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Climate Change Mitigation: "Annual Carbon Balance Accounting and Mapping in the National Forest Ecosystems (Continental Portugal)"

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Abstract:

We present in this article the carbon balance accounting and mapping in the Portugal continental forests (Mediterranean forest), which occupies 36% of the national territory, mostly private (93%). These forests are characterized by their economic, social and environmental importance values, but during these last years, they are undergoing natural and anthropogenic disturbances and also a strong wood demand for supplying the industry sector. The first goal of this study was to quantify the different components of the carbon (C) cycle, gain and losses, using atmospheric flow approach (gain-loss approach) developed by Intergovernmental Panel on Climate Change (IPCC). The carbon gain reflects the yearly photosynthetic sequestration. The carbon losses reflect the different yearly disturbances like fires, forest logging, pests and diseases attacks. This method allows us to assess the carbon balance evolution from 1995 until 2014 and to identify the most important species in climate change mitigation regarding the air purification or the greenhouse gases emissions contribution. Our second purpose is mapping the carbon-density areas with two different approaches, firstly the direct Remote Sensing (DRS) approach using MODIS images, secondly the indirect approach named Combine and Assign (CA) Approach. MODIS images allow the accounting of Net Primary Productivity (NPP) which presents the quantity of carbon absorbed by vegetation cover during a period of time as a key indicator of ecosystem performance. The CA Approach combines remote sensing and field data in GIS environment to assess the yearly carbon sequestration for each ecozone and the carbon losses by fires in 2010, using the atmospheric flow proposed by IPCC. Our third objective is to link the NPP in 2017 derived from MOD17A3 (MODIS product) with abiotic factors (precipitation, temperature, elevation), to find the best conditions for carbon sequestration. Several geostatistical technics were tested to interpolate climatic factors for all the country. Towards the end, mitigation measures will be proposed.

Keywords

Carbon Balance, photosynthetic sequestration, greenhouse gases emissions, MODIS, IPCC, Climate Change, Combine and Assign Approach.

Resumo:

Apresentamos nesta tese a quantificação e o mapeamento do balanço de carbono nas florestas de Portugal continental, que ocupa 36% do território nacional, maioritariamente privado (93%). A floresta portuguesa possui elevado valor económico, social e ambiental, mas durante os últimos anos tem sofrido distúrbios naturais e antropogénicos. Tem também crescido a procura de madeira para suprir o sector industrial. O primeiro objectivo deste estudo foi quantificar os diferentes componentes do ciclo de carbono (C), ganhos e perdas, utilizando a abordagem de fluxo atmosférico (abordagem ganho-perda) desenvolvida pelo Painel Intergovernamental sobre Mudanças Climáticas (IPCC). O ganho de carbono reflecte o sequestro fotossintético anual. As perdas de carbono reflectem as diferentes perturbações anuais, como incêndios, extracção de madeira, insectos e ataques de doenças. Este método permite-nos avaliar a evolução do balanço de carbono de 1995 até 2014 e identificar as espécies mais importantes na mitigação da mudança climática em relação à purificação do ar ou a contribuição das emissões de gases de efeito estufa. Nosso segundo objectivo foi mapear a densidade de carbono por áreas homogéneas com duas abordagens diferentes, em primeiro lugar a abordagem directa de Detecção Remota (DR) usando imagens MODIS, em segundo lugar a abordagem indirecta denominada "Combine and Assign" (CA). As imagens MODIS permitem a quantificação da Produtividade Primária Líquida (NPP) que apresenta a quantidade de carbono absorvida pela cobertura vegetal durante um período de tempo como um indicador chave do desempenho do ecossistema. A abordagem CA combina dados de DR e dados de campo em ambiente SIG para avaliar o sequestro anual de carbono para cada zona ecológica homogénea considerada e as perdas de carbono por incêndios em 2010, usando o fluxo atmosférico proposto pelo IPCC. O terceiro objectivo foi vincular a NPP de 2017 obtida a partir do MOD17A3 (produto MODIS) com factores abióticos (precipitação, temperatura, elevação), para pesquisar as condições mais favoráveis para o sequestro de carbono. Diversas técnicas geoestatísticas foram testadas para interpolar factores climáticos para todo o país. No final, algumas medidas de mitigação foram propostas.

Palavras-chave:

Balanço de Carbono, sequestro fotossintético, emissões de gases de efeito estufa, MODIS, IPCC, Mudança Climática, Combinar e Atribuir Abordagem.

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Symbols List:

AFOLU: Agriculture, Forestry, and Other Land Use

AGB: Above-Ground Biomass

BA: Burned Area

BGB: Below Ground Biomass

BPLUT: Biome-Property from Look Up Table

C: Carbon

CA Approach: Combine & Assign Approach

CBM-CFS3: Carbon Budget Model in Canadian Forest Sector

CH_4: Methane

Ci : Climate index (Ci=precipitation / average)

CO: Carbon monoxide

CO_2: Carbon dioxide

d: Distance

DAO: Data Assimilation Office

DOM: Dead Organic Matter

DRS Approach: Direct Remote Sensing Approach

DW: Dead Wood

E: Elevation

EOS: Earth Observing System

FCA: Forest Carbon Accounting

FPAR: Photosynthetically Active Radiation Absorbed

GHGs: Greenhouse Gases

GMAO: World Modeling and Assimilation Office

GPP: Gross Primary Production

HWPs: harvested wood products

ICNF: Instituto da Conservação da Natureza e das Florestas

IDW: Inverse Distance Weight

IPCC: Intergovernmental Panel on Climate Change

I_v : Average net annual increment

L: Litter

LAI: Leaf Area Index

LiDAR: Light Detection and Ranging

MODIS: Moderate Resolution Imaging Sensors

MtC: Megatonnes of Carbon (=10^6 tC)

NASA: National Aeronautics and Spaces Administration

NBP: Net Biome Production

NEP: Net Ecosystem Production

NFI: National Forest Inventory

NO_2: Nitrogen dioxide

NOAA: National Oceanic and Atmospheric Administration)

NOx: Nitrogen oxide

NPP: Net primary productivity

NTSG: Numerical Terra Dynamic Simulation

OECD: The Organization for Economic Co-operation and Development

P: Precipitation

PIUP: Industrial Processes and Product Use

PROF: Regional Forest Management Plans

REDD: Reducing Emissions from Deforestation and Degradation

SAR: Synthetic Aperture Radar

SEP: Standard Error Propagation

SOM: Soil Organic Matter

S_v: Unitary Stand Volume

tC/ha/yr: tons of carbon per hectare per year

Tn: Minimum temperature average

Tx: Maximum temperature average

UCEA: Unitary Carbon Emissions Average
UNEP: United Nations Environment Program

UNFCCC: United Nations Convention on Climate Change

WMO: World Meteorological Organization

x: Latitude

y: Longitudes

fd: Disturbance Fraction in biomass

α : Longitude effect

General Introduction: Context and Objectives

Climate's change is one of the most pervasive and threatening issues of our time. The consequences of this warming on the global climate system on the natural and human environment are many and already sensitive: rising water levels, melting glaciers and polar ice caps, extreme weather events, disturbances of precipitation systems (resulting in droughts and floods), loss of biodiversity by a very great acceleration of extinction of flora and fauna species, degradation of land and natural resources, lower agricultural yields, migrations…etc. All these consequences show an accentuation of these impacts where some of them already seem irreversible.

In many places in the world, temperature and precipitation changes and sea-level rise are already putting ecosystems under stress and affecting human well-being. The Intergovernmental Panel on Climate Change (IPCC) studies show that the Mediterranean basin as one of the hot spots due to climate change: Temperature increases (+ 2°C depending on the seasons and scenarios by 2050, 2°C to 7.5°C depending on projections by 2100), the average rainfall will drop to 60% and the rise of the water level (6mm/year on average in some regions) (Plan bleu, 2016), with an average increase of 0.4 to 0.5m is projected for most of the Mediterranean (IPCC, 2013), as well as the strengthening of extreme weather events are there and will be particularly pronounced. The consequences are known: droughts, floods, heat waves, forest fires, water stress, desertification, erosion, degradation of terrestrial and marine biodiversity…etc.

Faced with these challenges, Countries establish reports of data on their emissions and absorption of greenhouse gases (GHGs), from all sectors through National GHG Inventories, subject to United Nations Convention on Climate Change (UNFCCC), in accordance with the agreements of the international climate policy and technical guidelines developed by the Intergovernmental Group of Experts on Climate Change (IPCC). This inventory covers the four main sectors of development: Energy, Industry, Solid and liquid waste, and the 4^{th} sector is Concerning Agriculture, Forestry, and other land use (AFOLU). This last sector represents a unique challenge for national inventory managers, firstly because of the significant difficulties encountered in the compilation and regular updating of national statistics for this sector, secondly for the choice of the formulas of calculating which are related directly to the quality of the GHGs inventory (precision).

The main greenhouse gases in the AFOLU sector are CO_2, N_2O, CH_4 with other secondary gases: NOx, NH_3, NMVOC, CO; which are precursors to GHGs formation in the atmosphere (IPCC,2006). In this project, we will study Carbon flows between the atmosphere and the forest ecosystems from 1995 until 2014, based on the 2006 IPCC methodology to calculate the annual carbon balance in national forest ecosystems. This study will help us to understand more the carbon cycle in Portugal's forest ecosystems. In addition, we will develop some different approaches used in carbon balance mapping. Towards the end, develop a mitigation plan.

Objectives:

Objective 1: Assess the contribution of the Portuguese forests in climate change mitigation.

Objective 2: Carbon balance accounting in the forest ecosystems and its evolution from 1995 until 2014.

Objective 3: Carbon balance and carbon sequestration mapping for different eco-regions of Portugal using two different approaches for two periods, 2010 and 2017.

Objective 4: Comparison between: IPCC and MODIS methodologies used to follow the carbon dynamic in terrestrial ecosystems.

Objective 5: Relate the annual net primary productivity (NPP) variability with biophysics factors: temperature, precipitation, elevation, to find out what conditions most potentiate carbon sequestration.

Objective 6: Mitigation plan: this project also aims to assess the contribution of Portuguese forests to the climate change mitigation. After carbon balance accounting and mapping we will know the most affected species in a specified area (eco-regions), providing the location of areas where development programs should be prioritized, as well as strategies and policies for the conservation of endemic species, leading to the adoption of correct forest management measures, particularly in private forests.

Part 1: Bibliographical Review

Chapter 1: Forest Carbon Accounting

Introduction:

Forests play an important role in the carbon cycle. They absorb, by photosynthesis, a part of the atmospheric CO_2 to store it as biomass. This "carbon sink" role is important because it contributes to climate balance and limits the consequences of global warming (Malhi, Meir, & Brown, 2002). The continental biosphere is already functioning as a sink and absorbs at least 2 GtC/year (Robert & Saugier, 2003). In addition, the forest ecosystems provide a great service to the environment, for example by: a) preservation of biodiversity, b) soil protection against erosion, c) preservation of water resources, d) reduction of silting of dams (caused by hydrological erosion), e) protecting of downstream infrastructures and improving the quantity of water available and its quality and, f) creating microclimates that preserve or even optimize agricultural productivity. Sustainable forest management can also strengthen the resilience of local societies by expanding the range of sources of income and products available, while building the capacity of local and national institutions.

The forestry sector contributed to reducing the GHGs. Forests sequester and store more carbon than any other terrestrial ecosystem and they are an important natural 'brake' on climate change (Foley, 2007). The forestry sector represents upwards of 50% of global greenhouse gas mitigation potentiality (Golub, Hertel, Lee, Rose, & Sohngen, 2009). The forest can be a source of emission under the natural disturbances and human uses. Deforestation alone provoking approximately 20% of anthropogenic emissions in all the world (Gerber. et al., 2013). Accounting for the carbon within forest ecosystems and changes in carbon stocks resulting from human activities is a necessary first step towards the better representation of forests in climate change policy at regional, national and global scales (Watson, 2009). The national forest is under pressures of anthropogenic activity and natural's disturbances as: fires, insect, diseases, and wood removed from the forest. It will be interesting to account the carbon taking into consideration each one of these components.

Currently, carbon modeling and accounting is one of the major research areas. In fact, the increase in carbon dioxide (CO_2) concentrations has been increased dramatically during these last years. According to the Global Carbon Project 2017 report; 41 Gt (billion tons) of CO_2 including 36.8±2 Gt from fossil fuels and industries emitted into the atmosphere. Fortunately, all carbon emissions will not remain in the atmosphere as the carbon sinks of land (forest and agriculture) and oceans will absorb about 22 Gt of CO_2 in 2017. In other words, 19 Gt of CO_2 will be accumulated in the atmosphere (Le Quéré et al., 2017). At this point, we emphasize the importance of developing methods and modules to account the CO_2 quantity, which is stored at the sinks or emitted into the atmosphere and also its geographical distribution by mapping.

I. Definitions, Types and Advantages of Forest Carbon Accounting

1. Definition:

Forest Carbon Accounting (FCA) is the practice of making scientifically robust and verifiable measurements of carbon emissions. Although characteristics of forests have been recorded for numerous historical purposes, accounting for carbon is a more recent addition to forest inventories (Watson, 2009). The objective of the FCA is to realize the annual carbon balance, considering both storage and losses. This follows the growing need to quantify the stocks, sources and sinks of carbon and other GHGs in the context of anthropogenic impacts on the global climate, carbon accounting should be found in national inventories (Lohmann, 2009).

2. Types of Forest Carbon Accounting: Charlene Watson 2010

Watson classified CFA in 3 types (Table 1).

Table 1: Types of FCA according to Watson classification (2010)

Types	Definitions and characters
Stock Accounting	-Often forms a starting point for emissions and project level accounting. This approach can be used for carbon sequestration accounting. -Stock accounting allows carbon-dense areas to be prioritized in regional land use planning. -Establishing the terrestrial carbon stock of a territory and average carbon stocks for particular land uses.
Emissions Accounting	Accounting for amounts of GHG emissions due to natural disruption, and it is necessary to assess the scale of emissions from the forest sector in relation to other sectors. It also aids realistic goal-setting for GHG emissions targets.
Project Emission Reductions Accounting	Carbon accounting for forestry project emission reductions is required for both projects undertaken under the flexible mechanisms of the Kyoto Protocol and the voluntary carbon markets.

3. Advantages:

Historically, forest inventories recorded vegetation type, stand structure, age, growth rate, biomass accumulation, and the wood densities of tree species (Pretzsch, 2009). These have served both commercial purposes, such as determining merchantable timber volumes and use in the paper and pulp industry, and Firewood. As well as national or regional planning purposes (Watson, 2009).

The carbon accounting and modeling have main advantages:

- ✓ Identify areas with different carbon density,
- ✓ Providing information for low-carbon-impact land use planning,
- ✓ Accounting and reporting of emissions from the forestry sector. It allows comparison of the climate change impact of the forestry sector relative to other sectors, as well as allowing comparison between territories,
- ✓ National policy orientations' aim is to achieve a better sustainable forest management,
- ✓ Scenario analysis by the absence of a technique or policies,
- ✓ Evolution of national programs in forest conservation matters,
- ✓ To provide an assessment of likely future stocks and emissions in decadal periods,
- ✓ Finally, it enables trade of project emission reductions on carbon markets and for emission reductions to be included in policy targets.

II. Principles of Forest Carbon Accounting:

1. Good Practice of FCA

There are a number of principles for carbon accounting that should be followed (Table 2). Adherence to good practice promotes better understanding, legitimacy and trust in the accounting system, which is critical for both political and public acceptance (Greenhalgh, Daviet, & Weninger, 2006).

Table 2: Good Practice for Forest Carbon Accounting (Watson, 2009)

Uncertainty measures	It is desirable to have as much as possible input data more reliable and more accurate, and it will be necessary for the good practice to estimate the output variable error (by Error propagation or Monte Carlo simulation).
Comparable	FCA allow meaningful and valid comparisons between areas and pools.
Complete	Accounting should be inclusive of all relevant categories of sources and sinks and different Carbon Pools which we must take into consideration. based on documentation and justification.
Conservative	Where accounting relies on assumptions, values and procedures with high uncertainty. The most conservative option in the biological range should be chosen so as not overestimate sinks or underestimate sources of GHGs.
Consistent	The accounting must be consistent, follow one logical order according to the methods used.
Relevance	Recognizing that trade-offs must be made in accounting as a result of time and resource constraints, the data, methods and assumptions must be appropriate to the intended use of the information.
Transparent	The integrity of the reported results should be able to be confirmed by a third party or external actor. This requires sufficient and clear documentation of the accounting process to be available so that credibility and reliability of estimates can be assessed.

(Sources : Greenhalgh *et al.*, 2006 ; Pearson *et al.*, 2005 ; IPCC, 2006)

2. Carbon Pools:

Carbon pools are components of the ecosystem that can either accumulate or release carbon and have classically been split into five main categories (IPCC, 2006): aboveground (AGB) and belowground (BGB) biomass, litter (L), dead wood (DW), and soil organic matter (SOM) (Figure 1). Understanding of carbon cycle and its pools are a very important mind that several projections demonstrated that forests could be carbon sinks or sources in the future (Dixon et al., 1994).

The classification of carbon pools is not strict and it is not the number of categories that are important but their completeness, pools must not be double-counted and significant pools should not be excluded. Harvested wood products (HWPs) increasingly recognized as an additional and potentially substantial carbon pool which exists outside of traditional forest boundaries, some carbon is released when trees are harvested (Liu & Han, 2009), many carbon pool classifications are being adapted to also include HWPs. Because our interest is the accounting of the losses and the gains at the forest ecosystem level, HWPs must be considered as a loss in the carbon accounting of the forest ecosystems (Watson, 2009).

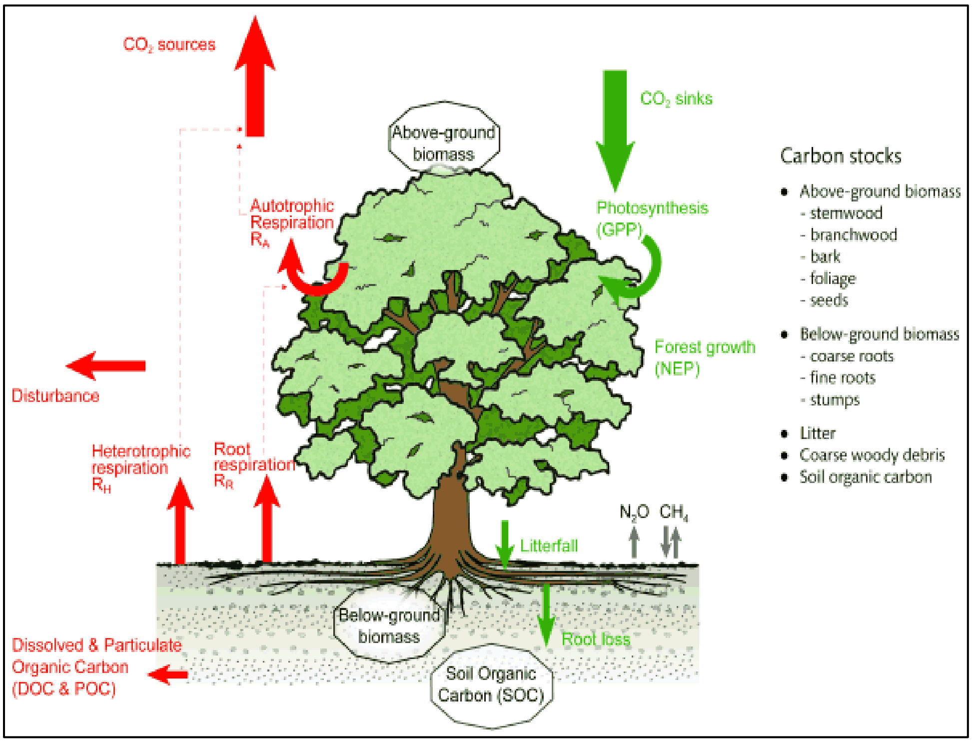


Figure 1:Carbon pools used in AFOLU sector according to IPCC

2.1 Biomass:

The plant biomass, including above-ground and below-ground parts, is the main conduit for CO_2 removal from the atmosphere through photosynthesis and breathing processes, they considerate as the major processes controlling the global carbon cycle (Andrews et al., 1999). The uptake of CO_2 through photosynthesis is referred to as Gross Primary Production (GPP). About half of the GPP is consumed by the respiration of the plants and returned to the atmosphere with the remainder constituting Net Primary Production (NPP), which is the total production of biomass and dead organic matter in a year. NPP minus losses from heterotrophic respiration (decomposition of organic matter in the litter, dead wood and soils) is equal to the net carbon stock change in an ecosystem. In the absence of disturbance losses, is referred to as Net Ecosystem Production (NEP) (Equation 1) (IPCC, 2006).

Equation 1:Net Ecosystem Production (NEP)

Net Ecosystem Production =Net Primary Production (NPP)– Heterotrophic Respiration

NEP minus additional C losses from disturbance (e.g. fire, deforestation…etc.), harvesting and land clearing during land-use change is often referred as Net Biome Production (NBP) (Equation 2) (BENJAMIN et al., 2010). The carbon stock change that is reported in national greenhouse gas inventories for land-use categories have to be equal to NBP (IPCC, 2006).

Equation 2:Net Biome Production (NBP)

Net Biome Production (NBP) = NEP – Carbon Losses from Disturbance/Land-Clearing/Harvest

The NPP is also related to several climatic parameters (Wang et el., 2013), and it is influenced by land use and management through a variety of anthropogenic actions such as afforestation, deforestation, fertilization, irrigation, harvest, and species choice (Havlík et al., 2011). For example, tree harvesting reduces biomass stocks on the land. However, harvested wood requires additional consideration because some of the carbon may be stored in durable wood products (e.g. stylish furniture) and in landfills for years to centuries (IPCC, 2006). Thus, some of the carbon removed from the ecosystem is rapidly emitted to the atmosphere while some carbon is transferred to other stocks in which the emissions are delayed (NAVIN et al., 2006).

Assessment of biomass provides information on the structure and functional attributes of a forest and is used to estimate the quantity of timber and fuel component (Brown & Nations, 1997). With approximately 50% of dry forest biomass comprised of carbon (F. Westlake, 1966).

2.2 Dead Organic Matter (DOM):

Same of the biomass production (NPP) contained in living plant material is eventually transferred to dead organic matter (DOM) pools such as litter (L) and dead wood (DW) under the process of decomposition, from where we obtain the CO_2 emission (IPCC, 2006).

2.3 Soils:

When the DOM decomposes it is transformed into Soil Organic Matter (SOM) by heterotrophic microorganisms and by consequent we will have the carbon returning to the atmosphere (IPCC,2006).

3. Approaches to Forest Carbon Accounting:

Many natural processes, physical factors and the biological processes, lead to emissions and removals of GHGs (K et al., 2003), for example, fires, insect attacks, diseases contamination and local climate variability. Fire management and harvesting have accelerated the release of GHGs from forests (Canadell et al., 2007). The forest management practices affect the balance of emissions into the atmosphere through biomass fluctuation, soil and litter disturbance, and the nutrients budget in its globality (Sajwaj, 2008), they have differing impacts on the various carbon pools. The purpose of emissions accounting is to quantify the exchange of carbon between the atmosphere, terrestrial vegetation and soils through photosynthesis, respiration, decomposition and combustion (Watson, 2009). Information on carbon stock changes and carbon balance can be obtained in various ways, there are two main approaches to FCA:

- Stock-Difference Method: This method can be used where carbon stocks in relevant pools are measured at 2 points in time to assess carbon stock changes. Using the Equation 3, but it requires more specific data about the area of study (IPCC,2006).

- Atmospheric-flow: In this Method, annual changes in carbon stocks are estimated by summing the differences between the gains and losses in carbon pools. Gains occur due to growth (an increase of biomass) and due to transfers of carbon from another pool. Losses occur due to transfers of carbon from one pool to another or other processes such as decay, burning or harvesting. For each pool, the carbon stock change is calculated using the *Equation 4.*

Equation 3:FCA/Periodic Accounting: Stock-Difference Method

$\Delta C = \sum (C_{t2} - C_{t1}) / (t_2 - t_1)$
ΔC = carbon stock change, tC/yr
C_{t1} = carbon stock at time t_1, tC/yr
C_{t2} = carbon stock at time t_2, tC/yr
Source: IPCC, 2006

Equation 4: FCA/Flux Accounting: Gain-Loss Method

$\Delta C = \sum [A * (C_I - C_L)]$

A = area of land, ha

C_I = rate of gain of carbon, tC/ha/yr.

C_L = rate of loss of carbon, tC/ha/yr.

Source: IPCC, 2006

The process method lends itself to modeling approaches using coefficients derived from empirical research data, such as IPCC data (IPCC, 2006). Both methods are valid so long as they are capable of representing actual disturbances, as well as continuously varying trends, and can be verified by comparison with actual measurements. Even if they have a difference in precision and each one requires some specific data, the still used to present the reality of carbon stock and sequestration potentiality of vegetation species in the forest ecosystems. The IPCC guidelines considered the Gain-Loss Method as a tier 1 or tier 2 methods. Though they considered the stock change method as a Tier 3 method (Maniatis & Mollicone, 2010).

III. Guidance and Tools

1. IPCC Guidelines:

The 2006 IPCC provides equations to carry out the national inventory of GHGs for different sectors such as AFOLU sector. Each estimation of these GHGs is associated with a level of precision, because IPCC provides several equations that are directly related to the availability of data and its quality, more we have detailed information more the accuracy of the inventory is improved (Tubiello *et al.*, 2015).

1.1 Definition:

The IPCC is the leading international body for climate change assessment. It was established in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific perspective on the current state of knowledge on the subject, as well as climate change and its environmental and socio-economic impacts. In the same year, the IPCC has been approved by the UN General Assembly (Tubiello *et al.*, 2015). Since 1992, the IPCC has developed methodologies and guidelines (IPCC's National Greenhouse Gas Inventories Program) in order to assist the parties of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol in the preparation of their national GHGs emission inventories by their sources and absorption by their sinks. The last major publication is the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

1.2 Main Activity:

IPCC activities are the preparation of comprehensive assessment reports on the state of scientific, technical and socio-economic knowledge of climate change, its causes, potential impacts and response strategies (Tubiello *et al.*, 2015). its first mission is the mitigation of climate change (Moomaw et al., 2011).

1.3 2006 IPCC Guidelines Structure:

The 2006 IPCC Guidelines for National greenhouse gas inventories were prepared at the invitation of the UNFCCC, to provide countries with best practice methodologies, to use it in the preparation of GHG inventories reporting. As shown in (Figure 2) below, the different sectors of the GHG emissions inventory are: energy, industrial processes and product use (PIUP), Agriculture, Forestry and Other Land Use (AFOLU) and waste.

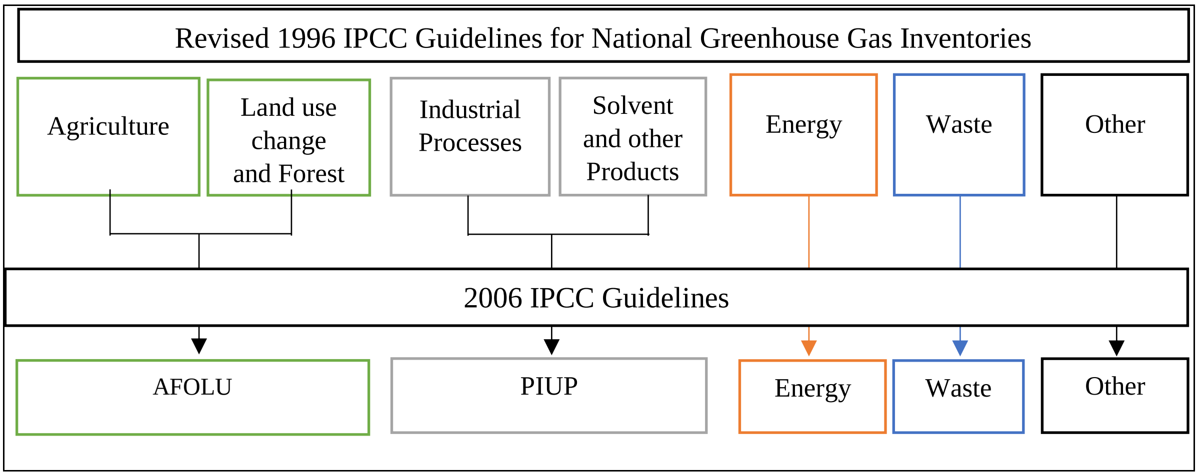


Figure 2:Main differences between 1996 and 2006 IPCC Guidelines and all concerning sectors

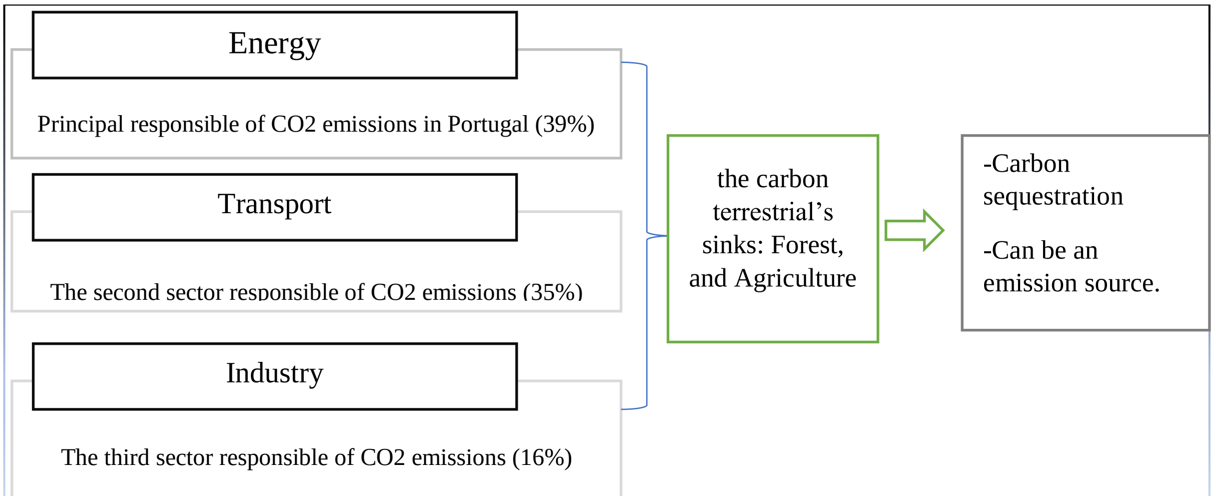


Figure 3: The carbon circuit in Portugal for all sectors concerning by IPCC

IPCC method seeks to elaborate an estimation about the GHGs in the main sectors of development and to have an interrelation between them, and to locate the main sources of emission. In the objective is to develop a mitigation plan. For examples the mains sectors emitting CO_2 in Portugal are energy, transport and industry sectors (Figure 3) (Saboori et al., 2014). Normally, we should take into consideration the CO_2 emission and sequestration in all sectors (Energy, Industrial, etc.) (IPCC, 2006). In the other hand, forest sector is the main terrestrial carbon sink by its higher carbon sequestration potentiality, and it can play the role of CO_2 emitter because of anthropogenic activities (logging) or natural disturbances (insect, fires, disease... etc.).

1.4 Choice of Method Levels:

The 2006 IPCC Guidelines report three approaches according to the method levels used to have an idea about accuracy (Sethi, 2017). They generally provide advice on estimation methods at three levels of detail, all tiers are intended to provide unbiased estimates, and accuracy and precision should, in general, improve from tier 1 to tier 3 (IPCC, 2006).

-**Tier 1** is the basic method. It is designed to be the simplest to use, for which equations and default parameter values (IPCC, 2006) as it does not follow emission factors specific to the country where assessment is being conducted (Sethi, 2017). this level is simple, it does not require detailed.

-**Tier 2** is the intermediate method. it requires that default emission factors are replaced by country-specific emission factors that take account of country- specific data. It 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.

-**Tier 3** is the most exigent method, in terms of complexity and data. 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 the sub-national level (IPCC, 2006). In tier 3 we require using the Stock-Difference approach in FCA.

Decision tree: According to the decision tree (Figure 4) developed by IPCC for identification of appropriate tier level to FCA approach for lands remaining in the same land-use category. We need firstly, identify the key categories (forest land). Secondly identifies the factors (components) that influenced the carbon pools (natural disturbances, afforestation, reforestation …etc.). Thirdly, these key category (forest) have to be delimited according to the ecozones. Finally evaluate the availability of data to know the tier level. Because this disaggregation of land categories and identification of the carbon balance components reduce the uncertainty. However, it increases the cost of the GHGs inventory process (IPCC, 2006).

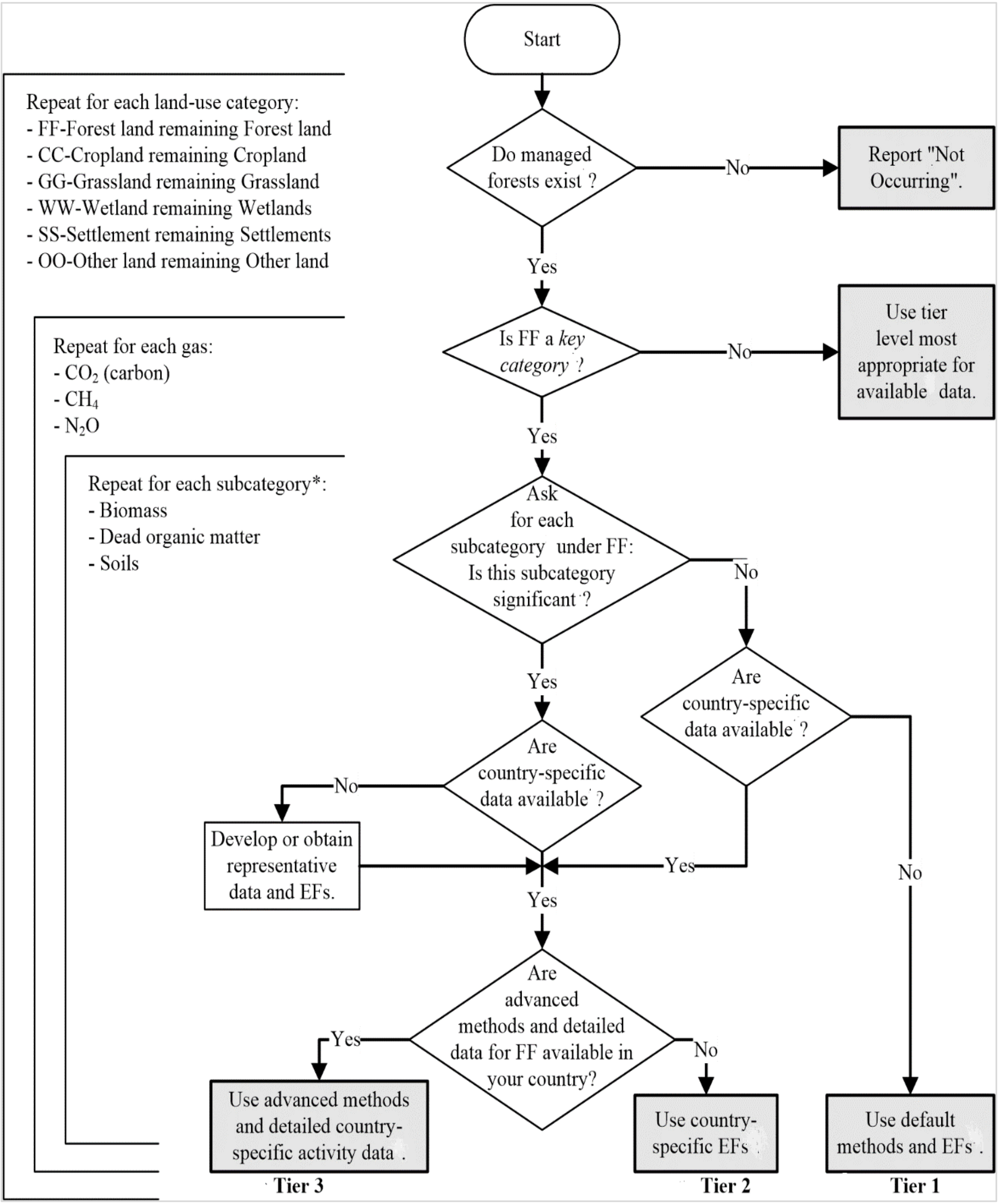


Figure 4:Decision tree for identification of appropriate tier level for land remaining in the same land-use category and the appropriate approach to quantify C emissions and sequestration (source: IPCC, 2006)

1.5 Greenhouse Gases in AFOLU Sector:

The main GHGs concerning in sector AFOLU are CO_2, N_2O, and CH_4, CO_2 fluxes between the atmosphere and ecosystems. They are primarily controlled by plant photosynthesis and releases via respiration, decomposition, and combustion processes. Other indirect emissions gases, from combustion and from soils are taking into consideration in IPCC reports, such as NOx, NH3, NMVOC and CO (IPCC, 2006). Carbon fluxes; between the biomass and the atmosphere, and between the oceans and the atmosphere are consecrated as fast flows, the exchanges between biomass and death biomass by the decomposition process are considered as slow flows (Figure 5).

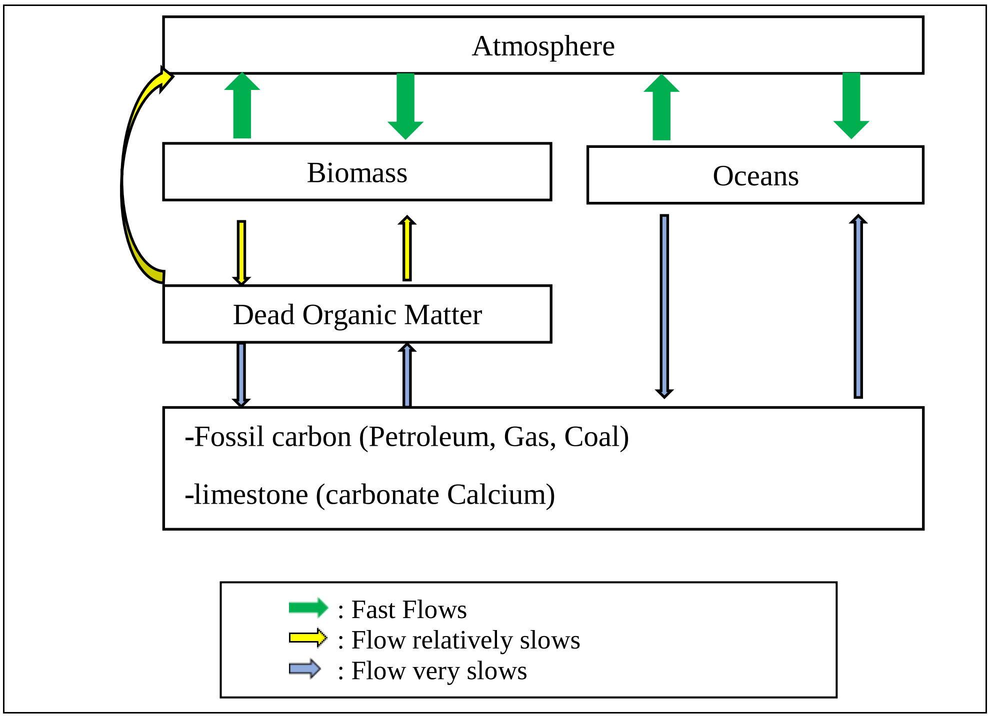


Figure 5: Biogeochemical carbon cycle simplified

2. Module MBC-SFC3:

The Carbon Budget Model in Canadian Forest Sector (CBM-CFS3) is the central model for Canada's National Forest Carbon Monitoring, Accounting and Reporting System (Kull et al., 2014). Which is used to report internationally the carbon balance of Canada's managed forests (Kurz & Apps, 2006). The MBC-SFC3 is recognized by the IPCC as a Tier 3 model and is a forest ecosystem carbon modeling framework applicable to any forest ecosystem (Stephen Kull, 2017). Also, it is a dynamic simulation model that incorporates forest inventory and growth and yield data, as well as statistics on natural disturbances, land-use change, and forest management activities (Apps, Kurz, Beukema, & Bhatti, 1999).

The MBC-SFC3 model contains the default ecological settings that apply in Canada, these settings can be changed by the user, allowing the model to be applied in other countries. Some modifications to the default Canadian ecological data in the model will likely be required to better reflect growth, decay, climate and disturbance conditions (Kull et el., 2014). So How can CBM-CFS3 results be used? Forest managers can use CBM-CFS3 to (Li et al., 2003):

- ✓ Create several projects for different forest management plan purposes. Taking into account carbon density.
- ✓ Observe the results of management actions in terms of carbon on individual stands in order to make an informed decision as to whether they should apply these actions to their entire management area,
- ✓ Modify ecological parameters and climate data to assess possible future changes in ecological conditions in their management areas.

3. OTHER Modules:

Largely from developed countries, a number of forest carbon accounting models exist. For example,

- ➢ from the United States: The Carbon On-Line Estimator, The Center for Urban Forest Research Tree Carbon Calculator (CTCC), FORCARB and the Landscape Management System (LMS).
- ➢ From the United Kingdom: CARBINE, C-Flow and C-Sort.
- ➢ From Australia: CAMfor module (Brack & Richards, 2002).
- ➢ From Europe: the European Forest Information Scenario model (EFI-SCEN) (Nabuurs, Schelhaas, & Pussinen, 2000)
- ➢ Further broad forest carbon-inventory models include CO2FIX and Graz/Oak Ridge Carbon Accounting Model (GORCAM). Version 3 of CO2FIX has detailed modules for biomass, soil, wood products and bioenergy, as well as modules for finance and carbon accounting. These models assume relatively homogenous forest stands in terms of vegetation structure, growth dynamics and species composition (Schelhaas et al., 2004).
- ➢ GORCAM, also a stand-level accounting model, considers changes of carbon in biomass, reduction of carbon emissions due to the replacement of fossil fuels or energy-intensive materials, carbon stored in wood products, and the recycling and burning of waste wood (Marland & Schlamadinger, 1999)

However, these tools are generally applicable only to forests of the nation in which they have been developed and are thus limited in application. But the MBC SFC3 model is applicable over wider geographical areas (Watson, 2009), it is an interesting model to know and to use but it is a very exigent model in terms of input data. At present, no single model is considered as standard. With a growing need to generate information on carbon stocks and stock changes cost-effectively and over large spatial scales, forest carbon accounting models are likely to continue to proliferate, especially those adhering to the guidelines of international conventions.

Conclusion:

FCA is a multidisciplinary task, uses several data. its complexity is first of all the stratification and delimitation of the ecozones (biomes), whose objective is integrated factors influencing the carbon sequestration and emission (climate, soil, slope, exposure, and the vegetation species itself...etc.). It requires more quality data to improve the precision.

The 2006 IPCC guidelines, the noble price of 2007, offering equations and hypotheses which facilitating FCA. It is not only for the carbon dioxide, but for all the other GHGs inventory. IPCC classified their hypotheses and their equations into 3 tiers according to the precision and data quality. IPCC guidance is comprehensive and represents a good source of default and regional data parameters. On the other hand, several states have developed programs and applications for monitoring carbon fluxes, such as the MBC-SFC3 Canadian’s model, which remains among the best model to adapted and to use, but it's more exigent.

This work will be about Stock and Emissions accounting (Carbon balance in Forest) and its evolution between 1995 and 2014. It will be done in a simpler way, basing in atmospheric flow approach, using the data already published by several national and European agencies, and defaults values from IPCC publications. The development of a mapping approaches will make it easier for us, to see these results in another way, and to established the regional prioritization.

Chapter II: Carbon Balance and Carbon Stock Mapping:

Introduction:

The aboveground biomass (AGB) of terrestrial ecosystems is an important constraint of dynamic global vegetation models to assess carbon stocks and feedbacks of vegetation with the global carbon cycle (Luther, Fournier, Piercey, Guindon, & Hall, 2006). Mapping of carbon stocks in forested regions of the world, particularly the tropics has attracted a great deal of attention in recent years as deforestation and forest degradation account for up to 30% of anthropogenic carbon emissions and are now included in climate change negotiations (S. J. Goetz et al., 2009).

Several techniques were developed to answer this question of carbon stock mapping. These techniques indirectly measure the AGB followed by a development of the regression modules or algorithms for the accounting of biomass production at a given time (NPP) and carbon stocks, by advantage the establishment of its maps. Therefore, in this chapter we will talk about a review of several approaches with a non-deep description, to measure carbon stocks, specifically AGB. We provide an overview of a range of approaches that have been developed and used to map AGB. We provide a summary of types of remote sensing measurements relevant to mapping AGB and assess the relative merits and limitations of each. We then provide an overview of traditional techniques of mapping AGB based on ascribing field measurements to vegetation or land cover type classes using the aerial photography, especially in forest inventory.

