbon stocks in forest systems that have cyclic harvesting. The 2006 IPCC GL do not develop a methodology for this situation because the IPCC methodology is inventory based, i.e. all losses and gains are incorporated.

In an earlier IPCC publication (IPCC, 2000), it was suggested that, for carbon stocks in forest systems with cyclic harvesting, the cycle average carbon stock is assumed for all cycles after the first cycle. During the first cycle the carbon stock changes between the reference carbon stock and the cycle average are included. Although this suggestion simplifies the dynamics of cyclic harvesting systems, it creates accounting problems because of the need to know the cycle average carbon stock value *a priori*.

A more tenable and realistic approach to forest systems with cyclic harvesting is to use a moving average with the amount of time over which the average is estimated is equal to the cycle length. This is equivalent to assuming that the activity is evenly distributed over time; this is a reasonable assumption that is equivalent to assuming a constant flow of bioenergy feedstocks once the activity reaches maturity.

Figure 3 compares approaches for dealing with forest systems with cyclic harvesting. A moving-average approach has the following advantages over other approaches:

- it does not require *a priori* knowledge of the average biomass in a cycle;

- it is easy to calculate;
- it represents a realistic situation of even production of the bioenergy feedstock.

The disadvantage of the moving-average approach is that it is a trailing estimate and does not respond to changes in emissions or removals as quickly as the other approaches. This is a conservative approach if the activity includes an increase in carbon stocks.

6.1.2.7 Timing of emissions

The IPCC methodology, being addressed to national governments, is designed for annual recording of GHG emissions and removals. To understand the total impact of an activity, we use the cumulative emissions over the first cycle (until the new system approximately reaches a dynamic *equilibrium*).

6.2 EU Renewable Energy Directive

The EU Renewable Energy Directive recognises the role that the implementation of European energy consumption and the increased use of energy from renewable sources—together with energy savings and increased energy efficiency—has on the fulfilment of the package of measures needed to reduce GHG emissions and comply with the UNFCCC agreements. Firstly, the Directive asserts that the lack of transparent rules and coordination between the different authorisation bodies has been shown to hinder the deployment of energy from renewable sources. In this regard the Directive makes out that it is necessary to lay down clear rules for the assessment of GHG balances from bio-fuels and bio-liquids. It does so in a simplified manner on the grounds that: "... economic operators should be able to use actual values for the carbon stocks associated with the reference land use and the land use after conversion. They should also be able to use standard values. The work of the IPCC is the appropriate basis for such standard values. That work is not currently expressed in a form that is immediately applicable by economic operators. The Commission should therefore produce guidance drawing on that work to serve as the basis for the calculation of carbon stock changes for the purposes of this Directive, including such changes to forested areas with a canopy cover of between 10 to 30%, savannahs, scrublands and prairies".
In 2010 the European Commission released three documents related to land use change and biofuels designed to clarify issues in the EU Renewable Energy Directive. These documents are:

1. Communication on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels (EU, 2010a);
2. Communication on voluntary schemes and default values in the EU biofuels and bioliquids sustainability scheme (EU, 2010b);
3. Commission decision on guidelines for the calculation of land carbon stocks for the purpose of Annex V of Directive 2009/28/EC (EU RED Guidelines). (European Union, 2010c).

6.2.1 Applicability

In order to protect areas of high biodiversity, the EU Renewable Energy Directive limits the areas allowed for the production of biofuels and bioliquids. The following areas may not be used (Art. 17(3)):

- primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

- areas designated for nature conservation purposes; or for the protection of rare, threatened or endangered ecosystems or species;
- highly biodiverse grassland.

Furthermore, to preserve areas of high carbon stock, the EU Renewable Energy Directive states that biomass production foe energy is not allowed in areas that had the following status in January 2008 and did not have that status at the time the feedstocks were obtained (Art. 17(4)):

- wetlands;
- continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30%, or trees able to reach those thresholds *in situ*;
- land spanning more than 1 ha hectare with trees higher than 5 metres and a canopy cover of between 10% and 30%, or trees able to reach those thresholds *in situ*, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in part C of Annex V is applied, the conditions laid down in paragraph 2 of this Article would be fulfilled (i.e. unless the carbon stock losses are accounted for using the methodology).