Carbon Balance Mapping integrates the carbon gain by sequestration and the other components which are present the losses (fires, insects, diseases…). Therefore, after building the carbon sequestration map we have to overlap it with these components to get the annual carbon balance map.

I. Forest Carbon Mapping: Approaches and Technics

Mapping and monitoring carbon stocks in forest land use are now included in climate change negotiations, because in the last decade's forest deforestation and degradation emit considerable amount of GHGs in all the world (Van der Werf et al., 2009). Gibbs and Foley and others scientists in 2007 were developed many available methods to count and mapping carbon stock, with their Benefits, limitations and Uncertainty to estimate national-level forest carbon stocks (annex 1) (Foley, 2007). Mapping of carbon stocks or carbon balance is a successful implementation of climate change mitigation policies related to reducing emissions from deforestation and degradation (REDD) (Saatchi et al., 2011). Here we present a benchmark of methods which can be used for REDD assessments at national or regional scales.

1. Aboveground Biomass Mapping:

Remote sensing of forests has an important role in mapping large forest tracts that are difficult to access on the ground, and in monitoring changes in these forests (Balzter, 2001). Moreover, the aerial photography using in National Forest Inventory (NFI).

Remote sensing technologies constitute an effective instrument to evaluate biophysical properties of terrestrial ecosystems (Turner et al., 2003), in particular forest structure and biomass. It has become the primary data source for biomass estimation. Remote sensing in combination with data analysis constitute a practical means for evaluation of forest implications in the carbon cycle, providing spatially explicit estimations of the amount, quality, and spatiotemporal dynamics of biomass and C stocks (Gómez Almaraz, 2014). Satellite observations contribute to measuring and monitoring carbon stocks by routinely classifying land cover types, extending in situ measurements over larger areas, informing ecosystem models, and through direct relationships between biophysical attributes of vegetation and remotely sensed observations (S. Goetz & Dubayah, 2011).

Remote sensing-based biomass estimation in arid environments is essential for monitoring degradation and carbon dynamics (Le Toan et al., 2004) . However, due to the low vegetation cover in same regions, specially arid and semi-arid zones, Remote sensing research is challenging and has a lot of limitations (Zandler, Brenning, & Samimi, 2015).

1.1 LiDAR Technology:

LiDAR (Light Detection and Ranging) is an optronic measurement method; it implements equipment or systems using both optics and electronics (Weibring, Edner, & Svanberg, 2003). It is one of active remote sensing instrument (Cracknell, 2007). This technology can be used to study the Earth's atmosphere, or to analyze the structure and topography of surfaces, in natural or urban environments (L.DRAIOUI & R.MEDESSI, 2014). There are two types of airborne sensors: topographic and bathymetric (ESRI, 2013):

-Topographic LiDAR: Topographic LiDAR can be used to derive surface models for use in many applications, such as forestry, hydrology, geomorphology, urban planning, landscape ecology, coastal engineering, survey assessments, and volumetric calculations.

-Bathymetric LiDAR: Bathymetric LiDAR is a type of airborne acquisition that is water penetrating. Most bathymetric LiDAR systems collect elevation and water depth simultaneously, which provides an airborne LiDAR survey of the land-water interface. With a bathymetric LiDAR survey, the infrared light (traditional laser system) is reflected back to the aircraft from the land and water surface, while the additional green laser travels through the water column. Analyses of the two distinct pulses are used to establish water depths and shoreline elevations. Bathymetric information is very important near coastlines, in harbors, and near shores and banks. Bathymetric information is also used to locate objects on the ocean floor.

Like radar, LiDAR is based on the concept of actively sensing the vegetation using a pulse of energy, in this case from a laser operating at optical wavelengths (rather than at radio wavelengths). Radio Detection and Ranging (RADAR) technology can observe through clouds because it uses light with wavelength much shorter than visible light (Turner et al., 2003). LiDAR cannot penetrate the clouds because it uses visible light but has the unique capability of measuring the three-dimensional vertical structure of vegetation in great detail (Vega & Durrieu, 2010), sometimes with hundreds of measurements in the vertical dimension for each location on the Earth (Dubayah & Drake, 2000). When applying LiDAR data, we often talk about altimetry and generation of DEM with great precision (S. J. Goetz et al., 2009). This ability to represent the land with great efficiency is most remarkable in the forest environment (Wehr & Lohr, 1999). A wide range of information can be obtained directly from LiDAR: Digital surface models, Digital Elevation Models, the height of trees, the forest structure and the canopy profile (Grau, Durrieu, Fournier, Gastellu-Etchegorry, & Yin, 2017).

LiDAR data allow the vertical structure of the forest, with access to the vertical nature of forest ecosystems, offering new opportunities for better monitoring, management and forest planning (Dubayah & Drake, 2000).

1.2 Synthetic Aperture Radar (SAR):

Since the 1960's, Synthetic Aperture Radar (SAR) has been used to produce images of earth-surface features based on the principles of radio RADAR, (often used as a synonym for SAR) and has been widely used to map vegetation cover (AGB) (Ausherman et al., 1984). SAR have provided and continue to provide a high quality SAR data, it can produce high-resolution two-dimensional images of mapped areas (Tomiyasu, 1978). SAR systems are active, which means they transmit microwave energy and measure the amount of that energy reflected back to the sensor. SAR sensors can operate day or night while penetrating through haze, smoke, and clouds (S Kasischke, M Melack, & Craig Dobson, 1997).

The microwave energy transmitted by a SAR also penetrates into forest canopies, with the amount of backscattered energy largely dependent on the size and orientation of canopy structural elements, such as leaves, branches and stems (S. J. Goetz et al., 2009). SAR data have three important wavelengths to map the biomass (L-, C-, and X-bands; 23.5, 5.8, and 3.1 cm, respectively), this three wavelengths having the capability to monitor variations in biomass in forested ecosystems (Vans & Plaut, 1996).

1.3 Optical Remote Sensing:

Optical remote sensing, considerate as passive sensing of visible and near-infrared reflectance from the earth (S. J. Goetz et al., 2009). Huge amounts of optical remote sensing images with a high spectral-spatial-temporal resolution are now available as Sentinel, Quickbird and Landsat (Zhong, Ma, Ong, Zhu, & Zhang, 2018). Optical measurements have been widely used in studies that link AGB measurements from the field to satellite observations, based on the sensitivity of the optical reflectance to variations in canopy structure (S. J. Goetz et al., 2009). Recording images repetitively from sensors such as Moderate Resolution Imaging Sensors (MODIS) has become frequent.

1.4 Forest inventory by Aerial Photography

-Definitions:

An aerial photograph, in broad terms, is any photograph taken from the air. Normally, air photos are taken vertically from an aircraft using a highly-accurate camera. There are several things you can look for to determine what makes one photograph different from another of the same area including the type of film, scale, and overlap (Natural Resources Canada, 2016). The photointerpretation is carried out based on the relation between the photographic response of the objects of the terrestrial surface.

-Principe:

After the acquisition of the images, the photointerpretation step by a group of experts takes place to determine the different thematic units according to the objectives wish to achieve: forest inventory, land use, management plans, operating plans, plans for fighting fires, plans for erosion control or restoration of mountains, and plans for grazing.

Aerial photography is also used to map forest stands. The photointerpretation should be confirmed on the ground by sampling. An experienced photo interpreter achieves an accuracy of over 95%. Forest inventories are typically designed based on statistical sampling to enable large area knowledge of the variables of interest, in particular to facilitate assessment of biomass and C resources. However, spatially explicit estimates of AGB over large areas that are derived from traditional field-based forest inventories may be incomplete and limited by the sampling intensity. Carbon accounting approaches requiring periodical reporting might also be limited by the temporal frequency of measurements (Gómez Almaraz, 2014).

2.Carbon Stock Mapping:

Remote sensing mapping has to be complemented with conventional forest inventory dendrometry data for adjustment of regression models (Viana et al., 2012). AGB is often determined using a combination of well documented allometric relationships between simple plot-level measurements (e.g. stem diameter, density and sometimes canopy height and/or depth) (S. J. Goetz et al., 2009). In many cases widely used values from research data (conversion factors) and correlations with AGB will be adequate to estimate carbon stocks in different pools (Foley, 2007). A number of approaches have been developed to map carbon stocks and AGB from the satellite observations described above, and we will describe only the most used in Table 3.

Table 3: Approaches of carbon stock mapping: Principe's, characteristics and Precision

Approach	Principe's and characteristics	Precision*	
		Statistic	Cartography
Stratify & Multiply (SM) Approach	-SM Approach: Assign an average biomass value to land cover/vegetation type (S. J. Goetz et al., 2009). -Creation one regression model to link biomass to carbon stock or carbon sequestration (Chave et al., 2005).	Low	Low
Combine & Assign (CA) Approach	-Extension of SM : using multi-layers information in GIS environment (Foley et al., 2007). Essentially makes use of a wider range of data sets and spatial information to extend the field AGB estimation in different biomes.	Medium or High	Medium (polygons overlapping can be as big source of errors)
Direct Remote Sensing (DRS) Approach	-Empirical Models Where Remote Sensing data is calibrated to field estimates. A more spatially consistent way to produce carbon stock maps is to extend the satellite measurements directly to maps by calibrating them to field estimates of AGB using any of a number of statistical techniques, such as neural networks or regression trees (Scott J Goetz et al 2009), or several algorithms, example of MOD17 used to estimate the NPP (Running & Zhao, 2015).	High	High

*Its depend on the quality of the input data and the algorithms used to link AGB and Carbon stock or to measured directly the NPP (i.e. MODIS products).

3-Annual Carbon Balance Mapping:

Annual Carbon Balance Mapping based on the mapping of annual carbon sequestration minus the losses are related to a spatial reference caused by disturbances (e.g. biomass losses by fires). This carbon balance reflects the NBP (S. Wang et al., 2011). Therefore, after using one of the inventory mapping approaches over a period of one year, losses must also be mapped over the same period. Nevertheless, most disturbances are difficult to relate to a spatial reference such as biomass losses by insects and diseases. Good practices require continuous forest condition monitoring to have all the data needed to further improve the mapping. The advantage of this approach is the location and prioritization of sites for mitigation interventions, for a better management planning (Watson, 2009).

II. MODIS images:

1. Definition and Utility:

The Moderate Resolution Imaging Spectroradiometer (MODIS) was launched into space aboard the National Aeronautics and Spaces Administration (NASA) Earth Observing System (EOS) platform Terra in December 1999. A second MODIS sensor was launched on the Aqua platform in May 2002 (NASA, 2001). Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every day, acquiring data in 36 spectral bands. The objective of MODIS is to provide a comprehensive series of global observations of Earth's (land, oceans, and atmosphere) at high spatiotemporal resolutions. MODIS observations are very useful for studies of climate, vegetation, pollution, global change, and many other important economic and environmental issues (NASA, 2001).

The MODIS sensor platform has a low orbit (altitude 705 km) with high radiometric sensitivity (recording of the 12-bit signal) which operates in 36 spectral bands between 0.4 and 14.4 µm corresponding to the spectrum visible and near, medium and thermal infrared (Meer, Jong, & Bakker, 2001). These different channels operate at a spatial resolution ranging from 250 m to 1 km (NASA, 2001). Data is available at no cost and is an excellent source of information for assessing floods, fires, vegetation cover, and weather conditions at national or regional scale.

2. Product MOD17:

MOD17 is a product provided by NASA allows studying mainly carbon sequestration by vegetation, the product MOD17 allows the presentation of Net Primary Productivity (NPP) related to a biome or the global Primary Productivity (GPP) (Robinson et al., 2018). NPP defines the rate at which all plants in an ecosystem produce net useful chemical energy. In other words, NPP is equal to the difference between the rate at which plants in an ecosystem produce useful chemical energy (or GPP), and the rate at which they expend some of that energy for respiration (NASA, 2001).

The big problem with this product is the atmosphere contaminations, on the other side, the products of MODIS, for instance, MOD13 and MOD15, their users can fill the contaminated pixels by the mathematic approaches, which are impossible and not practice for the product MOD17, because GPP / NPP are directly related to the meteorological conditions (RUNNING, Steven et ZHAO, 2011). Using directly the MOD17 product of NASA (version-4 NPP products) we will have to exclude previously the contaminated pixels by the atmosphere and for that reason the values of the sequestration of the carbon by the vegetation will be underestimated (Running & Zhao, 2015). Using the same NASA MOD17 product the estimation can be improved if the geometric and atmospheric correction suggested by Numerical Terra Dynamic Simulation (NTSG) Group in Montana University is applied previously (version-55 of the NPP product) (Running & Zhao, 2015).

2.1 Logic and Algorithms of MOD17

Terrestrial net primary production (NPP) quantifies the amount of atmospheric carbon fixed by plants and accumulated biomass (Zhao & Running, 2010). Several algorithms have been developed to estimate the NPP over a period of time, the MOD17A1 estimates the daily NPP, the MOD17A2 estimates the NPP by 8 days, while the MOD17A3 is the NPP estimated yearly (Running & Zhao, 2015).

The theoretical basis for the MOD17 algorithm stems from original work by Monteith (1972), directly relating GPP and NPP to the amount of solar radiation absorbed by the plant canopy (Running, Thornton, Nemani, & Glassy, 2000). Remotely sensed vegetation information was combined with light use efficiency logic and incident shortwave radiation to calculate daily GPP and annual NPP after accounting the losses due to respiration (Robinson et al., 2018). Monteith's logic combines the available sunlight (meteorological restriction) with the leaf area index (physiological restriction) and is therefore a measure of the capacity of the photosynthetic apparatus to absorb a given amount of light, this logic simplifies the theory of carbon balance (RUNNING, Steven et ZHAO, 2011). Users should note that the composite MOD17A2 is an 8-day summation of Daily Gross Primary Productivity (GPP) and Daily Net Photosynthesis (PSN_{net}), and annual sum of GPP and NPP for MOD17A3 are annual summations of two variables. Additionally, PSN_{net} is the daily Gross Primary Productivity (GPP) minus the daily maintenance respiration by leaves (R_{ml}) and by roots (R_{mr}):

Equation 5:daily Net Photosynthesis

$$\boldsymbol{PsnNet = GPP - R_{ml} - R_{mr}}$$

Also, NPP is the annual sum of PSNnet minus the cost of growth (R_g) and maintenance (R_{mo}) of living cells in permanent woody tissue (e.g., livewood) When the Annual NPP is expressed as:

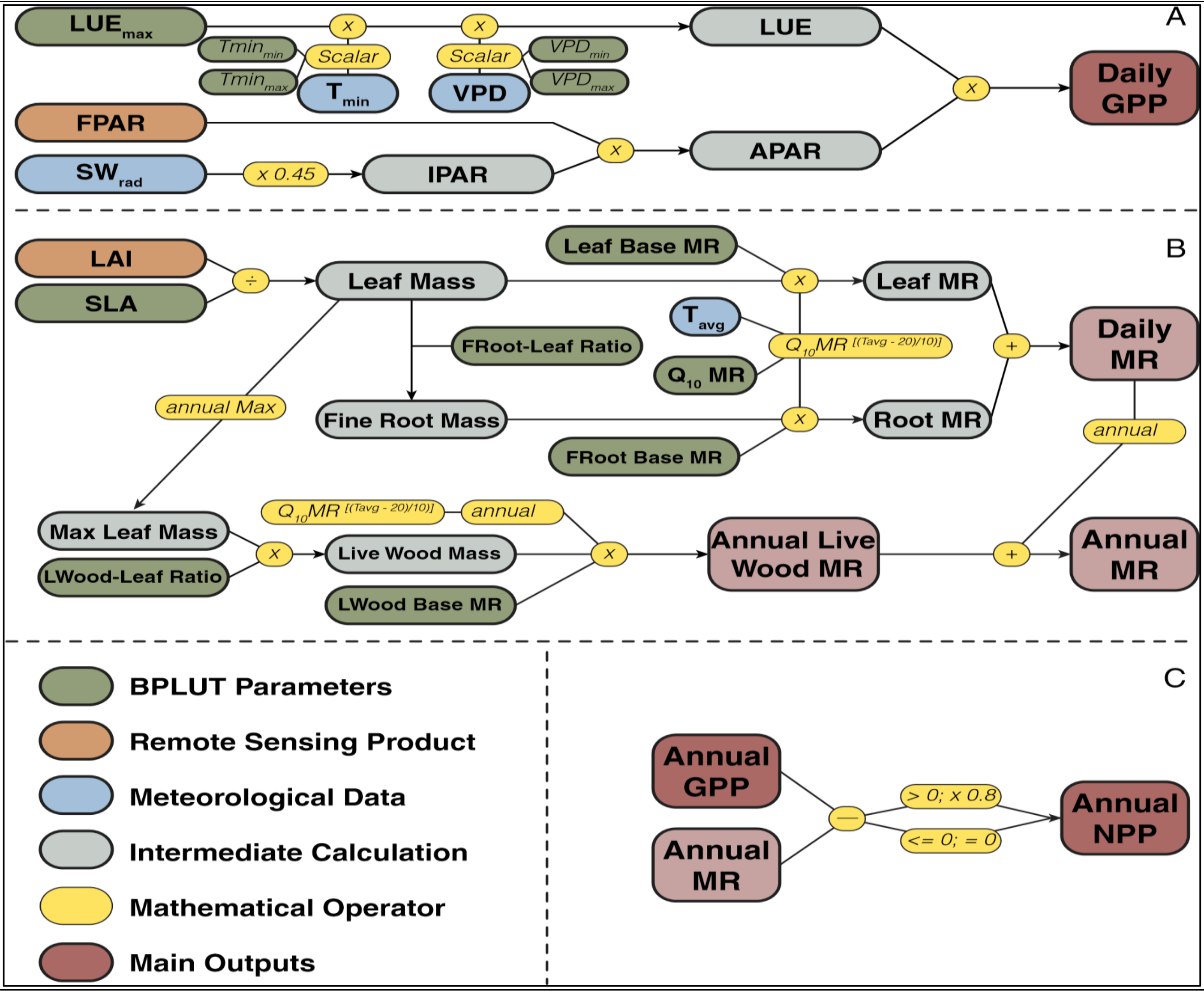
Equation 6:Annual NPP

$$NPP = \sum_{i=1}^{i=365} PsnNet - (R_{mo} + R_g)$$

The MOD17A2 / A3 algorithm requires two products: GMAO meteorological data and LAI / FPAR data obtained from MOD15A2 product. Meteorological data, obtained from the World Modeling and Assimilation Office (GMAO), has improved several times, and now GEOS-5 is the version currently used.

The NPP algorithm generally implements the fraction of photosynthetically active radiation absorbed by the Earth's surface (FPAR), leaf area index (LAI), biome specific conversion efficiency parameters which translate the energy absorbed into tissue growth (biomass), and reductions in the conversion efficiency due to temperature and water constraints (P. Turner et al., 2006). This is done by combining spectral vegetation indices derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the TERRA and AQUA satellite platforms with daily surface meteorology and biome specific vegetation parameters to globally map GPP and NPP at 1-km resolution (Robinson et al., 2018). GPP calculated daily and provided as an 8-day product, is the amount of carbon fixed during photosynthesis period, which is directly affected by temperature, water, and light availability as constraints on theoretical growth potential (Running, Nemani, Glassy, & Thornton, 1999). NPP has calculated annually from GPP by considering both maintenance and growth respiration costs; the carbon consumed by these processes is subtracted from GPP to obtain annual NPP, including both aboveground and belowground biomass production. For a detailed description of the algorithm and logic, refer to (Running & Zhao, 2015).

We summarized in (Figure 6) the different data given in the product development MOD17 and the equations used in NPP calculations, based on the theoretical from the original work of Monteith (1972), which directly links the GPP and the NPP the amount of solar radiation absorbed by the plant cover. For further explanations about MOD17A3 algorithms consult Table 4.



Acronyms: LUE_{max}: maximum light use efficiency ; LUE: light use efficiency ; T_{min}: minimum daily temperature; VPD: daily vapor pressure deficit; $Tmin_{min}$: minimum daily minimum temperature; $Tmin_{max}$: maximum daily minimum temperature; VPD_{min}: minimum daily vapor pressure deficit; VPD_{max}: maximum daily vapor pressure deficit; SW_{rad}: short wave radiation; FPAR: fraction absorbed photosynthetically active radiation; IPAR: incident photosynthetically active radiation; APAR: absorbed photosynthetically active radiation; LAI: leaf area index; SLA: specific leaf area; MR: maintenance respiration; FRoot: fine root; LWood: live wood; T_{avg}: average daytime temperature.

Figure 6:Flowchart of the MOD17 GPP and NPP algorithms Adapted from the MOD17 user's guide (Running and Zhao ,2015; Matthew O. Jones et al., 2018)

Table 4: Resume of algorithms in MOD17 product (Running and Zhao, 2015)

Bloc	input	Mathematical operation	output	Explications
A	_TMINmax and TMINmin _VPDmin and VPDmax _LUEmax _FPAR _SWRad	LUE=LUEmax * TMIN_scalar * VPD_scalar APAR = IPAR * FPAR IPAR = (SWRad * 0.45) GPP = LUE * APAR	GPP	LUE is a Biophysical variable represents PAR conversion efficiency (PAR: photosynthetically active radiation), linked to the biome (climatic and vegetation types). The two parameters for TMIN and the two parameters for VPD (BULT parameters) are used to calculate the scalars that attenuate LUEmax produce the final LUE (kg C MJ-1) used to predict GPP. IPAR (PAR incident on the vegetative surface) must be estimated from incident shortwave radiation (SWRad, provided in the GMAO/NASA dataset) FPAR obtained from MOD15A2 product, the Photosynthetically active radiation (PAR) is the spectral range from 400-700nm that is used by plants in photosynthesis. The fraction of PAR (fPAR) is a parameter used in remote sensing and in ecosystem modeling that signifies the portion of PAR used by plants.

Bloc	input	Mathematical operation	output	Explications
B	_Specific leaf area (SLA) -Leaf area index (LAI) -Fine root_leaf_ratio -Leaf_MR_base -Fine_Root_Mass -Fine root_MR_base -Q10 : temperature coefficient Average daytime temperature (Tavg) - Annual maximum leaf mass -Live wood Leaf Ratio -Live wood base MR	Leaf_Mass = LAI / SLA Fine_Root_Mass = Leaf_Mass * froot_leaf_ratio Leaf_MR = Leaf_Mass * leaf_MR_base * Q10_mr^[(Tavg - 20) / 10] Root_MR = Fine_Root_Mass * froot_mr_base * Q10_mr ^[(Tavg - 20) / 10] Dialy MR =Leaf_MR+Root_MR Livewood_Mass = ann_leaf_mass_max * livewood_leaf_ratio Livewood_MR = Livewood_Mass *livewood_mr_base*annual sum of MR Annual MR= (Leaf MR+Root_MR+LivewoodMR) annual PSNnet = GPP – Leaf_MR - Froot_MR	Dialy MR Dialy live wood MR Annual MR PSNnet	The calculation of annual respiration is obtained from several mathematical operations that require several other variables obtained from several sources (remote sensing, meteorology, BPLUT parameters, and the MODIS data itself we talk here about FPAR and LAI), LAI is obtained from MOD15 and the specific surface area of the leaves (SLA, projected leaf area kg^{-1} leaf C) for a given pixel is obtained from the BPLUT. mod17 is one product that takes into consideration several carbon pools such as leaf fine roots and Live wood.
C	Annual GPP annual MR growth respiration (Rg =0,25 NPP)	NPP = GPP – Rm – Rg = GPP – Rm – 0.25*NPP NPP = 0.8 * (GPP – Rm) when GPP – Rm >=0 NPP = 0 when GPP – Rm < 0	NPP	Daily estimates of LAI, meteorological data, and the relevant MOD17 algorithm BPLUT parameters were used to calculate daily maintenance respiration (MR). The logic and parameters were based on allometric relationships between estimated leaf area, leaf mass, fine root mass, and live wood mass. Annual NPP was calculated as the sum of the daily differences between GPP and MR minus annual growth respiration (GR). Rm and Rg are calculated using leaf area index (LAI) from the MOD15 product, climate data, and parameters from the BPLUTs.

2.2 MOD17 products Uncertainty:

MODIS continuously provide information on NPP of terrestrial ecosystems, using several series of the algorithms where we find Meteorological Data, biome-property from lookup table (BPLUT) Parameters and Remote Sensing Products, FPAR and LAI, which are calculated and modulated by using the bands 1,2, 3, 4, 5,6, 7 and the two thermal bands 31 and 32 (Running & Zhao, 2015). For each pixel, biome type information is derived from MODIS land cover products (MOD12Q1), daily meteorological data are derived from the Data Assimilation Office (DAO data set), and FPAR and LAI are obtained from MOD15A2 (Running & Zhao, 2015). Consequently, the uncertainties in MOD12Q1, DAO, MOD15A2, and the algorithm itself would all influence MOD17 results precision.

Conclusion:

Carbon mapping (stock, annual sequestration, and Annual balance) in forest ecosystems is a complicated task, related to the approach used, which itself depends on the data available and the realization cost.

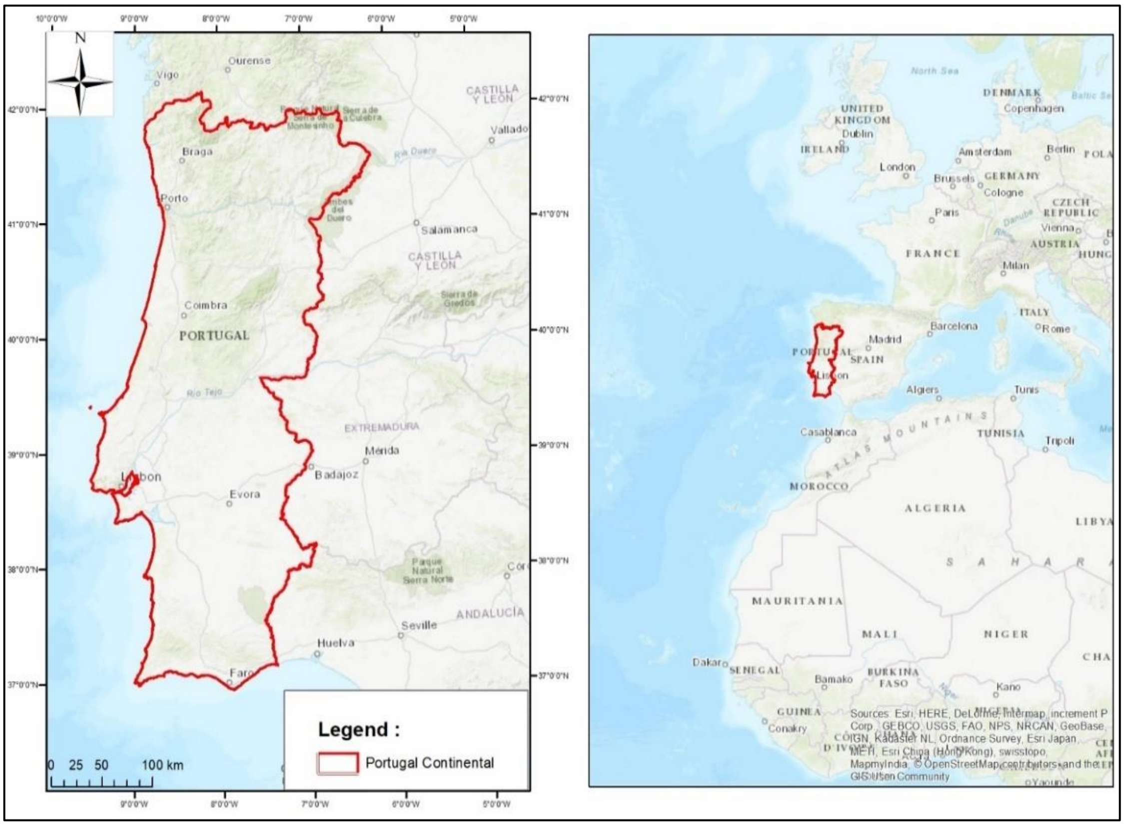
The DRS approach is the most effectiveness approach to use from a statistic and a cartographic point of view. While, the CA approach is more difficult to use and can generate more errors. The use of the MODIS image (product MOD17), as a tool of the optical remote sensing, is a very responsive technique in the world, to follow the vegetation carbon dynamics, this tool is free and it is provided by NASA from 2001 until present. In the framework of NASA project which followed the state of the Earth by measurements of a several environmental factors.

The MOD17A3 product of vegetation NPP is one of the most highly used data sources for studies the global carbon cycle. But it needs to tested more in serval biomes, especially for heterogeneous areas in terms of its accuracy and potential bias (Gulbeyaz, et al., 2018). To improve the quality of this interesting product, which is present the Terrestrial primary production as fundamental ecological process and a crucial component in understanding the energy flow through trophic levels.

PART II- METHODOLOGY AND MATERIALS

Chapter I: Study Area Presentation: Continental Portugal

I. Geographic Area:



Map 1:Area of study

Portugal is located in the Iberian Peninsula, being the most western country in Europe. Its proximity to Africa gives it an important geostrategic position (Map 1). The insular part of Portugal integrates the archipelagos of Madeira and the Azores. Continental Portugal occupies approximately 92.391 km².

II. Climate and Environment:

1.Climate:

Continental Portugal is characterized overall by Mediterranean temperate climate (Pons & Quézel, 1998), which is distinguished by dry and hot summers associated with relatively mild winters (Barbero et al, 1992). The Atlantic has a significant influence on the climate in the northern and coastal zones. Precipitation and temperature are characterized by differences in regional distribution and variations in seasonality (de Lima et al., 2013). We can distingue between two types of temperate climate in continental Portugal: maritime and continental climate.

Climatic stratification is a very important step in the carbon accounting (Watson, 2009) because the NPP of vegetation cover and the biomass losses are related to the climate variation (Nemani et al., 2003). Indeed, the risk of fires, the insects and diseases occurrences are linked to climate change and environmental conditions (DALE et al., 2001). Therefore, the integration of climatic factors in biomes classification stage is one important step to increase accuracy assessment. We dispose annual increment and standing volumes data per specie, but not according to climate zones. The vegetation types are the only classification factor used in this work.

2. Climate Change:

2.1 Climate change and Temperature:

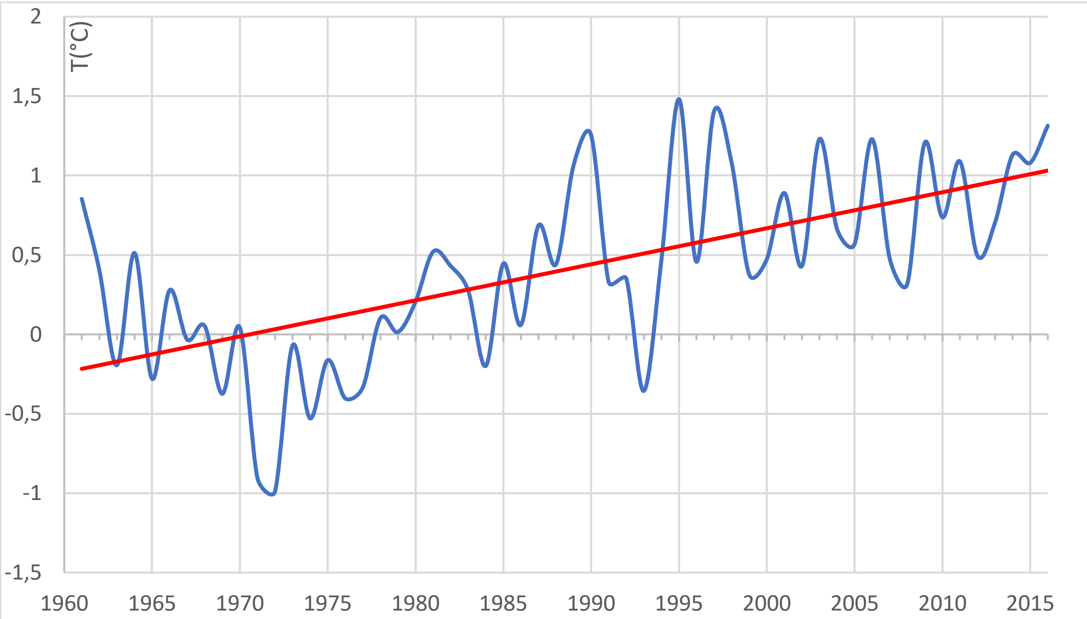


Figure 7: Temperature deviations from the average in Portugal between 1960-2015 (FOASTAT)

Several studies were performed by NASA and they clearly show that the temperature of the planet has increased sharply in the last century (0.96 °C between 1910 and 2010). The temperature of the planet warmed more in the northern hemisphere than the southern hemisphere and also warmed more in the continents than in the other zones (J., R., M., & K., 2010). While, in Portugal the average temperature increased by 1.2ºC between 1960-2015 (Figure 7). The main reason for this global warming is the effect of greenhouse gases emission, in which The CO_2 present the second important gases how provoked this temperatures anomaly after water evaporation (H_2O). Heat and cold waves will be predicted to be more frequent in the near future, with vegetation being affected much more severely than the average temperature increase (DOUROZONE, 2018). The great forest fire of Pedrógão-o-grande in 2017 was the consequence of an abnormal period of consecutive days of high temperature, reduced precipitation and very low atmospheric humidity.

2.2 Carbon Emissions:

The American scientist Charles David Keeling began measuring CO_2 concentrations in the atmosphere in the 1950s, the CO_2 concentrations in the atmosphere increased from 310 ppm in 1958 to 400 ppm in 2013 as shown in the Keeling curve (Figure 8). The concentration of CO2 decreases between May and October, a period of greatest vegetative growth in the northern hemisphere, and increases between November and April, vegetation dormancy period (Keeling, 1979). While the direct CO_2 emission measurements published by NOAA (National Oceanic and Atmospheric Administration) since 2005 to present shows that the concentration of CO_2 increases over the years it has increased from 375 ppm in 2005 to 405 ppm in 2017 (NOAA, 2017). CO_2 is an important heat-trapping (greenhouse) gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions (Wuebbles & Jain, 2001).

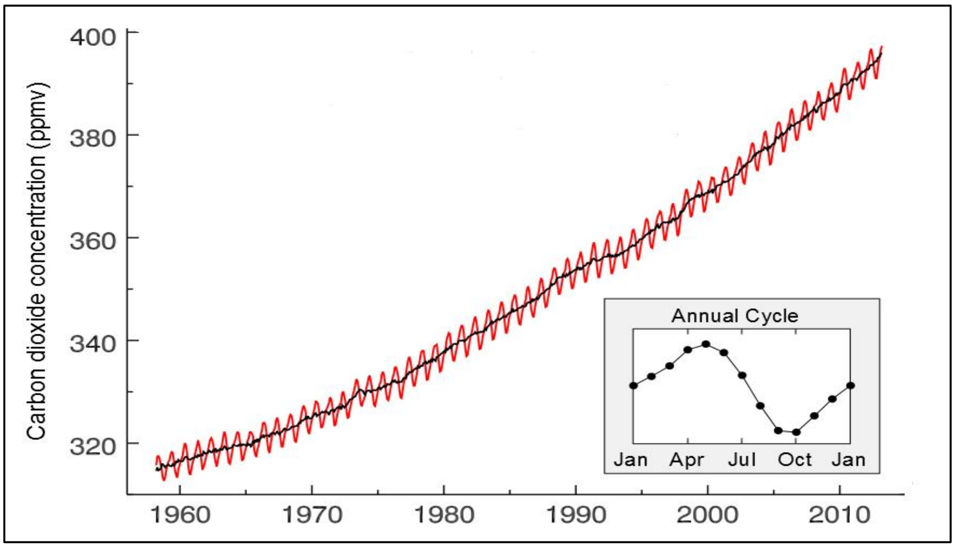


Figure 8:Keeling curve showing the increasing of CO2 concentration in the atmosphere since the late 1950s

Before 1950 there was a relative stabilization of CO_2 emissions in Portugal, which did not exceed 2000 Mt/year (Figure 9). Since 1950, it has been dramatically augmented, it is reaching 15.000 Mt CO2/year in 2002. This increase can be explained by human activities such as industrial activity, energy, transport, agriculture…etc.

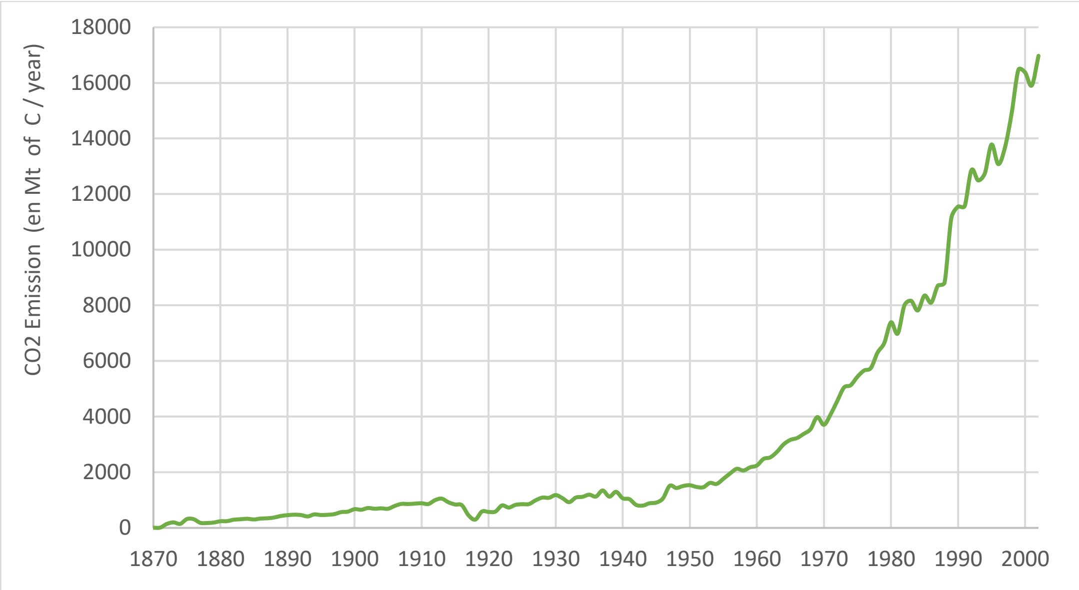
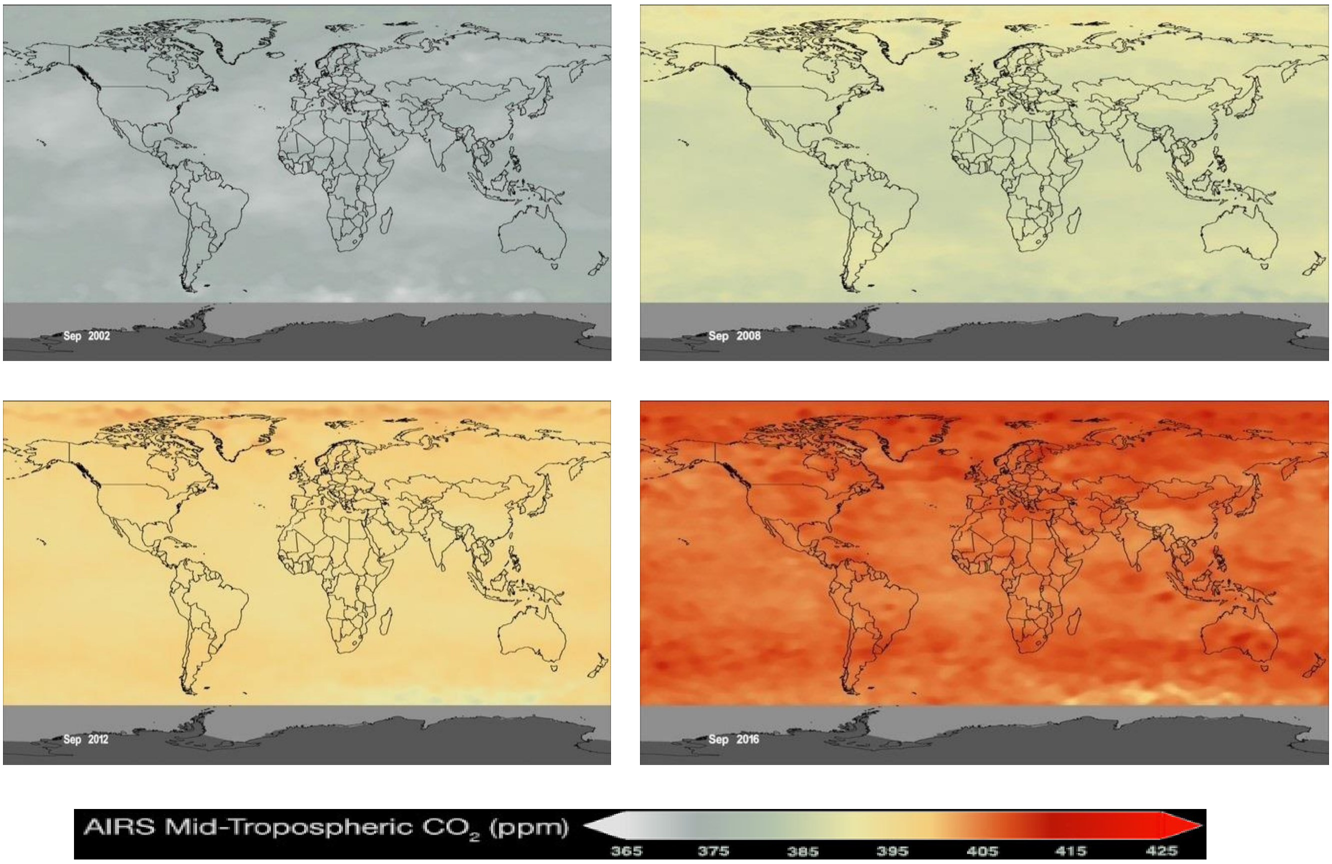


Figure 9:Anthropic CO_2 emission in Portugal (FOASTAT)



Map 2: Maps Series of CO2 emission in the World (2002, 2008,2012, 2016, NOAA)

The time series Maps (Map 2) are reflecting the global distribution and variation of the CO2 concentration (ppm) in the atmosphere. There is a dramatically increasing in CO2 in all the world. Immediate intervention is required to mitigate the global warming, as one universal commitment recommended in kyoto protocol (Breidenich et al., 1998).

Portugal has an important progress in protecting the environment and improving the quality of air, by dint of the replacement of some fossil fuels by renewable energy source and the strength environmental policies. This policy has focused its efforts on energy sector because it is the main sector responsible of GHGs emissions, particularly CO_2 (OCDE, 2011). Therefore, the environmental policy in Portugal has made it possible to reduce CO_2 emissions by capita Over the last decade (Figure 10), a strategy that classified Portugal country as one of the best environment modules in Europe countries. Despite these efforts, the national economy was slowed down and causing several social problems, such as rural exodus, Low income, land use change...etc. which are actually more accentuated (OCDE, 2011), all these results, requires the state to have other strategies' and programs in the context of sustainable development for each sector.

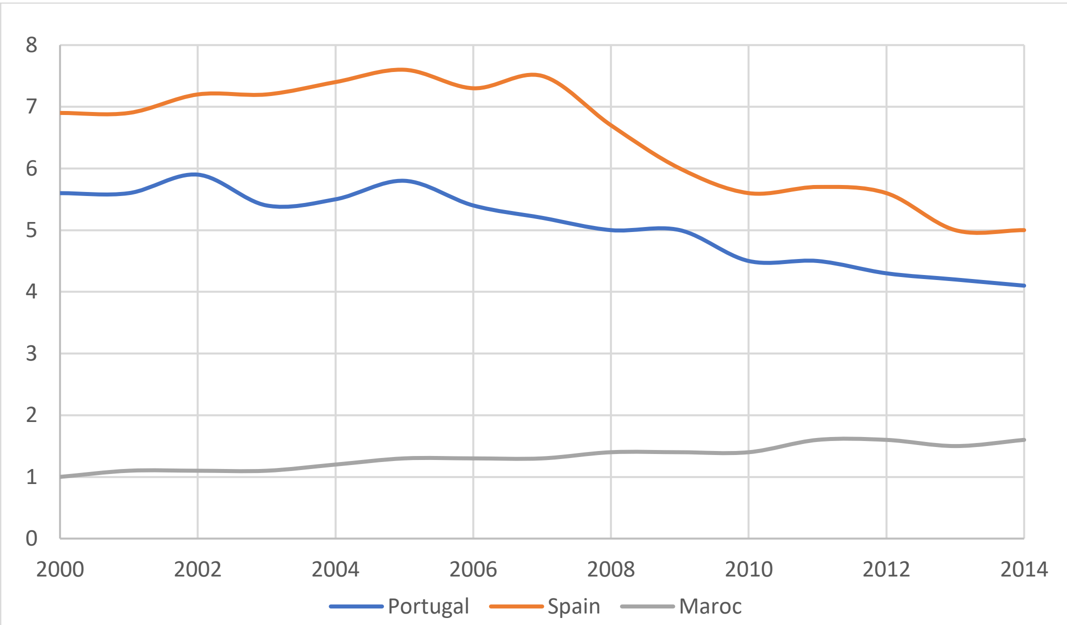


Figure 10:Evolution of CO_2 emissions per capita in three Mediterranean countries (source: OECD)

Up to this point, we talk about the sources of GHGs emissions, essentially CO_2 emissions. What about CO_2 sinks? We are talking here about the continental Portugal forest ecosystems, is it in the process of improvement or disruption? What must be done to improve this CO_2 sink? It is our purposes to answer these questions in this project.

IV. Forest Resources:

1. Land use:

Table 5: Land use in Portugal continental from 1995 until 2010.

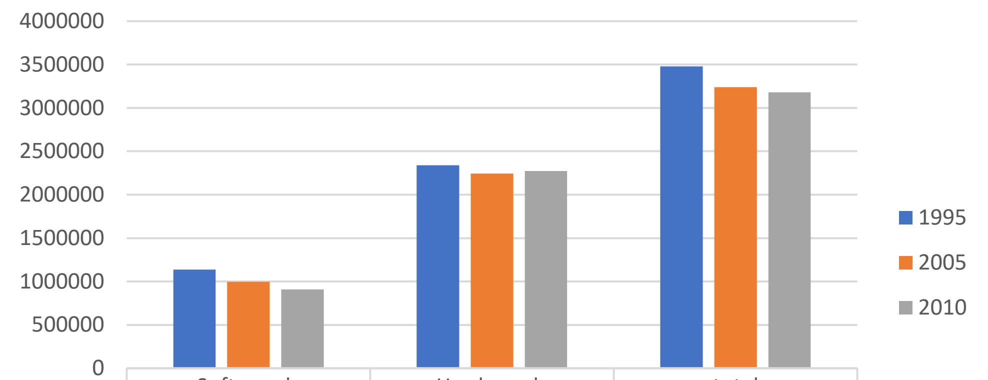
Evolution from 1995 to 2010		1995 (ha)					
		Forest	Agriculture	Rangelands	Inland waters	Urban	Unproductive
2010 (ha)	Forest	2 715 346	105 075	327 353	575	1 200	5 251
	Agriculture	35 909	1 943 787	132 982	175	700	725
	Rangelands	501 994	298 021	2 022 081	600	2 576	27 957
	Inland waters	9 602	7 127	15 304	148 785	25	1 725
	Urban	29 107	48 737	29 707	200	310 399	7 377
	Unproductive	13 453	5 026	11 853	250	575	147 335
forest land use losses and gains	Xii	2 715 346	1 943 787	2 022 081	148 785	310 399	147 335
	x+i	3 305 411	2 407 773	2 539 280	150 585	315 475	190 370
	LOSSES	17,9%	19,3%	20,4%	1,2%	1,6%	22,6%
	xi+	3 154 800	2 114 278	2 853 229	182 568	425 527	178 492
	GAINS	13,9%	8,1%	29,1%	18,5%	27,1%	17,5%
changes	Change (ha)	-150611	-293495	313949	31983	110052	-11878
	Change (%)	-0,05	-0,12	0,12	0,21	0,35	-0,06
	Annual change (%)	0,00	-0,01	0,01	0,01	0,02	0,00
	Annual change (ha)	-10040,73	-19566,33	20929,93	2132,20	7336,80	-791,87
Contribution in forest change (%)			6%	85%	2%	5%	2%

$Change\ (ha) = x_{i.} - x_{.i}$

$Change\ (\%) = (x_{i;} - x_{;i})/x_{.i}$

where i: land use

According to the ICNF, we notice a forest reduction of 4,6% during the period from 1995 to 2010, corresponding to 150.611 ha (10.041 ha/yr). The landscape dynamics shows that the rangelands are the most important source of changes (85%), responsible by the 17,9% of forest losses and 13,9% of forest gains (*Table 5*) (ICNF, 2013). The forest fires and natural factors like insect and diseases occurrences contribute considerably to the forest reduction. In addition, the forest resources were affected by the increasing wood demand to industry supplying (23%). This kind of interference was more important in broadleaves than coniferous (Figure 11). while hardwoods were characterized by a stable area during 2005 until 2010 because there was an increase in *Eucalyptus* area and other agroforestry species despite the diminution of native species of Portugal as Quercus Suber and Quercus Ilex.

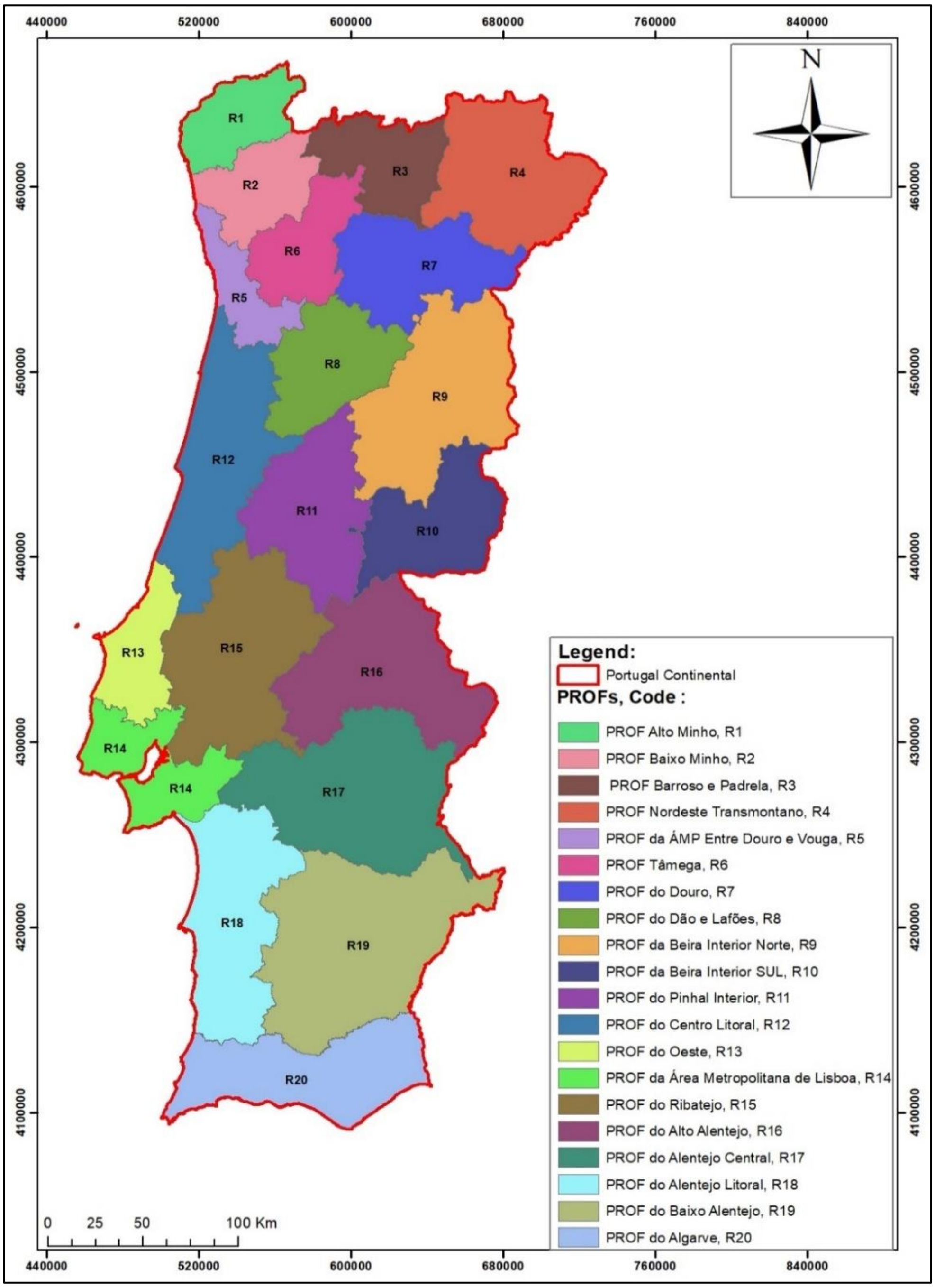


	Softwoods	Hardwoods	total
1995	1136918	2341150	3478068
2005	995543	2245300	3240843
2010	906530	2273398	3179928

Figure 11:Occupation areas evolution for Broadleaves and coniferous

2. Ownership Status and Administrative Division

The Portuguese forest sector occupies about 3179928 hectares (ICNF, 2013). Portugal has one of the largest forest sectors in Europe (35.8%), about 93,4 % of it is privately owned, and only 5,4 % is a Communal forest, the remaining 1,2 % belong to the Public forest (Feliciano et al., 2015). These forests are organized and developed according to 21 regional forest management plans (PROF). PROF is a sectorial instruments of territorial management, provided in the framework of the Portuguese forest policy (ICNF, 2014), which defined specific standards for the forest management practices, in order to guarantee the sustained production of all the goods and services associated with them. their mission is :a) assess the potential of forest areas, b) define the list of species to be favored in the expansion and conversion of the forest heritage, c) identify the most appropriate general models for sustainable management of forest resources, d) define critical areas from the point of view of fire risk, sensitivity to erosion and the ecological, social and cultural importance, e) as well as, specific managements and sustainable uses of resources that have to be applied to these areas (ICNF, 2014). In this work we will consider the two PORFs, Pinhal Interior Norte and Pinhal Interior sul as a single PROF region named Pinhal Interior (Map 3).



Map 3: Regional Forest management Plans (PROFs regions)

3. Forest Stands:

The main tree species in 2010 is *Eucalyptus* with the largest forest area of the country (811 943 ha), cork the second (736 775 ha), followed by maritime pine (714 445 ha) (*Table 6*). The main alterations of the forest species' zones between 1995 and 2010 occurs at the *Pinus pinaster* stands which were decreasing by approximately 263.438 ha and in *Eucalyptus* stand which was increasing by 94.697 ha. Also, it is worth mentioning the *Pinus pinea*, *Castanea sativa* and *Ceratonia siliqua* (alfarroba) areas were increasing. For all oaks stand there is a considerable decrease in their total area.

Table 6:Forest Stands area (ha) for 3 NFI (1995,2005 and 2010)

species		**1995**	**2005**	**2010**
Softwoods	*Pinus pinaster*	977 883	795 489	714 445
	Pinus pinea	120 129	172 791	175 742
	other Softwoods	38 906	27 263	16 343
	Total	1 136 918	995 543	906 530
Hardwoods	*Eucalyptus* spp.	717 246	785 762	811 943
	Quercus suber	746 828	731 099	736 775
	Quercus ilex	531 743	476 515	470 380
	other Oaks	91 897	66 016	67 116
	Castanea sativa	32 633	38 334	41 410
	Acacia spp.	12 278	12 203	11 803
	Ceratonia siliqua	2 701	4 726	5 351
	other Hardwood	205 824	130 645	128 620
	Total	2 341 150	2 245 300	2 273 398
Total of Forest		3 478 068	3 240 843	3 179 928

There is a significant unsteadiness between forest species from the point of view the evolution of area occupancy between 1995 and 2010 (Figure 12):

- *Pinus pinaster* has undergoing degradation; it was decreasing by 24%
- *Eucalyptus* was increased by 17%
- degradation of oaks (native species in Portugal) by 25%
- *Pinus pinea* is increased by 57%
- The agroforestry species (*Ceratonia siliqua*) is increased by 90%

The areas of *Eucalyptus* and *Pinus pinea* were increased because of their importance, but Portugal is leading to lost others important species as oaks (ICNF, 2013).

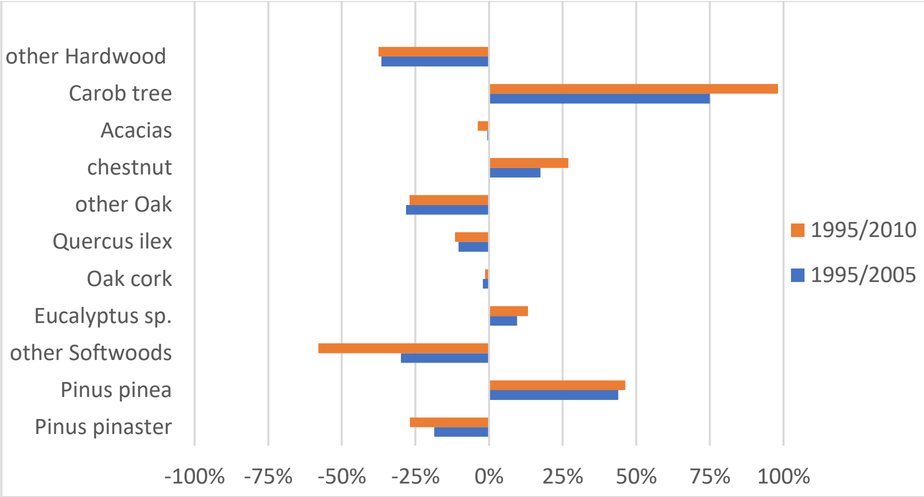


Figure 12:Rate of changes in the forest species occupation between 1995 and 2010

4. Forest Natural disturbances:

4.1 Fires:

In Figure 13 we present the burned area (BA) in Portugal from 1995 until 2017 (ICNF,2018). The BA varied from one year to another, in the years 2003, 2005 and 2017 the BA was exceeded 300000 ha, the maximum is recorded in 2017 with a new record which exceeds 500000 ha. Fires are dependent on several environmental conditions: water stress, wind speed, temperature, forest species, herbaceous cover and other factors (Martín, Diez, & Soriano, 1997). Fires have several environmental, social, economic implications and quite a lot of consequences in biodiversity. We will discuss only GHGs emissions from forest biomass burns for each forest species.

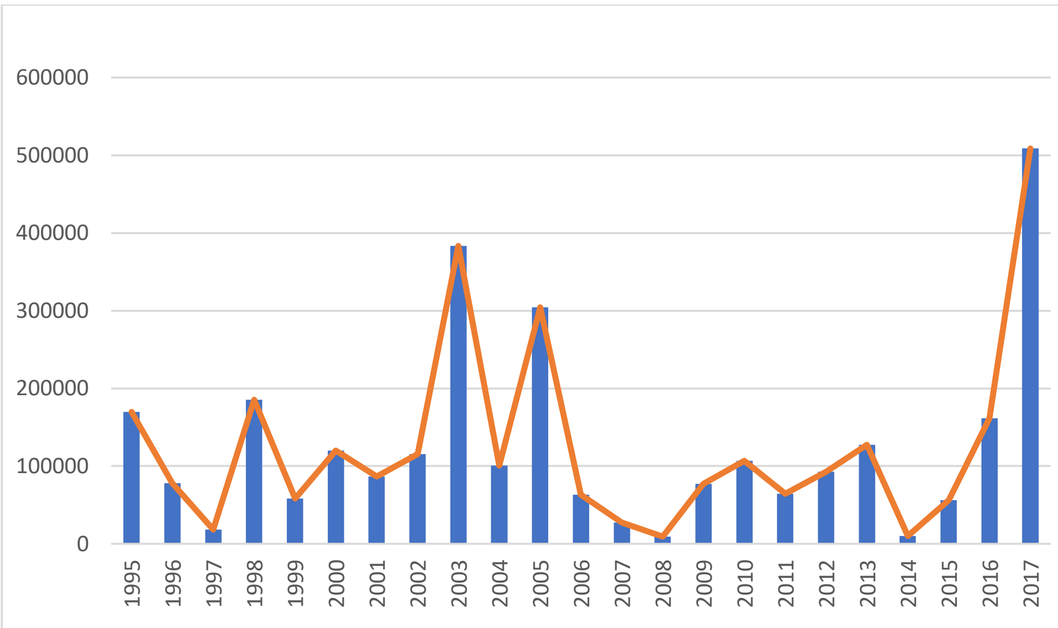
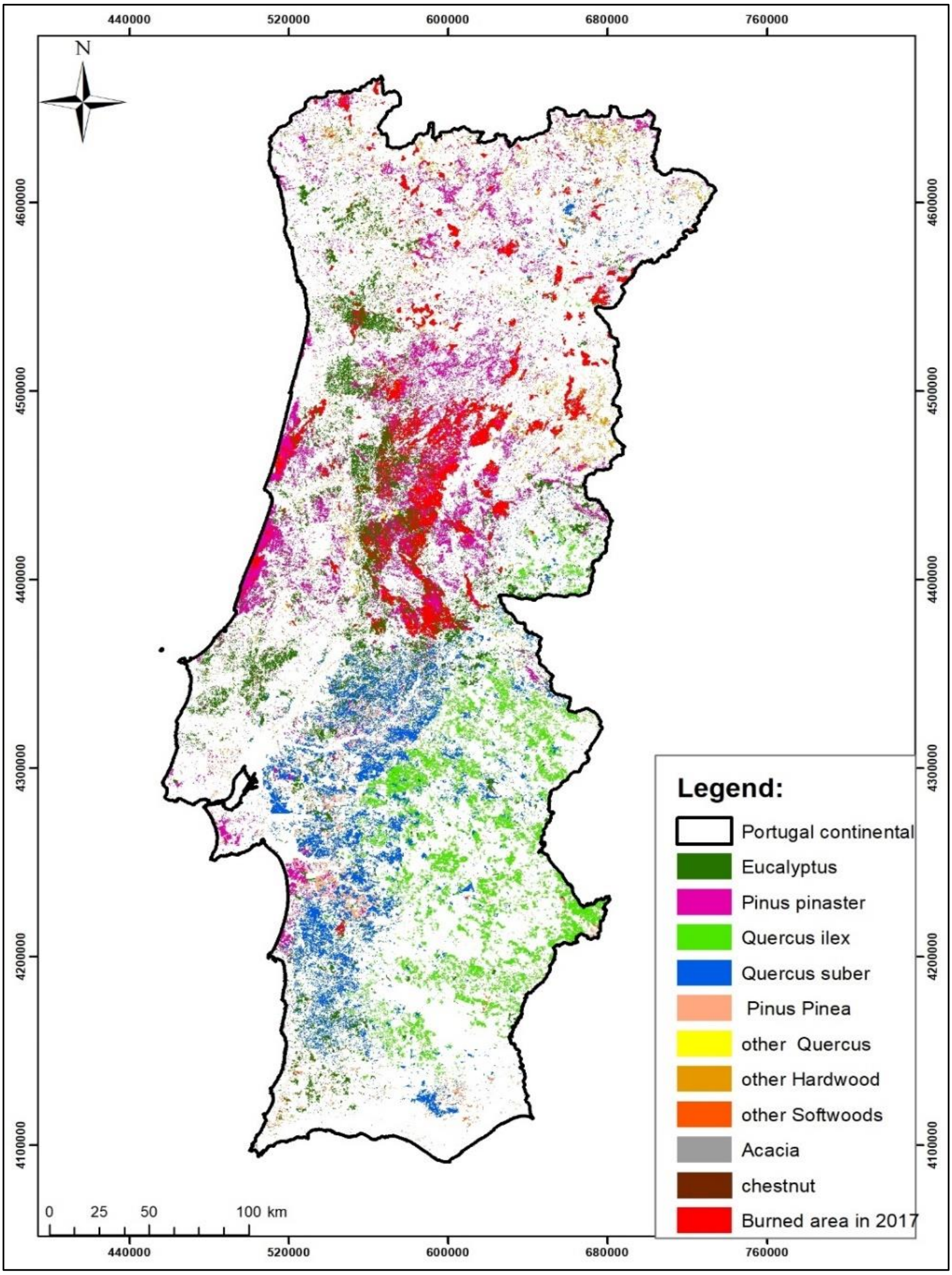


Figure 13: Burned area between 1995 and 2017 (ICNF,2018)

The *Pinus pinaster* is very sensitive to fire (Fernandes, Vega, Jiménez, & Rigolot, 2008) and *Eucalyptus* are highly flammable (Doerr, Shakesby, & Walsh, 1998). Fires risk is more frequent in central and northern regions of the country, where we find these two species occurs (Map 4).



Map 4:Burned Area in 2017 (ICNF)

4.2 Insects and Diseases:

Table 7: Forest area affected by insect and diseases for two main species in Portugal forest

Sup (ha) affected by insect and diseases			total (ha)
Years	Pinus pinaster	*Eucalyptus*	
1990	220 006	232 794	452 800
2000	126 231	133 569	259 800
2005	138 346	146 283	284 629
2010	135 738	154 262	290 000

Insects and diseases disturbances are related to the environmental conditions (DALE et al., 2001). Pests and diseases seriously threaten the productivity and sustainability of forest plantations. In fact, there is a very high disturbance of the Portugal forest ecosystems by these two biotic agents (Table 7) (J.M. Rodrigues, 2018, verbal communication). These disturbances triggering the mortality of the stands or slow-down the photosynthesis process, because they provoke the trees defoliation and leaf area reduction (Lovett et al., 2006), reducing its carbon sequestration capacity. Besides they affect stand productivity and wood quality especially by their impacts on growth rate and mortality rate in forest cover (Held, 2015).

The pine nematode (Bursaphelenchus xylophilus Steiner and Buher N), organism with high potential to cause mortality of pines in Portugal (Mota et al., 1999), and the pine processionary (Moth, Thaumetopoea pityocampa), are the most destructive insects in forest Pine stands (Arnaldo, Chacim, & Lopes, 2010). The *Eucalyptus* specie is an exotic species in Portugal, it suffering from several risks, especially biotic agents, 11 species of Australian insects have been identified and they eat exclusively *Eucalyptus* leaves and damaging plants/trees. Eucalyptus weevil (Gonipterus platensis) (Reis, Ferreira, Tomé, Araujo, & Branco, 2012) and Eucalyptus longhorn (Phoracantha semipunctata) are two kind of beetles with strong damages in Eucalyptus stands.

5. Forest woods Production:

The Portugal forests are very dynamic, their first objective is the production of the woods, especially timber and pulp wood. and it was recorded that the forest ecosystem supplied $34*10^6$ m^3 of the wood in 2015. The statistics in Table 8 show the wood production in Portugal forests from 1995 until 2015, published by the European Commission responsible for statistical information (EUROSTAT database). Here we can find that the wood demand was increased by 23% in this period.

Table 8: Amount of annual wood removals (m3/yr) (EUROSTAT)

Years	volumes lumber (m^3)			volume industry wood (m^3)			volumes Firewood (m^3)		
	Softwoods	Hardwoods	Total lumber	Softwoods	Hardwoods	Total industry wood	Softwoods	Hardwoods	Total Firewood
1995	9 892 000	8 127 000	18 019 000	5 089 000	3 942 000	9 031 000	185 000	315 000	500 000
1996	9 190 000	8 036 000	17 226 000	4 720 000	3 888 000	8 608 000	185 000	365 000	550 000
1997	9 190 000	8 036 000	17 226 000	4 720 000	3 888 000	8 608 000	185 000	365 000	550 000
1998	8 418 000	7 898 000	16 316 000	4 334 000	3 794 000	8 128 000	200 000	400 000	600 000
1999	8 410 000	8 766 000	17 176 000	4 330 000	4 228 000	8 558 000	200 000	400 000	600 000
2000	10 014 000	10 868 000	20 882 000	5 132 000	5 279 000	10 411 000	200 000	400 000	600 000
2001	7 566 000	9 546 000	17 112 000	3 908 000	4 618 000	8 526 000	200 000	400 000	600 000
2002	6 220 000	10 484 000	16 704 000	3 235 000	5 087 000	8 322 000	200 000	400 000	600 000
2003	6 714 000	11 852 000	18 566 000	3 482 000	5 771 000	9 253 000	200 000	400 000	600 000
2004	8 004 000	12 954 000	20 958 000	4 127 000	6 322 000	10 449 000	200 000	400 000	600 000
2005	6 586 800	14 125 680	20 712 480	3 418 400	6 907 840	10 326 240	200 000	400 000	600 000
2006	7 051 800	13 777 480	20 829 280	3 650 900	6 733 740	10 384 640	200 000	400 000	600 000
2007	7 323 960	13 542 520	20 866 480	3 786 980	6 615 190	10 402 170	200 000	400 000	600 000
2008	6 281 340	13 276 170	19 557 510	3 265 670	6 483 080	9 748 750	200 000	400 000	600 000
2009	6 888 900	11 459 240	18 348 140	3 569 450	5 574 620	9 144 070	200 000	400 000	600 000
2010	6 951 790	11 563 240	18 515 030	3 603 010	5 627 040	9 230 050	200 000	400 000	600 000
2011	7 087 680	14 063 680	21 151 360	3 658 190	6 874 710	10 532 900	200 000	400 000	600 000
2012	5 715 510	14 803 410	20 518 920	3 026 870	7 386 650	10 413 520	200 000	400 000	600 000
2013	4 809 680	15 643 460	20 453 140	2 417 210	7 758 410	10 175 620	200 000	400 000	600 000
2014	5 384 990	16 048 420	21 433 410	2 699 940	8 123 760	10 823 700	200 000	400 000	600 000
2015	5 719 430	16 428 370	22 147 800	2 862 140	8 390 190	11 252 330	200 000	400 000	600 000

Chapter II: Annual Carbon Balance

This section presents a systematic approach to estimate the annual carbon balance, where we associated the CO_2 emissions and absorption from biomass pool in forest lands. We assumed that they remained in the same land-use category (forest). The objective is to assess the forest evolution state from 1995 until 2014.

The annual carbon balance in forest ecosystems treat both two processes: emission and the sequestration. The first process is controlled by: breathing, decomposition, and combustion of organic matter (fires), they have been provoking the direct CO_2 emission in the atmosphere. The second process reflects the photosynthetic sequestration. The emissions and removals calculations using the gain-loss method, require each country to officially publish specific data.

We have to define firstly the balance components and discussed each one of them and demonstrate the tier chosen to do the calculations (precision level). In this study, only the carbon stock available in biomass was considered in the accounting, as the major sources of carbon in the terrestrial ecosystem, that associates with a higher dynamic than the other pools (Watson, 2009). The accounting will be according to the atmospheric flux approach.

I. Forest Carbon Accounting Steps

In this paragraph, we will present the key steps to carbon balance accounting in the forest ecosystems (Figure 14), with respect to the IPCC recommendations (IPCC, 2006; Watson, 2009):

- land use delimitation (type of species and forest stands),
- biogeographic Realm delimitation (biomes): subdivide forest lands according to climates, soil types, vegetation types (i.e. strata) …etc.
- Available resources: take into consideration budget and time,
- Fixe the tier of the approach used in the accounting,
- Estimation of CO_2 emissions and absorptions: choose adequate equations, according to the approach used in forest carbon accounting,
- Uncertainties estimation.

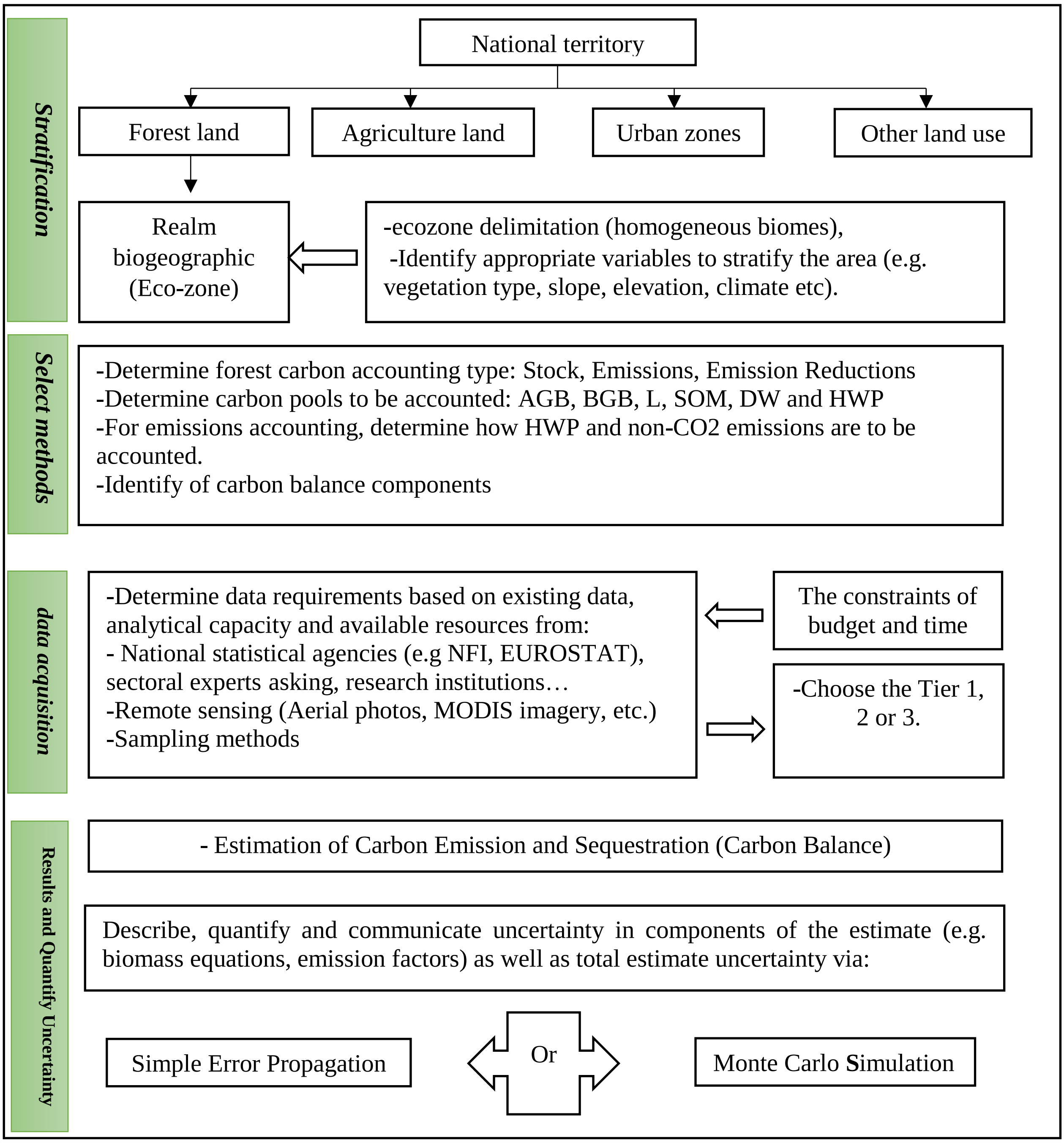


Figure 14:Carbon accounting steps in Forest Land

II. Carbon balance and its components:

The IPCC guidelines previously require the key categories, which represents the source and the sinks that they have a significant effect on the greenhouse gases emission. The only factor that we used in classification stage was the vegetation type, to choose the sources/sinks with significantly impact in the forest Carbon balance. According to NFI, the different components influencing the carbon sources/sinks are:

-**Annual Growth**: Carbon storage at trees level corresponding to net annual increment, due to the photosynthesis process. This storage is translated by an increase in AGB and

BGB, so it is necessary to have this sink in carbon balance. Annual Growth translates tree growth (in height, in diameter, in volume) during a given period (one year in this project).

-**Disturbances by fires, insects and diseases**, according to the statistics published by ICNF (Table 7 and figure 13), it is a very significant component in CO2 emission. We must estimate the superficies affected by these abiotic and biotic agents for each year and for each species.

-**Woods Removal in forests**: Portugal forests are characterized by the highest productivity of wood, a process that has a big influence on the ecosystem carbon cycle.

Consequently, we will estimate carbon balance in Portugal forest ecosystems using the gain-loss approach (atmospheric flow) established by IPCC guidelines, taking into account the net annual increment, the forests harvesting, and the disturbances by fires, insects and diseases (Equation 15).

III. Gain-Loss approach:

According to IPCC guidelines, the CO_2 emissions must be calculated for all land-use categories in AFOLU sector using the Equation 7, considering only the annual carbon stock changes in Forest land (ΔC_{FL}).

Equation 7:Annual carbon stock changes for the entire AFOLU sector estimated as the sum of changes in all land use categories

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Where:

- ΔC = Carbon stock change
- Indices denote the following land-use categories:
- AFOLU = Agriculture, Forestry and Other Land Use
- FL = Forest Land
- CL = Cropland
- GL = Grassland
- WL = Wetlands
- SL = Settlements
- OL = Other Land

We applied the IPCC equations and formulas to the different carbon pools. The carbon stock change in forest lands will be calculated by the following equation:

Equation 8:Carbon stock in Forest lands for each pool

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

Where:

- AB = above-ground biomass
- BB = below-ground biomass
- DW= deadwood
- LI = litter
- SO = soils
- HWP = harvested wood products

According to our budget, data availability, and depending on country circumstances and which tiers are chosen, stock changes are not estimated for all pools shown in the *Equation 8* (IPCC, 2006). In Figure 15, we have summarized the pools and the main processes of carbon fluxes, that we have integrated into the carbon balance level.

A carbon source is a carbon pool from which more carbon flows out than flows. The forest stands can often represent a net source (rather than sink) of carbon due to the processes of decay, combustion and respiration (Brown, 2005). Conversely carbon sink can be a carbon pool from which more carbon flows in than out. The forest stands can act as sink through the process of tree growth as result of photosynthetic sequestration (Brown, 2005), but they can switch between being a source and a sink of carbon over time (Noble et al, 2000).

Changes in the carbon pools are often estimated as the product of an area of land and an emission or removal factor that describes the rate of gain or loss in each carbon pool per unit of land area (IPCC, 2006).

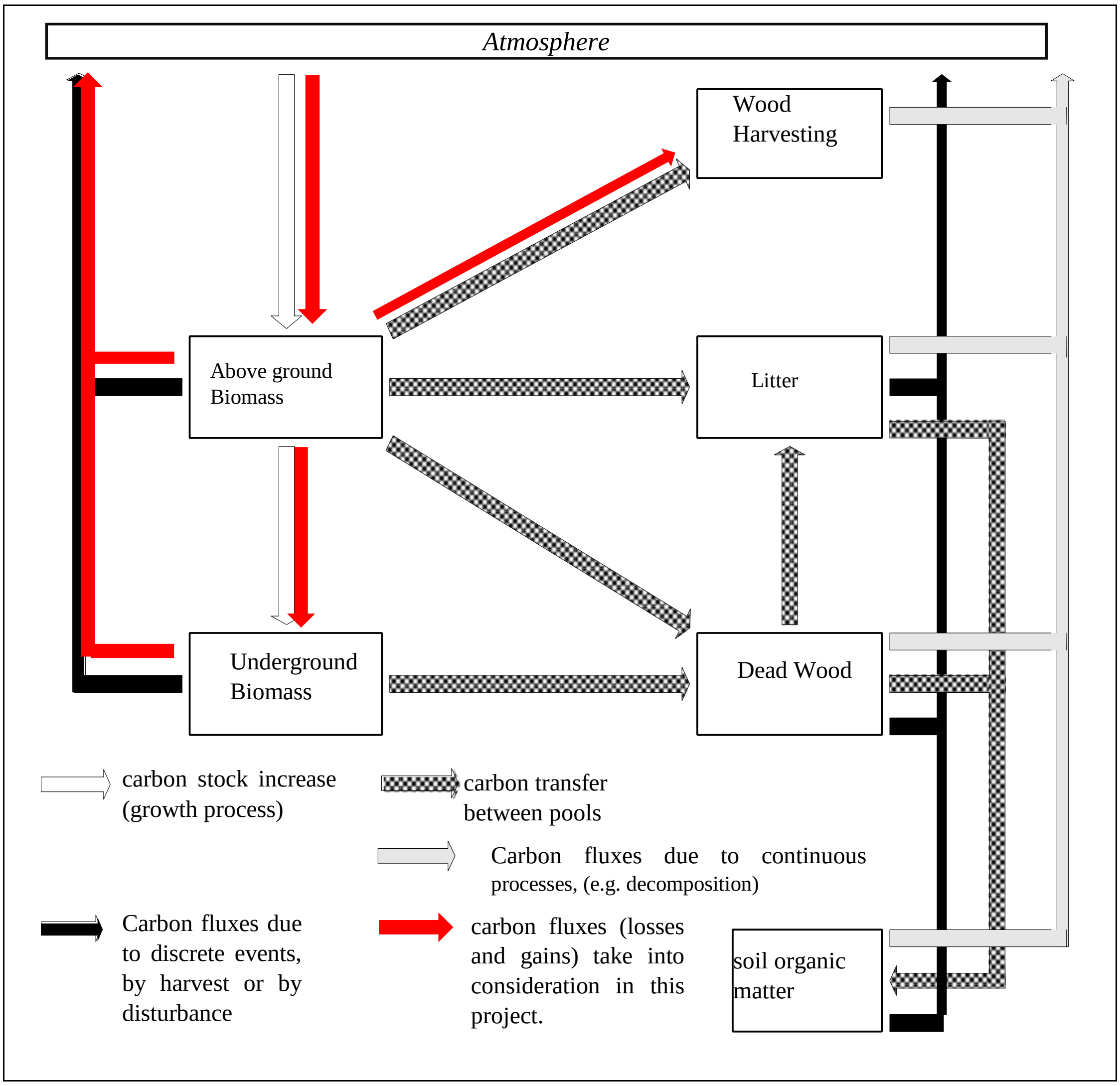


Figure 15:Generalized carbon cycle forest ecosystems showing the flows of carbon into and out of the system as well as the mains processes that we have to take in consideration in this study

Hypotheses:

- The ratios of below-ground to above-ground biomass can be used to estimate below-ground stock changes under Tier 2,
- at tier 1, the below-ground biomass C stocks are assumed to be zero and dead wood and litter pools are lumped together as dead organic matter (DOM). It is assumed that the average transfer rate into DOM is equal to the average transfer rate out of DOM, so that the net stock change is zero.
- Depending on the availability of data we may or may not neglect the carbon emission caused by continuous processes (ie, decomposition). It does not imply that this process is not important, but it is only negligible in front of the other processes (ie, combustion) in one year, which we have integrated into the carbon balance.

- The precision will be mixed between tier 1 and 2.

These hypotheses highlight that our study, it is only about the biomass of woody species and it is the most important pool evaluated in forest ecosystems, either at emission level (under disturbance), either at the level of carbon absorption (sequestration by photosynthesis).

Annual carbon stock changes in any pool can be estimated using the process-based approach in Equation 9 which sets out the Gain-Loss Method that can be applied to all carbon gains or losses. Gains can be attributed to growth (an increase of biomass) and to the transfer of carbon from another pool. Gains are always marked with a positive (+) sign. Losses can be attributed to transfers of carbon from one pool to another or emissions due to decay, harvest, burning, etc. Losses are always marked with a negative (-) sign (IPCC, 2006).

Equation 9:Annual carbon stock change in a given pool as a function of gains and losses

$$\Delta C = \Delta C_G + \Delta C_L$$

Where:

- ΔC = annual carbon stock change in the pool, tons C yr^{-1}
- ΔC_G = annual gain of carbon, tons C yr^{-1}
- ΔC_L = annual loss of carbon, tons C yr^{-1}

We calculate the variations of C stocks in biomass for forest land remaining in forest land category. We estimated annual gains and losses in biomass stocks by anthropogenic and natural disturbances.

IV. Equations used of each component

1. Annual Growth:

In this component, we are looking to estimate the annual increase in biomass carbon stocks ΔC_G. The Tier 1 method allows for any country to calculate the annual increase in biomass, using estimates of area and means annual biomass increment, for each land-use type and stratum (e.g., climatic zone, ecological zone, vegetation type). More we have a good stratification about eco-zones more we have good precision (IPCC, 2006).

Equation 10:Annual increase in biomass carbon stocks due to biomass increment in land remaining in the same land use category.

$$\Delta C_G = \sum_{i,j} (A_{i,j} * G_{Total_{i,j}} * CF_{i,j})$$

Where:

- ΔC_G = annual increase in biomass carbon stocks owing to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tC/yr
- A = area of land remaining in the same land-use category, ha
- G_{TOTAL}= mean annual biomass growth, tones d.m/ha/yr
- CF = carbon fraction of dry matter, tC (tone d.m)$^{-1}$
- i = ecological zone (i = 1 to n)
- j = climate domain (j = 1 to m)

We will assume that the climate in Portugal is temperate and the ecology zone will be divided according to the types of vegetation, the forest stands and its compositions.

G_{TOTAL} is the total biomass growth expanded from the AGB (G_w) and BGB. Following Tier 1 method, this quantity may be accounted directly by using default values of G_W assuming that the ratio (R) of BGB to AGB differentiated by woody vegetation type equal to zero. But in this work, we will use Tier 2 method, where the net annual increment (I_V) and biomass conversion and expansion factor ($BCEF_I$) were used to estimate mean annual biomass growth (G_{TOTAL}) for each vegetation type. We take into consideration the R ratio (Equation 11), using the default values published by IPCC.

We recommend using stock variation approach, if we have $BCEF_I$ specific to Portugal forest. If not, default values are offered by IPCC and we will use atmospheric flow approach. the equation 11 shows this relationship between these different parameters I_v, $BCEF_I$ and R (IPCC, 2006) under tier 2 or 3 methods.

Equation 11:Average annual increment in biomass

$\Delta C_{Total} = \sum G_W * (1 + R)$ (Tier 1)

Biomass increment data (dry matter) are used directly

$\Delta C_{Total} = \sum I_V * BCEF_I * (1 + R)$ (Tiers 2 or 3)

The Net annual increment data are used to estimate G_w by applying a biomass conversion and expansion factor.

Where:

- G_{TOTAL} = average annual biomass growth above and below-ground, tones d.m/ha/yr
- G_W = average annual above-ground biomass growth for a specific woody vegetation type, tones d.m/ha/yr.
- R = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tone d.m. below-ground biomass (tone d.m. above-ground biomass)$^{-1}$.
- I_V = average net annual increment for specific vegetation type, m^3/ha/yr.
- $BCEF_I$ = biomass conversion and expansion factor for conversion of net annual increment to ton d.m (m^3 net annual increment)$^{-1}$.

R must be set to zero if assuming no changes in below-ground biomass allocation patterns (Tier 1). But in this project, we cannot neglect it because we will use it in the second formula in equation 11 (default values of R and $BCEF_I$, are offering by IPCC, see annex 2 and annex 4).

To use the second formula in equation 11 (tiers 2 and 3). We will put some recommendations and steps to make easily the calculations:

- Determination of the forest species area (ha), hardwoods and coniferous, using data from the National Forest Inventory (NFI: 1995,2005, 2010) (Table 6),
- Use of annual average increment (I_v) (m^3/ha/an) per tree species, provided by NFI (annex **7)**,
- Use of standing volumes per tree species (m^3), provided by the NFI (*annex 8*). We used the stand volume (m^3/ha) available in FLORSTAT and AREASTAT databases for each species for 1995 and 2005, and we interpolate for 2010 using Iv,
- Calculation of unitary volume standing (S_v) for each species (m3/ha) dividing standing volumes for each specie by their surface. The result will be used to

choose the expansion factors $BCEF_I$ and R (root expansion) from the *annex 2* and *annex 4*.

2. Natural disturbances:

Natural disturbances affect Portugal forests in a very significant way with large interannual variability, related to the climatic factors. These perturbations cause enormous losses of biomass, which is directly affecting the carbon stock at the forest level. Therefore, we are looking to estimate the decrease in biomass and carbon due to disturbances. We will use two equations to calculate these carbon losses. The first equation (*equation 12*) is concerned the biomass losses due to insects and diseases, taking in consideration the disturbance fraction (f_d), defined as the rate of biomass losses under a specific disturbance, we assumed that $f_d = 0{,}2$. The second equation (equation 13) is used to estimate carbon losses due to fires. Under tier 1, $f_d = 1$, which means all biomass is totally disturbed (IPCC, 2006).

2.1 Decrease of Biomass and Carbon due to Insects and Diseases

A generic approach for estimating the amount of carbon lost from disturbances is provided in Equation 12 (IPCC, 2006).

Equation 12:Annual Carbon losses in biomass due to disturbances

$$L_{disturbance} = A_{disturbance} * B_W * (1 + R) * CF * fd$$

Where:

- $L_{disturbances}$ = annual other losses of carbon, tC/yr
- $A_{disturbance}$ = area affected by disturbances, ha/yr
- B_W = average above-ground biomass of land areas affected by disturbances (tons d.m/ha)
- R = ratio of below-ground biomass to above-ground biomass, in ton d.m. below-ground biomass
  (ton d.m. above-ground biomass$)^{-1}$ affected by disturbances (under Tier 1, R=0)
- CF = carbon fraction of dry matter, tC (tons d.m.)$^{-1}$ (annex 3)
- fd = fraction of biomass lost in the disturbance, we assumed that fd = 20%

2.2 Decrease of Biomass and Carbon due to Fires

For the Decrease of Biomass and Carbon due to Fires we will use the *equation 13*, which also allows us to calculate other indirect greenhouse gases emissions due to the biomass combustion. The choice of the tier can be made following the steps in the

Decision Tree presented in *annex 11*. Under the Tier 1 approach, the formulation presented in *Equation 13* can be applied to estimate CO_2 and non-CO_2 emissions from fire, using the IPCC default data (provided in the annexes 6 and 5) (IPCC, 2006). We aggregate data on biomass burning area according to vegetation types. Equation 13 could also be applied in tier 2 and 3 methods, if there was adequate data available.