It is important to note that the applicability conditions preclude the possibility of deforestation for the creation of biofuels and bioenergy under the EU Renewable Energy Directive. However, as stated by many environmental organisations, such as BirdLife, this can potentially allow a relevant rate of forest areas to be converted to biofuel production. Moreover it does not take into account the recognised forest definition of the FAO (integrated by many for which forest is defined as: "land spanning more than 0.5 hectares, with trees higher than 5 metres and a canopy cover of more than 10%, or trees able to reach these thresholds in situ" (FAO, 2006).

6.2.2 Methodology

The EU Renewable Energy Directive (RED) and the EU RED Guidelines are designed to estimate the emissions from the changes in carbon stocks due to land use change only. They are very simple methodologies based on the IPCC Guidelines for Tier 1 calculation of terrestrial carbon stocks. It annualises the carbon stock changes caused by land use change over a 20-year period; carbon stocks take account of both vegetation and soil pools. Thus, it is a stock-difference method. The methodology uses the following equation:

$$e_l = ((CSR - CSA) * 3.664)/(20 * P)) - e_B \quad (5)$$

where:

- e_l annualised GHG emissions from carbon stock change due to land use change (measured as mass of CO_2-equivalent per unit biofuel energy)
- CS_R the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use is the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later. Vegetation includes above- and belowground living vegetation as well above- and belowground dead organic matter (dead wood and litter).
- CS_A the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). This is taken as:
    - in the case of loss of carbon stock: the estimated equilibrium carbon stock that the land will reach in its new use;
    - in the case of carbon stock accumulation: the estimated carbon stock after 20 years or when the crop reaches maturity, whichever is earlier.

Vegetation includes above- and belowground living vegetation as well as above- and belowground DOM (dead wood and litter).

- 3.664 the quotient obtained by dividing the molecular weight of CO_2 (44.010 g/mol) by the molecular weight of carbon (12.011 g/mol)
- P the productivity of the crop (measured as biofuel or bioliquid energy per area unit)

- e_B bonus of 29 g CO_2eq/MJ biofuel or bioliquid if biomass is obtained fro stored degraded land

For comparison with the IPCC methodologies, which use tC year^{-1} as the unit for emissions, we modify the EU Renewable Energy Directive methodology to:

$$\Delta C = ((CSR - CSA))/20 \quad (6)$$

Therefore the main difference between the EU Renewable Energy Directive and the other methodologies stays in the use of a period of annualisation of 20 years.

Furthermore, the 2006 IPCC Guidelines use a tiered approach for the carbon accounting, in which Tier 1 does not include litter and dead wood, but Tiers 2 and 3 do. By contrast, the EU Renewable Energy Directive suggests that dead wood and litter play a minor role in carbon stock changes with the exception of conversion of closed forest to cropland or grassland (deforestation). The EU RED Guidelines provide the following equations for the calculation of carbon stocks.

$$CS_i = A * (C_{VEG} + SOC) \quad (7)$$

where:
A a factor scaling to the area concerned (ha per unit area)
C_{Si} the carbon stock per unit area associated with the land use (measured as mass of carbon per unit area, including both soil and vegetation)
C_{VEG} the above- and belowground vegetation carbon stock (measured as mass of carbon per hectare)
SOC the soil organic carbon (measured as mass of carbon per ha)
and

$$C_{VEG} = BAGB * (1 + R) * CFB + DOMDW * CFDW + DOMLI * CFLI \quad (8)$$

where:
C_{VEG} the above- and belowground vegetation carbon stock (measured as mass of carbon per ha)
B_{AGB} aboveground living biomass (measured as mass of dry matter per ha)
R ratio of belowground carbon stock in living biomass to aboveground carbon stock in living biomass
CF_B carbon fraction of dry matter in living biomass (measured as mass of carbon per mass of dry matter); default value = 0.47
DOM_{DW} mass of dead wood pool (measured as mass of dry matter per hectare)
CF_{DW} carbon fraction of dry matter in dead wood pool (measured as mass of carbon per mass of dry matter); default value = 0.509
DOM_{LI} mass of litter (measured as mass of dry matter per ha);
CF_{LI} carbon fraction of dry matter in litter (measured as mass of carbon per mass of dry matter); default value = 0.40
However, equation 8 is seldom used because the EU RED Guidelines encourage using default values in methodology application.

6.2.3 Baseline

Because the emissions are estimated against a reference land use of 'January 2008 or 20 years before the raw material was obtained, whichever was the later', the EU Renewable Energy Directive assumes constant carbon stocks in the baseline. This means that in the absence of the project there is:

- no land use change;
- no growth or removals of carbon stocks on the land.