Equation 13:Estimation of GHGs emissions from fires

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3}$$

Where:

- Lfire = amount of greenhouse gas emissions from fire, tons of each GHG e.g., CO_2, CH4, N2O, etc.
- A = area burnt, ha;
- MB = mass of fuel available for combustion, tons d.m/ha.
- Cf = combustion factor, dimensionless (default values in *annex 6*)
- Gef = emission factor, g kg^{-1} dry matter burnt (default values in *annex 5*)

M_B includes biomass, ground litter and dead wood. When Tier 1 methods are used then litter and dead wood pools are assumed zero, except where there is a land-use change. and at first, it was assumed that we will stay in the same land-use categories (forest remain forest). The M_B was calculated using this formula, $M_B = fd$*stand volume* BCEFi.

The amount of biomass (M_B) that can be burnt is given by the area burnt and the density of fuel present in that area, taking into account fd. The fuel density can include biomass, dead wood and litter, which vary as a function of the type, age and condition of the vegetation (L. et al., 2009). The fuel available for low-intensity ground fires in forests will be largely restricted to litter rand dead organic matter on the surface, while a higher-intensity ‘crown fire’ can also consume substantial amounts of tree biomass (IPCC, 2006), fd coefficient reflect fires behaviors and intensity (DALE et al., 2001), we assumed the fd of fires equal to 1 under the tier 1 method.

The combustion factor C_f is a measure of the fuel proportion that is actually combusted. It varies as a function of size, shape and moisture rate in the fuel, and the fire type (i.e., intensity, duration and rate of spread) (IPCC,2006). Cf is not fd, the biomass can be total disturbed but not all combusted.

The emission factor G_{ef} gives the amount of a particular greenhouse gas emitted per unit of dry matter combusted. NOx and N_2O emissions from the fires can vary as a function of the N content of the fuel for the different species (Lobert et al., 1990). A comprehensive review of emission factors was conducted by Andreae and Merlet (2001) and it is summarized in *annex 5* (IPCC, 2006).

3. Logging

The wood extraction (logging) present a significant loss of carbon, and it is an important component in FCA. The different woods exploited are: industry wood, lumber wood and firewood. According to IPCC guidelines, the extraction can be on two levels. Firstly, the extraction of living trees used as industry wood or lumber (e.g timber, pulp), which will lead to a reduction of carbon in the biomass and it should be considered as a loss of carbon. Secondly, a collection of dead wood (usually used as firewood), which causes a decrease in the dead organic matter carbon pool. Good practice indicates a separate estimate of these two elements. We have the data which is published by EUROSTAT database, organized in three categories of wood harvested (*Table 8*). For Biomass carbon losses estimation in each category of wood harvested from broadleaves and coniferous forest, we will use the *equation14* (IPCC, 2006).

Equation 14:Annual varbon loss in biomass of wood removals

$$L_{wood-removals} = H * BCFF_R * (1+R) * CF$$

Where:

- $L_{wood-removals}$ = annual carbon loss due to biomass removals, tC/yr
- H = annual wood removals, $m^3\ yr^{-1}$
- R = ratio of below-ground biomass to above-ground biomass, in ton d.m. below-ground biomass (ton d.m. above-ground biomass)$^{-1}$. R assuming equal to zero (Tier 1, no changes of below-ground biomass allocation patterns, the Roots stay in the under the ground).
- CF = carbon fraction of dry matter, ton C (ton d.m.)$^{-1}$ (*annex 3*)
- $BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), tons biomass removal (m^3 of removals)$^{-1}$, (*annex 2*).

To choose $BCEF_R$ from IPCC tables (annex 2), we have to previously calculate the unitary standing volume average for all coniferous and for all broadleaves separated (*annex 8*).

4. Carbon Balance:

Finally, carbon balance will be calculated by the Equation 15, which reflects the atmospheric flow approach:

Equation 15: General equation used to account the carbon balance

$$\mathbf{Balance_{CO2} = \Delta C_G - L_{fire} - L_{insects} - L_{diseases} - L_{wood\ removals}}$$

$$\mathbf{Balance_{carbon} = \left(\frac{12}{44}\right) * Balance_{\ CO2}}$$

where:

- ΔC_G = annual increase in biomass carbon stocks due to biomass growth
- L_{fire} =disturbance by fires
- L_{insect} =disturbance by insects
- $L_{disease}$ =disturbance by disease
- $L_{wood\text{-}removals}$ =wood Harvesting

N. B: to make all calculations consistent, all estimates in carbon stocks must be in carbon units, based on the ratio of molecular weights (44/12) in the conversion of C to CO_2.

5. Uncertainties Evaluation: Standard Error Propagation

To comply with the IPCC recommendations for the National GHG Inventory, GHG inventories must be neither overestimated nor underestimated as much as can, reducing uncertainties as much as possible (Rehg & Staley, 2017). According to the IPCC Good Practice Guidance it is mandatory to manage the uncertainties for the inventories of GHGs. There are two approaches to evaluate these uncertainties called the Tier 1 method and the Tier 2 method. Both methods assume that the data evaluated should respect a format in which an activity is multiplied by a transmission factor. The two methods differ only in the way in which the total uncertainty is calculated from the estimated uncertainties of the activity data and emission factors (IPCC, 2006).

The Tier 1 method is an analytical solution applying standard error propagation (SEP) equations. The data that does not meet the presumptions required under this level can be analyzed using the Tier 2 method, which calculates a numerical estimate of the propagation of uncertainty using Monte-Carlo simulation (IPCC, 2006).

We will use the SEP, just for the carbon sequestration in 1995 and 2005 because we don’t dispose the errors for the other components, providing a global indication of the quality of these estimations. Two equation are proposed by IPCC guidelines (IPCC, 2006) to estimate the uncertainties:

Equation 16: Combining Uncertainties – Approach 1 – Multiplication

$$U_{total} = \sqrt{(U_1^2 + U_2^2 + \cdots U_n^2)}$$

Where:

- U_{total} = the percentage uncertainty in the product of the quantities
- Ui = the percentage uncertainties associated with each of the quantities.

Equation 17:Combining Uncertainties – Approach 1 – Addition and Subtraction

$$U_{Total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 + \cdots (U_n * x_n)^2}}{|x_1 + x_2 \ldots + x_n|}$$

Where:

- U_{total} = the percentage uncertainty in the sum of the quantities
- x_i et U_i = Uncertain quantities and their respective percentages of uncertainty

6. Data Sources for each Component:

The following table shows the sources of data used in the annual carbon balance accounting (Table 9). The used methods are mixed between tier 1 and 2. The use of Tier 3 method (Stock-Difference) requires other more specific data about Portugal country, the Portuguese research on forests could bring other studies about these coefficients which are more specific to the country (e.g. R, CF, BCEF, fd , Iv/climatic zones…etc) to have a better precision.

Table 9: Data Sources and The Different Tiers Used for Each Component

Component	Variables	Symbol	Unit	Data	Sources	Tier
Annual growth	Area of species occupation	A	ha	Table 6	NFI	2
	Average of net annual increment	Iv	m^3/ha/yr	annex 7	NFI	
	Carbon fraction	CF	tone C (tone d.m.)$^{-1}$	annex 3	IPCC	
	Biomass conversion and expansion factor	$BCEF_I$	t.d.m/m^3	annex 2	IPCC	
	The ratio of below-ground biomass to above-ground biomass	R	%	annex 4	IPCC	
	Standing volume	V	m^3/ha	annex 8	NFI	
Losses by insect and diseases	Area affected by disturbances	$A_{disturbance}$	Ha/yr	Table 7	ICNF	1
	Fraction of biomass lost in disturbance	fd	%	proposed equal to 20%	-----	
	Average above-ground biomass of land areas affected by disturbances	Bw	tons d.m. ha^{-1}	-----	-----	
Losses by fires	Area burnt	A	ha	*annex 9*	ICNF	1
	Mass of fuel available for combustion	MB	tons d.m/ha	___	NFI	
	Combustion factor	C_f	dimensionless	*annex 6*	IPCC	
	Emission factor	Gef	g kg^{-1} dry matter burnt	*annex 5*	IPCC	
	Biomass conversion and expansion factor	$BCEF_I$	t.d.m/m^3	*annex 2*	IPCC	
Logging	Annual wood removals	H	m^3/yr	*Table 8*	EUROSTAT	1
	Biomass conversion and expansion factor	$BCEF_R$	t.d.m/m^3	*annex 2*	IPCC	
	Carbon fraction of dry matter	CF	ton C (ton d.m.)$^{-1}$	*annex 3*	IPCC	
Uncertainties (1995 and 2005)	Area of species occupation	A	%	*annex 10*	NFI	1
	$BCEF_I$	B		*annex 2*	IPCC	
	Carbon fraction	CF		*annex 3*	IPCC	
	Average of net annual increment	Iv		*annex 7*	NFI	
	Ratio of below-ground biomass to above-ground biomass	R		*annex 4*	IPCC	

National forest inventory data are organized in two databases, FlORSTAT (http://www.icnf.pt/portal/florestas/ifn/resource/ficheiros/ifn/IFN-2010.rar) and AREASTAT (http://www.icnf.pt/portal/florestas/ifn/resource/ficheiros/ifn/areastat.zip) available in the ICNF website.

Chapter III: Mapping of Carbon Stock and its Balance:

Net primary production (NPP) represents the amount of atmospheric carbon, that is fixed by vegetation during photosynthesis period and accumulated as biomass. In chapter 2 of methodology we have detailed all the equations used to calculate the carbon balance, photosynthetic sequestration and carbon losses, it is the Net Biome Production (NBP). Another effective approach to the carbon dynamics assessment is the use of remote sensing data, like MODIS products, combined with ecological data. As seen in the review part, there are several approaches using to map the carbon dynamic. In this chapter we will present two useful approaches to achieve this purpose, “Combine and Assign” (CA) and Direct Remote Sensing (DRS) (S. J. Goetz et al., 2009). We will compare the photosynthetic sequestration calculated by IPCC and the NPP derived from MOD17A3 in 2010. Biophysical factors as elevation, temperature and precipitation, will be integrated with NPP results (MOD17A3 algorithms), to highlight possible geospatial correlations.

I-Combine & Assign (CA) Approach

The Combine & Assign (CA) approach is an extension of the simple approach which is based only on a single information layer (vegetation cover types), directly linked to its carbon sequestration values. CA approach can integrate other information layers, such as carbon balance components and the information related to the ecozone classification, in order to give more detailed information about the potential growth of vegetation.

For eucalyptus and pine, we have data of average net annual increment (I_v) and unitary stand volume (S_v) per PROF for 2005. The values for 2010 were calculated using I_v and the updated land use mapping. For the remaining species we have only the national mean values (see Table 10). And using the same IPCC equations developed in chapter 2 of methodology part, yearly unitary carbon sequestration per species was accounted for each PROF region (homogenous ecozones). Carbon mapping using CA approach will only be used for pure forest stands.

Table 10:Average net annual increment (I_v) (, m^3/ha/yr) and unitary stand volume (S_v) (m^3/ha) in PORFs regions per specific vegetation type (NFI, 2005):

PROFs	Pinus pinaster		Pinus pinea		other Softwoods		Eucalyptus		Oak cork		Quercus ilex		other Oak		chestnut		Ceratonia siliqua		Acacias		other Hardwood	
	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v	I_v	S_v
Alto Minho	3,5	90,4					5,9	55,4														
Baixo Minho	4,2	102,3					3,5	73,5														
Barroso e Padrela	3,8	76,8					5,9	55,4														
Nordeste Transmontano	2,3	45,4					5,9	55,4														
Área Metropolitana do Porto e Entre Douro e Vouga	4,2	88,0					4,6	55,4														
Tâmega	4,8	77,4					5,9	55,4														
PROF do Douro	5,8	91,5					5,9	55,4														
Dão e Lafões	7,9	154,7					7,7	79,2														
Beira Interior Norte	4,5	54,2					5,9	55,4														
Beira Interior SUL	3,6	57,3	4,2	37,1	3,9	80,9	4,6	55,4	0,8	34,0	0,4	11,0	1,3	16	1,4	22	1,0	32	2,1	34	3,0	23
Pinhal Interior Norte	5,5	107,0					5,8	45,8														
Centro Litoral	3,5	135,1					7,2	74,4														
Oeste	5,2	168,5					10,6	95,7														
Área Metropolitana de Lisboa	4,2	94,1					5,9	55,4														
Ribatejo	3,9	78,2					4,9	42,7														
Alto Alentejo	4,2	94,1					2,9	22,6														
Alentejo Central	4,2	94,1					4,2	39,8														
Alentejo Litoral	2,3	58,4					4,0	32,7														
Baixo Alentejo	4,2	94,1					5,9	55,4														
Algarve	4,2	34,0					5,2	40,10														

The different stages used to complete this approach successfully are summarized in the next diagram (Figure 16). Firstly, we download the PROF regions and the extent of the BA (shapefiles) in 2010, from the ICNF website (http://www.icnf.pt/). We gathered all the PROFs region in a single information layer. Secondly, we calculate the yearly unitary carbon sequestration using atmospheric flow approach and the forest data (table 10). Finally, unitary carbon sequestration per species was associated with the vegetation cover (geodatabase), allowing the mapping of carbon sequestration. For the BA we assume zero carbon sequestration ($f_d = 1$).

Map overlay (carbon losses by fires and yearly carbon sequestration) provides the annual carbon balance mapping. We used the "WGS 1984 UTM Zone 29" in geoprocessing. Eventual topology errors correction will depend to the geoprocessing scale of the CA approach.

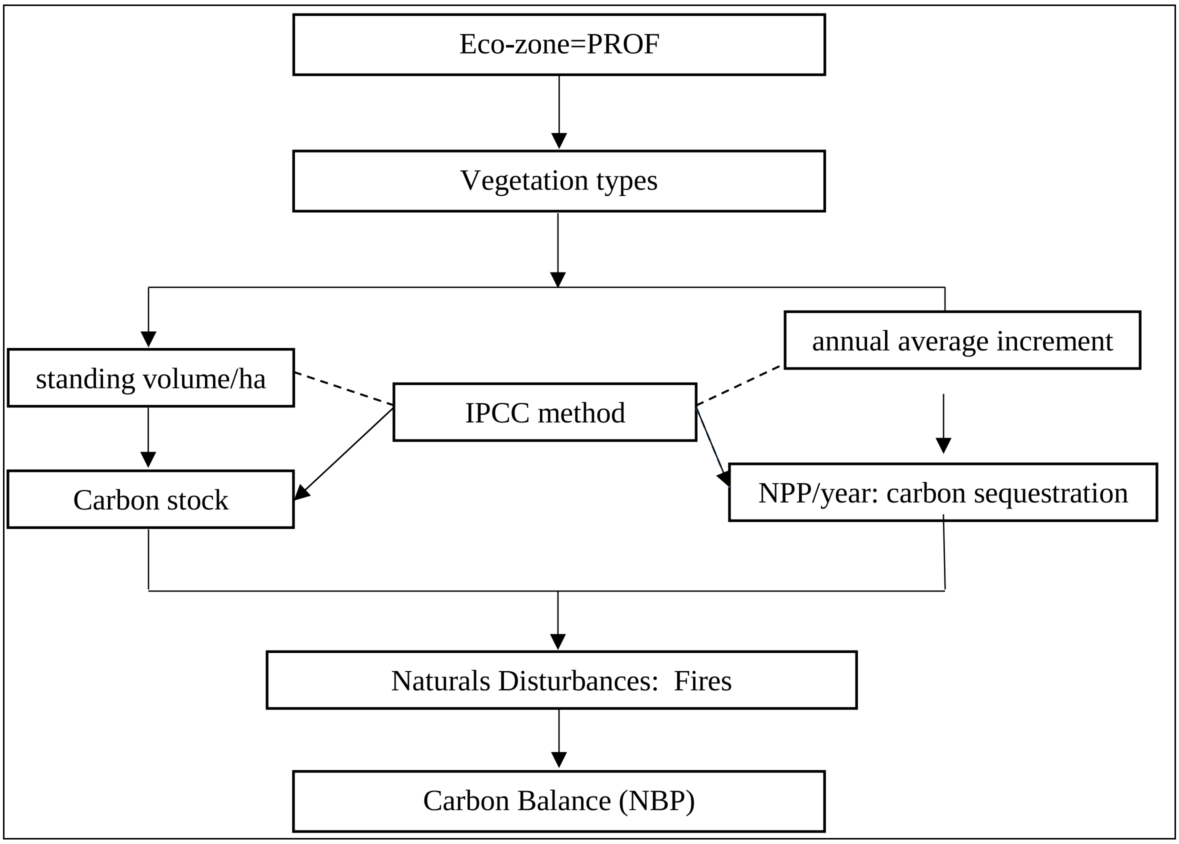


Figure 16:Methodolgy of Combine & Assign (CA) Approach

II- Direct Remote Sensing (DRS) Approach:

DRS approach is performed using the MODIS imagery. NPP was derived from the MOD17 algorithm using FPAR, LAI , land cover, climate data and BPLUT to calculate global NPP data every 8 days (Running & Zhao, 2015).

Two tiles will be used in this study: H17V04 and H17V05 (Figure 17). For each tile we download the MOD17A3 and MOD17A2 products, from "Earth Data" website (https://search.earthdata.nasa.gov/search).

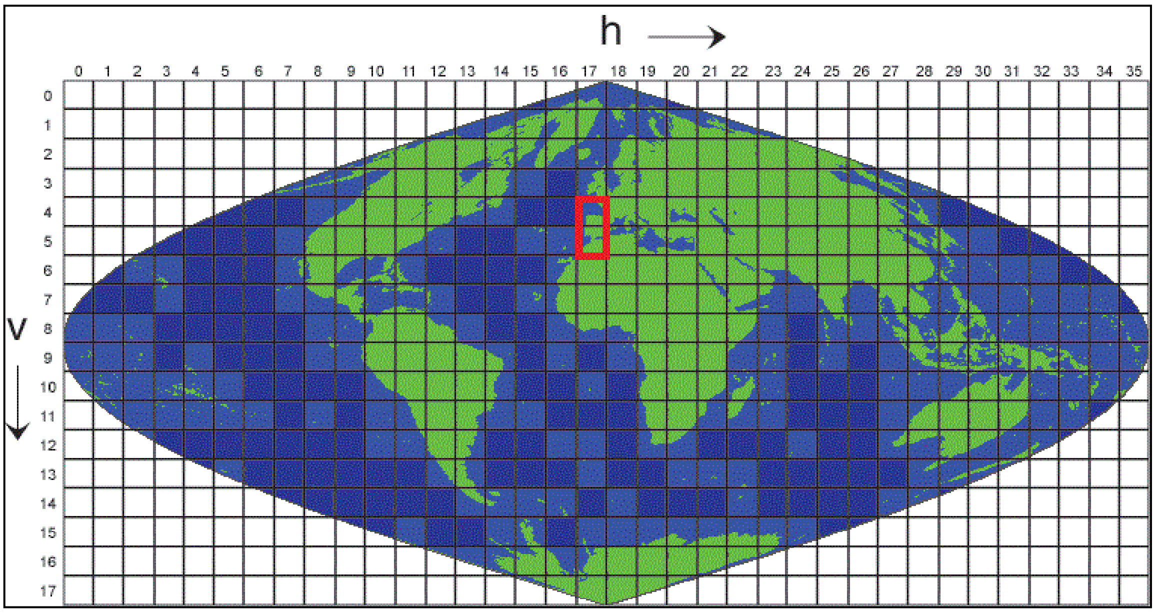


Figure 17: MODIS sinusoidal grid scheme

-Annual NPP mapping in 2010 and 2017:

In the direct approach (DRS) we used two different MODIS products. The first one was the MOD17A3, atmospherically and geometrically corrected by NTSG group for the year 2010. The second one, MOD17A2 product, allows the elaboration of seasonal NPP and yearly NPP in 2017 using the equation resumed in the Table 12. Since the MOD17A2 product is not corrected atmospherically, all contaminated pixels should be excluded, underestimating the results.

During the processing, we create a Boolean matrix (0,1), and we multiply it by MODIS images, to isolate all the not null values of NPP. All the null values represent different classes without vegetation (Table 11).

Table 11: The others pixels classes that we were multiplied by zero in the Boolean matrix

Value	Description
65535	Fill value: conventional HDF-EOS fill value assigned to non-modeled pixels not falling into other categories below
65534	Perennial salt or inland fresh water body cover type
65533	Barren, sparsely vegetated (rock, tundra, desert) cover type
65532	Perennial snow or ice cover type
65531	Permanent wetlands/inundated marshland type
65530	Urban/built-up cover type
65529	Unclassified pixel

Table 12:Fundamental equations used to calculate the yearly NPP in 2017

Sessions	Equations
	$NPP(w1) = \sum_{i=1}^{i=57} PsnNet - (R_{mo} + R_g)$
	$NPP(w2) = \sum_{i=337}^{i=365} PsnNet - (R_{mo} + R_g)$
Winter	$NPP(w) = NPP(w1) + NPP(w2)$
Spring	$NPP(sp) = \sum_{i=65}^{i=153} PsnNet - (R_{mo} + R_g)$
Summer	$NPP(Su) = \sum_{i=161}^{i=241} PsnNet - (R_{mo} + R_g)$
Autumn	$NPP(a) = \sum_{i=249}^{i=329} PsnNet - (R_{mo} + R_g)$
Year 2017	$NPP(2017) = NPP(w) + NPP(sp) + NPP(Su) + NPP(a)$

II -MODIS and IPCC Comparison:

The comparison between the NPP values derived from product MOD17A3 and the values obtained by the IPCC method (based on field-measured data), was done by simple random sampling, taking 1000 points inside of the pure forests of *Eucalyptus* and *Pinus pinaster* using "create random points" tool in ArcGIS® (map 5). After extraction of the values for each variable (paired samples), we test the data normality, and the variance equality. According to the result of these two tests we will choose an adequate statistical test to make the comparison of both method results (Figure 18).

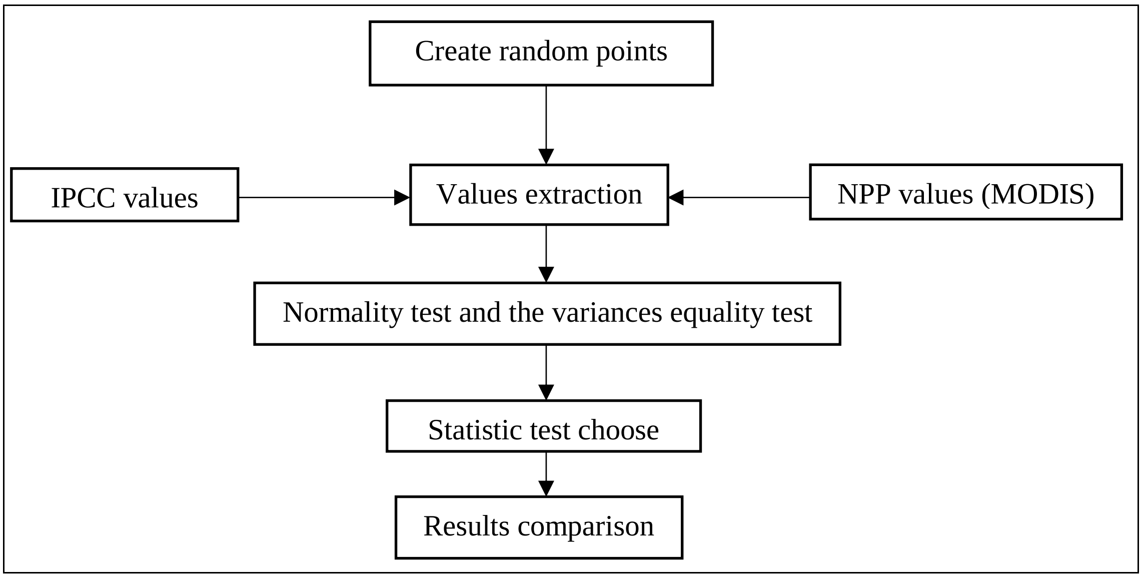
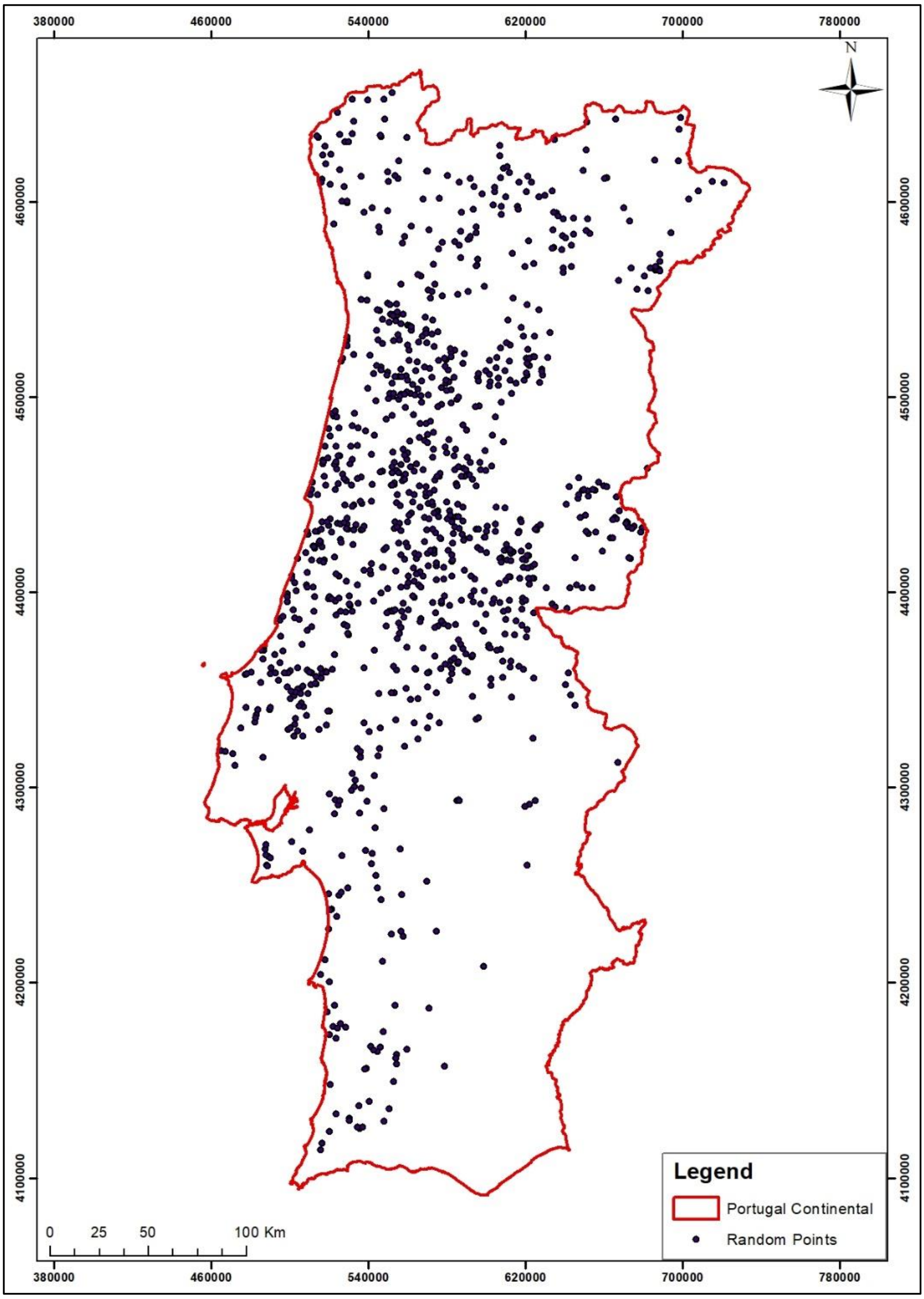


Figure 18:Methodology used to compare IPCC and MODIS

We will confront the results obtained with the MODIS images with those of the IPCC methodology. As indirect alternative methods we can only find out if they agree with each other, but in a non-discriminatory way. That is to say, we cannot assume that one method is better than another, we can only confirm if the results are similar.



Map 5:Random points used to compare IPCC and MODIS

III. Annual NPP variability with biophysics factors:

We download climatic data (precipitation and temperature) from the Portuguese Institute of the Sea and Atmosphere (IPMA: https://www.ipma.pt/en/oipma/) and the National Hydraulic Resources Information System agency (SNIRH: https://snirh.apambiente.pt/). To verify the Annual NPP variability with biophysics factors, we used a digital elevation model (DEM) (annex 21) (Gonçalves and Fernandes, 2005; Gonçalves and Morgado, 2008). We interpolated climatic data using several geostatistical tools in ArcGIS software.

a) For precipitation:

We used a local regression to link the precipitation with 4 main factors (annex 22):

- Longitude effect (α): the more we go to the north, the more we have precipitation where tan (α)=y/x (Figure 19),
- The distance to the interior of the country (d): when we go towards the interior, the precipitation decreases (Figure 19), Where: d =$\sqrt{x^2+y^2}$
- Elevation (E)
- the coefficient Ci (Ci=precipitation / average) was used as climate index that presents the variability of annual precipitation in 2017, compared to an average that was measured for 21 years.

A multiple regression model P(mm) = f (α, d, E, Ci), was implemented and processed by SPSS software to interpolate precipitation data. We realized a local interpolation by regression (Figure 20), as suggested by (Wu, Hao Xu, 2013).

N.B: To find the relationship between, α, d, latitude (x) and longitudes (y), the geoprocessing has to be in a local reference the “Lisboa Hayford Gauss GeoE” coordinate system.

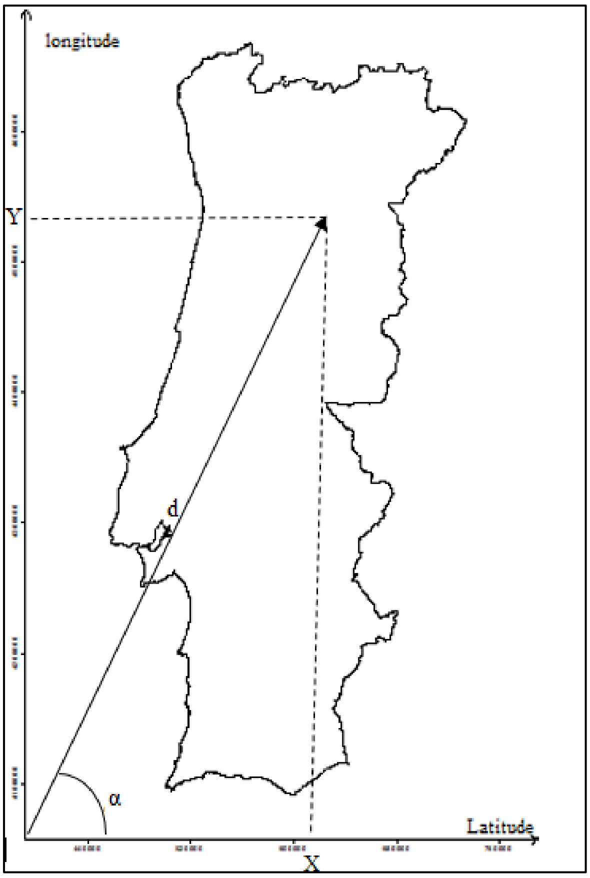


Figure 19: Relationship between, Longitude, Latitude, α and the distance to the interior of the country.

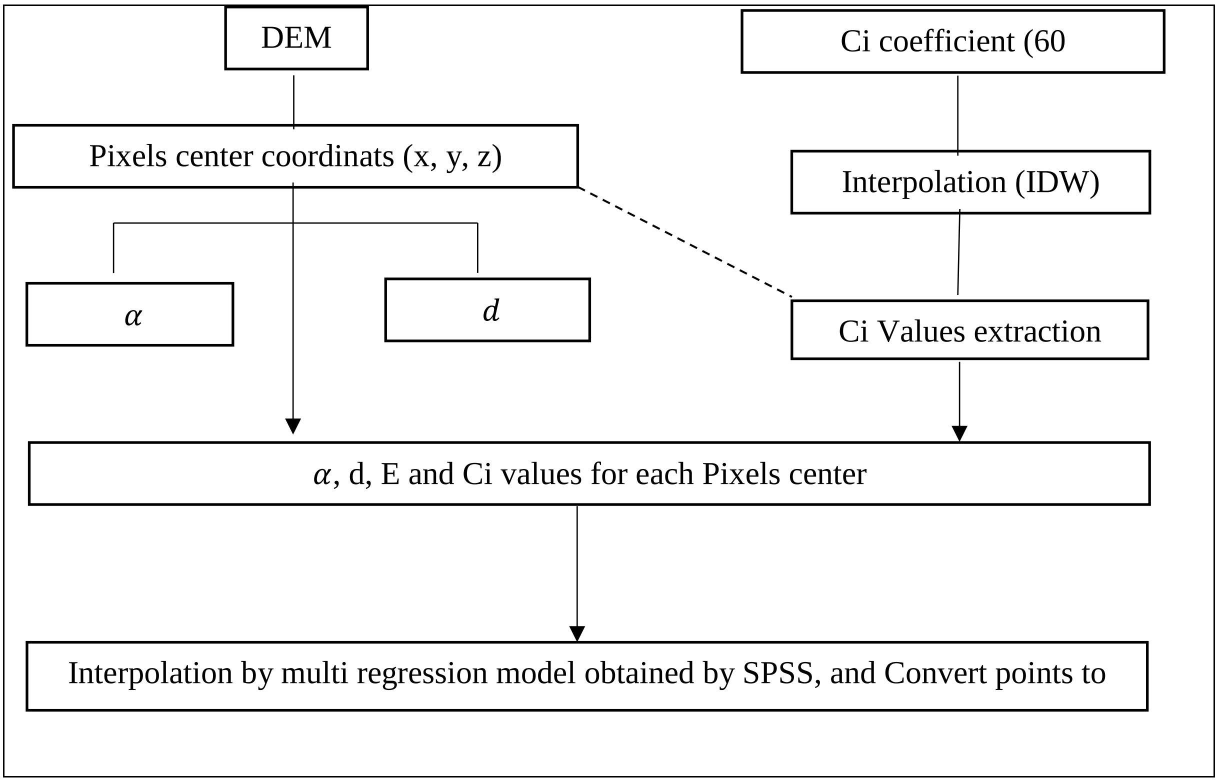


Figure 20:Steps used to interpolate precipitation data

b) For temperature:

We used an empiric simple kriging method to interpolate the temperature data for all the country. This method of interpolation is empirical. The best results should be those that produce the lowest values of relative mean error (MRE) and mean absolute error (MAE) (Wu, Hao Xu, 2013). We also test the inverse distance weight (IDW) interpolation method, which presented worse results in the interpolation (data redundancy) with higher MRE and MAE. The kriging method requires spatial dependence of the variables. To evaluate the spatial autocorrelation and forecast the unknown values, it is necessary to adjust the model according to the points, forming an empirical semivariogram. In addition, the interpolation process must meet the following criteria:

- The Root mean square of the difference between the predicted and the measured values (residuals) should be closer as much as possible to 1.
- The average of the residuals must be equal to 0.
- The mean standardized difference of the residuals should be equal to 0.

Minimum temperature average (Tn) presents the mean of minimum temperatures obtained for each month. maximum temperature average (Tx) presents the mean of maximum temperatures obtained for each month. The Tx and Tn data are in the annex 23.

Therefore, we made a simple random sampling (1000 points inside of all Portugal forest, see annex 25), we extracted for each pixel the: Tn (°C), Tx (°C), total Precipitation (mm), Elevation (m) and the NPP values (tC/ha). A multivariate analysis was applied to analysis these data using SPSS software.

PART III: RESULTS AND DISCUSSION

I. Carbon Accounting Results:

1.Carbon Sequestration and Carbon stock:

1.1 Annual Carbon Sequestration:

The results obtain by IPCC methodology in this project show that the yearly C sequestration is depending on species, and it is varied from one year to another. Figure 21 reflects the total of C sequestration in the continental Portugal forest for each species expressed in MtC/yr, and their changes rate between 1995 and 2010 (evolution rate), it is expressed in percentage for each species. The study finding shows that all species had a negative evolution rate except *Pinus pinea* (46%), *Eucalyptus spp* (13%), *Ceratonia siliqua* (98%) and *Castanea sativa* (27%) (Figure 21).

At the national Forest ecosystems level, *Eucalyptus* sp and *Pinus pinaster* present a very important position in air purification. Indeed, in 1995 Eucalyptus contributes 37% to C sequestration (2.10 MtC), 44% in 2005 (2.30 MtC), and 47% in 2010, which is more than the total contribution of coniferous. The contribution rate of *Pinus pinaster* in 1995 was 22% (1.26 MtC), in 2005 it was 20% (1.02 MtC) and in 2010 it become 18% (0.93 MtC). The other species contribution average in C sequestration is 37% in 2010, which is distributed between: *other Broadleaves* (12.3%), *Quercus suber* (9.0%), *other Oaks* (6.9%), *Pinus pinea* (3.7%), *Quercus ilex* (3.5%), *Castanea sativa (*0.8%), *other Coniferous* (0.7%), *Acacias (*0.43%) and *Ceratonia siliqua* (0.05%) (Figure 21and *Figure 22*).

Generally, during the period 1995 to 2010, the contribution rate in C sequestration is augmented for some species, and decreased for others or relatively stable (for more details see annex 12):

- The *Eucalyptus* spp contribution in C sequestration has been increased and the contribution of *Pinus pinaster* has decreased considerably,
- The oaks showing a significant decreasing in their contributions,
- The contributions of *Pinus pinea* and *Ceratonia siliqua* were also increased,
- The other species had relatively stable contributions.

The Portugal forests are an important carbon sink, contributing significantly to the mitigation of climate change, by the regulation of CO2 emissions:

- In 1995: The total of C sequestrated is 20.7 $MtCO_2$ in which the *Broadleaves* and *Coniferous* had absorbed successively 15.3 $MtCO_2$ and 5.4 $MtCO_2$.
- In 2005: The total carbon sequestrated is 19.1 $MtCO_2$ in which *Broadleaves* present 14.3 $MtCO_2$ and *Coniferous* present 4.7 $MtCO_2$.
- In 2010: The total carbon sequestrated is 18.9 $MtCO_2$ where 14.6 $MtCO_2$ had sequestrated by *Broadleaves* and 4.3 $MtCO_2$ by *coniferous*.

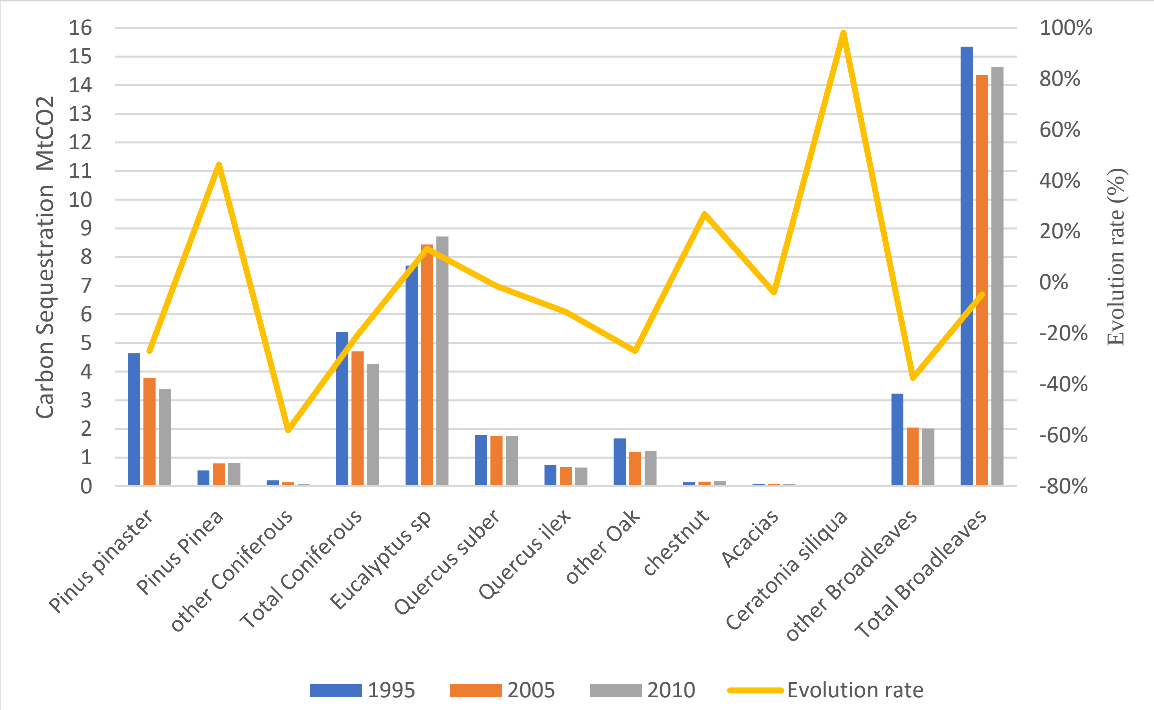


Figure 21:Total carbon sequestration (MtCO2.year-1) per species and its evolution rate (%) (IPCC)

In order to compare the contribution of species to C sequestration, we have to calculate the yearly unitary carbon sequestration per species (*Figure 23*). All *coniferous* showing almost the same carbon sequestration potentiality, it is between 1.2 tC/ha/yr and 1.4 tC/ha/yr. The *Broadleaves* show a large variability of yearly unitary carbon sequestration from one species to another. Indeed, *Eucalyptus* spp., *Acacias* and categories of *Other oaks* and *other hardwood* stands have a unitary carbon sequestration superior of 2 tC/ha/yr. While, the other *Broadleaves* species (*Quercus suber*, *Quercus ilex*, *Castanea sativa* and *Ceratonia siliqua*) shown a unitary sequestration inferior or equal to 1 tC/ha/yr.

The average of unitary carbon sequestration for all forest is 1.89 tC/ha/yr, much higher than the average of the Mediterranean region, where the carbon sequestration by forests range between 0.01 and 1.08 tC/ha/yr (Croitoru, L., Merlo, 2005).