Indirect land use change and leakage
The EU Renewable Energy Directive acknowledges that bioenergy activities may cause iLUC but does not propose a methodology to account for these emissions.

6.2.4 Cyclic harvesting systems

For cyclic harvesting systems such as cropland, perennial crops and forest plantations, the EU Renewable Energy Directive adopts the time average of above- and belowground living biomass during the production cycle or, in the case of carbon stock sequestration, the stock after 20 years or the first cycle, whichever is earlier.

6.2.5 Timing of emissions

The EU Renewable Energy Directive amortises the total carbon stock change over the first 20 years.

7 REFORESTATION: GRASSLAND TO SHORT ROTATION COPPICE PLANTATION IN LAZIO, ITALY

Short rotation coppice (SRC) plantation is a specialized woody crop planned and managed to produce relatively high quantity of woody biomass in few years (2-3) years. Maximal biomass production is an obvious target for SRC plantation and it varies considerably depending on the tree species and are affected by the influence of genetics, soil, climate and management on survival, competition, and vigor of the stand. Harvestable yields in temperate and Mediterranean regions of Europe range between 17 and 26 m^3 ha^{-1} yr-^{1}, or about 10 and 15 tons (t) of dry matter (d.m.) ha^{-1} yr^{-1}. After each harvest the new shoots re-grow from the coppice stools, starting a new rotation cycle. The time of rotation varies from 2 to 3 years, in order to produce shoots of about 4 centimeters in diameter at breast height (dbh), a dimension that best bestow to machineries typically used for harvesting (Facciotto e Schenone, 1998). Rotations shorter than 3 years lead to reduced yields after several rotations due to physiological problems including stump aging and depletion of carbohydrate reserves, and maximum biomass productivity is expected with harvest cycles of 3 to 11 years.

The species typically used for SRC for production of biomass for energy in Europe are the *Betula pendula Roth*, *Betula pubescens Ehrh.*, *Corylus avellana L.*, *Populus* ssp., *Salix* ssp, *Rhamnus frangula L.*, *Juglans regia L.*, the exotic *Acer negundo L.*, *Ailanthus altissima (Mill.)*, *Juglans nigra L.*, *Eucalyptus camaldulensis Dehnh.*, *Pawlonia tomentosa (Thunb.)*, *Robinia pseudoacacia* L. and various clones of *Populus* x *euramericana*. However, most plantations consist of specific poplar clones (Bianco and Ciccarese, 2013; Bianco et al., 2014).

Table 1 - *Deciduous species to be used for SRF planting and their characteristics (Source: Bianco et al., 2014)*

Species	Coppice shoots (length of annual shoot [cm])	Yield of wood(annual volume increment: m^3 * ha^{-1} * $year^{-1}$)	Calorific value(GJ * m^{-3})	Biomass production ODT(oven dry tonnes) * ha^{-1} * $year^{-1}$
Acer pseudoplatanus L.	150	15 -19.5	10,1	3-7
Ailanthus altissima (Mill.)	80-180	20	4,9	
Alnus glutinosa (L.) Gaertn	120	> 10^2	9,2	3-5
Castanea sativa Miller	100	10.43 (3 ys)	16	3-6
Corylus avellana L.		> 6^2	10.79	1-2
Populus x euramericana L.		> 10^2	9.8-9.9	5–24
Populus nigra L.	150	> 10^2	7.4	7.5
Populus alba L.	100	> 10^2	7.4	9
Populus tremula L.		> 10^2	8.6	10
Robinia pseudoacacia L.	150	23 (ten ys)	17.83- 18.62	10-15
Salix sp.	150	> 10^2	7.7	2,95-36,61

8 MATERIALS AND METHODS

For estimating the carbon sequestration potential of a SRF plantation, in this study we consider a black locust (*Robinia pseudoacacia* L.) SRF plantation on an abandoned cropland in central Italy, in a site approximately 50 km from the Tyrrhenian Sea coast, at 550 meters above sea level. The soil of the studied area is characterized by volcanic origin, and a meso-mediterranean climate, with higher temperatures in July-August and summer low rainfalls (Figure 4).