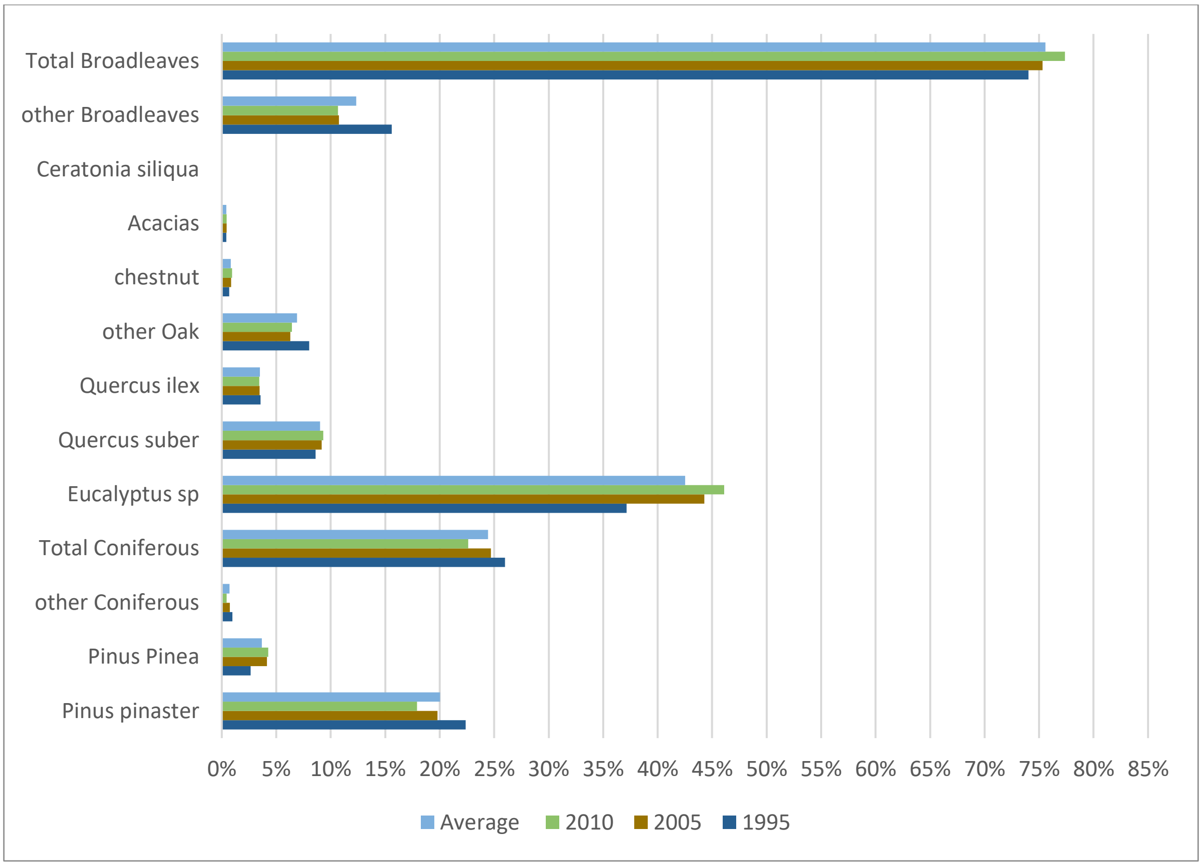


Figure 22:The contribution rate (%) for each species in C sequestration at National Forests level (IPCC)

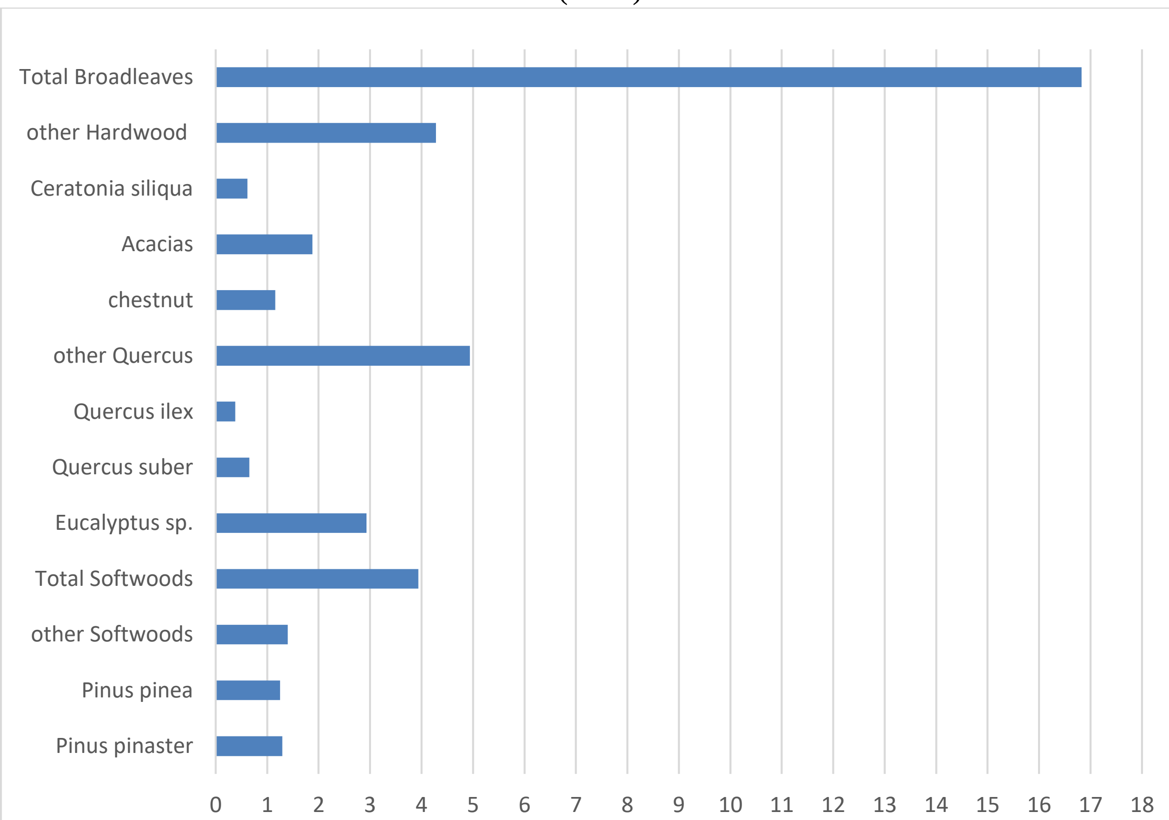


Figure 23:Yearly unitary carbon sequestration per specie (tC/ha/yr) (IPCC)

Another study using FOREST-BGC model had shown that *Eucalyptus globulus* and *Pinus pinaster* ecosystems in the North region of Portugal produce successively 4.021 tC/ha/yr and 3.899 tC/ha/yr as the mean absolute deviation (Lopes, D and Manuel, 2005).

Sánchez-Costa, Poyatos and Sabaté in 2015, find that above NPP (ANPP) of *Quercus ilex* in Mediterranean forests is 0.25±0.026 tC/ha/yr, while, in Portugal *Quercus ilex* stands we obtain *0.2* tC/ha/yr in ANPP, and 0.38 tC/ha/yr for the total NPP (AGB and BGB). On the other hand, *Quercus suber* in Portugal context sequestrate approximatively 0.68 tC/ha/yr, relatively low comparing to other Mediterranean countries 1.4 tC/ha/yr (N, C, S, James, & G, 2011). This difference can be explained by the fact that the majority of current stands in Portugal are adult, characterized by low density, 85% of the stands have less than 120 trees / ha, and the average density of stands in the country is 65 trees/ha (Palma, Paulo, & Tomé, 2014). Oaks are a very important species in Portugal for two main reasons. Firstly, because in the majority of its occupancy, they are used as agroforestry species. Secondly, by their productions, specifically cork extracted (Palma et al., 2014).

Castanea sativa stands demonstrated also a significant sequestration. Patrício et al. (2009) found an ANPP average of 0.46 tC / ha / year for *Castanea sativa* in three regions of Portugal (Marao, Padrela and Bornes). While, the national mean value of biomass sequestered and stocked (AGB and BGB) for this species is 1.1 tC / ha / year.

With its high evolution rate (98%), *Ceratonia siliqua* assimilates approximately 0.62 tC/ha/yr as national average. It is a value relatively higher than the value measured by GERALDO in 2011 for a stand in middle-aged (30 years old) in Algarve region (0.253 tC/ha/yr).

The total of carbon sequestrated from the atmosphere by forest stands is decreased from 5.6 MtC in 1995 to 5.1 MtC in 2010 (Figure 24). The carbon sequestration capacity of the Portugal forests had decreased by 9% during this period. This reduction is due to several factors, principally by forest deforestation, where, the forest losses (17,9%) were more than forest gains (13,9%) (ICNF, 2013). In spite of this reduction of yearly carbon sequestrated, Portugal forests remain one of the best forests from the point of view of climate change mitigation by dint of its potentiality of C sequestration (1.89 tC/ha/yr). This good potentiality is due to the fact that most of Portugal's forests belong to Atlantic arc forests, which are characterized by their higher productivity due to favorable climatic conditions and a wide variety of substrates (FAO, 2003).

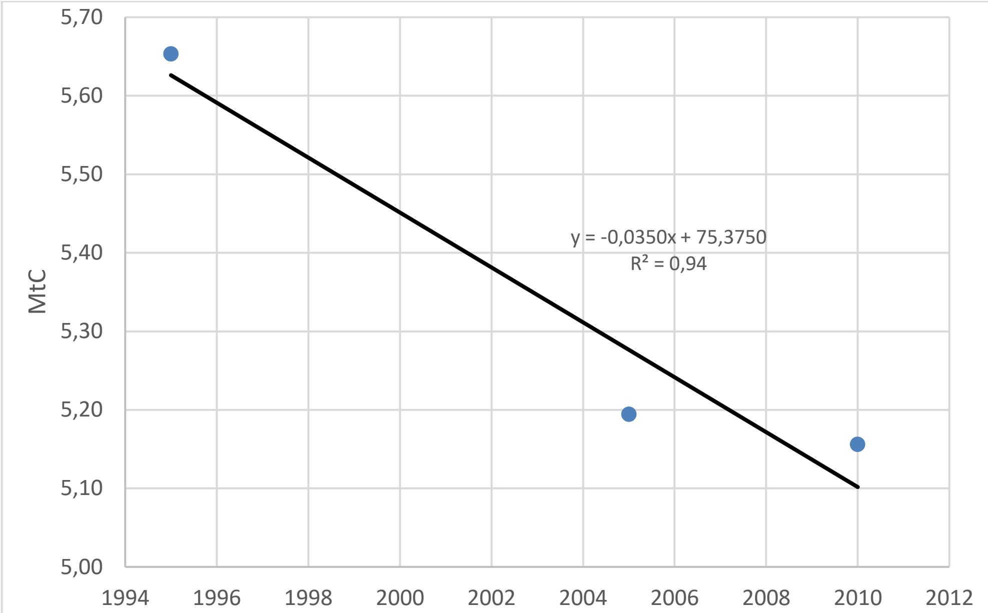


Figure 24:Carbon sequestration evolution (MtC) in all Portugal forest (1995-2010) (IPCC)

The linear regression in Figure 24 reflects the diminution in total of carbon sequestrated per year, explaining 94% of the total variability of the carbon sequestration (MtC) (R^2 = 0.94). We used this equation to interpolate the results until 2014.

1.2 Carbon Stock:

The carbon stock includes BGB and AGB per species. IPCC method were used to convert total stand volume to carbon stocks, a very important amount of carbon stocked in the biomass carbon pool (Table 13*)*. Any disturbance of these stocks can be a significant source of GHGs emissions. The global carbon stock of the Portuguese forest in 1995 was 75.34 MtC, decreasing to 68.7 MtC in 2010 (decrease of 6% during the period 1995-2005 and 4% during the period 2005/2010).

From 1995 until 2010, *Pinus pinaster* carbon stock decreased by 26 %, principally because of the forest fires (Silva & Catry, 2006), when *Eucalyptus* show an increasing in carbon stock about 15%, because of its industry importance (supplying industry pulp). The oaks carbon stocks also were relatively decreased, and it is more or less stable for the other species.

Table 13: Carbon Stocks per vegetation types (tC/yr) (IPCC)

Vegetation type		Stock tC/yr		
		1995	2005	2010
Coniferous	*Pinus pinaster*	24391912,6	19842351,5	17820823,2
	Pinus pinea	1342869,5	1931555,0	1964542,9
	other Softwoods	1112474,9	779555,9	467310,4
	Total Coniferous	26847257,0	22553462,4	20252676,4
Broadleaves	*Eucalyptus* spp.	20173344,2	22100433,2	22836803,0
	Quercus suber	15393419,0	15069217,0	15186209,2
	Quercus ilex	6088969,2	5456555,4	5386303,7
	other Oaks	1468503,3	1054927,9	1072505,8
	Castanea sativa	633883,2	744622,9	804373,0
	Acacias	373852,6	371568,9	359389,3
	Ceratonia siliqua	54087,6	94638,3	107153,9
	other Broadleaves	4305592,5	2732937,5	2690577,0
	Total Broadleaves	48491651,5	47624901,1	48443314,9
all Forest		75338908,5	70178363,5	68695991,4

Three mainly factors can explain the variability of Carbon Stock and annual carbon sequestration. Firstly, the structure and composition of the forest stand: age, density and vegetation types. This last factor was considered in the classification stage of carbon accounting. The integration of the other factors such as density will be an important step for a better accuracy. Secondly, silvicultural practices, that are related to the species, production objectives and production system (coppice or high forest). Thirdly, it is depending on the site ecologic conditions, such as soil and climate. The integration of these factors is also important in the ecozones stratification.

2. Annual Carbon Losses:

2.1 Losses by Fires:

In the Mediterranean countries, the fire is the most important natural threat to forests and wooded areas (FAO, 1998). The critical period of forest fires is normally between June and September (Miranda, Coutinho, & Borrego, 1994). Every year in Portugal a large forestry area is burned by wildfires, approximately 500000 ha was burned last year, the worst ever recorded (ICNF, 2017). Portugal's forests release considerable quantities of carbon dioxide and other greenhouse gases under fire disturbance.

2.2.1 Carbon Dioxide Emissions:

The Portugal forests emitted at least 0.22MtC/yr to the atmosphere, it is the minimum of carbon emissions recorded from 1995 until 2014. Though, the maximum of carbon emissions was recorded in 2003 (1.8MtC/yr) and 2005 (1.4 MtC/yr). In more extreme condition, carbon emissions from wildfires tend to 2 MtC/yr (Table 14). The herbaceous and shrub stratum show low carbon emissions compared to the forest stands, their maximum emissions was 0.06 MtC/yr in 2003. Despite that, their emissions are not significant, but they contribute considerably to fires patterns (Butler et al., 2012). Carbon emissions from broadleaves forests (63%) are higher than coniferous forests (37%).

The minimum of broadleaves emission was recorded in 2014 (0.018MtC/yr) and the maximum was recorded in 2003 (1.3MtC/yr) and in 2005 (0.85 MtC/yr). For the coniferous, the minimum emission was in 2014 (0.004MtC/yr) and the maximum was recorded in 2003 (0.54 MtC/yr) and in 2005 (0.5 MtC/yr) (Table 14). The contribution of forest fires to the global warming in Portugal is very significant.

Table 14: Carbon Emissions from all forest stands under fires disturbance (tC/ha) (IPCC)

Year	Total Coniferous	Total Broadleaves	secondary species	Shrub and herbaceous	all forest
1995	334 090,7	249 319,9	0,0	3 335,8	586 746,4
1996	78 800,6	58 806,1	2 974,5	2 322,1	142 903,2
1997	20 189,7	26 672,5	773,2	486,7	48 122,1
1998	194 249,0	218 584,0	13 239,1	5 173,9	431 246,1
1999	73 981,0	88 367,2	2 366,9	1 438,1	166 153,2
2000	114 715,0	122 103,6	5 459,7	3 500,7	245 779,1
2001	87 943,7	114 216,3	3 739,8	2 355,9	208 255,7
2002	169 058,5	193 722,7	7 913,5	2 631,5	373 326,2
2003	493 540,7	1 295 574,6	13 270,7	6 372,8	1 808 758,7
2004	66 360,4	187 777,6	1 183,5	2 634,5	257 956,0
2005	539 912,4	853 225,9	26 083,7	5 382,5	1 424 604,5
2006	55 382,3	176 195,7	591,7	1 513,9	233 683,5
2007	18 362,6	42 657,7	2 193,4	786,6	64 000,2
2008	6 987,4	18 646,4	0,0	258,6	25 892,3
2009	32 339,6	72 418,1	2 753,5	2 583,2	110 094,4
2010	92 223,7	195 787,8	7 952,9	2 927,3	298 891,8
2011	34 228,1	89 178,4	0,0	2 007,0	125 413,5
2012	100 430,1	240 842,3	591,7	2 006,6	343 870,7
2013	103 197,3	214 646,7	2 966,6	3 617,0	324 427,6
2014	4 570,6	17 837,8	0,0	301,9	22 710,3

The main species contribute to the carbon emissions are *Eucalyptus and Pinus pinaster*. For examples in 2003 their emission was successively 0.95 MtC and 0.47 MtC. And in 2005 it was 0.52 MtC for *Pinus pinaster* and 0.73 MtC for *Eucalyptus* (Figure 25). The average contribution rate in emissions of these two species is going up to 78% in which Eucalyptus present 44.8% (Figure 26). The other vegetation types had different carbon emission amounts and different contribution rate of CO_2 emission between 1995 and 2014, they are illustrated in the Figure 25,Figure 26 and annex 15.

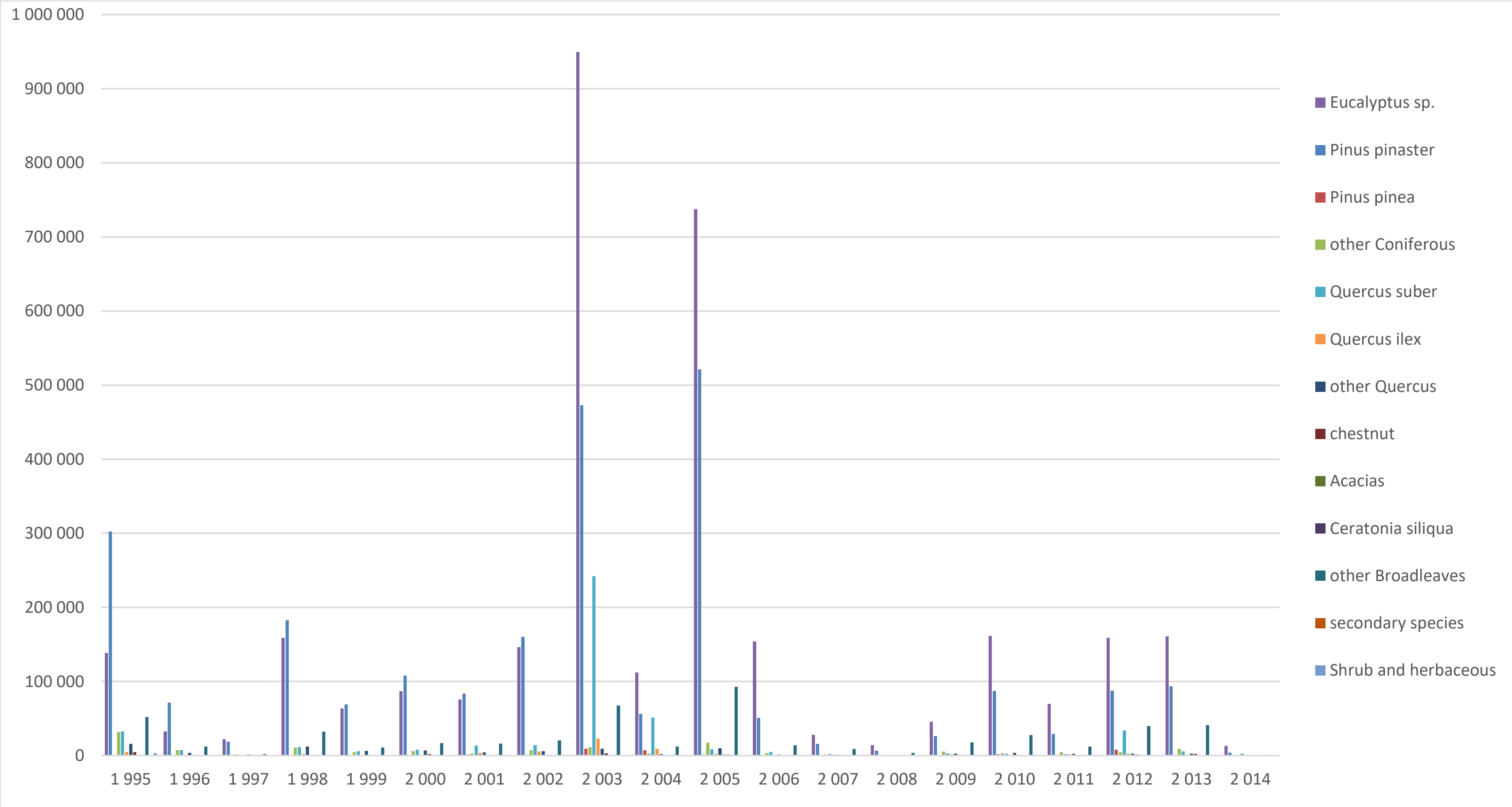


Figure 25: Carbon emissions per species under fires disturbance (tC/year) (IPCC)

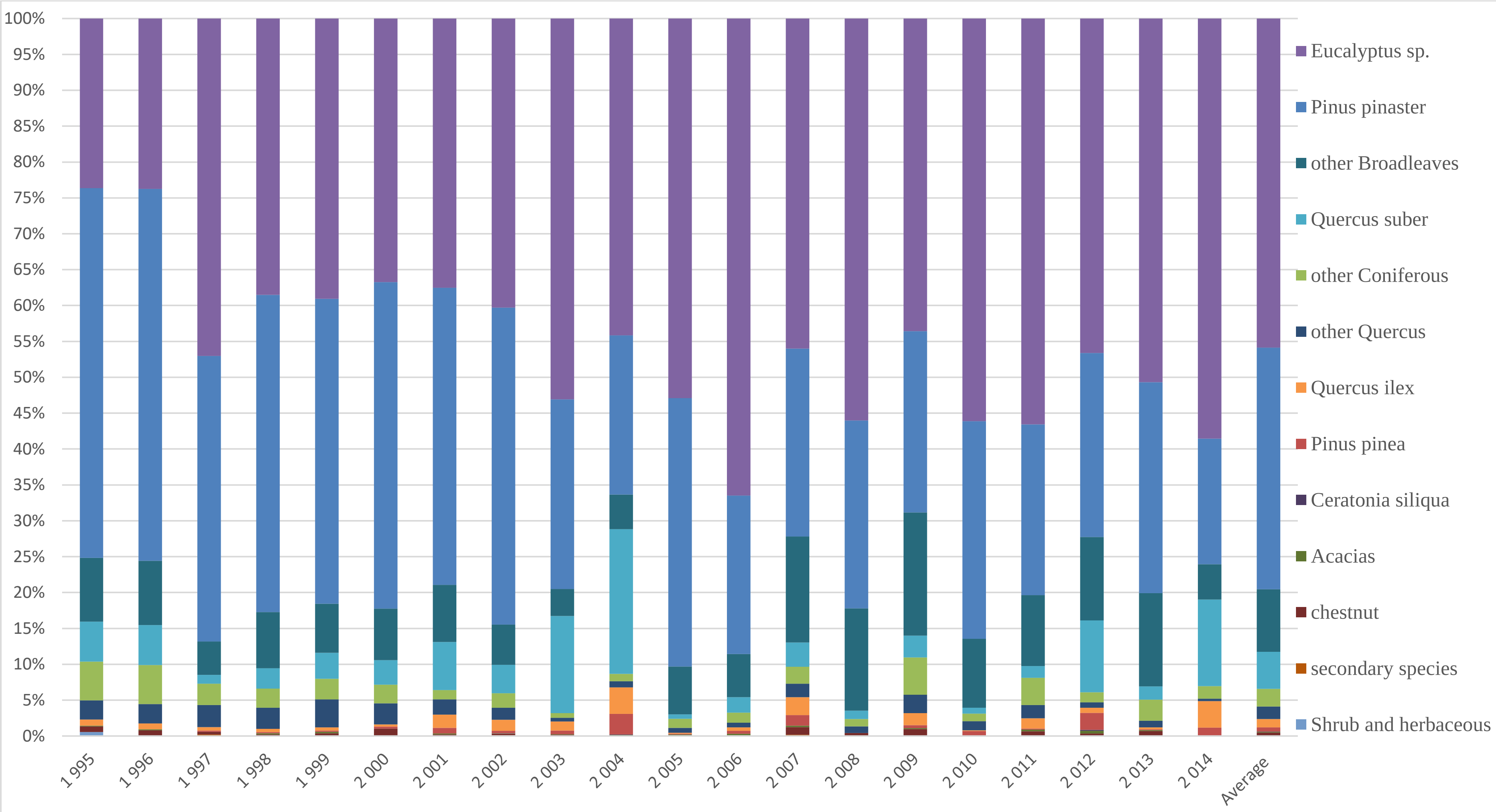


Figure 26:Contribution rate in Carbon emission for each specie (%) under fires disturbance (IPCC)

The carbon emissions comparison between different species requires the calculation of Unitary Carbon Emissions Average (UCEA) (Figure 27). There is a big difference of CO_2 emitted between different vegetation types. For example, *Eucalyptus* stand had UCEA equal to 11.82 tC/ha, *Pinus pinaster* with UCEA equal to 5.9 tC/ha, and *Quercus suber* also have an important UCEA of 5.7 tC/ha.

This variability of carbon emission can be explained by several factors. But the fires sensitivity and management practices (i.e thinning, composition,) remained the most important factors that provoked this difference of UCEA (James, Fortin, Fall, Kneeshaw, & Messier, 2007). The management of tree density and species composition with a good silvicultural system at the landscape scale remains one of the best methods to reduce fire risk (Graham, Harvey, Jain, & Tonn, 1999), and Consequently reducing carbon emissions. Eucalyptus is the most carbon emitter species in Portugal forests because of its higher flammability (Doerr et al., 1998). Pinus pinea has a higher fire resistance in relation to the remaining Mediterranean Basin pines (RODRIGO et al., 2007), that is why we find that Pinus pinea (2.8 tC/ha) has a low carbon emission comparing to Pinus pinaster (5.7 tC/ha), which is considered more sensitive to fires (Fernandes et al., 2008).

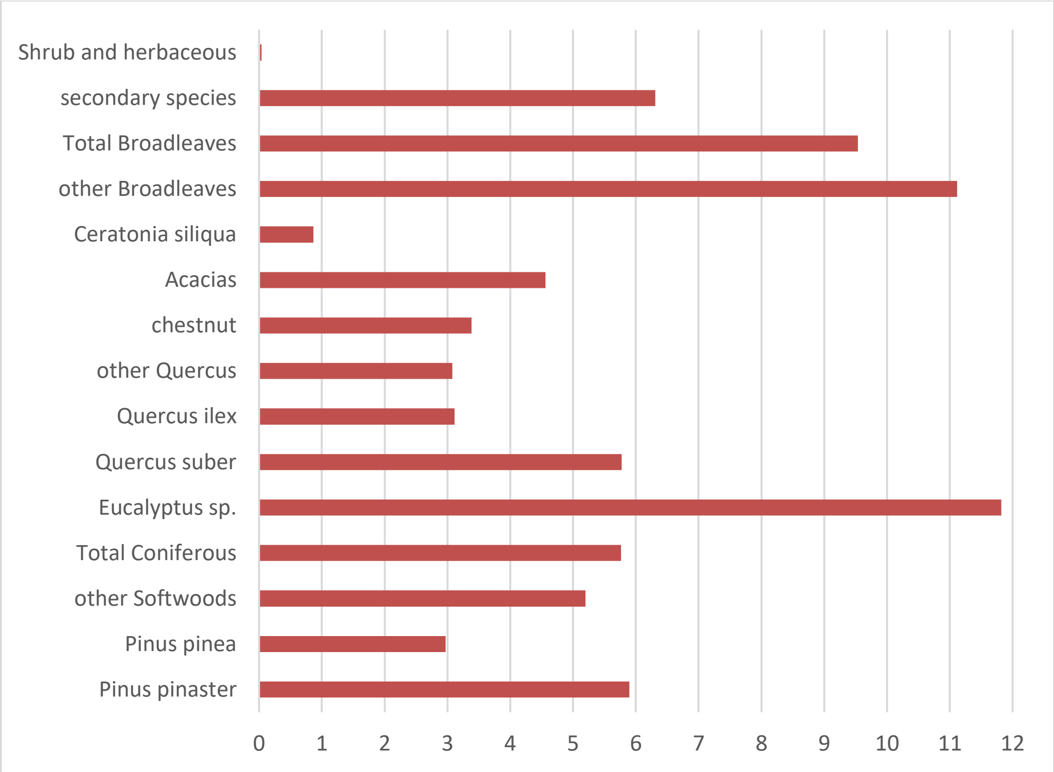


Figure 27:Unitary carbon emission average under fires per specie (tC/ha) (1995-2014) (IPCC)

2.2.2 Other GHGs Emissions:

The emissions of carbon monoxide (CO), methane (CH_4), nitrogen dioxide (NO_2) and nitrogen oxide (NOx) are very low compared to CO_2 emissions (Figure 28), but they have a higher global warming potential than CO_2, which depend on their ability to absorb energy (radiative efficiency) and their lifetime in the atmosphere (IPCC, 2006). The maximum of Other GHGs Emissions was recorded in 2003 where the CO, CH_4, NO_2 and NOx emissions into the atmosphere were respectively: 0.45 Mt, 0.02Mt, 0.001 Mt and 0.012 Mt (for more details refer to annex 16, *annex 17*, annex 18 and annex 19).

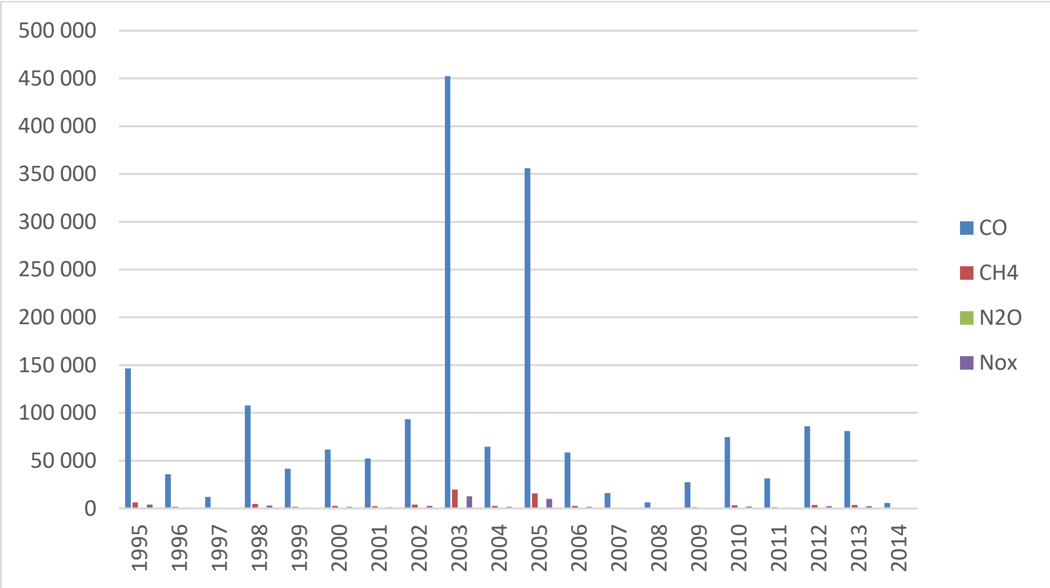


Figure 28:other GHGs emissions (ton/year) (IPCC)

2.2 Losses by insects and diseases:

Table 15:Carbon losses under insects and diseases attacks (IPCC)

Years	unit	Pinus pinaster	*Eucalyptus*	total forest
1990	tCO_2	579,4	900,2	1479,6
2000		238,2	516,5	754,7
2005		261,1	565,6	826,8
2010		256,2	596,5	852,7
1990	tC	158,0	245,5	403,5
2000		65,0	140,9	205,8
2005		71,2	154,3	225,5
2010		69,9	162,7	232,6

Carbon losses by insects and diseases are lower comparing to the losses by fires and logging (Table 15). But their integration in the accounting module is important. Because these biotic agents can cause stand mortality or reducing the carbon sequestration potentiality by defoliation of the stands. The affected trees can be collected and used as firewood, one sub-component integrated in the carbon losses by harvesting. In addition, insect and diseases accelerate the process of degradation of organic matter which generates additional carbon emissions. As well, they reduce the economic value of wood products (wood quality), which does not allow the producers to export its wood production. The regression module, illustrated in *annex 13* $(y = -0{,}11x^3 + 671.94x^2 - 1\,346\,724.66x + 899\,716\,985.24)$ was used to interpolate data from 1995 until 2014. This module explains 90% of the carbon losses by year variability (R^2=90%). It is a module that does not take into account the environmental factors that controlling the distribution of these agents. We can show that the occurrences of insects and diseases in the *Eucalyptus* and *Pinus pinaster* stands are generally decreasing (Table 7). Nevertheless, the occurrences of these agents in this last years (including 2017) was very high, and more serious than before (J.M. Rodrigues, 2018; A.Turbé et al., 2012). However, we need more details information that linking this component with environment conditions for each biome to improve the precision about carbon losses by pests and diseases.

2.3 Losses by Harvesting:

Figure 29 shows the contribution of each category of wood products in the total carbon losses by logging. We find that the lumber wood products exporting 65%, the industry wood products are exporting 32% and the firewood contributes by 3%.

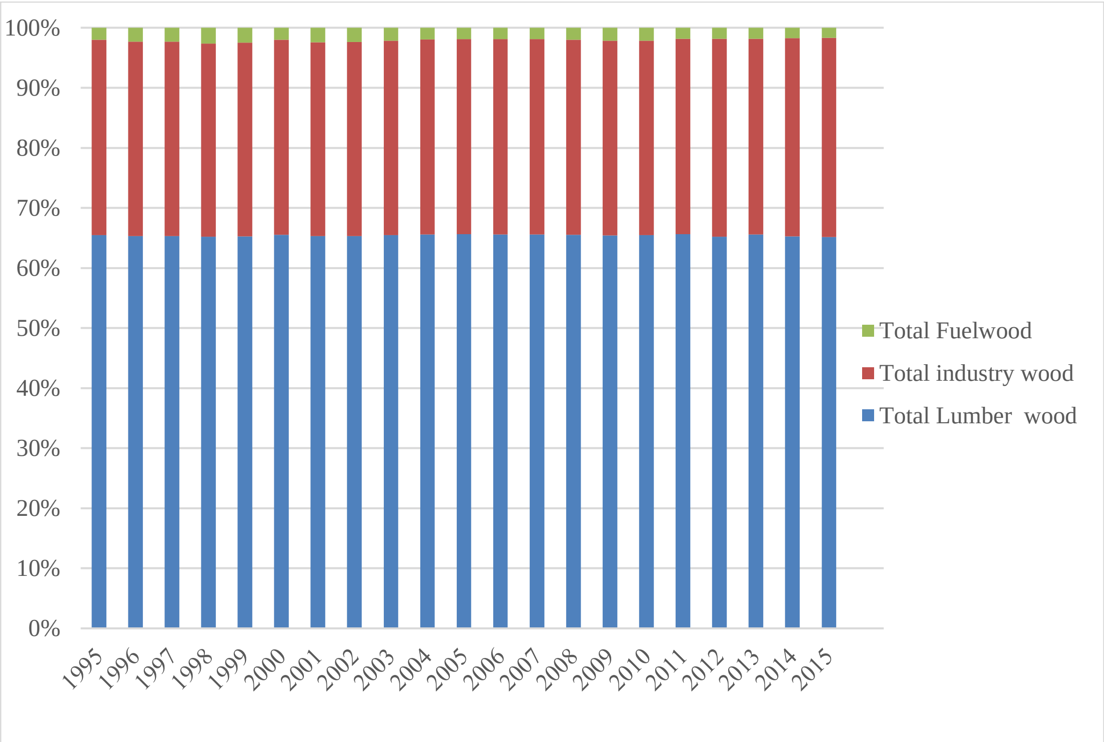


Figure 29 :Contribution of different wood categories in carbon losses by logging (%) (IPCC)

The carbon exports in wood products are increased by 48% between 1995 and 2015. Indeed, in 1995 the total of carbon exported from forest ecosystems was 1MtC. In 2015 it becomes 1.44 MtC. The maximum was exported by lumber wood, which augmented from 0.65 MtC in 1995 to 0.9 MtC in 2015. The carbon exports in firewood was low and relatively constant in 0.02MtC /year. The carbon exports in industry wood were increased from 0.32 in 1995 to 0.47 MtC in 2015 (Figure 30).

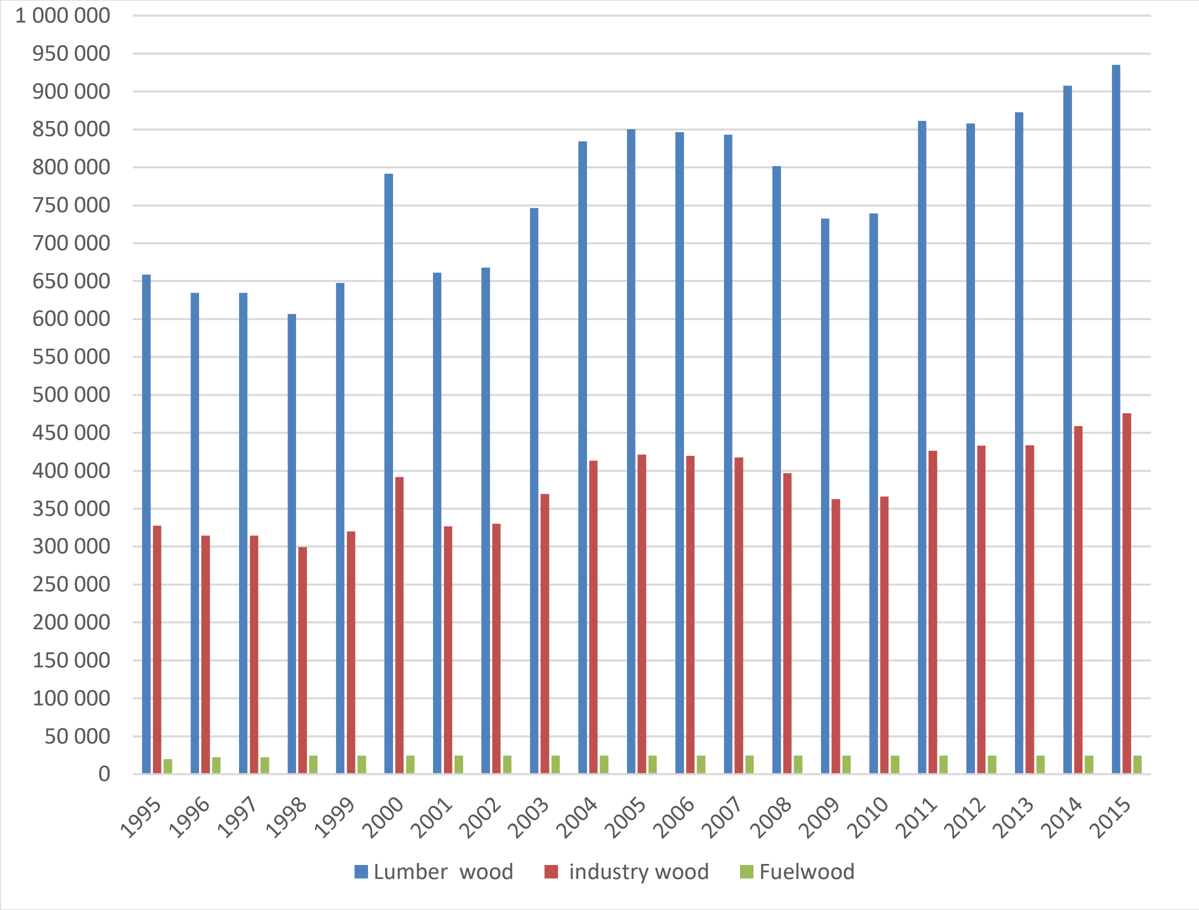


Figure 30:Carbon Loss by Forest Logging (MtC) (IPCC)

The wood products sector characterized by a highly developed wood processing industry in Portugal. This sector has an important economic value, especially the *Eucalyptus* spp. and *Pinus pinaster* forests, owing to supply the pulp and timber wood industry. We underline that the private properties are dominant (93%) like in all the other western countries. Their first objective is to maximize the wood production. The oaks forest is often used as agroforest systems. Extraction of wood is accompanied by a high export of carbon in biomass.

The carbon losses in HWPs are not directly accounted as direct emissions because it is depending on the wood uses. According to the approach used in this study, only firewood has a direct carbon emission, while, both categories lumber wood and industry wood emissions are depended on their lifetime (Ellison, Lundblad, & Petersson, 2011).

3. Carbon Balance Evolution:

Atmosphere flow developed by IPCC reflects the interactions between the atmosphere and terrestrial ecosystems. The application of this method allows the carbon balance accounting. Table 16 presents the results of this method used to estimate annual gain and losses of C (emissions and sequestration). The C balance is the sum of gains and losses in carbon pools on forest lands, which are remained in the same land use categories for each year. The significance of terrestrial ecosystems to global climate change will not be fully recognized until all components which contribute to their flux are accurately quantified. All significant components of the carbon cycle in Portugal forest ecosystems are considered in this project.

Table 16: Carbon Gain and losses for each component (tC/yr) (IPCC)

(gain-loss)/year	components	Year	tC/year	tCO2/year
Gain	Carbon Sequestration	1995	5653395,3	20729116,1
		2005	5194640,3	19047014,6
		2010	5156251,7	18906256,2
Losses	Fires	1995	-586746,4	-2151403,6
		2005	-1424604,5	-5223549,8
		2010	-298891,8	-1095936,6
	Insects and Diseases	1995	-257,1	-942,7
		2005	-225,5	-826,8
		2010	-232,6	-852,7
	Harvesting	1995	-1006000,5	-3688668,5
		2005	-1295928,1	-4751736,4
		2010	-1129586,4	-4141816,9
Balance		1995	4060391,3	14888101,3
		2005	2473882,2	9070901,5
		2010	3727540,9	13667650,0

The carbon balance is generally decreased. Indeed, in 1995 it was 4.06 MtC, in 2005 it was 2.5 MtC, and in 2010 it becomes 3.7 MtC. This variability in the balance depends on the contribution rate in carbon losses by different disturbances (*Figure 31*). The insects and diseases show a negligible contribution rate in carbon losses, the logging and fires presenting the most components that influence the carbon balance in Portugal forest. Their contribution in carbon losses are fluctuates from one year to another:

- In 1995: logging present 63% of carbon losses, though fires present 33% of carbon losses,
- In 2005: logging contribution rate in carbon losses was 47%, and for fires it was 52%,
- In 2010 the contribution rate in carbon losses by logging equal to 78%, and it was 21% for fires.

We distinguished that in the normal years where the environmental conditions are not very severe, the logging has a higher contribution rate in carbon losses than fires. Because there is permanently market demand for wood. Whereas, the fires are mainly dependent on climatic conditions.

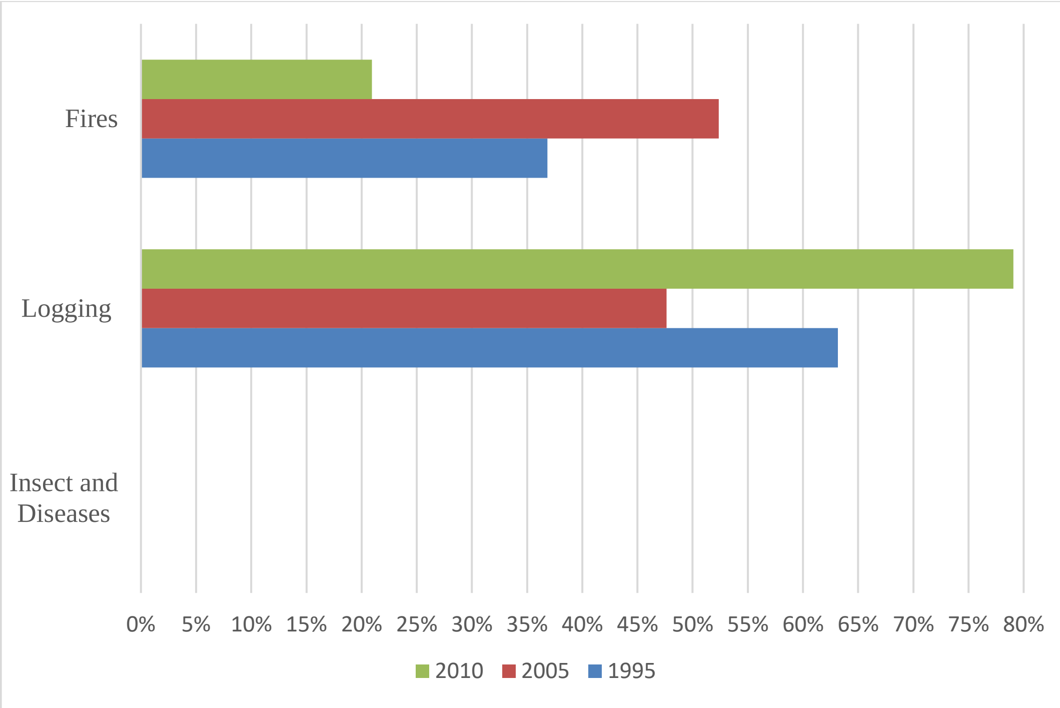


Figure 31: Contribution rate in carbon losses by different disturbances (IPCC)

The calculation of the losses rate compared to gains presented by this ratio of loss/gain, expressed in percentage, can help us to understand more the carbon cycle situation in Portugal forest ecosystems (*Table 17*). The average of this rate is 29%. Namely 29% of the total carbon sequestrated was losing and return back to the atmosphere. Sometimes under extreme conditions this rate may exceed 50%. Though, in 2003 it was 55.6% the equivalent of 2.92 MtC and in 2005 it was 52% the equivalent of 2.68 MtC.

Figure 32 reflects the carbon balance evolution with its components from 1995 until 2014. The total carbon balance decreased from 4 MtC in 1995 to 3.5 MtC in 2014, and its lowest values were recorded in 2003 (2.34 MtC) and 2005 (2.51 MtC).

This diminution is explained by two main reasons. Firstly by the effect that the reforestation rate does not cover the yearly degradation rate (4%), and according to FAO classification of land use, the Portuguese lands had classified as the categories where we have a net gain of agricultural land and a net loss of forest area (FAO, 2016), this criteria of land use management can explains this decrease in yearly carbon sequestration component. Secondly by carbon losses, that are directly related to the losses of biomass by fires and the logging.