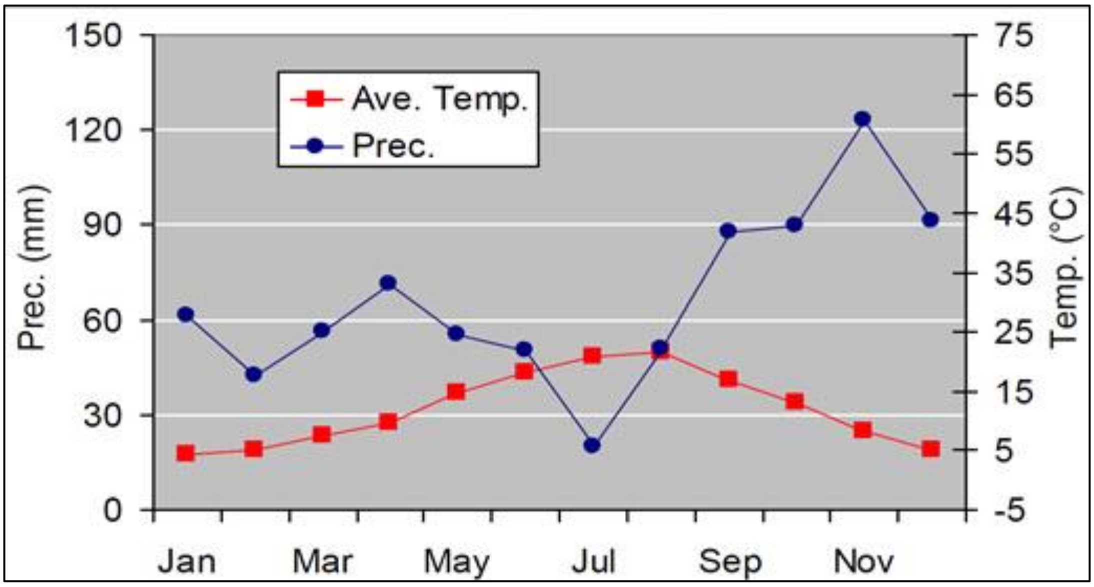

Figure 4 - *Thermo-pluviometric diagram at the black locust plantation site*

Plantation lasts 15 years and it is harvested every three years. After 5 rotation cycles, plantation is removed and soil re-established. The density of plantation is 9,260 seedlings ha^{-1}, where distance between plants on the same row is 0.6 m and the distance between rows is 1,8 m. In this study we assume that average yield of black locust SRF at first harvest are expected to be 10 cubic meters per hectare per year (m^3 ha^{-1} yr^{-1}), or 5.9 oven dry tons per hectare per year (odt ha^{-1} yr^{-1}) the first three years since plantation.

After the first harvesting, average yield increases to 20 m^3 ha^{-1} yr^{-1}, or 11.8 odt ha^{-1} yr^{-1}, for the next three rotation cycles and decrease to an average of 16,7 m^3 ha^{-1} yr^{-1}, or 9.7 odt ha^{-1} yr^{-1}, over the last cycle, before the plantation is removed (Figure 5). At each harvest we assume that whole foliage remains on site as litter and dead wood (Table 3). The roots do not die and enter the dead wood and litter pools. The most significant cultivation operations that characterize the black locust SRF plantation are shown in Table 2 below here.

Table 2 - *Cultivation operations of black locust SRF plantation over five rotation cycles*

Practices and operations per year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Plant operations																
Tillage	X															
Harrowing		X														
Transport and distribution of fertilizers (P, K)		X														
Planting out	X															
Cultivation practices																
Pest and desease control																
Mechanical weed control between rows		X			X			X			X			X		
Chemical weed control between rows		X			X			X			X			X		
Fertilization (N)		X														
Irrigation		X														
Harvesting and transport				X			X			X			X			X
Soil re-establishment (removal of SRF)																X

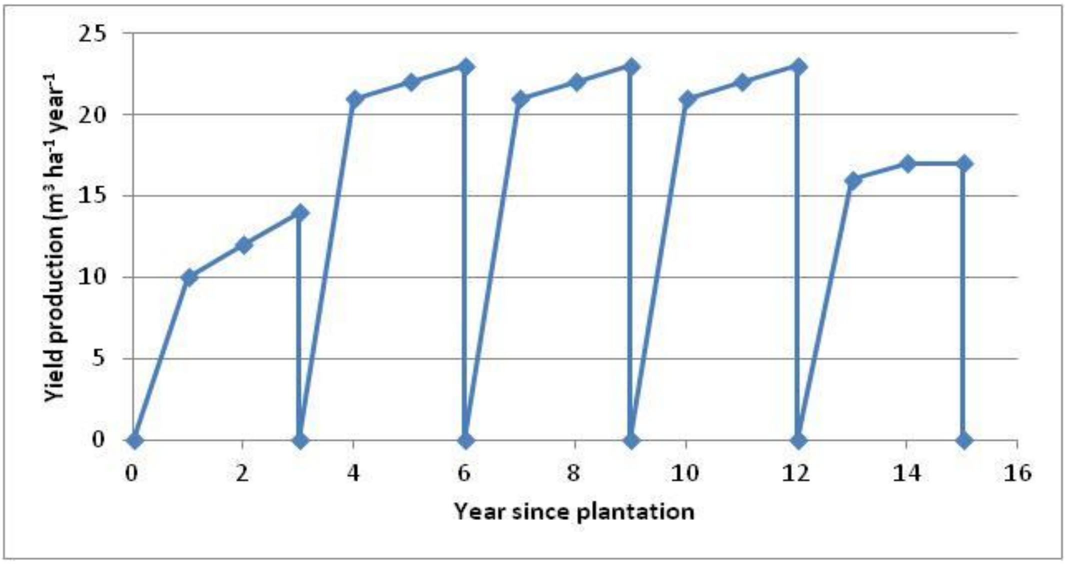

Figure 5 - *Evolution of SRF annual crop yield (m^3 ha^{-1}) over 5 rotation periods*

9 THE CO_2FIX MODEL

For assessing the carbon sequestration the CO_2FIX model (Masera et al., 2003) was used. CO_2FIX model is a stand level simulation tool for estimating the carbon sequestration potential of forest management, agroforestry and afforestation projects. It is a multi-cohort ecosystem-level model on carbon accounting of forest stands, including forest biomass, soils and products. The model calculates the carbon balance with a time-step of 1 year. Basic input is current annual increment of stem volume and corresponding allotment patterns to the other tree pools: foliage, branches and roots. Carbon stocks in living biomass are calculated as the balance between growth (accumulation) on the one hand and turn-over, mortality, harvest and decomposition on the other hand. The model is divided into six major modules: biomass, soil (litter and humus), wood products, bioenergy, and both financial (which is not considered here) and carbon accounting. Figure 6 illustrates the modular structure of the model.