By and large, Portugal's forests emit carbon when they are disturbed (fires), deforested, overexploited or degraded. On the other hand, they have a higher potential to absorb carbon dioxide, and they react sensitively to climate change. 29% of the total carbon sequestrated was returned to the atmosphere through logging and wildfires. This higher rate reflects the importance of urgent government interventions, by good policy, strict legislation and good management, to protect the forest resources and improve its contribution capacity in climate change mitigation. As well as, the forestry community needs to evaluate the long-term effects of climate change on forests and determine what the community might do now and in the future to respond to this threat, with regional prioritization and adapting to forest disturbance while maintaining the genetic diversity and resilience of forest ecosystems.

Table 17: Carbon balance (MtC) and the ratio losses/Gain (%) (1995/2014)

Years	Yearly sequestration	Losses by Fires	Losses by Insects and Diseases	Loss by Logging	Total Losses	Carbon Balance	% Losses (losses/Gain)
1995	5,55	0,5834	0,000257	1,006	1,590	3,960	28,6%
1996	5,515	0,1376	0,000237	0,972	1,110	4,405	20,1%
1997	5,48	0,0469	0,000223	0,972	1,019	4,461	18,6%
1998	5,445	0,2186	0,000213	0,931	1,150	4,295	21,1%
1999	5,41	0,1623	0,000207	0,992	1,155	4,255	21,3%
2000	5,375	0,2368	0,000206	1,208	1,445	3,930	26,9%
2001	5,34	0,2022	0,000206	1,012	1,214	4,126	22,7%
2002	5,305	0,3628	0,000210	1,023	1,386	3,919	26,1%
2003	5,27	1,7891	0,000214	1,140	2,929	2,341	**55,6%**
2004	5,235	0,2541	0,000220	1,272	1,526	3,709	29,2%
2005	5,2	1,3931	0,000225	1,296	2,689	2,511	**51,7%**
2006	5,165	0,2316	0,000230	1,291	1,522	3,643	29,5%
2007	5,13	0,0610	0,000234	1,285	1,346	3,784	26,2%
2008	5,095	0,0256	0,000236	1,223	1,249	3,846	24,5%
2009	5,06	0,1048	0,000236	1,120	1,225	3,835	24,2%
2010	5,025	0,2880	0,000232	1,130	1,418	3,607	28,2%
2011	4,99	0,1234	0,000225	1,312	1,436	3,554	28,8%
2012	4,955	0,3413	0,000213	1,316	1,657	3,298	**33,4%**
2013	4,92	0,3178	0,000196	1,331	1,649	3,271	**33,5%**
2014	4,885	0,0224	0,000172	1,391	1,414	3,471	28,9%

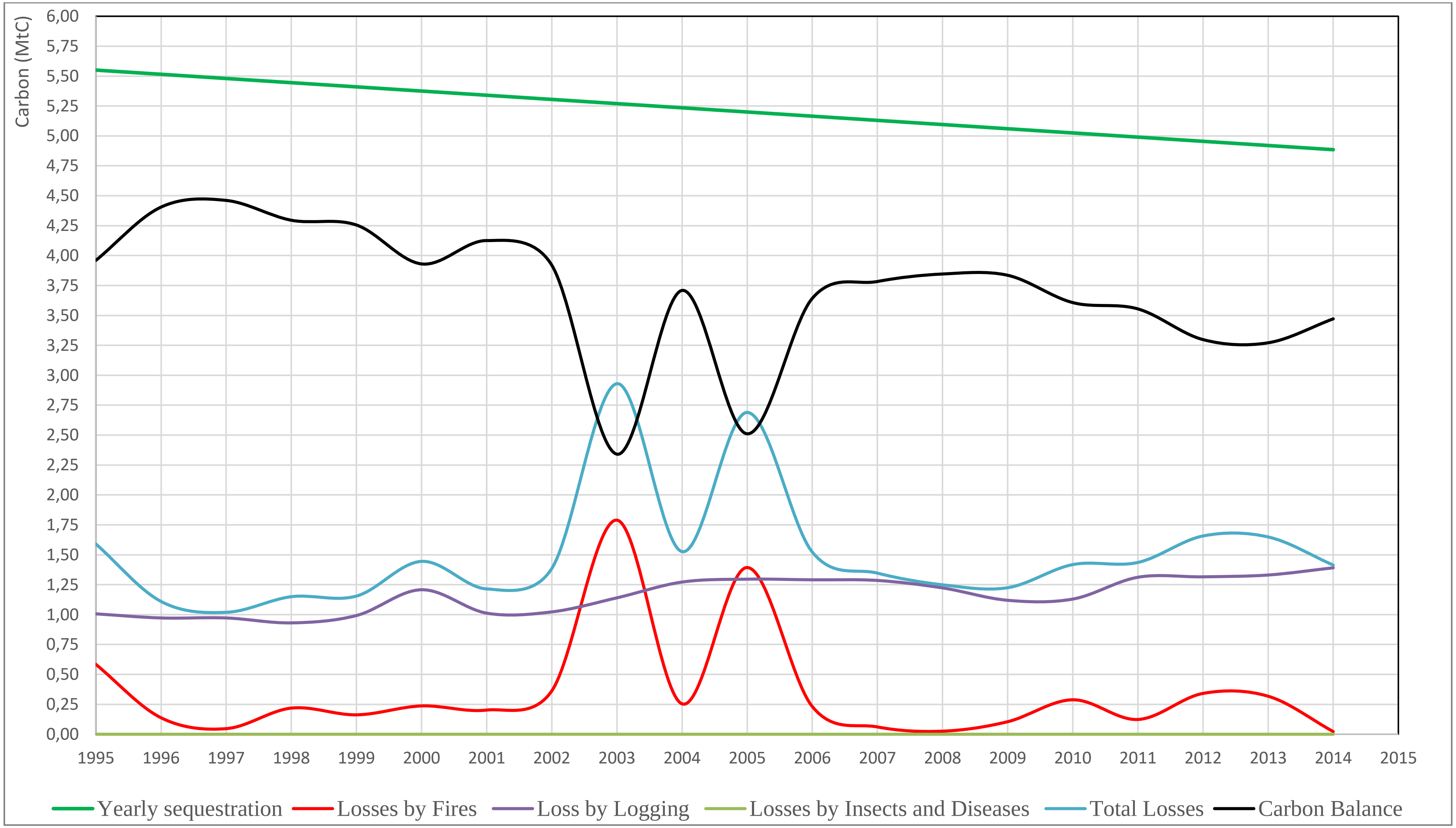


Figure 32 : Carbon Balance Evolution with and without disturbances and logging (MtC)

4. Uncertainty:

The uncertainties were obtained using SEP method. The yearly sequestrations by *Eucalyptus*, *Pinus pinaster* and *Quercus Suber* stands are showing lower error compared to other stands such as *Castanea sativa* and *Acacias* stands (Figure 33). For example, in 2005 for *Eucalyptus*, *Pinus pinaster* and Quercus Suber stands had a standard error equal to 14.5%, 15,5% and 14,8% respectively, while for *Castanea sativa*, *Acacias* and *Ceratonia siliqua* it was 35% 38% and 27% respectively (Table 18).

Table 18 :Uncertainties of yearly carbon sequestration per species in 1995 and 2005

	standard error (%)		**Yearly sequestration MtC/Year**		**absolute uncertainty ($t_{95\%}$ *SE)**	
year	1995	2005	1995	2005	1995	2005
Pinus pinaster	17,0	15,5	1,2644	1,0286	0,2153	0,1596
Pinus pinea	20,1	17,3	0,1500	0,2158	0,0301	0,0374
Other Coniferous	31,6	35,4	0,0544	0,0381	0,0172	0,0135
Eucalyptus spp.	14,8	14,5	2,0997	2,3003	0,3108	0,3327
Quercus suber	15,2	14,8	0,4867	0,4765	0,0742	0,0705
Quercus ilex	16,1	19,3	0,2008	0,1799	0,0323	0,0347
Other oaks	17,7	22,5	0,4538	0,3260	0,0802	0,0733
Castanea sativa	26,8	35,0	0,0378	0,0444	0,0101	0,0155
Acacias	17,4	38,3	0,0230	0,0229	0,0040	0,0088
Ceratonia siliqua	17,4	27,0	0,0017	0,0029	0,0003	0,0008
other Broadleaves	17,4	27,0	0,8809	0,5592	0,1535	0,1510

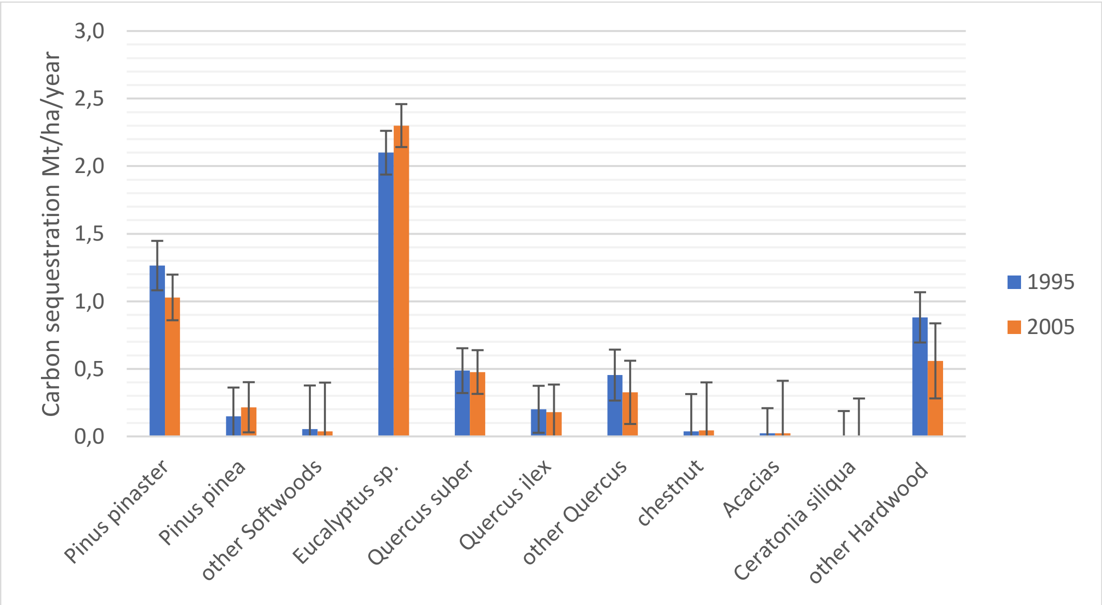


Figure 33:Carbon sequestration (MtC/ha) and its uncertainty for each specie in 1995 and 2005

This difference in uncertainty can be explained mainly by the sample number during the forest inventory. This number was higher for *Eucalyptus, Pinus pinaster* and *Quercus Suber* stands than the other stands. Because they have more land occupation. In addition, the expansion factors, which can vary widely by species, age, biome and silviculture, are a significant source of error in this work.

The uncertainties improvement requires an increase in the number of samples and detailed stratification of biomes. Also, using the conversion and expansion factors that are more specific to Portugal context than those proposed by IPCC guidelines, will be an important step towards a better accuracy. But the costs assessment must be taken into consideration.

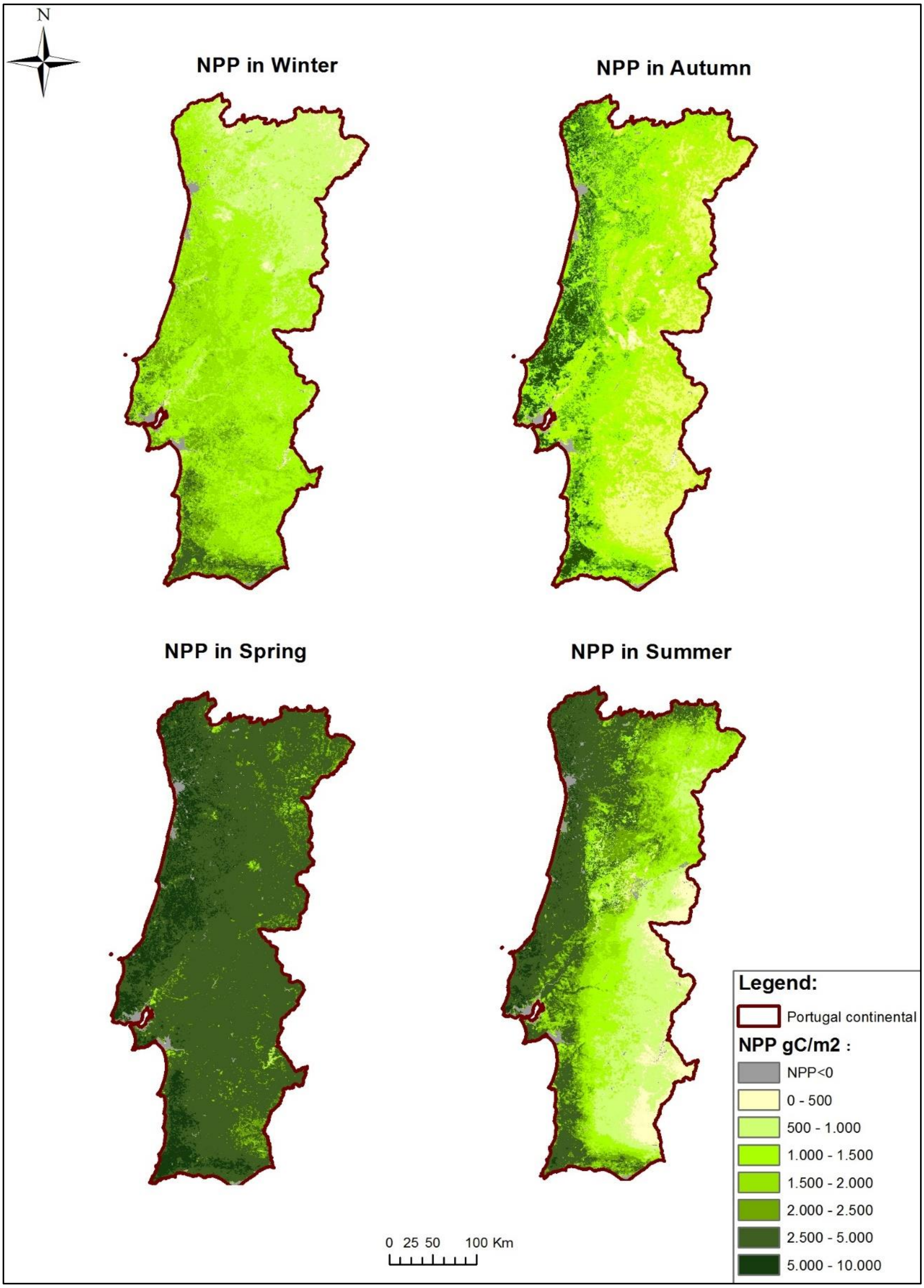
II. Carbon Mapping Results:

1. Direct Remote Sensing approach:

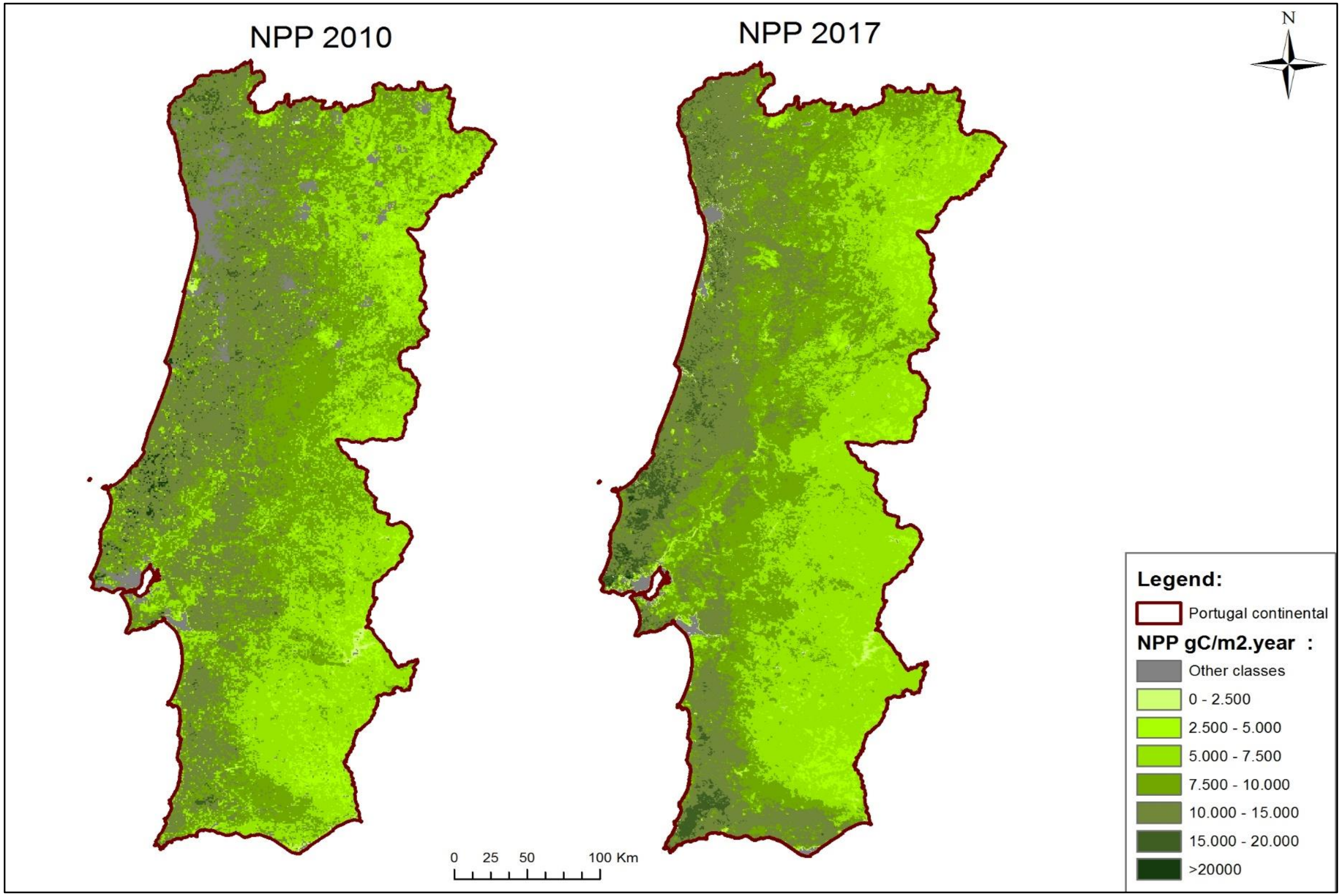
MODIS provides continuous temporal and spatial information of carbon dynamics of terrestrial ecosystems. This technic of optical remote sensors is considerate as a DRS approach to mapping the carbon sequestration by terrestrial vegetation. In addition, it allows the visualization of carbon dynamic by a given period, using MOD17A1 or MOD17A2 products.

The Following map shows the carbon dynamic by seasons in 2017, obtained from MOD17A2 (Map 6):

- In spring season, we had the highest NPP values, it was varied between 2500 gC/m^2 and 5000 gC/m^2.
- In summer, the NPP was higher in costal and Northwest zones than the center and south areas.
- In Autumn, NPP also higher in costal zones, and it decreased until it reached its low values in winter.
- In winter NPP value varied from 1000 to 2000 gC/m^2 in the costal zones, and it was very low in the other areas.



Map 6: NPP and carbon dynamic by season



Map 7:Annual NPP map in 2010 and 2017

The product MOD17A2 used to calculate the MOD17A3 product, that presents the annual NPP in 2017. Generally, in coastal and center zones, we have the highest carbon sequestration potentiality, it was superior or equal to 10 tC/ha. While, in Northeast and Southeast zones we have the lowest carbon sequestration potentiality, it was inferior than 10 tC/ha (Map 7). An NPP interpolation for the whole European territory provided the values for Portugal between 10 tC / ha to 50 tC / ha (A. Moreno, 2017).

Due to the atmospheric correction done by NTSG group, explained before, we find to 2010 higher frequency of NPP null values than in 2017 NPP map (Map 7) (classified as “other classes”).

The NPP per species was derived from MOD17A3 in 2010 after using the pure forest land as a mask, the NPP average was calculated using 1000 points random points (annex 20). NPP varied from 7 tC/ha to 11 tC/ha depending on the species types (Figure 34). Eucalyptus is a fast-growing forest species with the highest NPP values, compared to other species. These values are very higher than those obtained by IPCC (Figure 23).

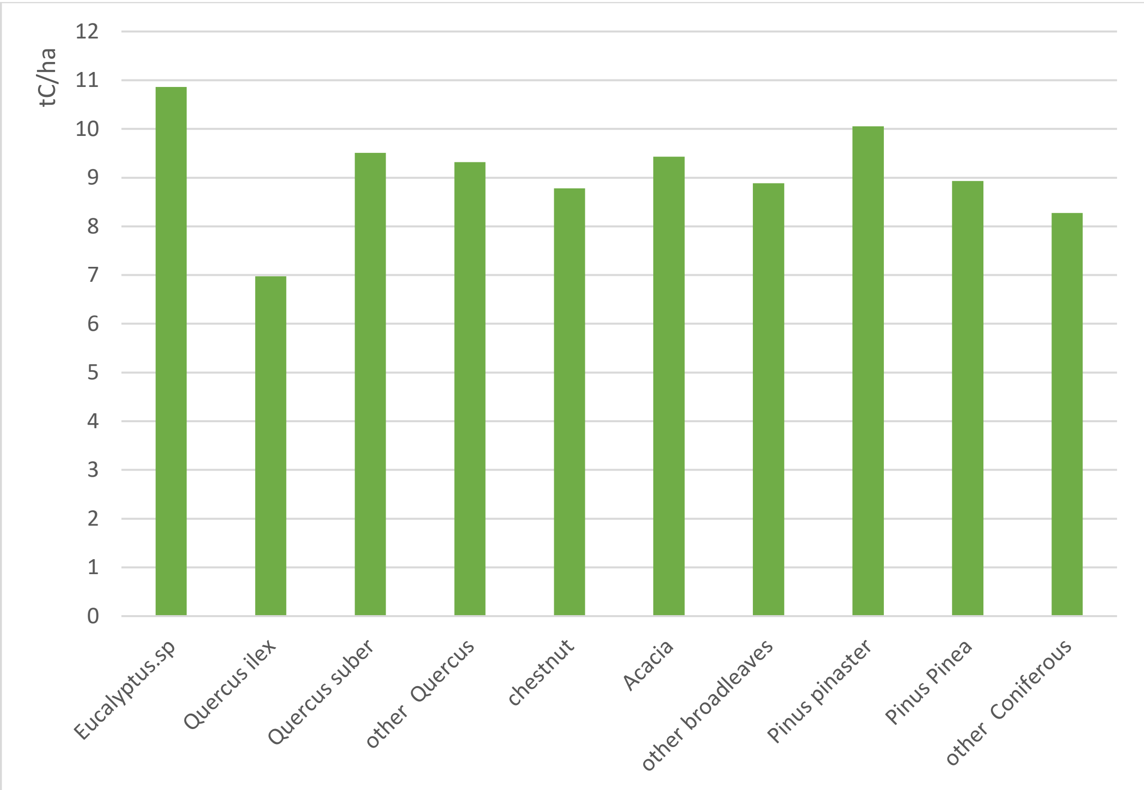
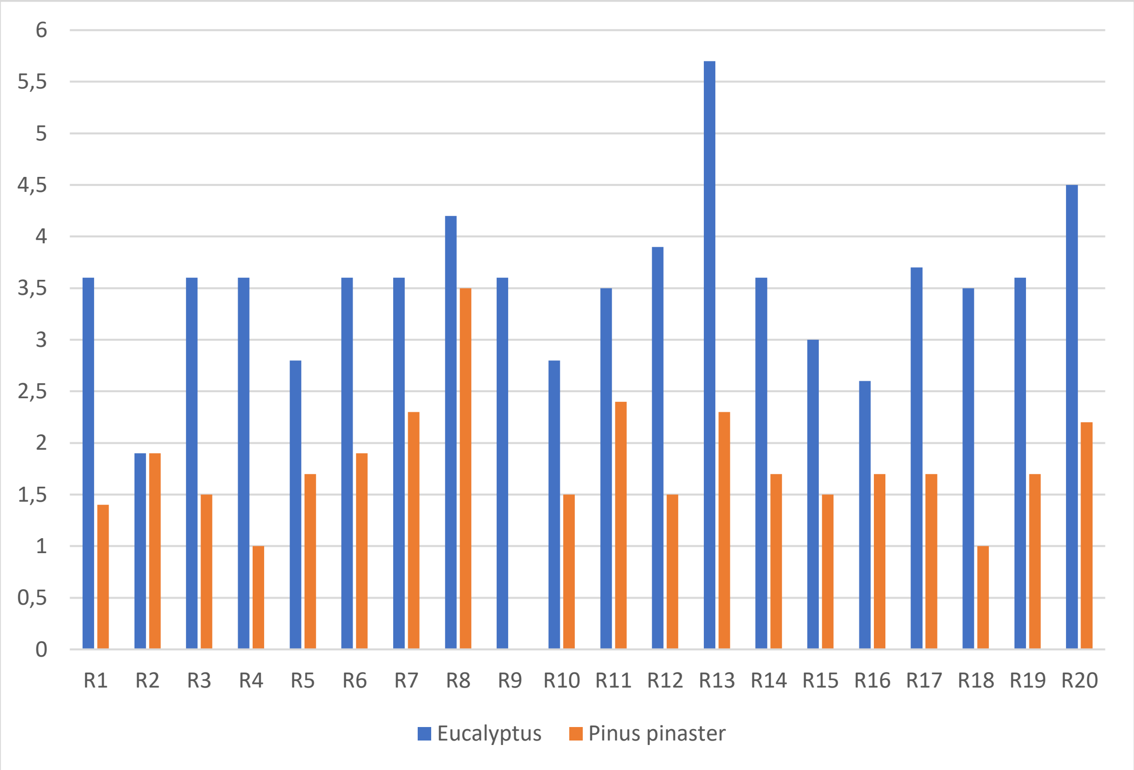


Figure 34: Carbon sequestration in 2010 derived from MODIS product (DRS approach)

The MOD17 products have several sources of errors related to climatic data, the BPLUT parameters, which generate more uncertainties. It is necessary to test these products on several biomes of the different structural configuration (Gulbeyaz et al., 2018). MODIS products are a very good alternative for countries with no official forest inventory data.

2. CA approach:

We present in Figure 35 the carbon sequestration (tC/ha) in 2010 at PROFs regions for 2 main species in Portugal forest. For *Eucalyptus* stand, the maximum of carbon sequestration was in *Oeste* PROF (5.7 tC/ha), and the minimum of carbon sequestration recorded in *Baixo Minho* PROF (1.7 tC/ha). For *Pinus pinaster* stand, the maximum of carbon sequestration was recorded in *Dão e Lafões* PROF (3.5 tC/ha, and its minimum was recorded in *Alentejo Litoral* and *Nordeste Transmontano* PROFs (1 tC/ha).



Legend :R1: PROF Alto Minho, R2: PROF Baixo Minho, R3: PROF Barroso e Padrela, R4:PROF Nordeste Transmontano, R5:PROF da AMP e Entre Douro e Vouga, R6 :PROF Tâmega, R7: PROF do Douro, R8:PROF do Dão e Lafões, R9:PROF da Beira Interior Norte, R10:PROF da Beira Interior SUL,R 11:PROF do Pinhal Interior Norte, R12:PROF do Centro Litoral, R13:PROF do Oeste, R14:PROF da Área Metropolitana de Lisboa, R15:PROF do Ribatejo, R16:PROF do Alto Alentejo, R17:PROF do Alentejo Central, R18:PROF do Alentejo Litoral, R19:PROF do Baixo Alentejo, R20: PROF do Algarve

Figure 35:carbon sequestration (tC/ha) in PROFs regions for 2 main species in Portugal forest in 2010 (IPCC)

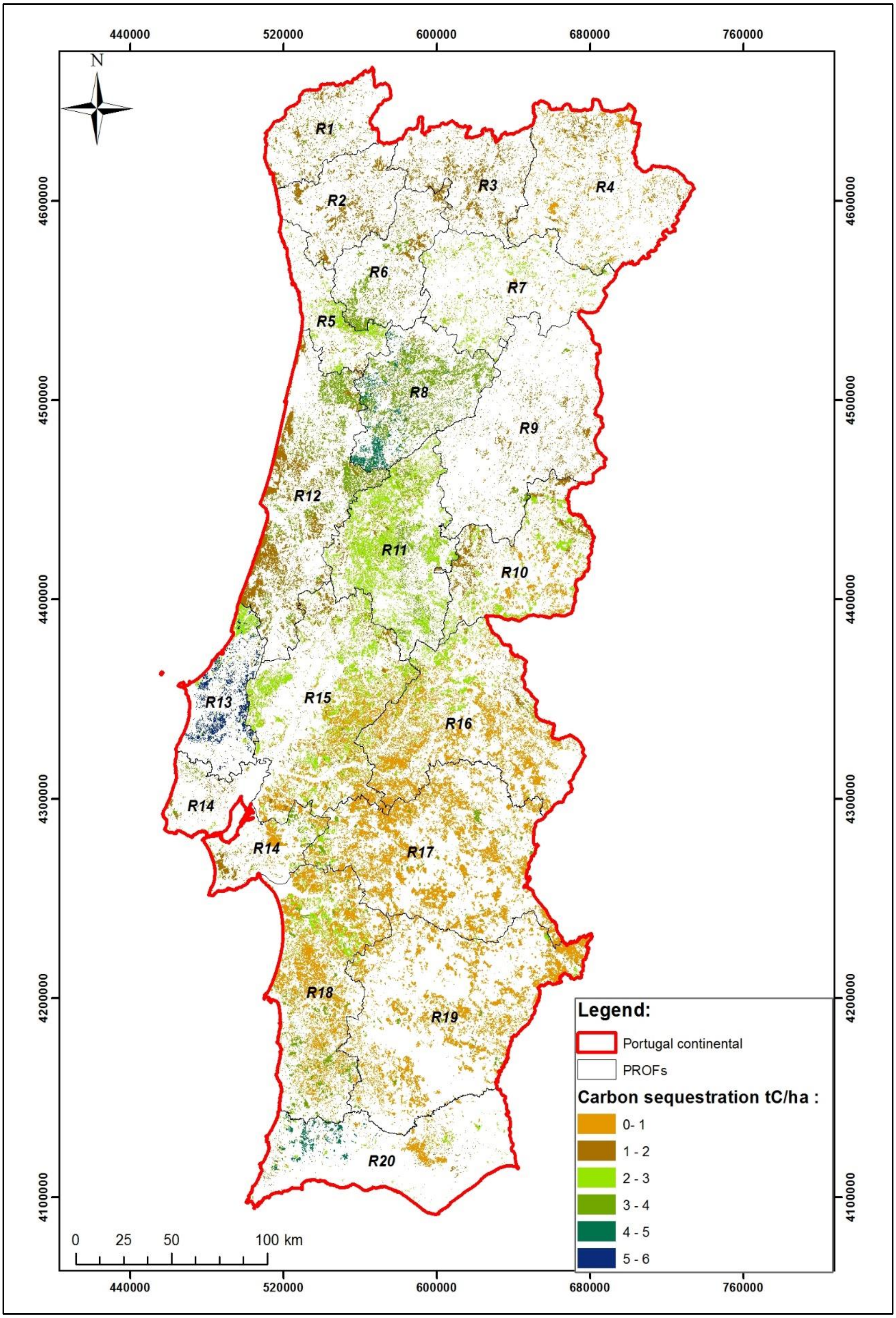
The mapping of carbon sequestration and carbon balance was done using CA Approach. The development of statistical models to link between carbon amount and biomass (AGB and BGB) using IPCC equations required field data (I_V and S_v) and default factors from the IPCC guidelines. The integration of PROFs region as ecozones in the classification stage gives more detail about carbon sequestration by *Pinus pinaster* and *Eucalyptus* (Figure 35).

In center and coastal PROFs like *Tâmega, Dão e Lafões, Pinhal Interior Norte, Oeste* and *AMP e Entre Douro e Vouga* we distinguished the higher carbon sequestration capacity, ranging from 2 tC/ha to 6 tC/ha. For West, Southwest and North PROFs such as *Beira Interior Norte, Alentejo Central, Baixo Alentejo, Alto Minho, Baixo Minho,* and *Barroso e Padrela* regions, we had the lower carbon sequestration capacity, inferior than 2 tC/ha, and often between 0.1 tC/ha and 1tC/ha (Map 8).

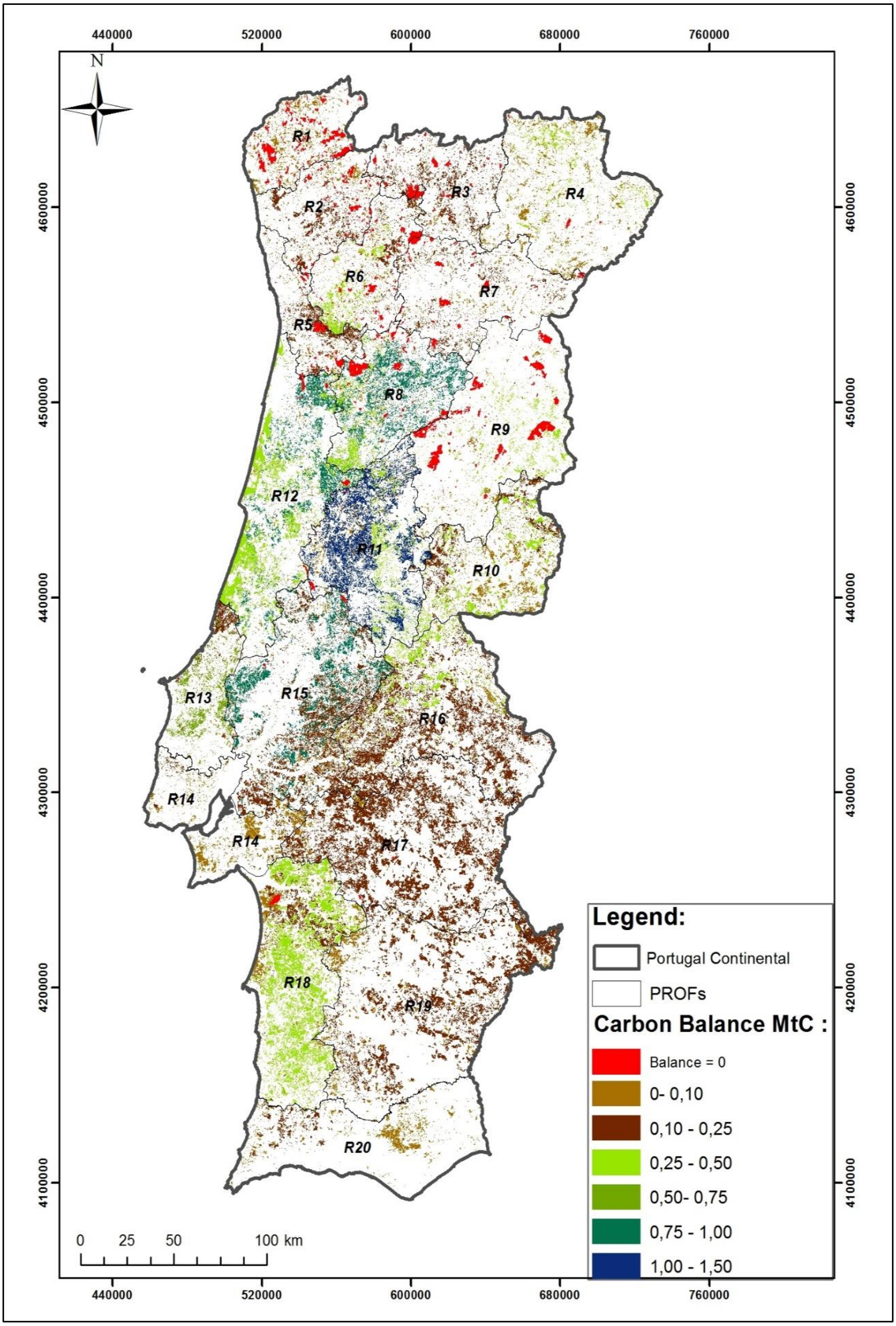
The carbon balance map is obtained after overlapping the carbon losses by fires and carbon sequestration maps (Map 9). The areas most affected by fires are the northern regions, which are emitting a very considerable CO_2 emission. If we take into considerations the results published by ICNF in 2017 (Map 4) the central regions are also very affected by this threat.

Annual carbon balance mapping demonstrates that in BA we have a balance equal to 0 MtC. But, in fact, it is less than zero, because during the combustion of the biomass, stocks of several years are lost. As we talk about annual balance in this project, we consider that the balance in these BA is equal to 0.

Both mapping approaches CA and DRS informs that the forest stands, generally *Pinus pinaster* and *Eucalyptus* stands, in central and coastal zones contribute equally in the air purification process, through a very good CO_2 sequestration potentiality. Both species, contribute significantly to GHGs emissions, their contributions to the CO_2 sequestration from the atmosphere in these zones are very high. This is a very important point to consider in climate change mitigation policies at the national level.



Map 8:Carbon sequestration in Portugal pure forest



Map 9: Carbon Balance Map in Portugal pure forest (sequestration -losses by fires)

2. IPCC and MODIS comparison result:

Table 19:Descriptive statistics of IPCC and MODIS results (460 points: annex 20)

Descriptive				
Carbon sequestration			Statistic	Std. Error
IPCC (tCO2/ha)	Mean		10,15	0,121
	95% Confidence Interval for Mean	Lower Bound	9,91	
		Upper Bound	10,38	
	5% Trimmed Mean		9,98	
	Median		10,26	
	Variance		14,65	
	Std. Deviation		3,82	
	Minimum		3,67	
	Maximum		20,90	
MODIS (tCO2/ha)	Mean		10,49	0,078
	95% Confidence Interval for Mean	Lower Bound	10,34	
		Upper Bound	10,64	
	5% Trimmed Mean		10,37	
	Median		10,33	
	Variance		6,04	
	Std. Deviation		2,46	
	Minimum		4,4	
	Maximum		20,4	

Table 20: Wilcoxon test results

Wilcoxon Test			
Null Hypothesis	**Test**	**Sig.**	**Decision**
The median of differences between IPCC (tC02/ha) and MODIS (tC02/ha) equals 0.	Related Samples Wilcoxon Signed Rank Test	0,021	Reject the null hypothesis.
Asymptotic significances are displayed. The significance level is 0,05 (α).			

According to the result obtained from a Simple Random Sample use to compare the NPP derived from MOD17A3 in 2010 and IPCC result (yearly carbon sequestration in 2010) in *Pinus pinaster* and *Eucalyptus* stands, the IPCC mean is 10.15 ± 0.24 tCO_2/ha with a large variability (Variance = 14.65) comparing to MODIS result, where the mean is equal to 10.34 ±0.15 tCO_2/ha with lower variability (Variance =6,04) (*Table 19*). We note that both data of IPCC and MODIS used in this Sampling, do not have a normal distribution. Also, they have not a variances equality. In this condition we used a no parametric test to achieve this comparison (Table 20).

Wilcoxon Test used as no parametric test, where the hypothesis testing assumes that the median of differences between IPCC and MODIS equal to 0. There is a significative difference between these two methods ($P_{value} < \alpha$). The two samples do not have the same mean. Several reasons can be explained this difference. Firstly, the uncertainty sources of these two methods. Secondly, the CFA by IPCC was in AGB and BGB, while in MODIS the NPP was measured for all the vegetation cover (herbaceous, shrubs, forest stands). Finally, because of the spatial resolution in MODIS imagery (1 km^2). An improvement in the spatial resolution of MODIS will be an important step for a better result. Both methods averages are very similar, the use of IPCC methodology with a high precision (Tier 3) will be a very good method to use in the MODIS products (MOD17) validation.

3.NPP and Biophysical Factors:

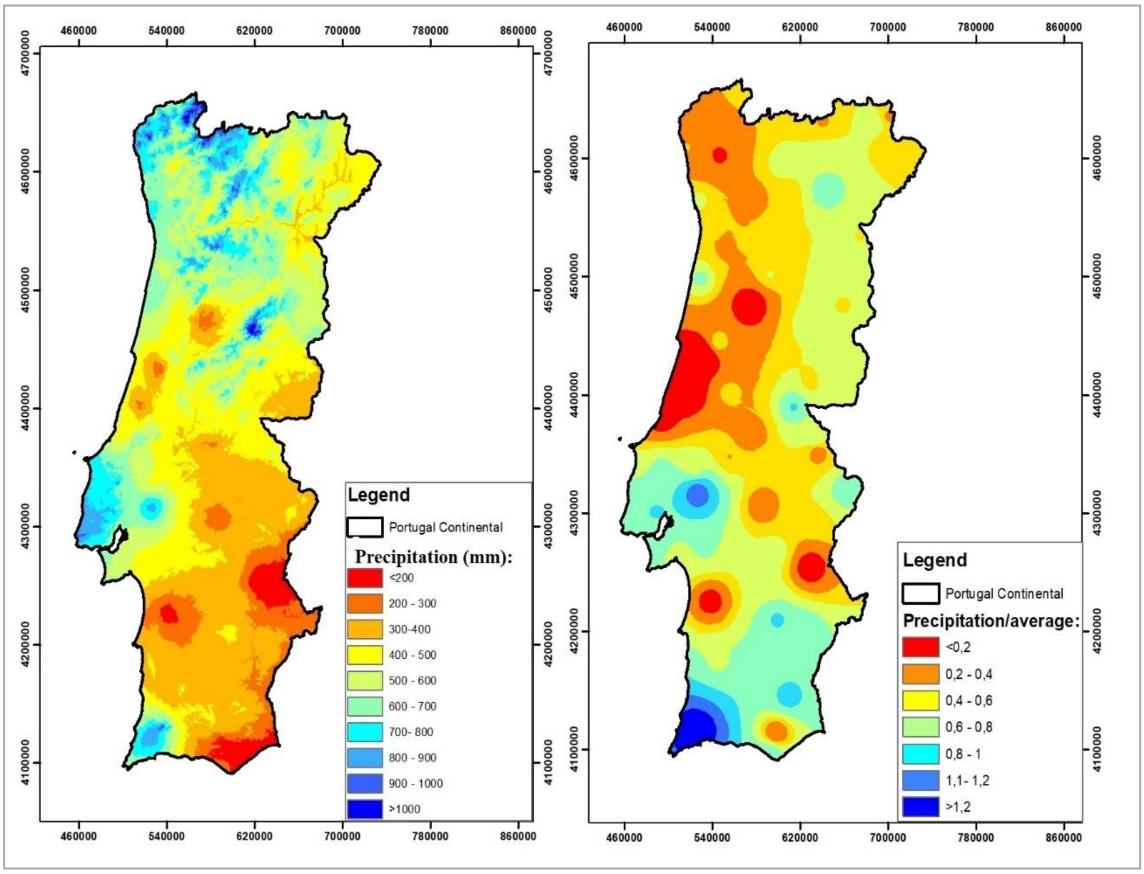
After the analysis of the data in annex 22 by SPSS we elaborate a linear model to interpolate the precipitation for all the country. According to the ANOVA table, this model is statistically significant (F_{obs}=26) and explain 66% of the total variability of precipitation at the national level (annex 26). The general interpolation equation founded was:

$$P(mm) = \mathrm{f}(\alpha, d, E, C_i)$$

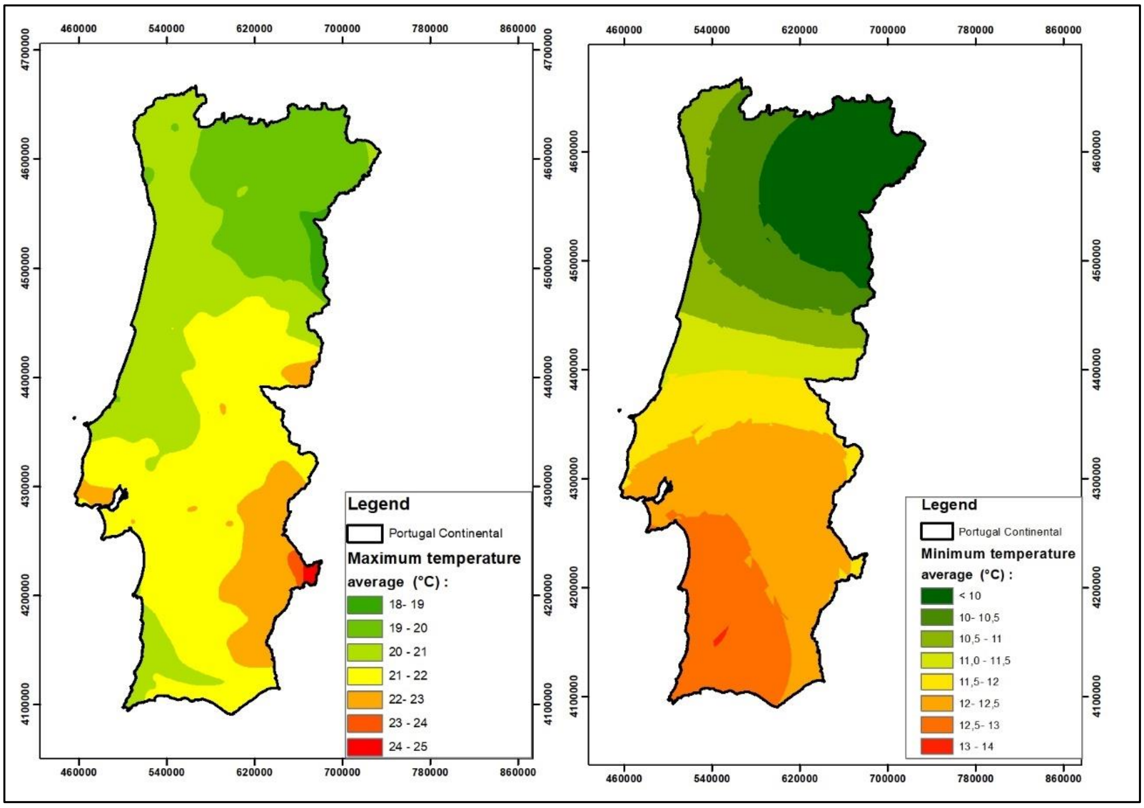
$$P(mm) = \tan(\alpha) \times 275.796 - \mathrm{d} \times 0.001 + \mathrm{E} \times 0.423 + C_i \times 747.78 – 169.806$$

The results of this interpolation can be founded in the Map 10 with the precipitation variation map in 2017 comparing to the average recorded for 21 years (Ci coefficient map). It confirmed that the northern and center zones in Portugal received less than 40% of the average (Ci<0,4), one of the reasons that can explain the total of BA in Portugal center last year. We find also that the north and the coastal zones received more than 500 mm while the southern and Eastern regions received less than 400 mm.

The interpolations of the averages of Minimum (Tn) and Maximum temperature (Tx) was obtained using a simple kriging. After several adjustments, the Prediction models used in Tx and Tn interpolation are configured in annex 24. And its results are in the Map 11. The lowest Tn is in the northeast and north zones with values below than 10°C, increasing to the south until it reaches 14°C. Tx in coastal zones is between 20°C and 22°C, inferior to 20°C in northeast regions, and superior than 22°C in the south zones.



Map 10:Precipitation in 2017 (mm) and the coefficient Ci



Map 11: Average of Minimum and Maximum temperature (°C) Maps

After a multivariate analysis the Relationship between NPP and biophysical variables in 2017, analysis results are presented by a linear regression model (Table 21). This model explains 57% of NPP variability through all continental Portugal Forest, with very high statistical significance ($P_{value}<\alpha$) with a very good quality, except for the existence of residual autocorrelations (Durbin-Watson test in table 21), this phenomenon is faced when the data are chronologic or spacey related. to avoid it, the integration of other explanatory variables such as soils type, slopes, expositions... etc. seems to be necessary.

We observe an increase of NPP with higher minimum temperature and precipitation, and a decreasing at higher elevations and maximum temperature.

Table 21:Linear module explains the relationship between NPP and biophysics variables

Correlation and Determination Coefficients

R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
				R Square Change	F Change	df1	df2	Sig. F Change	
0,758	0,575	0,573	2143,408	0,575	223,180	4	986	0,000	0,922

ANOVA[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	4101336297	4	1025334074	223	0,000[b]
Residual	4529877112	986	4594196		
Total	8631213409	990			

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	26761,219	2218,232		12,064	0,000
	Tn	1267,920	117,390	0,438	10,801	0,000
	Tx	-1663,700	131,936	-0,469	-12,610	0,000
	P	11,058	0,556	0,541	19,897	0,000
	E	-6,754	0,371	-0,541	-18,224	0,000

a. Dependent Variable: NPP2017

b. Predictors: (Constant), E, P, Tx, Tn

The locations with higher carbon sequestration capacity (NPP higher) are the coastal and center zones (environmental conditions: 20°C<Tx<22°C, Tn>11°C, P>500 mm, E<400 m). The low carbon sequestration capacity is in the south regions (Tx> 22°C) and in northeast mountain regions (Tn<10°C). This variability of NPP according to the previous biophysical factors is also related to the species, its geographical distribution and its environmental constraints (L. Wang et al., 2013).

General Conclusion and Recommendations:

Portugal has 38% forested area, 93% for private ownership. Its development is an important key in the mitigation of climate change and to ensure its functions: production, biodiversity reservoir and recreation. These forests undergo intensive natural and man-made disturbances, each year causing large carbon emissions and degradation of the forest ecosystems. Climate change mitigation has to regard firstly forest conservation, management, and restoration.

The two methods IPCC and MODIS allow to evaluate the ecosystem performances. In fact, IPCC method makes it possible to follow the Carbon stock and to calculate the annual carbon sequestration (NPP) which is an indicator of the forest capacity to climate change mitigation, while MODIS directly quantify the NPP stored as biomass during a period of time, by vegetation cover. Although the forests of continental Portugal presenting high carbon sequestration capacity, they suffer huge losses of carbon every year. Consequently, it is necessary to implement a national forest policy that must ensure a sustainable forest management and optimize its functions (economic, environmental and social), providing a strategic framework for harmonizing land uses, at the national, sub-national and landscape levels. This policy must take into account several considerations and plans to apply on different scales.

Firstly, species selection influences the carbon cycle and the greenhouse effect. Indeed, *Eucalyptus* spp. and *Pinus pinaster* contributed considerably in CO2 sequestration in central and coastal zones should be encouraged their planting in these areas. But in parallel other measures should be take into account such as management practices, to reduce the fire risk within these stands, because they contributed significantly in CO2 emissions. In the southern regions that use often the oaks as agroforestry species, a conservation plan of these species has higher priority. The native's species in Portugal forest they were very threats in these last years. Also, *Ceratonia siliqua* had demonstrated a strong carbon sequestration potentiality with lowest carbon emissions comparing to all other species, recommending that it be more used in agroforestry.

Secondly, the silviculture techniques and species selection must take into account the climate change as the reduction of afforestation density would increase the probability of survival of trees decreasing water consumption and fires risk in the center zones.

Thirdly, improvements in plans for the monitoring of disturbances (fires, insects and diseases), especially against forest fires (the most serious natural disaster occurring in Portugal's forests in the north and central regions), and also against pine nematodes.

We also highlight that the sustainable development of private forest ecosystems is a key factor for a greater forest exploitability and a greater contribution to mitigate climate change. This policy must focus primarily on:

- Strengthen the capacity of actors in the private forestry sector to guide the management of their forests, producing products with higher added value and more representative of the forest situation. Three tools are needed to achieve this goal are: First, describe the state of forest ecosystems. Second, bring the practices that promote ecosystem resilience, taking into consideration the cost and the productivity. Third, take into account the maintenance of the forest ecosystem functions.
- Improve knowledge on the state of private forests and produce reliable information to foresters about their properties,
- Provide solutions for the forest actors to apply the national forest policy to ensure sustainable management of forest ecosystems such as the development of integrate management (cooperation, association),
- To assess the productivity and increase the usability of wood,
- Orienting forest management to preserve favorable conditions for biodiversity,
- Choose adequate management practices to conserve forest ecosystems globally.

By and large, strategic forest conservation plans are required immediately in the southern regions and incentive measures of agroforestry. We propose to plant fast-growing species in the coastal areas as one important measure of climate change mitigation, while in the zones where the perturbations (fires) are more frequent, as the center and the northern regions, we need a good management plan, according to the species types and production objectives, accompanied by strict legislation for a better management. In addition, the measures of the natural risks attenuation (forest fire disturbance, insects and diseases) must be in urgency priority for Portugal government.

In order to get a better precision, the Portuguese Forest research actors should give more focus on the estimation of these factors (conversion, expansion, emissions) such as R, Cf, BCEF, fd...etc. Besides, the measurement of Iv and Sv according to PROF lead to more statistical bias during the forest inventory. As an alternative, the use of biomes seems to be more accurate due to the fact that this latest take into consideration the environmental conditions. Consequently, the adoption of advanced modules in carbon modeling should be considered. For instance, the Canadian MBC-SFC3 Modul.

References:

A. Moreno, M. N. and H. H. (2017). Forest structures across Europe. *Geoscience Data Journal*, *4*(1), 17–28.

A.Turbé et al. (2012). *disturbance of THE forest caused by biotic agents (Final report)*. European Commission.

Andrews, J. A., Harrison, K. G., Matamala, R., & Schlesinger, W. H. (1999). Separation of root respiration from total soil respiration using carbon-13 labeling during Free-Air Carbon Dioxide Enrichment (FACE). (F. A. O).

Apps, M. J., Kurz, W. A., Beukema, & Bhatti, &. (1999). Carbon budget of the Canadian forest product sector. *Environmental Science & Policy*, *2*(1), 25–41.

Arnaldo, P. S., Chacim, S., & Lopes, D. (2010). Effects of defoliation by the pine processionary moth Thaumetopoea pityocampa on biomass growth of young stands of Pinus pinaster in northern Portugal. *IForest - Biogeosciences and Forestry*, *3*(6), 159–162.

Ausherman, D. A., Kozma, A., Walker, J. L., Jones, H. M., & Poggio, E. C. (1984). Developments in Radar Imaging. *IEEE Transactions on Aerospace and Electronic Systems*, *AES-20*(4), 363–400. https://doi.org/10.1109/TAES.1984.4502060

Balzter, H. (2001). Forest mapping and monitoring with interferometric synthetic aperture radar (InSAR). *Progress in Physical Geography: Earth and Environment*, *25*(2), 159–177.

Barbero, M., Loisel, R., & Quézel, P. (1992). Biogeography, ecology and history of Mediterranean Quercus ilex ecosystems. *Vegetatio*, *99*(1), 19–34.

BENJAMIN, P., LUIZ, A., URSULA, H., MARLIES, G., JENS, H., FANNY, L., … WOLFGANG, C. (2010). Net biome production of the Amazon Basin in the 21st century. *Global Change Biology*, *16*(7), 2062–2075. https://doi.org/10.1111/j.1365-2486.2009.02064.x

Brack, C. L., & Richards, G. P. (2002). Carbon accounting model for forests in Australia. *Environmental Pollution*, *116*, S187–S194.

Breidenich, C., Magraw, D., Rowley, A., & Rubin, J. W. (1998). The Kyoto Protocol to the United Nations Framework Convention on Climate Change. *American Journal of International Law*, *92*(2), 315–331. https://doi.org/DOI: 10.2307/2998044

Brown. (2005). Linking the global carbon cycle to individual metabolism. *Functional Ecology*, *19*(2), 202–213. https://doi.org/10.1111/j.1365-2435.2005.00952.x

Brown, S., & Nations., F. and A. O. of the U. (1997). *Estimating biomass and biomass change of tropical forests : a primer*. Rome: Food and Agriculture Organization of the United Nations.

Butler, B. W., Ottmar, R. D., Rupp, T. S., Jandt, R., Miller, E., Howard, K., … Jimenez, D. (2012). Quantifying the effect of fuel reduction treatments on fire behavior in boreal forests. *Canadian Journal of Forest Research*, *43*(1), 97–102. https://doi.org/10.1139/cjfr-2012-0234

Canadell, J. G., Kirschbaum, M. U. F., Kurz, W. A., Sanz, M.-J., Schlamadinger, B., & Yamagata, Y. (2007). Factoring out natural and indirect human effects on terrestrial carbon sources and sinks. *Environmental Science & Policy*, *10*(4), 370–384.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., … Kira, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*(1), 87–99.

Cracknell, A. P. (2007). *Introduction to Remote Sensing, Second Edition*. CRC Press.

Croitoru, L., Merlo, M. (2005). *Valuing Mediterranean forests: towards total economic value. Forest Policy and Economics* (Vol. 10). Padua, Italy: The University of Padova.

DALE, V. H., JOYCE, L. A., MCNULTY, S., NEILSON, R. P., AYRES, M. P., FLANNIGAN, M. D., … MICHAEL WOTTON, B. (2001). Climate Change and Forest Disturbances. *BioScience*, *51*(9), 723–734. https://doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2

de Lima, M. I. P., Santo, F. E., Ramos, A. M., & de Lima, J. L. M. P. (2013). Recent changes in daily precipitation and surface air temperature extremes in mainland Portugal, in the period 1941–2007. *Atmospheric Research*, *127*, 195–209. https://doi.org/https://doi.org/10.1016/j.atmosres.2012.10.001

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A., Trexier, M. C., & Wisniewski, J. (1994). Carbon Pools and Flux of Global Forest Ecosystems. *Science*, *263*(5144),185 LP-190. Retrieved from http://science.sciencemag.org/content/263/5144/185.abstract

Doerr, S. H., Shakesby, R. A., & Walsh, R. P. D. (1998). SPATIAL VARIABILITY OF SOIL HYDROPHOBICITY IN FIRE-PRONE EUCALYPTUS AND PINE FORESTS, PORTUGAL. *Soil Science*, *163*(4).

DOUROZONE. (2018). O objetivo do projeto DOUROZONE é avaliar o risco de exposição ao ozono das vinhas da Região Demarcada do Douro em clima presente e futuro. In *Conference*. vila real, portugal. Retrieved from http://dourozone.web.ua.pt/pt

Dubayah, R. O., & Drake, J. B. (2000). Lidar Remote Sensing for Forestry. *Journal of Forestry*, *98*(6), 44–46.

Ellison, D., Lundblad, M., & Petersson, H. (2011). Carbon accounting and the climate politics of forestry. *Environmental Science & Policy*, *14*(8), 1062–1078. https://doi.org/https://doi.org/10.1016/j.envsci.2011.07.001

ESRI. (2013). ArcGIS for Desktop. Retrieved January 12, 2018, from http://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/types-of-lidar.htm

F. Westlake, D. (1966). *The Biomass and Productivity of Glyceria Maxima: I. Seasonal Changes in Biomass*. *The Journal of Ecology* (Vol. 54).

FAO. (2016). *State of the World's Forests*. Costa Rica; Georgia; Viet Nam; Tunisia; Gambia;Ghana;Retrieved from http://www.fao.org/documents/card/en/c/b7632255-54bb-478c-bd2c-7a70129565de/

Feliciano, D. M. S., Alves, R., Mendes, A., Ribeiro, M., & Sottomayor, M. (2015). Forest Land Ownership Changes in Portugal. European Forest Institute Central-East and South-East European Regional Office.

Fernandes, P. M., Vega, J. A., Jiménez, E., & Rigolot, E. (2008). Fire resistance of European pines. *Forest Ecology and Management*, *256*(3), 246–255.

Foley, H. K. G. and S. B. and J. O. N. and J. A. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters*, *2*(4), 45023.

GERALDO, D. R. de B. (2011). *Avaliação da alfarrobeira como sumidouro de carbono e o mercado de carbono*. Universidade do Algarve.

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., … Tempio, G. (2013). *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities.* Rome: Food and Agriculture Organization of the United Nations (FAO).

Goetz, S., & Dubayah, R. (2011). Advances in remote sensing technology and implications for measuring and monitoring forest carbon stocks and change. *Carbon Management*, *2*(3), 231–244. https://doi.org/18

Goetz, S. J., Baccini, A., Laporte, N. T., Johns, T., Walker, W., Kellndorfer, J., … Sun, M. (2009). Mapping and monitoring carbon stocks with satellite observations: a comparison of methods. *Carbon Balance and Management*, *4*, 2.

Golub, A., Hertel, T., Lee, H.-L., Rose, S., & Sohngen, B. (2009). The opportunity cost of land use and the global potential for greenhouse gas mitigation in agriculture and forestry. *Resource and Energy Economics*, *31*(4), 299–319.

Gómez Almaraz, C. (2014). *Assesment of biomass and carbon dynamics in pine forests of the Spanish central range: A remote sensing approach*. Universidad de Valladolid.

Gonçalves,J.A, Fernandes, 2005. Assessment of SRTM-3 DEM in Portugal with topographic map data. EARSel 3D remonte sensing workshop,Porto, Portuugal

Gonçalves,J.A, Morgado, A., 2008 use of the SRTM DEM as geo-referencing tool by elevation matching. Internaltional Archives photogrammetry, Remote sensing and spatial information sciences. vol.XXXVII part B2, 879-883. Beijing.

Graham, R. T., Harvey, A. E., Jain, T. B., & Tonn, J. R. (1999). Effects of thinning and similar stand treatments on fire behavior in western forests.

Grau, E., Durrieu, S., Fournier, R., Gastellu-Etchegorry, J.-P., & Yin, T. (2017). *Estimation of 3D vegetation density with Terrestrial Laser Scanning data using voxels. A sensitivity analysis of influencing parameters*. *Remote Sensing of Environment* (Vol. 191).

Greenhalgh, S., Daviet, F., & Weninger, E. (2006). land use, land-use change, and forestry guidance for GHG project accounting. (F. A. O. of the UN, Ed.).

Gulbeyaz, O., Bond-Lamberty, B., Akyurek, Z., & West, T. O. (2018). A new approach to evaluate the MODIS annual NPP product (MOD17A3) using forest field data from Turkey. *International Journal of Remote Sensing*, *39*(8), 2560–2578.

Havlík, P., Schneider, U. A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., … Obersteiner, M. (2011). Global land-use implications of first and second generation biofuel targets. *Energy Policy*, *39*(10), 5690–5702. https://doi.org/https://doi.org/10.1016/j.enpol.2010.03.030

Held, A. (2015). *Scoping Study for a European Forest Risk Facility*.

ICNF. (2013). *Áreas dos usos do solo e das espécies florestais de Portugal continental*. Retrieved from http://www2.icnf.pt/portal/florestas/ifn/ifn6

ICNF. (2014). O que são os PROF? — ICNF. Retrieved March 29, 2018, from http://www2.icnf.pt/portal/florestas/profs/obj

IPCC. (2006a). *2006 IPCC Guidelines for National Greenhouse Gas Inventories,Volume 4'' Agriculture, Forestry and Other Land Use'': Introduction*. Geneva: IPCC organisation.

IPCC. (2006b). *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Vol. 3). Geneva.

IPCC. (2006c). *General methodologies applicable to multiple land-use categories*. Geneva: IPCC organisation.

IPCC. (2013). *Sea level change*. (C. X. (China) Jean Jouzel (France), Roderik van de Wal (Netherlands), Philip L. Woodworth (UK), Ed.). Cambridge, United Kingdom and New York, NY, USA.: PM Cambridge University Press.

J., H., R., R., M., S., & K., L. (2010). GLOBAL SURFACE TEMPERATURE CHANGE. *Reviews of Geophysics*, *48*(4). https://doi.org/10.1029/2010RG000345

James, P. M. A., Fortin, M.-J., Fall, A., Kneeshaw, D., & Messier, C. (2007). The Effects of Spatial Legacies following Shifting Management Practices and Fire on Boreal Forest Age Structure. *Ecosystems*, *10*(8), 1261–1277. https://doi.org/10.1007/s10021-007-9095-y

K, S., T., B., F., C., E., D. K., J., M., & A., R. (2003). Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. *European Journal of Soil Science*, *54*(4), 779–791. https://doi.org/10.1046/j.1351-0754.2003.0567.x

Keeling, C. D. (1979). The Suess effect: 13Carbon-14Carbon interrelations. *Environment International*, *2*(4), 229–300.

Kull, S.J; Rampley, G.J.; Morken, S.; Metsaranta, J.; Neilson, E. T. . K. (C. F. S. (2014). *Operational-scale carbon budget model of the Canadian forest sector (CBM-CFS3) version 1.2: user's guide.* Edmonton,, Alberta: Canadian Forest Service.

Kurz, W. A., & Apps, M. J. (2006). Developing Canada's National Forest Carbon Monitoring, Accounting and Reporting System to Meet the Reporting Requirements of the Kyoto Protocol. *Mitigation and Adaptation Strategies for Global Change*, *11*(1), 33–43.

L., S. S., J., M. J., Carl, E., E., F. C., Sally, H., Michael, H., … Andrew, Y. (2009). Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. *Ecological Applications*, *19*(2), 305–320. https://doi.org/10.1890/07-1755.1

L.DRAIOUI, & R.MEDESSI. (2014). *Caractérisation d'une essence végétale à partir de données LiDAR aéroporté*. Institut agronomique et vétérinaire Hassan II.

Le Quéré C, Moriarty R, Andrew RM, Canadell JG, Sitch S, Korsbakken JI, Friedlingstein P, Peters GP, Andres RJ, Boden TA, et al. (2017). Global Carbon Budget 2017. journal Earth Syst. Sci. Data.

Le Toan, T., Quegan, S., Woodward, I., Lomas, M., Delbart, N., & Picard, G. (2004). Relating Radar Remote Sensing of Biomass to Modelling of Forest Carbon Budgets. *Climatic Change*, *67*(2), 379–402. https://doi.org/10.1007/s10584-004-3155-5

Li, Z.; Kurz, W.A.; Apps, M.J.; Beukema, S. . (2003). Le modèle du bilan du carbone | Ressources naturelles Canada. https://doi.org/126-136

Liu, G., & Han, S. (2009). Long-term forest management and timely transfer of carbon into wood products help reduce atmospheric carbon. *Ecological Modelling*, *220*(13), 1719–1723.

Lobert, J. M., Scharffe, D. H., Hao, W. M., & Crutzen, P. J. (1990). Importance of biomass burning in the atmospheric budgets of nitrogen-containing gases. *Nature*, *346*, 552. Retrieved from http://dx.doi.org/10.1038/346552a0

Lohmann, L. (2009). Toward a different debate in environmental accounting: The cases of carbon and cost–benefit. *Accounting, Organizations and Society*, *34*(3), 499–534.

Lopes, D Manuel, M. (2005). *Estimating net primary production in'Eucalyptus globulus' and'Pinus pinaster'ecosystems in Portugal*. Kingston University and Universidade de Trás-os-Montes e Alto Douro,Vila Real, p. 291.

Lovett, G. M., Canham, C. D., Arthur, M. A., Weathers, K. C., & Fitzhugh, R. D. (2006). Forest ecosystem responses to exotic pests and pathogens in eastern North America. *BioScience*, *56*(5), 395–405.

Luther, J. E., Fournier, R. A., Piercey, D. E., Guindon, L., & Hall, R. J. (2006). Biomass mapping using forest type and structure derived from Landsat TM imagery. *International Journal of Applied Earth Observation and Geoinformation*, *8*(3), 173–187.

Malhi, Y., Meir, P., & Brown, S. (2002). Forests, carbon and global climate. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *360*(1797), 1567 LP-1591.

Maniatis, D., & Mollicone, D. (2010). Options for sampling and stratification for national forest inventories to implement REDD+ under the UNFCCC. *Carbon Balance and Management*, *5*(1), 9. https://doi.org/10.1186/1750-0680-5-9

Marland, G., & Schlamadinger, B. (1999). The Kyoto Protocol could make a difference for the optimal forest-based CO2 mitigation strategy: some results from GORCAM. *Environmental Science & Policy*, *2*(2), 111–124.

Martín, L. D., Diez, A. G., & Soriano, E. L. G. (1997). Meteorology and Forest Fires: Conditions for Ignition and Conditions for Development. *Journal of Applied Meteorology*, *36*(6), 705–710.

Meer, F. van der, Jong, S. De, & Bakker, W. (2001). Imaging Spectrometry: Basic Analytical Techniques BT - Imaging Spectrometry: Basic Principles and Prospective Applications. In F. D. van der Meer & S. M. De Jong (Eds.) (pp. 17–61). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-0-306-47578-8_2

Miranda, A. I., Coutinho, M., & Borrego, C. (1994). Forest fire emissions in Portugal: A contribution to global warming? *Environmental Pollution*, *83*(1), 121–123. https://doi.org/https://doi.org/10.1016/0269-7491(94)90029-9

Moomaw, W., Burgherr, P., Heath, G., Lenzen, M., Nyboer, J., & Verbrugge, A. (2011). IPCC special report on renewable energy sources and climate change mitigation. *Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., Eds*.

Mota, M., Braasch, H., Antonia Bravo, M., Catarina Penas, A., Burgermeister, W., Metge, K., & Sousa, E. (1999). *First report of Bursaphelenchus xylophilus in Portugal and in Europe*. *Nematology* (Vol. 1).

N, B. M., C, C. M., S, P. J., James, A., & G, P. J. (2011). Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. *Frontiers in Ecology and the Environment*, *9*(5), 278–286. https://doi.org/10.1890/100084

Nabuurs, G.-J., Schelhaas, M. J., & Pussinen, A. (2000). *Validation of the European Forest Information Scenario Model (EFISCEN) and a Projection of Finnish Forests*. *Silva Fennica 34 (2000), 2: 167-179* (Vol. 34).

NASA. (2001). MODIS Web. Retrieved February 13, 2018, from https://modis.gsfc.nasa.gov/

Natural Resources Canada. (2016). Concepts of Aerial Photography. Retrieved February 2, 2018, from http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/air-photos/about-aerial-photography/9687

NAVIN, R., K., G. H., FRÉDÉRIC, A., RUTH, D., A., F. J., & A., H. R. (2006). Challenges to estimating carbon emissions from tropical deforestation. *Global Change Biology*, *13*(1), 51–66. https://doi.org/10.1111/j.1365-2486.2006.01272.x

Nemani, R. R., Keeling, C. D., Hashimoto, H., Jolly, W. M., Piper, S. C., Tucker, C. J., … Running, S. W. (2003). Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. *Science*, *300*(5625), 1560 LP-1563. Retrieved from http://science.sciencemag.org/content/300/5625/1560.abstract

NOAA. (2017). Climate Change: Vital Signs of the Planet: Carbon Dioxide. Retrieved February 18, 2018, from https://climate.nasa.gov/vital-signs/carbon-dioxide/

Noble, I., Bolin, B., Ravindranath, N. H., Verardo, D. J., & Dokken, D. J. (2000). *Land use, land use change, and forestry*. Cambridge University Press.

OCDE. (2011). *LES PERFORMANCES ENVIRONNEMENTALES DU PORTUGAL SE SONT AMÉLIORÉES MAIS LE PAYS DEMEURE CONFRONTÉ À UNE SITUATION ÉCONOMIQUE DIFFICILE*. Paris. Retrieved from https://data.oecd.org/fr/air/emissions-de-ges-et-de-polluants-de-l-air.htm

P. Turner, D., D. Ritts, W., B. Cohen, W., Gower, S., W. Running, S., Zhao, M., … E. Ahl, D. (2006). *Evaluation of MODIS NPP and GPP products across multiple biomes*. *Remote Sensing of Environment* (Vol. 102). https://doi.org/10.1016/j.rse.2006.02.017

Palma, J. H. N., Paulo, J. A., & Tomé, M. (2014). Carbon sequestration of modern Quercus suber L. silvoarable agroforestry systems in Portugal: a YieldSAFE-based estimation. *Agroforestry Systems*, *88*(5), 791–801. https://doi.org/10.1007/s10457-014-9725-2

Plan bleu. (2016). *Mediterranean Strategy for Sustainable Development 2016-2025: Investing in environmental sustainability to achieve social and economic development*. ((UNEP/MAP), Ed.). Valbonne: Environment and development in the Mediterranean.

Pons, A., & Quézel, P. (1998). On the installation of the Mediterranean climate. *Comptes Rendus de l'Académie Des Sciences - Series IIA - Earth and Planetary Science*, *327*(11), 755–760.

Pretzsch, H. (2009). Forest Dynamics, Growth, and Yield BT - Forest Dynamics, Growth and Yield: From Measurement to Model. In H. Pretzsch (Ed.) (pp. 1–39). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-88307-4_1

Rehg, W., & Staley, K. (2017). "Agreement" in the IPCC Confidence measure. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics ,57*,126–134. https://doi.org/https://doi.org/10.1016/j.shpsb.2016.10.008

Reis, A. R., Ferreira, L., Tomé, M., Araujo, C., & Branco, M. (2012). Efficiency of biological control of Gonipterusplatensis (Coleoptera: Curculionidae) by Anaphes nitens (Hymenoptera: Mymaridae) in cold areas of the Iberian Peninsula: Implications for defoliation and wood production in Eucalyptus globulus. *Forest Ecology and Management*, *270*, 216–222. https://doi.org/https://doi.org/10.1016/j.foreco.2012.01.038

Robert, M., & Saugier, B. (2003). Contribution des écosystèmes continentaux à la séquestration du carbone. *Comptes Rendus Geoscience*, *335*(6), 577–595. https://doi.org/https://doi.org/10.1016/S1631-0713(03)00094-4

Robinson, N. P., Allred, B. W., Smith, W. K., Jones, M. O., Moreno, A., Erickson, T. A., … Running, S. W. (2018). Terrestrial primary production for the conterminous United States derived from Landsat 30 m and MODIS 250 m. *Remote Sensing in Ecology and Conservation*, 17. https://doi.org/10.1002/rse2.74

RODRIGO, A., QUINTANA, V., & RETANA, J. (2007). Fire reduces Pinus pinea distribution in the northeastern Iberian Peninsula. *Ecoscience*, *14*(1), 23–30.

RUNNING, Steven et ZHAO, M. (2011). Note to users on use of MODIS GPP/NPP (MOD17) datasets. *Numerical Terradynamic Simulation Group*. Missoula.

Running, S. W., Nemani, R., Glassy, J. M., & Thornton, P. E. (1999). MODIS daily photosynthesis (PSN) and annual net primary production (NPP) product (MOD17) Algorithm Theoretical Basis Document. *University of Montana, SCF At-Launch Algorithm ATBD Documents (Available Online at: Www. Ntsg. Umt. Edu/Modis/ATBD/ATBD_MOD17_v21. Pdf)*.

Running, S. W., Thornton, P. E., Nemani, R., & Glassy, J. M. (2000). Global Terrestrial Gross and Net Primary Productivity from the Earth Observing System. In O. E. Sala, R. B. Jackson, H. A. Mooney, & R. W. Howarth (Eds.) (pp. 44–57). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4612-1224-9_4

Running, S. W., & Zhao, M. (2015). *User's Guide Daily GPP and Annual NPP (MOD17A2/A3) Products NASA Earth Observing System MODIS Land Algorithm*. MONTANA: MODIS Land Team.

S Kasischke, E., M Melack, J., & Craig Dobson, M. (1997). *The use of imaging radars for ecological applications — a review. Remote Sens Environ 59:141-156. Remote Sensing of Environment* (Vol. 59).

Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T. A., Salas, W., … Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, *108*(24), 9899 LP-9904.

Saboori, B., Sapri, M., & bin Baba, M. (2014). Economic growth, energy consumption and CO2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: A fully modified bi-directional relationship approach. *Energy*, *66*, 150–161. https://doi.org/https://doi.org/10.1016/j.energy.2013.12.048

Sajwaj, T. (2008). *Forest Management Impacts on Ecosystem Services*. (E. Review, Ed.). United Kingdom: University of North Texas Libraries.

Sánchez-Costa, E., Poyatos, R., & Sabaté, S. (2015). Contrasting growth and water use strategies in four co-occurring Mediterranean tree species revealed by concurrent measurements of sap flow and stem diameter variations. *Agricultural and Forest Meteorology*, *207*, 24–37. https://doi.org/https://doi.org/10.1016/j.agrformet.2015.03.012

Schelhaas, M. J., Esch, Groen, T., Jong, H., Jong, B., Kanninen, M., … Vilén, T. (2004). *CO2FIX V 3.1 A modelling framework for quantifying carbon sequestration in forest ecosystems*. Alterra, Wageningen: researchgate.

Sethi, M. institute of U. A. (2017). *Climate Change and Urban Settlements A Spatial Perspective of Carbon Footprint and Beyond*. *Climate Change and Urban Settlements: A Spatial Perspective of Carbon Footprint and Beyond*. London: Routledge, Taylor & Franci.

Silva, J. S., & Catry, F. (2006). Forest fires in cork oak (Quercus suber L.) stands in Portugal. *International Journal of Environmental Studies*, *63*(3), 235–257.

Tomiyasu, K. (1978). Tutorial review of synthetic-aperture radar (SAR) with applications to imaging of the ocean surface. *Proceedings of the IEEE*, *66*(5), 563–583. https://doi.org/10.1109/PROC.1978.10961

Tubiello, F. N., Cóndor-Golec, R. D., Salvatore, M., Piersante, A., Federici, S., Ferrara, A., … (FAO). (2015). *Estimating greenhouse gas emissions in agriculture: a manual to address data requirements for developing countries.* Rome: Food and Agriculture Organization of the United Nations (FAO).

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution*, *18*(6), 306–314. https://doi.org/https://doi.org/10.1016/S0169-5347(03)00070-3

Van der Werf, G. R., Morton, D., Defries, R., G. J. Olivier, J., Kasibhatla, P. S., Jackson, R. B., … Randerson, J. T. (2009). *CO2 emissions from forests*. *Nature Geoscience* (Vol. 2). https://doi.org/10.1038/ngeo671

Vans, D. L., & Plaut, J. (1996). *Science Results from the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR): Progress Report*. Los Angeles: NASA,Jet Propulsion Laboratoly California Institute of Technology Pasadena, California.

Vega, C., & Durrieu, S. (2010). *Extraction de paramètres d'arbre à partir de modèles numériques de canopée lidar*. *Revue Francaise de Photogrammetrie et de Teledetection* (Vol. 191).

Viana, H., Aranha, J., Lopes, D., & Cohen, W. B. (2012). Estimation of crown biomass of Pinus pinaster stands and shrubland above-ground biomass using forest inventory data, remotely sensed imagery and spatial prediction models. *Ecological Modelling*, *226*, 22–35. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2011.11.027

Wang, L., Gong, W., Ma, Y., & Zhang, M. (2013). Modeling Regional Vegetation NPP Variations and Their Relationships with Climatic Parameters in Wuhan, China. *Earth Interactions*, *17*(4), 1–20. https://doi.org/10.1175/2012EI000478.1

Wang, S., Zhou, L., Chen, J., Ju, W., Feng, X., & Wu, W. (2011). Relationships between net primary productivity and stand age for several forest types and their influence on China's carbon balance. *Journal of Environmental Management*, *92*(6), 1651–1662. https://doi.org/https://doi.org/10.1016/j.jenvman.2011.01.024

Watson, C. (2009). *Forest carbon accounting: overview and principles*. New York: United Nations Development Programme (UNDP).

Wehr, A., & Lohr, U. (1999). Airborne laser scanning—an introduction and overview. *ISPRS Journal of Photogrammetry and Remote Sensing*, *54*(2), 68–82.

Weibring, P., Edner, H., & Svanberg, S. (2003). Versatile mobile lidar system for environmental monitoring. *Applied Optics*, *42*(18), 3583–3594. https://doi.org/10.1364/AO.42.003583

Wu, Hao Xu, C. (2013). Comparison of Spatial Interpolation Methods for Precipitation in Ningxia, China. *International Journal of Science and Research*, *2*, *no*, 198–184.

Wuebbles, D. J., & Jain, A. K. (2001). Concerns about climate change and the role of fossil fuel use. *Fuel Processing Technology*, *71*(1), 99–119.

Zandler, H., Brenning, A., & Samimi, C. (2015). *Quantifying dwarf shrub biomass in an arid environment: Comparing empirical methods in a high dimensional setting*. *Remote Sensing of Environment* (Vol. 158).

Zhao, M., & Running, S. W. (2010). Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009. *Science*, *329*(5994), 940 LP-943.

Zhong, Y., Ma, A., Ong, Y. soon, Zhu, Z., & Zhang, L. (2018). Computational intelligence in optical remote sensing image processing. *Applied Soft Computing*, *64*, 75–93. https://doi.org/https://doi.org/10.1016/j.asoc.2017.11.045

Annexes:

annex 1: Benefits and limitations of available methods to estimate national-level forest carbon stocks (Holly K Gibbs et al 2007).

Method	Description	Benefits	Limitations	Uncertainty
Biome averages	Estimates of average forest carbon stocks for broad forest categories based on a variety of input data sources.	• Immediately available at no cost • could increase accuracy Data refinements • Globally consistent	• Fairly generalized • data sources data not properly sampled to describe large areas	High
Forest inventory	Relates ground-based measurements of tree diameters or volume to forest carbon stocks using allometric relationships	• Generic relationships readily available • Low-tech method widely understood • Can be relatively inexpensive as field-labor is largest cost	• Generic relationships not appropriate for all regions • Can be expensive and slow • Challenging to produce globally consistent results	Low
Optical remote sensors	• Uses visible and infrared wavelengths to measure spectral indices and correlate to ground based forest carbon measurements Ex: Landsat, MODIS	• Satellite data routinely collected and freely available at global scale • Globally consistent	• Limited ability to develop good models for tropical forests • Spectral indices saturate at relatively low C stocks • Can be technically demanding	High
Optical remote sensors	• Uses very high resolution (~10–20 cm) images to measure tree height and crown area and allometry to estimate carbon stocks • Ex: Aerial photos, 3D digital aerial imagery	• Reduces time and cost of collecting forest inventory data • Reasonable accuracy • Excellent ground verification for deforestation baseline	• Only covers small areas (10 000s ha) • Can be expensive and technically demanding • No allometric relations based on crown area are available	Low to medium
Radar remote sensors	Uses microwave or radar signal to measure forest vertical structure • Ex: ALOS PALSAR, ERS-1, JERS-1, Envisat)	• Satellite data are generally free • New systems launched in 2005 expected to provide improved data • Can be accurate for young or sparse forest	• Less accurate in complex canopies of mature forests because signal saturates • Mountainous terrain also increases errors • Can be expensive and technically demanding	Medium
Laser remote sensors	• LiDAR uses laser light to estimates forest height/vertical structure • Ex: Carbon 3-D satellite system combines Vegetation canopy LiDAR (VCL) with horizontal imager	• Accurately estimates full spatial variability of forest carbon stocks • Potential for satellite based system to estimate global forest carbon stocks.	• Airplane-mounted sensors only option • Satellite system not yet funded • Requires extensive field data for calibration • Can be expensive and technically demanding	Low to medium

annex 2:Default Biomass Conversion and Expansion Factors (BCEF), tones biomass (m^3 of wood volume)$^{-1}$ (IPCC, 2006)

BCEF for expansion of merchantable growing stock volume to above-ground biomass ($BCEF_S$), for conversion of net annual increment ($BCEF_I$) and for conversion of wood and firewood removal volume to above-ground biomass removal ($BCEF_R$) (BEF =Total volume of trees/ha)/(merchantable volume of trees/ha) and BCEF (in t/m3) = BEF x density (t/m3))							
Climatic zone	**Forest type**	**BCEF**	**Growing stock level (m^3/ha)**				
			<20	**21-40**	**41-100**	**100 -200**	**>200**
Temperate	hardwoods	$BCEF_S$	3.0 (0.8-4.5)	1.7 (0.8-2.6)	1.4 (0.7-1.9)	1.05 (0.6-1.4)	0.8 (0.55-1.1)
		$BCEF_I$	1.5	1.3	0.9	0.6	0.48
		$BCEF_R$	3.33	1.89	1.55	1.17	0.89
	pines	$BCEF_S$	1.8 (0.6 -2.4)	1.0 (0.65 -1.5)	0.75 (0.6-1.0)	0.7 (0.4-1.0)	0.7 (0.4-1.0)
		$BCEF_I$	1.5	0.75	0.6	0.67	0.69
		$BCEF_R$	2.0	1.11	0.83	0.77	0.77
	other conifers	$BCEF_S$	3.0 (0.7-4.0)	1.4 (0.5-2.5)	1.0 (0.5-1.4)	0.75 (0.4-1.2)	0.7 (0.35-0.9)
		$BCEF_I$	1.0	0.83	0.57	0.53	0.60
		$BCEF_R$	3.33	1.55	1.11	0.83	0.77

Sources: TABLE 4.5 in 2006 IPCC guidelines V4 chp2 Forêts tempérées : Fang J. et al., 2001 ; Fukuda M. et al., 2003 ; Schroeder P. et al., 1997 ; Snowdon P. et.al., 2000 ; Smith J. et. al., 2002; Brown S., 1999; Schoene D. et A. Schulte, 1999; Smith J. et al., 2000

annex 3:Carbon fraction of aboveground forest biomass (IPPC,2006)

Domain	Part of tree	Carbon fraction, (CF) [tonne C (tonne d.m.)$^{-1}$]	References
Default value	All	0.47	McGroddy et al., 2004
Tropical and Subtropical	All	0.47 (0.44 - 0.49)	Andreae and Merlet, 2001; Chambers et al., 2001; McGroddy et al., 2004; Lasco and Pulhin, 2003
	wood	0.49	Feldpausch et al., 2004
	wood, tree d < 10 cm	0.46	Hughes et al., 2000
	wood, tree d ≥ 10 cm	0.49	Hughes et al., 2000
	foliage	0.47	Feldpausch et al., 2004
	foliage, tree d < 10 cm	0.43	Hughes et al., 2000
	foliage, tree d ≥ 10 cm	0.46	Hughes et al., 2000
Temperate and Boreal	All	0.47 (0.47 - 0.49)	Andreae and Merlet, 2001; Gayoso et al., 2002; Matthews, 1993; McGroddy et al., 2004
	broad-leaved	0.48 (0.46 - 0.50)	Lamlom and Savidge, 2003
	conifers	0.51 (0.47 - 0.55)	Lamlom and Savidge, 2003

annex 4:Ratio of below-ground biomass to above-ground biomass (R) (IPCC, 2006)

Domain	Ecological zone	Above-ground biomass	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	References
Tropical	Tropical rainforest		0.37	Fittkau and Klinge, 1973
	Tropical moist deciduous forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany et al., 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany et al., 2006
	Tropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany et al., 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany et al., 2006
	Tropical shrubland		0.40	Poupon, 1980
	Tropical mountain systems		0.27 (0.27 - 0.28)	Singh et al., 1994
Subtropical	Subtropical humid forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany et al., 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany et al., 2006
	Subtropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany et al., 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany et al., 2006
	Subtropical steppe		0.32 (0.26 - 0.71)	Mokany et al., 2006
	Subtropical mountain systems		no estimate available	
Temperate	Temperate oceanic forest, Temperate continental forest, Temperate mountain systems	conifers above-ground biomass < 50 tonnes ha^{-1}	0.40 (0.21 - 1.06)	Mokany et al., 2006
		conifers above-ground biomass 50-150 tonnes ha^{-1}	0.29 (0.24 - 0.50)	Mokany et al., 2006
		conifers above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.12 - 0.49)	Mokany et al., 2006
		Quercus spp. aboveground biomass >70 tonnes ha^{-1}	0.30 (0.20 - 1.16)	Mokany et al., 2006
		Eucalyptus spp. aboveground biomass < 50 tonnes ha^{-1}	0.44 (0.29 - 0.81)	Mokany et al., 2006
		Eucalyptus spp. aboveground biomass 50-150 tonnes ha^{-1}	0.28 (0.15 - 0.81)	Mokany et al., 2006
		Eucalyptus spp. aboveground biomass > 150 tonnes ha^{-1}	0.20 (0.10 - 0.33)	Mokany et al., 2006
		other broadleaf above-ground biomass < 75 tonnes ha^{-1}	0.46 (0.12 - 0.93)	Mokany et al., 2006
		other broadleaf above-ground biomass 75-150 tonnes ha^{-1}	0.23 (0.13 - 0.37)	Mokany et al., 2006
		other broadleaf above-ground biomass >150 tonnes ha^{-1}	0.24 (0.17 - 0.44)	Mokany et al., 2006
Boreal	Boreal coniferous forest, Boreal tundra woodland, Boreal mountain systems	above-ground biomass <75 tonnes ha^{-1}	0.39 (0.23 - 0.96)	Li et al., 2003; Mokany et al., 2006
		above-ground biomass >75 tonnes ha^{-1}	0.24 (0.15 - 0.37)	Li et al., 2003; Mokany et al., 2006

annex 5: Emission factors (g kg-1 dry matter burnt) for various types of burning. Values are means ± sd and are based on the comprehensive review by ANDREAE AND MERLET (IPCC)

Category	**CO_2**	**CO**	**CH_4**	**N_2O**	**NO_X**
Savanna and grassland	1613 ± 95	65 ± 20	2.3 ± 0.9	0.21 ± 0.10	3.9 ± 2.4
Agricultural residues	1515 ± 177	92 ± 84	2.7	0.07	2.5 ± 1.0
Tropical forest	1580 ± 90	104 ± 20	6.8 ± 2.0	0.20	1.6 ± 0.7
Extra tropical forest	1569 ± 131	107 ± 37	4.7 ± 1.9	0.26 ±0.07	3.0 ± 1.4
Biofuel burning	1550 ± 95	78 ± 31	6.1 ± 2.2	0.06	1.1 ± 0.6

annex 6:Combustion factor values (proportion of pre-fire fuel biomass consumed) for fires in a range of vegetation types (IPCC, 2006)