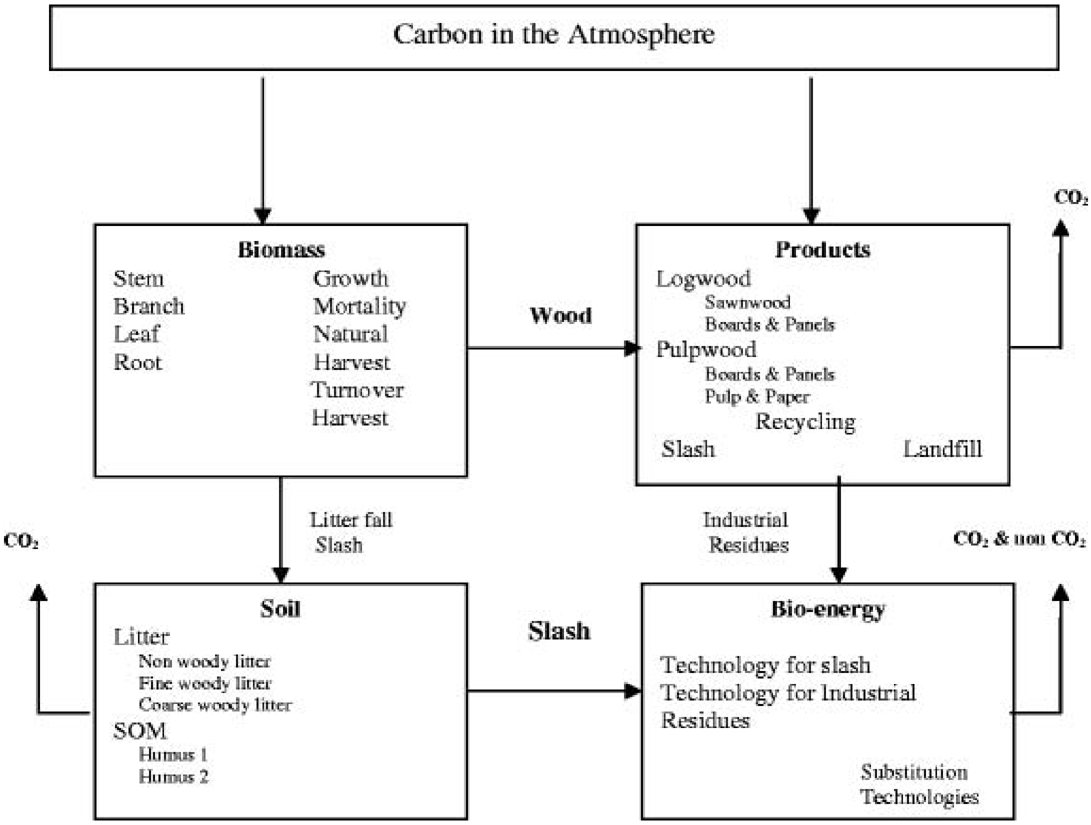

Figure 6 - *Structure of CO_2FIX V3 model, including major compartments used in each module, processes affecting the pools (right hand side in the boxes), major flows between modules and fluxes of CO_2 from modules to the atmosphere.*

For the soil carbon module, the litter is grouped as non-woody litter (foliage and fine roots), fine woody litter (branches and coarse roots) and coarse woody litter (stems and stumps). Litter is produced in the biomass module through biomass turnover, natural mortality (mortality due to senescence and competition), mortality due to logging and harvesting of trees, and logging slashes. Litter remaining from thinning and final harvest is distributed over the decomposition compartments of extractives, celluloses and lignin-like compounds according to chemical composition. The principle of the product module is that it tracks the carbon from harvesting to final decay. The harvested wood is allocated to different product groups depending upon the type of use of tree species, and taking into account the use of processing losses to other product groups.

Products are assumed to decay with a certain fraction per year depending upon the life span estimates. Carbon is released to the atmosphere through combustion, as—in the case study presented in this report—products used for fuel-wood. The product not used for bioenergy is allocated as slash (Table 3).

The model was parameterized for the simulations using published data on growth rate and biomass amounts. The carbon content of dry matter was calculated assuming that the carbon fraction in live biomass is 50%. Wood density for the species considered was 0.58 Mg m^{-3}. The litter production rate for the separate biomass compartments was derived by multiplying the biomass stock with corresponding turnover coefficients (per year).

The soil module of CO_2FIX model uses climate data about precipitation, evapotranspiration and mean monthly temperatures. Initial soil and carbon data were derived from the procedure as reported by Masera et al. (2003). Degree days above zero were calculated from the mean monthly temperatures using the method described by Liski et al. (2003).
In the product module, harvested wood was divided into fuelwood (97%) and harvest residues and foliage (3%) was categorized as slash.

Table 3 - *Product allocation for each harvesting cycle*

	Logwood	Pulpwood	Slash
***Robinia pseudoacacia* L.**			
Stem-harvesting	0.97	0	0.03
Branch	0.97	0	0.03
Foliage	0.00	0	1.00

Table 4 - *Summary of parameters used in simulating carbon dynamics in a SRF plantation of Robinia pseudoacacia L.*

Parameter	**Value**
Basic wood density, (Mg m^{-3})	*0.58*
Turn-over rates (1/yr)	
Foliage	0.95
Branches	0.10
Roots	0.04

Ratio of dry weight increase relative to dry weight increase of stem (dimensionless)															
Stand age (years)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Foliage	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Branch	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Root	0.3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Fraction removed during thinning or harvest															
Age (years)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0	0	0	0	0.97	0	0	0	0.97	0	0	0	0.97	0	0

10 RESULTS

Here we present results from a case study of land-based activities, which is relevant for the scope of this Proforbiomed pilot action: the establishment of a short rotation forestry plantations on a former abandoned cropland using *Robinia pseudoacacia* L..

The trend of carbon stocks in soil, litter a living biomass (roots, stems, branches and foliage) in a SRF plantation of black locust with rotation span of 15 years, harvested every 3 years is showed in figure 7. The soil C pool, based on Yasso model, highlights an increase in stock from 3.5 Mg C ha^{-1} in the initial year to 5.19 Mg C ha^{-1} by the end of the rotation cycle and before the final harvest; this can be mainly due to an accumulation of litter and dead wood on the ground. The stock in living biomass increased from 0.01 Mg C ha−1 to 15.08 Mg C ha−1 at year 15 (Table 5). In the same period, the amount of carbon in the litter layer had increased from 1.05 to 4.57 Mg C ha^{-1} after the last harvest.

The total carbon amount accumulated before the last harvest is represented by the sum of the living biomass (12.53 Mg Cha^{-1}), plus the litter layer (1.32 Mg C ha^{-1}), plus harvested products (13.67 Mg C ha^{-1}). For the same period the carbon stock reached the value of about 26 Mg Cha^{-1} (10.42 Mg C ha^{-1} for the ecosystem C stock, plus 15.57 Mg C h^{-1} for the products). At the end of the rotation cycle the total bioenergy mitigation was estimated in about 26 Mg C ha^{-1} (Table 5). Total carbon sequestration reached 52 Mg C ha^{-1} (10.42 Mg C ha^{-1} for ecosystem carbon stock, plus 15.57 Mg C ha^{-1} for the products by the 15^{th} harvest), plus 26.01 Mg C ha−1 from bioenergy mitigation contribution). Moreover at the final harvest the estimated balance for the atmosphere was -21.43 Mg C ha^{-1}.

Detailed data about the partitioned biomass carbon between above and below the ground pools, are shown in table 6.

Finally, table 7 represents the total carbon cumulated at the end of the rotation period (15 years) by using the tier 3 IPCCC Carbon Accounting Method, in the black locust stand for fuel-wood production.

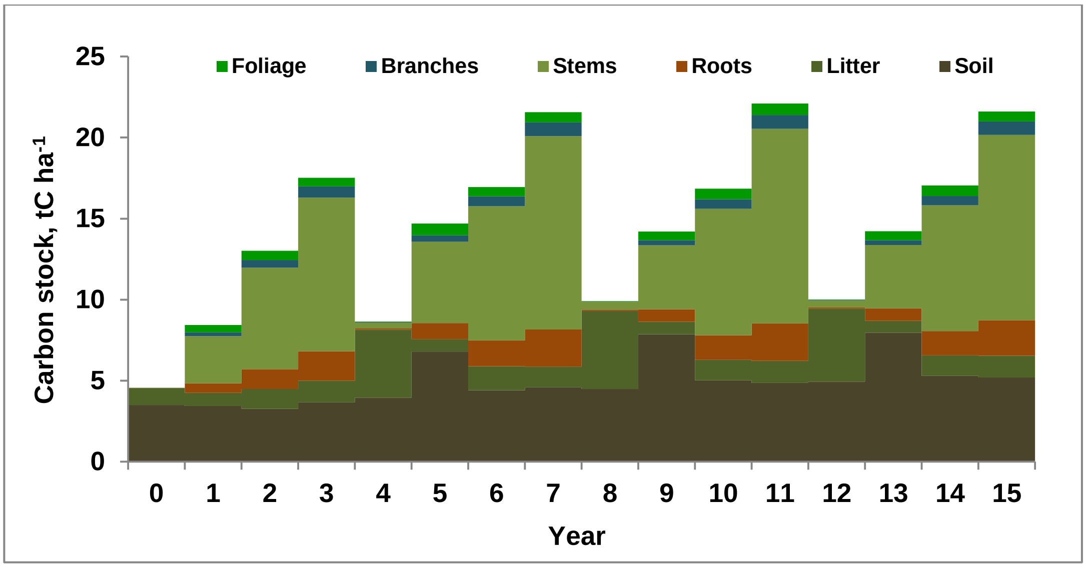

Figure 7 - *Evolution of stand-based carbon stocks in a black locust SRC plantation*

Table 5 - *SRF plantation of Robina pseudoacacia L., from planting out (year 0) to planting removal (Year 16): C in ecosystem pools, bioenergy mitigation and C removal from the atmosphere*

	Ecosystem pool			**Total ecosystem**	**Products**	**Bioenergy mitigation**	**Total**	**Atmosphere**
	Biomass	**Litter**	**Soil**					
Year	[$MgCha^{-1}$]							
0	0.01	1.05	3.5	4.56	0	0	4.56	0
1	4.18	0.82	3.43	8.43	0	0	8.43	-3.87
2	8.53	1.23	3.25	13.01	0	0	13.01	-8.44
3	12.53	1.32	3.67	17.52	0	0	17.52	-12.95
4	0.51	4.2	3.94	8.65	13.67	0	22.32	-17.74
5	7.14	0.77	6.79	14.7	0	7.86	22.56	-10.14
6	11.06	1.47	4.41	16.94	0	7.86	24.80	-12.37
7	15.69	1.29	4.58	21.56	0	7.86	29.42	-16.98
8	0.62	4.82	4.48	9.92	16.6	7.86	34.38	-21.97
9	5.58	0.77	7.86	14.21	0	17.39	31.60	-9.64
10	10.55	1.27	5.02	16.84	0	17.39	34.23	-12.28
11	15.88	1.37	4.86	22.11	0	17.39	39.50	-17.54
12	0.56	4.5	4.94	10	15.01	17.39	42.40	-20.44
13	5.52	0.74	7.96	14.22	0	26.01	40.23	-9.67
14	10.5	1.25	5.3	17.05	0	26.01	43.06	-12.49
15	15.08	1.34	5.19	21.61	0	26.01	47.62	-17.04
16	0.58	4.57	5.27	10.42	15.57	26.01	52.00	-21.43

Table 6 - *Biomass carbon in above and below-ground pools in a SRF plantation of Robina pseudoacacia L., from planting out (year 0) to planting removal (Year 16)*

Year	**Stems**	**Foliage**	**Branches**	**Roots**	**Total**
[MgC ha^{-1}]					
0	0.01	0	0	0	0.01
1	2.91	0.46	0.23	0.58	4.18
2	6.26	0.56	0.48	1.23	8.53
3	9.48	0.54	0.69	1.82	12.53
4	0.39	0.02	0.03	0.07	0.51
5	5.01	0.74	0.39	1	7.14
6	8.27	0.56	0.62	1.61	11.06
7	11.94	0.62	0.85	2.28	15.69
8	0.48	0.02	0.03	0.09	0.62
9	3.94	0.55	0.31	0.78	5.58
10	7.8	0.65	0.58	1.52	10.55
11	12.01	0.71	0.86	2.3	15.88
12	0.44	0.01	0.03	0.08	0.56
13	3.9	0.55	0.3	0.77	5.52
14	7.76	0.65	0.58	1.51	10.5
15	11.45	0.62	0.82	2.19	15.08
16	0.45	0.02	0.03	0.08	0.58

Table 7 - *SRF Robinia pseudoacacia L. stand for fuel-wood: cumulative C at the end of the rotation period (15 years) by using the Tier 3 IPCCC Carbon Accounting Method*

Pool	**tC ha^{-1}**
Deadwood	0.99
Aboveground biomass, tC ha^{-1}	17.50 (stems: 14.31; branches: 1.02; foliage: 2.17)
Belowground biomass, tC ha^{-1}	5.47
Litter, tC ha^{-1}	3.20
Soil, tC ha^{-1}	12.05
Total, tC ha^{-1}	23.70

11 FINAL REMARKS

The scope of this report was to describe the role that SRF energy plantations may have on reducing GHG emissions, to illustrate the concepts that bioenergy is carbon neutral and to point up existing methodologies to estimate GHG emissions linked to the bioenergy systems and in particular to the establishment and management of SRF plantations. Moreover we presented a specific example of land-based activities which have been relevant for the scope of a Proforbiomed project pilot action: the establishment of a short rotation forestry plantations on a former abandoned cropland using *Robinia pseudoacacia* L.

The used methodology was derived from the IPCC Guidelines (2006), which adopts a tiered approach: the lowest tier (Tier 1) uses *default* parameters for the estimation and a simplified methodology; the middle tier (Tier 2) uses in general the same methodology but with national or regional data to make the estimates. The highest tier (Tier 3) makes use of complicated carbon flow models that are parameterized with site specific information. In our case we used Tier 3 method, as it integrates — differently from the other tiers — the calculation of carbon stock changes dead wood and litter pools in the estimation of GHG emissions, using a linearisation period over the first rotation and not fixing a specific preset length of time.

The estimates presented here are based on empirical data derived from small experimental plots, not from commercial cases, and do not take into account the effects that technology (e.g. harvesting losses) and management may have on the final calculations. Estimations based on the direct extrapolation of yields from small experimental plots can also over-estimate the real productivity of the area. As shown by Hansen (1991), the yield levels derived from small-plot experiments could be up to 4–7 times higher than average yields originate from commercial plantations. It has to be underlined that these results do not provide regional-scale figures, as the productivity can vary broadly in different Mediterranean countries and in different areas of the same country, depending on many bioclimatic and environmental factors, including temperature, elevation, precipitation, and soil fertility, frequency and intensity of biotic and abiotic disturbances.

The results of this research can contribute to describe and to deepen the role that SRF plantations for energy purpose, may have on reducing GHG emissions and to illustrate the concept that bioenergy is carbon neutral, pointing up existing methodologies to estimate GHG emissions linked to the bioenergy systems, in particular to the establishment and management of SRF plantations. Moreover the data highlight interesting applications about the use of SRC practice and its high potential in fast-growth woody biomass production, representing a concrete support for the stakeholders in taking decisions related to a sustainable woods management and to the GHG control environmental policies.

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