Vegetation type	**Subcategory**	**Mean**	**SD**
Primary tropical forest (slash and burn)	Primary tropical forest	0.32	0.12
	Primary open tropical forest	0.45	0.09
	Primary tropical moist forest	0.50	0.03
	Primary tropical dry forest	-	-
All primary tropical forests		0.36	0.13
Secondary tropical forest (slash and burn)	Young secondary tropical forest (3-5 yrs)	0.46	-
	Intermediate secondary tropical forest (6-10 yrs)	0.67	0.21
	Advanced secondary tropical forest (14-17 yrs)	0.50	0.10
All secondary tropical forests		0.55	0.06
All tertiary tropical forest		0.59	-
Boreal forest	Wildfire (general)	0.40	0.06
	Crown fire	0.43	0..21
	surface fire	0.15	0.08
	Post logging slash burn	0.33	0.13
	Land clearing fire	0.59	-
All boreal forest		0.34	0.17
Eucalyptus forests	Wildfire	-	-
	Prescribed fire – (surface)	0.61	0.11
	Post logging slash burn	0.68	0.14
	Felled and burned (land-clearing fire)	0.49	-
All *Eucalyptus* forests		0.63	0.13
Other temperate forests	Post logging slash burn	0.62	0.12
	Felled and burned (land-clearing fire)	0.51	-
All “other” temperate forests		0.45	0.16

Annex6 (CONTINUED)			
Vegetation type	**Subcategory**	**Mean**	**SD**
Shrublands	Shrubland (general)	0.95	-
	Calluna heath	0.71	0.30
	Fynbos	0.61	0.16
All shrublands		**0.72**	**0.25**
Savanna woodlands (early dry season burns)	Savanna woodland	0.22	-
	Savanna parkland	0.73	-
	Other savanna woodlands	0.37	0.19
All savanna woodlands (early dry season burns)		**0.40**	**0.22**
Savanna woodlands (mid/late dry season burns)	Savanna woodland	0.72	-
	Savanna parkland	0.82	0.07
	Tropical savanna	0.73	0.04
	Other savanna woodlands	0.68	0.19
All savanna woodlands (mid/late dry season burns)		**0.74**	**0.14**
Savanna Grasslands/ Pastures (early dry season burns)	Tropical/sub-tropical grassland	0.74	-
	Grassland	-	-
All savanna grasslands (early dry season burns)		**0.74**	**-**
Savanna Grasslands/ Pastures (mid/late dry season burns)	Tropical/sub-tropical grassland	0.92	0.11
	Tropical pasture~	0.35	0.21
	Savanna	0.86	0.12
All savanna grasslands (mid/late dry season burns)		**0.77**	**0.26**
Other vegetation types	Peatland	0.50	-
	Tropical Wetlands	0.70	-
Agricultural residues (Post harvest field burning)	Wheat residues	0.90	-
	Maize residues	0.80	-
	Rice residues	0.80	-
	Sugarcane [a]	0.80	-

annex 7: National average net annual increment for specific vegetation type, $m^3\ ha^{-1}\ yr^{-1}$

Species	Uncertain quantities	Uncertainties (%)
Pinus Pinaster	3,02	5
Pinus pinea	2,33	
Other Softwoods	2,36	
Eucalyptus sp.	4,81	
Quercus Suber	0,63	
Quercus Ilex	0,37	
Others Quercus	4,80	
Castanea sativa	1,30	
Acacias	2,10	
Ceratonia siliqua	1,00	
other broadleaves	4,80	

annex 8:Stand Volume (m3/ha) of forest trees in Portugal (NFI):

species		standing volume (m3/ha)		1995 (m^3)	2005(m^3)	2010 (m^3)
coniferous	Pinus pinaster	58	42	41633008	41614769	41598560
	Pinus pinea	21		3662758	3668024	3668614
	other Softwoods	48		791898	790734	788550
broadleaves	*Eucalyptus*	46	25,5	37479380	37486232	37491468
	Quercus Suber	20		14754357	14752784	14753919
	Quercus Ilex	11		5239727	5234205	5232978
	other Oaks	16		1044344	1041756	1041976
	Castanea sativa	22		900517	901088	901703
	Acacias	34		402963	402956	402876
	Ceratonia siliqua	32		173179	173381	173506
	other broadleaves	23		3024062	3016544	3016139

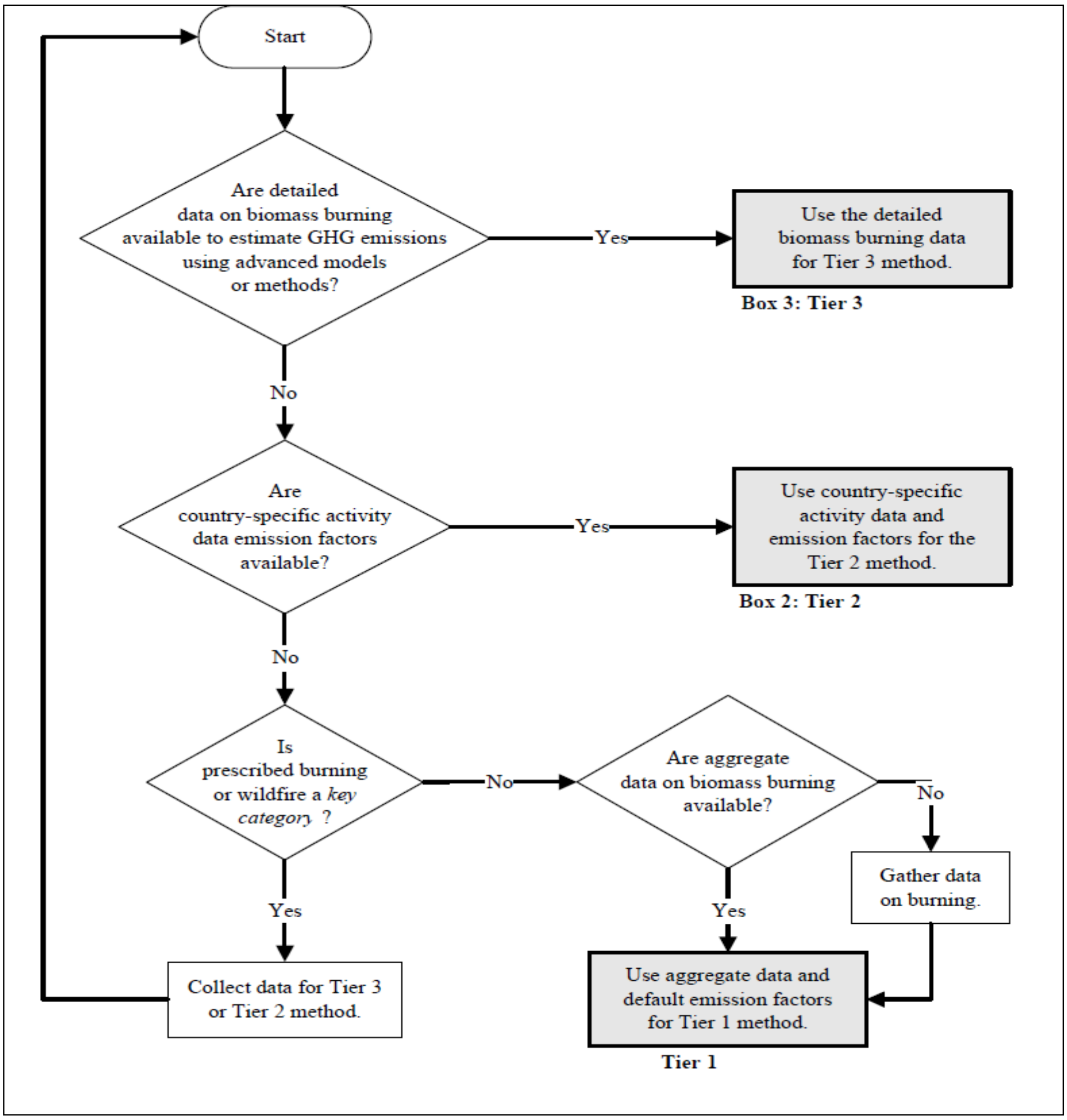
annex 9: Burned Area (ha) for each vegetation types in Portugal from 1995 until 2014 (ICNF)

Species /years	Softwoods				Hardwood									secondary specs	Shrub and herbaceous	forest total	Total (FORES + herbaceous)
	Pinus pinaster	*Pinus pinea*	other Softwoods	Total	*Eucalyptus*	Quercus suber	Quercus ilex	other Quercus	Castanea sativa	Acacias	*Ceratonia siliqua*	other broadleaves	total				
1995	51296	0	6080	57376	11731	5652	1598	5117	1280	106	0	4693	30178	0	82058	87554	169612
1996	12099	0	1434	13533	2767	1333	377	1207	302	25	0	1107	7118	377	57123	20651	78151
1997	3171	25	270	3466	1868	98	74	467	49	0	0	197	2753	98	11972	6219	18289
1998	30961	175	2129	33265	13451	2029	626	3933	225	125	0	2906	23295	1678	127275	56560	185513
1999	11709	75	899	12683	5368	1024	250	2047	150	50		999	9888	300	35376	22571	58247
2000	18291	198	1186	19675	7366	1409	222	2274	618	0	0	1532	13421	692	86115	33096	119903
2001	14208	449	499	15156	6417	2347	1224	1398	100	50	0	1448	12984	474	57955	28140	86569
2002	27202	351	1429	28982	12385	2482	1805	1956	226	25	25	1830	20734	1003	64734	49716	115453
2003	80179	2687	2185	85051	80355	41960	7383	2988	829	201	0	6077	139793	1682	156767	224844	383293
2004	9569	2099	500	12168	9494	8894	3048	700	50	25	25	1099	23335	150	64808	35503	100461
2005	88380	376	3356	92112	62384	1478	626	3206	426	225	0	8340	76685	3306	132407	168797	304510
2006	8678	275	625	9578	13030	875	375	475	50	75	0	1250	16130	75	37240	25708	63023
2007	2716	258	278	3252	2379	357	496	377	178	20	0	813	4620	278	19350	7872	27500
2008	1140	0	51	1191	1216	51	0	76	25	0	0	329	1697	0	6361	2888	9249
2009	4487	125	1047	5659	3864	548	573	873	274	25	0	1620	7777	349	63545	13436	77330
2010	14815	529	580	15924	13681	403	101	1184	25	0	0	2494	17888	1008	72010	33812	106830
2011	4984	50	897	5931	5906	349	573	748	224	50	0	1097	8947	0	49370	14878	64248
2012	14836	2327	926	18089	13460	5904	776	851	350	200	75	3578	25194	75	49360	43283	92718
2013	15863	75	1807	17745	13629	1004	301	929	627	75	0	3715	20280	376	88977	38025	127378
2014	666	74	74	814	1110	469	271	25	0	0	0	99	1974	0	7426	2788	10214

annex 10:Uncertain quantities of species area and their respective percentages of uncertainty (NFI)

	Uncertain quantities		percentage uncertainty	
	1995	2005	1995	2005
Pinus pinaster	977 883	795 489	9,00	5,64
Pinus pinea	120 129	172 791	13,93	9,56
other Softwoods	38 906	27 263	28,05	32,30
Eucalyptus sp.	717 246	785 762	6,71	5,92
Quercus suber	746 828	731 099	7,35	6,38
Quercus ilex	531 743	476 515	9,00	13,94
Other Quercus	91 897	66 016	11,58	18,08
Castanea sativa	32 633	38 334	23,22	32,30
Acacias	12 278	12 203	11,18	35,93
Ceratonia siliqua	2 701	4 726	11,18	23,47
other Hardwood	205 824	130 645	11,18	23,47

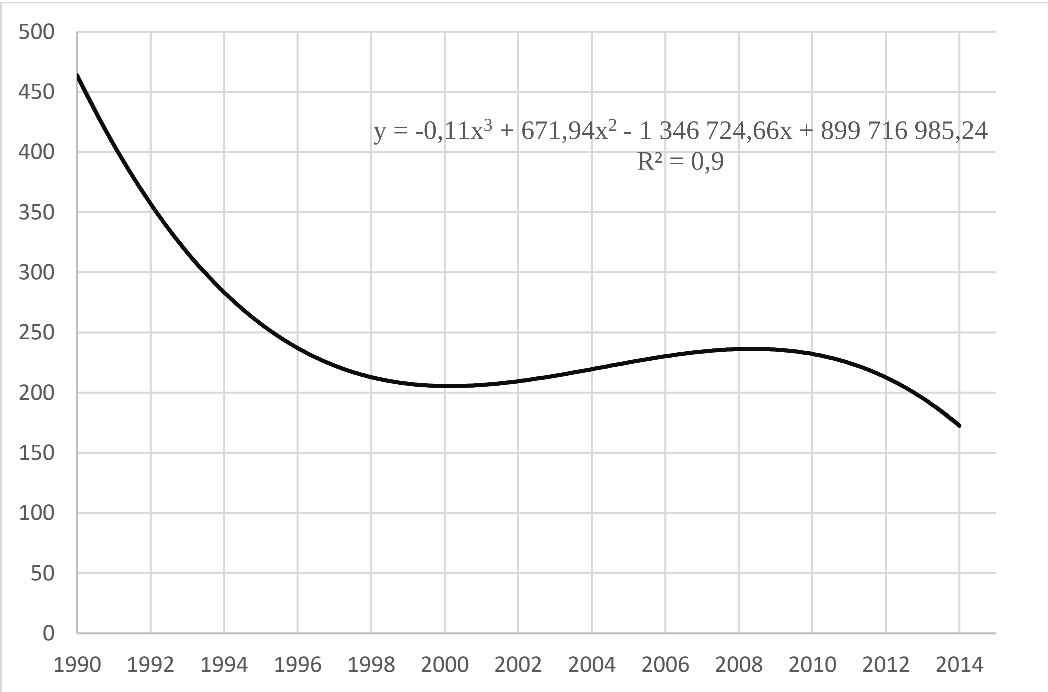
annex 11:Generic decision tree for identification of appropriate tier to estimate greenhouse gas emissions from a fire in a land-use category (IPCC, 2006)



annex 12:Total carbon sequestration (tCO2/yr) per species and the changes rate (%)

Vegetation type		Total carbon sequestration – (tC/year)			Total carbon sequestration (tCO2/year)			Evolution rate (%)
		1995	2005	2010	1995	2005	2010	
Coniferous	*Pinus pinaster*	1264398	1028563	923774	4636125	3771399	3387171	-27
	Pinus pinea	150014	215777	219462	550052	791183	804696	46
	other Coniferous	54427	38139	22863	199567	139845	83831	-58
	Total Coniferous	1468840	1282480	1166099	5385745	4702427	4275697	-21
Broadleaves	*Eucalyptus sp*	2099729	2300309	2376954	7699007	8434466	8715496	13
	Quercus suber	486749	476497	480197	1784745	1747157	1760721	-1
	Quercus ilex	200771	179919	177602	736161	659702	651209	-12
	other Oaks	453838	326024	331456	1664074	1195420	1215339	-27
	Castanea sativa	37812	44418	47982	138644	162866	175934	27
	Acacias	23045	22904	22153	84497	83980	81228	-4
	Ceratonia siliqua	1668	2919	3305	6116	10702	12117	98
	Other Broadleaves	880943	559171	550504	3230126	2050294	2018515	-38
	Total Broadleaves	4184556	3912160	3990152	15343371	14344588	14630559	-5
All Forest		5653395	5194640	5156252	20729116	19047015	18906256	**-10**

annex 13:Total Carbon losses by insect and diseases in Portugal for Eucalyptus and Pinus pinaster stands (1990-2014) (IPCC)



annex 14:Carbon losses by logging in coniferous and broadleaves stands (tC)

Years	Carbon losses in lumber wood (tons)			Carbon losses in industry wood (tons)			Carbon losses in Firewood. (tons)			Total Harvesting MtC
	Coniferous	Broadleaves	Total	Coniferous	Broadleaves	Total	Coniferous	Broadleaves	Total	
1995	274503	384001	658504	141220	186260	327479	5134	14884	20018	1,01
1996	255023	379701	634724	130980	183708	314688	5134	17246	22380	0,97
1997	255023	379701	634724	130980	183708	314688	5134	17246	22380	0,97
1998	233600	373181	606780	120269	179267	299535	5550	18900	24450	0,93
1999	233378	414194	647571	120158	199773	319931	5550	18900	24450	0,99
2000	277889	513513	791402	142413	249433	391846	5550	18900	24450	1,21
2001	209957	451049	661005	108447	218201	326648	5550	18900	24450	1,01
2002	172605	495369	667974	89771	240361	330132	5550	18900	24450	1,02
2003	186314	560007	746321	96626	272680	369305	5550	18900	24450	1,14
2004	222111	612077	834188	114524	298715	413239	5550	18900	24450	1,27
2005	182784	667438	850222	94861	326395	421256	5550	18900	24450	1,30
2006	195687	650986	846673	101312	318169	419482	5550	18900	24450	1,29
2007	203240	639884	843124	105089	312568	417656	5550	18900	24450	1,29
2008	174307	627299	801606	90622	306326	396948	5550	18900	24450	1,22
2009	191167	541449	732616	99052	263401	362453	5550	18900	24450	1,12
2010	192912	546363	739275	99984	265878	365861	5550	18900	24450	1,13
2011	196683	664509	861192	101515	324830	426345	5550	18900	24450	1,31
2012	158605	699461	858067	83996	349019	433015	5550	18900	24450	1,32
2013	133469	739153	872622	67078	366585	433662	5550	18900	24450	1,33
2014	149433	758288	907721	74923	383848	458771	5550	18900	24450	1,39
2015	158714	776240	934955	79424	396436	475861	5550	18900	24450	1,44

annex 15 :Carbon emission per species under fire disturbance (tCO_2 *1000)

Stand	**Species**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Coniferous	Pinus pinaster	1109,1	261,6	68,6	669,4	253,2	395,5	307,2	588,1	1733,6	206,9	1910,9	187,6	58,7	24,6	97,0	320,3	107,8	320,8	343,0	14,4
	Pinus pinea	0,0	0,0	0,3	2,2	1,0	2,5	5,8	4,5	34,4	26,9	4,8	3,5	3,3	0,0	1,6	6,8	0,6	29,8	1,0	0,9
	other Softwoods	115,9	27,3	5,1	40,6	17,1	22,6	9,5	27,2	41,7	9,5	64,0	11,9	5,3	1,0	20,0	11,1	17,1	17,7	34,5	1,4
	Total Coniferous	1225,0	288,9	74,0	0,0	271,3	420,6	322,5	619,9	1809,6	243,3	1979,7	203,1	67,3	25,6	118,6	338,2	125,5	368,2	378,4	16,8
Broadleaves	*Eucalyptus* sp.	508,4	119,9	81,0	582,9	232,6	319,2	278,1	536,7	3482,2	411,4	2703,4	564,7	103,1	52,7	167,4	592,9	255,9	583,3	590,6	48,1
	Quercus suber	119,6	28,2	2,1	42,9	21,7	29,8	49,7	52,5	888,2	188,3	31,3	18,5	7,6	1,1	11,6	8,5	7,4	125,0	21,3	9,9
	Quercus ilex	18,0	4,3	0,8	7,1	2,8	2,5	13,8	20,4	83,3	34,4	7,1	4,2	5,6	0,0	6,5	1,1	6,5	8,8	3,4	3,1
	Other Quercus	57,7	13,6	5,3	44,4	23,1	25,7	15,8	22,1	33,7	7,9	36,2	5,4	4,3	0,9	9,9	13,4	8,4	9,6	10,5	0,3
	Castanea sativa	16,7	3,9	0,6	2,9	2,0	8,1	1,3	3,0	10,8	0,7	5,6	0,7	2,3	0,3	3,6	0,3	2,9	4,6	8,2	0,0
	Acacias	2,4	0,6	0,0	2,8	1,1	0,0	1,1	0,6	4,5	0,6	5,0	1,7	0,4	0,0	0,6	0,0	1,1	4,5	1,7	0,0
	Ceratonia siliqua	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,6	0,0	0,0
	Other Hardwood	191,3	45,1	8,0	118,5	40,7	62,4	59,0	74,6	247,7	44,8	340,0	51,0	33,1	13,4	66,0	101,7	44,7	145,8	151,4	4,0
	Total Broadleaves	914,2	215,6	97,8	801,5	324,0	447,7	418,8	710,3	4750,4	688,5	3128,5	646,1	156,4	68,4	265,5	717,9	327,0	883,1	787,0	65,4
others	Secondary species	0,0	10,9	2,8	48,5	8,7	20,0	13,7	29,0	48,7	4,3	95,6	2,2	8,0	0,0	10,1	29,2	0,0	2,2	10,9	0,0
	Shrub and herbaceous	12,2	8,5	1,8	19,0	5,3	12,8	8,6	9,6	23,4	9,7	19,7	5,6	2,9	0,9	9,5	10,7	7,4	7,4	13,3	1,1
all Forest Stand		2139,2	504,6	171,8	801,5	595,3	868,3	741,3	1330,2	6560,1	931,8	5108,2	849,1	223,7	94,0	384,1	1056,0	452,5	1251,3	1165,4	82,2
Total (Forest Stand, Shrubs and herbaceous)		2151,4	524,0	176,4	869,0	609,2	901,2	763,6	1368,9	6632,1	945,8	5223,5	856,8	234,7	94,9	403,7	1095,9	459,8	1260,9	1189,6	83,3

annex 16:Carbon monoxide emissions tCO per species

Stand	Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Coniferous	Pinus pinaster	75635	17840	4676	45651	17265	26970	20949	40109	118222	14109	130314	12796	4005	1681	6616	21844	7349	21875	23390	982
	Pinus pinea	0	0	22	153	66	173	392	307	2348	1834	329	240	225	0	109	462	44	2033	66	65
	other Softwoods	7905	1865	351	2768	1169	1542	649	1858	2841	650	4364	813	361	66	1361	754	1166	1204	2350	96
	Total Coniferous	83540	19704	5048	48573	18499	28685	21991	42274	123411	16594	135007	13849	4592	1747	8087	23061	8559	25113	25805	1143
Broadleaves	Eucalyptus sp	34670	8177	5521	39752	15864	21769	18964	36602	237474	28058	184364	38508	7031	3594	11419	40432	17454	39779	40278	3280
	Quercus suber	8158	1924	141	2929	1478	2034	3388	3583	60571	12839	2134	1263	515	74	791	582	504	8523	1449	677
	Quercus ilex	1230	290	57	482	192	171	942	1389	5681	2345	482	289	382	0	441	78	441	597	232	209
	Other Quercus	3938	929	359	3027	1575	1750	1076	1505	2299	539	2467	366	290	58	672	911	576	655	715	19
	Chestnut	1140	269	44	200	134	550	89	201	738	45	379	45	158	22	244	22	199	312	558	0
	Acacias	161	38	0	190	76	0	76	38	306	38	342	114	30	0	38	0	76	304	114	0
	Ceratonia siliqua	0	0	0	0	0	0	0	36	0	36	0	0	0	0	0	0	0	108	0	0
	Other Broadleaves	13047	3077	548	8078	2777	4259	4025	5087	16893	3055	23184	3475	2260	915	4503	6933	3049	9946	10327	275
	Total Broadleaves	62343	14705	6670	54658	22096	30532	28560	48441	323962	46954	213352	44058	10667	4663	18108	48957	22299	60223	53673	4460
others	Secondary species	0	744	193	3310	592	1365	935	1979	3318	296	6522	148	548	0	689	1989	0	148	742	0
	Shrub and herbaceous	834	581	122	1294	360	875	589	658	1594	659	1346	379	197	65	646	732	502	502	904	75
all Forest Stand		145884	34409	11718	103230	40596	59217	50551	90715	447374	63548	348359	57907	15258	6410	26195	72018	30858	85336	79478	5603
Total (Forest Stand, Shrubs and herbaceous)		146718	35733	12033	107834	41547	61458	52075	93351	452286	64503	356227	58433	16003	6474	27529	74739	31360	85986	81124	5679

annex 17: Methane emission under fires disturbance (tCH4)

Vegetation types		**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Coniferous	Pinus pinaster	3322	784	205	2005	758	1185	920	1762	5193	620	5724	562	176	74	291	960	323	961	1027	43
	Pinus pinea	0	0	1	7	3	8	17	13	103	81	14	11	10	0	5	20	2	89	3	3
	other Softwoods	347	82	15	122	51	68	29	82	125	29	192	36	16	3	60	33	51	53	103	4
	Total Coniferous	3670	866	222	2134	813	1260	966	1857	5421	729	5930	608	202	77	355	1013	376	1103	1133	50
Broadleaves	*Eucalyptus* sp.	1523	359	242	1746	697	956	833	1608	10431	1232	8098	1691	309	158	502	1776	767	1747	1769	144
	Quercus suber	358	85	6	129	65	89	149	157	2661	564	94	55	23	3	35	26	22	374	64	30
	Quercus ilex	54	13	3	21	8	8	41	61	250	103	21	13	17	0	19	3	19	26	10	9
	Other Quercus	173	41	16	133	69	77	47	66	101	24	108	16	13	3	30	40	25	29	31	1
	Castanea sativa	50	12	2	9	6	24	4	9	32	2	17	2	7	1	11	1	9	14	25	0
	Acacias	7	2	0	8	3	0	3	2	13	2	15	5	1	0	2	0	3	13	5	0
	Ceratonia siliqua	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	5	0	0
	Other Broadleaves	573	135	24	355	122	187	177	223	742	134	1018	153	99	40	198	305	134	437	454	12
	Total Broadleaves	2738	646	293	2401	971	1341	1255	2128	14230	2062	9372	1935	469	205	795	2150	980	2645	2358	196
others	Secondary species	0	33	8	145	26	60	41	87	146	13	286	6	24	0	30	87	0	6	33	0
	Shrub and herbaceous	37	26	5	57	16	38	26	29	70	29	59	17	9	3	28	32	22	22	40	3
all Forest Stand		6408	1511	515	4534	1783	2601	2220	3985	19651	2791	15302	2544	670	282	1151	3163	1355	3748	3491	246
Total (Forest Stand, Shrubs and herbaceous)		6445	1570	529	4737	1825	2700	2287	4100	19867	2833	15647	2567	703	284	1209	3283	1377	3777	3563	249

annex 18 : Nitrogen dioxide emission under fires disturbance (tCH4)

Vegetation types		**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Coniferous	Pinus pinaster	183,8	43,3	11,4	110,9	42,0	65,5	50,9	97,5	287,3	34,3	316,7	31,1	9,7	4,1	16,1	53,1	17,9	53,2	56,8	2,4
	Pinus pinea	0,0	0,0	0,1	0,4	0,2	0,4	1,0	0,7	5,7	4,5	0,8	0,6	0,5	0,0	0,3	1,1	0,1	4,9	0,2	0,2
	other Softwoods	19,2	4,5	0,9	6,7	2,8	3,7	1,6	4,5	6,9	1,6	10,6	2,0	0,9	0,2	3,3	1,8	2,8	2,9	5,7	0,2
	Total Coniferous	203,0	47,9	12,3	118,0	45,0	69,7	53,4	102,7	299,9	40,3	328,1	33,7	11,2	4,2	19,6	56,0	20,8	61,0	62,7	2,8
Broadleaves	*Eucalyptus* sp.	84,2	19,9	13,4	96,6	38,5	52,9	46,1	88,9	577,0	68,2	448,0	93,6	17,1	8,7	27,7	98,2	42,4	96,7	97,9	8,0
	Quercus suber	19,8	4,7	0,3	7,1	3,6	4,9	8,2	8,7	147,2	31,2	5,2	3,1	1,3	0,2	1,9	1,4	1,2	20,7	3,5	1,6
	Quercus ilex	3,0	0,7	0,1	1,2	0,5	0,4	2,3	3,4	13,8	5,7	1,2	0,7	0,9	0,0	1,1	0,2	1,1	1,5	0,6	0,5
	Other Quercus	9,6	2,3	0,9	7,4	3,8	4,3	2,6	3,7	5,6	1,3	6,0	0,9	0,7	0,1	1,6	2,2	1,4	1,6	1,7	0,0
	Castanea sativa	2,8	0,7	0,1	0,5	0,3	1,3	0,2	0,5	1,8	0,1	0,9	0,1	0,4	0,1	0,6	0,1	0,5	0,8	1,4	0,0
	Acacias	0,4	0,1	0,0	0,5	0,2	0,0	0,2	0,1	0,7	0,1	0,8	0,3	0,1	0,0	0,1	0,0	0,2	0,7	0,3	0,0
	Ceratonia siliqua	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0		0,0	0,0	0,0	0,0	0,3	0,0	0,0
	Other Broadleaves	31,7	7,5	1,3	19,6	6,7	10,3	9,8	12,4	41,0	7,4	56,3	8,4	5,5	2,2	10,9	16,8	7,4	24,2	25,1	0,7
	Total Broadleaves	151,5	35,7	16,2	132,8	53,7	74,2	69,4	117,7	787,2	114,1	518,4	107,1	25,9	11,3	44,0	119,0	54,2	146,3	130,4	10,8
others	Secondary species	0,0	1,8	0,5	8,0	1,4	3,3	2,3	4,8	8,1	0,7	15,8	0,4	1,3	0,0	1,7	4,8	0,0	0,4	1,8	0,0
	Shrub and herbaceous	2,0	1,4	0,3	3,1	0,9	2,1	1,4	1,6	3,9	1,6	3,3	0,9	0,5	0,2	1,6	1,8	1,2	1,2	2,2	0,2
all Forest Stand		354,5	83,6	28,5	250,8	98,6	143,9	122,8	220,4	1087,1	154,4	846,5	140,7	37,1	15,6	63,7	175,0	75,0	207,4	193,1	13,6
Total (Forest Stand, Shrubs and herbaceous)		356,5	86,8	29,2	262,0	101,0	149,3	126,5	226,8	1099,0	156,7	865,6	142,0	38,9	15,7	66,9	181,6	76,2	208,9	197,1	13,8

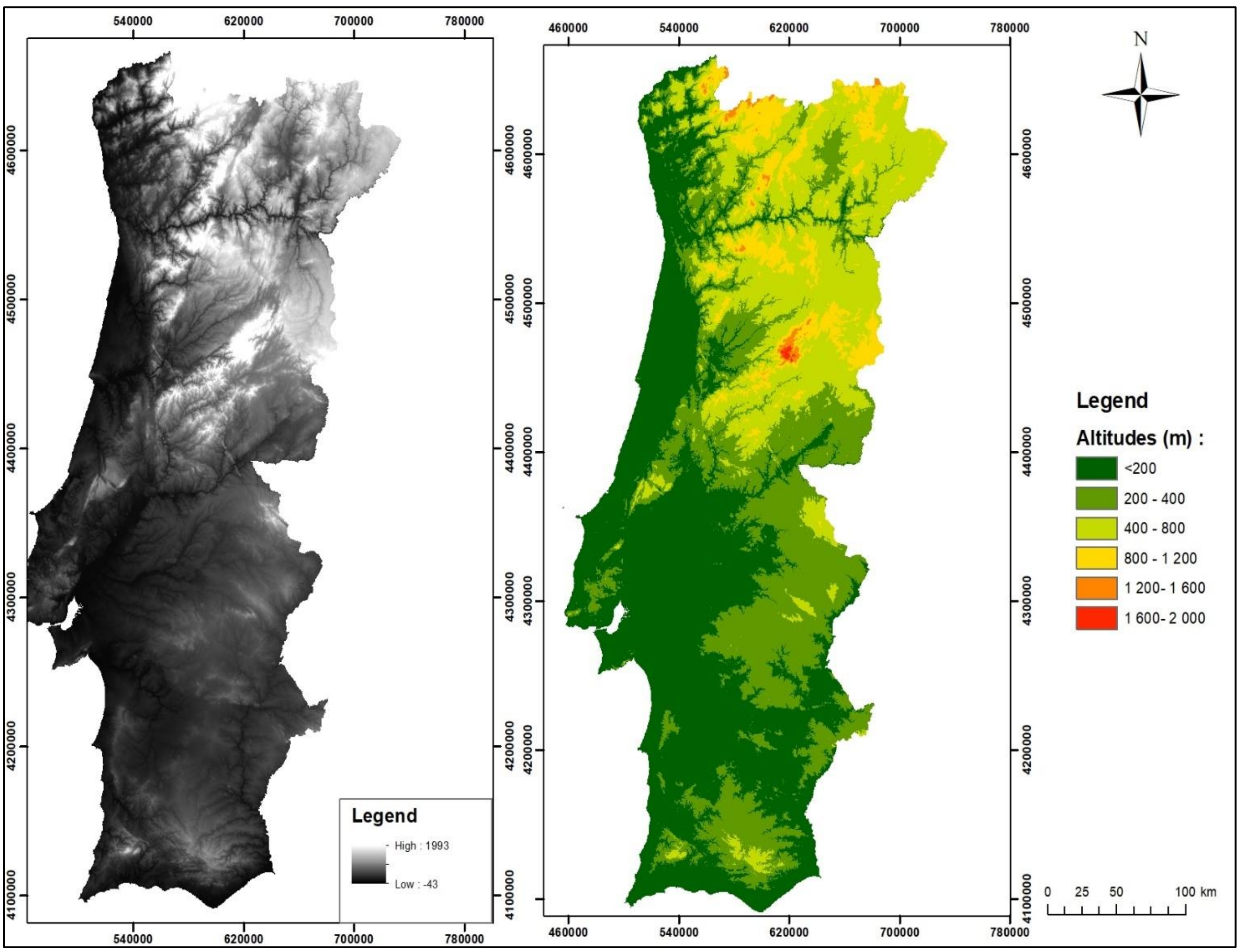
annex 19:Nitrogen oxide emission under fires disturbance (tNOx)

Vegetation types		**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Coniferous	Pinus pinaster	2121	500	131	1280	484	756	587	1125	3315	396	3654	359	112	47	185	612	206	613	656	28
	Pinus pinea	0	0	1	4	2	5	11	9	66	51	9	7	6	0	3	13	1	57	2	2
	other Softwoods	222	52	10	78	33	43	18	52	80	18	122	23	10	2	38	21	33	34	66	3
	Total Coniferous	2342	552	142	1362	519	804	617	1185	3460	465	3785	388	129	49	227	647	240	704	723	32
Broadleaves	*Eucalyptus* sp.	972	229	155	1115	445	610	532	1026	6658	787	5169	1080	197	101	320	1134	489	1115	1129	92
	Quercus suber	229	54	4	82	41	57	95	100	1698	360	60	35	14	2	22	16	14	239	41	19
	Quercus ilex	34	8	2	14	5	5	26	39	159	66	14	8	11	0	12	2	12	17	6	6
	Other Quercus	110	26	10	85	44	49	30	42	64	15	69	10	8	2	19	26	16	18	20	1
	Castanea sativa	32	8	1	6	4	15	2	6	21	1	11	1	4	1	7	1	6	9	16	0
	Acacias	5	1	0	5	2	0	2	1	9	1	10	3	1	0	1	0	2	9	3	0
	Ceratonia siliqua	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3	0	0
	Other Broadleaves	366	86	15	226	78	119	113	143	474	86	650	97	63	26	126	194	85	279	290	8
	Total Broadleaves	1748	412	187	1532	620	856	801	1358	9083	1316	5982	1235	299	131	508	1373	625	1689	1505	125
others	Secondary species	0	21	5	93	17	38	26	55	93	8	183	4	15	0	19	56	0	4	21	0
	Shrub and herbaceous	23	16	3	36	10	25	17	18	45	18	38	11	6	2	18	21	14	14	25	2
all Forest Stand		4090	965	329	2894	1138	1660	1417	2543	12543	1782	9767	1624	428	180	734	2019	865	2393	2228	157
Total (Forest Stand, Shrubs and herbaceous)		4114	1002	337	3023	1165	1723	1460	2617	12681	1808	9988	1638	449	182	772	2095	879	2411	2275	159

annex 20: The number of observations obtained after a Simple Random Sample in pure forest

Species	Observation number	NPP (Tco2/ha)	tC/ha
Acacia	11	35	9,4
other Coniferous	13	30	8,3
chestnut	15	32	8,8
Pinus Pinea	21	33	8,9
other Quercus	75	34	9,3
Quercus ilex	161	26	7,0
Eucalyptus.sp	220	40	10,9
other broadleaves	61	33	8,9
Pinus pinaster	240	37	10,1
Quercus suber	183	35	9,5

annex 21 :Digital Elevation Model of Portugal (25m, 25m)



annex 22 :Precipitation data (mm) in 60 climatic Stations with its coordinates (Coordinate system: Lisboa Hayford Gauss GeoE)

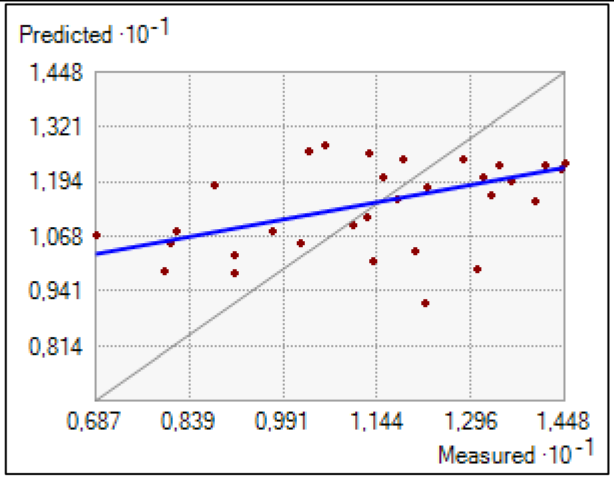
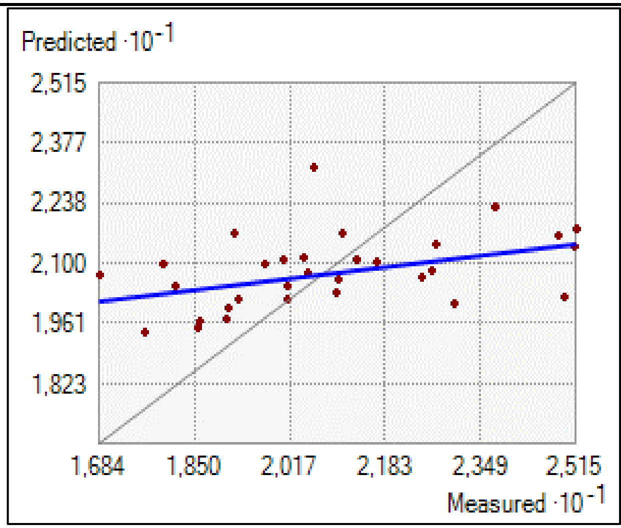
station	LOCAL	latitude	longitude	tan(a)	distance (d)	Elevation	Ci (Climate index)	Precipitation (mm)	Precipitation average (2016/1995)
1	PINELO	331652,33	519751,32	1,57	616551	604	0,51	323,5	639
2	DEILÃO	328404,57	543242,27	1,65	634793	897	0,49	404,4	827
3	ESCALHÃO	301674,59	442951,57	1,47	535923	614	0,56	308	549
4	PINHEL	290406,32	423180,9	1,46	513243	607	0,59	364,3	622
5	BARRAGEM DO CAIA	285979,86	226592,82	0,79	364868	222	0,70	347,7	495
6	PEGA	283923,05	385503,4	1,36	478775	773	0,55	454,3	823
7	LADOEIRO	274130,74	318149,06	1,16	419960	219	0,61	373,2	608
8	FOLGARES	271113,93	482084,89	1,78	553090	730	0,72	448,6	624
9	RIO TORTO	271043,08	508156,99	1,87	575923	315	0,62	344,9	554
10	TRAVANCAS	268647,07	540347,99	2,01	603446	880	0,49	499,1	1012
11	VILA VIÇOSA	261814,22	202371,85	0,77	330909	417	0,56	420,1	754
12	CASTELO DE VIDE	258516,76	271894,51	1,05	375177	558	0,63	549,2	874
13	COVILHÃ	252864,1	368831,4	1,46	447188	726	0,60	963,3	1603
14	REGUENGOS	252835,21	162124,29	0,64	300350	214	0,25	139,2	561
15	SERPA	246420,48	108738,55	0,44	269346	209	0,71	372,4	526
16	VILA VELHA DE RODÃO	239624,01	298176,28	1,24	382529	77	0,74	552,2	744
17	MARTIM LONGO	232494,21	52630,972	0,23	238377	296	0,78	415,6	535
18	SANTA MARTA DA MONTANHA	232223,14	503744,75	2,17	554695	863	0,63	1129,1	1799
19	SÃO BRÁS DE ALPORTEL	220907,8	22066,311	0,10	222007	332	0,40	347,3	873
20	CASTRO D'AIRE	216381,75	435910,76	2,01	486661	572	0,51	827,3	1628
21	VIANA DO ALENTEJO	210955,07	151442,7	0,72	259686	303	0,59	416,9	701
22	PAVIA	210260,43	214497,03	1,02	300364	187	0,43	260,4	611
23	AMARANTE	205230,87	477387,52	2,33	519633	134	0,47	557,2	1197
24	CASTRO VERDE	203407,01	81412,575	0,40	219095	217	0,67	368,9	548
25	ABRANTES	202579,13	276394,19	1,36	342684	107	0,45	297,5	665
26	SANTA COMBA DÃO	201197,32	385116,78	1,91	434506	293	0,22	257,2	1189
27	PORTELINHA	196656,55	564855,01	2,87	598110	1027	0,55	1204,9	2187
28	CHOUTO	181100,33	256394,84	1,42	313904	132	0,50	396	791
29	REGO DA MURTA	180717,04	311205,55	1,72	359872	220	0,53	555,9	1045
30	BARRAGEM DE CASTELO BURGÃES	179146,24	431725,25	2,41	467419	305	0,49	883,9	1799

31	PONTE DA BARCA	176097,41	537278,8	3,05	565401	29	0,43	736,8	1730
32	RELÍQUIAS	169080,91	82063,543	0,49	187944	246	0,62	434,2	697
33	GRÂNDOLA	162560,63	134060,46	0,82	210709	95	0,30	203,5	686
34	PONTE DE LIMA	161416,84	533485,89	3,31	557371	20	0,48	795,3	1650
35	BARCELOS	159421,65	507270,74	3,18	531732	39	0,47	724,5	1541
36	SOURE	157921,72	342912,25	2,17	377529	21	0,16	139,9	861
37	MOINHOLA	157779,51	179922,41	1,14	239304	43	0,65	442,8	683
38	BARRAGEM DE MAGOS	151265,24	225005,26	1,49	271125	38	1,07	711	662
39	BARRAGEM DA BRAVURA	149689,8	25973,77	0,17	151927	64	1,37	957	699
40	CELA	119563,08	289984,57	2,43	313666	3	0,29	228,1	774
41	PRAGANÇA	119467,02	248461,65	2,08	275691	196	0,65	603,4	924
42	SÃO JULIÃO DO TOJAL	113983,88	208970,94	1,83	238036	7	0,75	533,7	713
43	Viana do Castelo	144328,6	518614,72	3,59	538323	51	0,51	741,4	1466,5
44	Braga	173364,74	512060,95	2,95	540612	65	0,34	487,9	1448,6
45	Vila Real	234756,38	478593,03	2,04	533068	560	0,50	516,5	1023,2
46	Bragança	315444,51	538275,81	1,71	623896	687	0,63	486	772,8
47	Porto/P. Rubras	154973,88	474546,06	3,06	499210	74	0,58	723,5	1236,8
48	Aveiro	156167,33	407468,39	2,61	436370	12	0,66	616,7	934,5
49	Viseu	219270,83	410634,15	1,87	465511	449	0,57	681,7	1198,5
50	Guarda	273311,86	396594,19	1,45	481650	996	0,63	580,5	914,2
51	Coimbra	171474,84	353721,14	2,06	393093	115	0,56	500,2	886
52	Castelo Branco	255917,28	319393,65	1,25	409275	381	0,54	424,5	783,3
53	Leiria	140976,95	312876,14	2,22	343170	41	0,15	136,4	886
54	Santarém	148044,98	248359,8	1,68	289136	68	0,59	383	651,9
55	Portalegre	261296,02	258880,11	0,99	367824	590	0,45	379,1	836,1
56	Lisboa/G. Coutinho	113266,76	202032,93	1,78	231617	96	0,72	550,2	765,7
57	Setúbal	133852,67	176129,69	1,32	221220	21	0,61	438,4	715,5
58	Évora	221674,68	174206,08	0,79	281935	243	0,62	360,6	585,3
59	Beja	223209,09	117863,14	0,53	252416	252	0,75	419,9	557,8
60	Faro	214708,9	3997,1231	0,02	214746	2	0,73	372,7	508,8

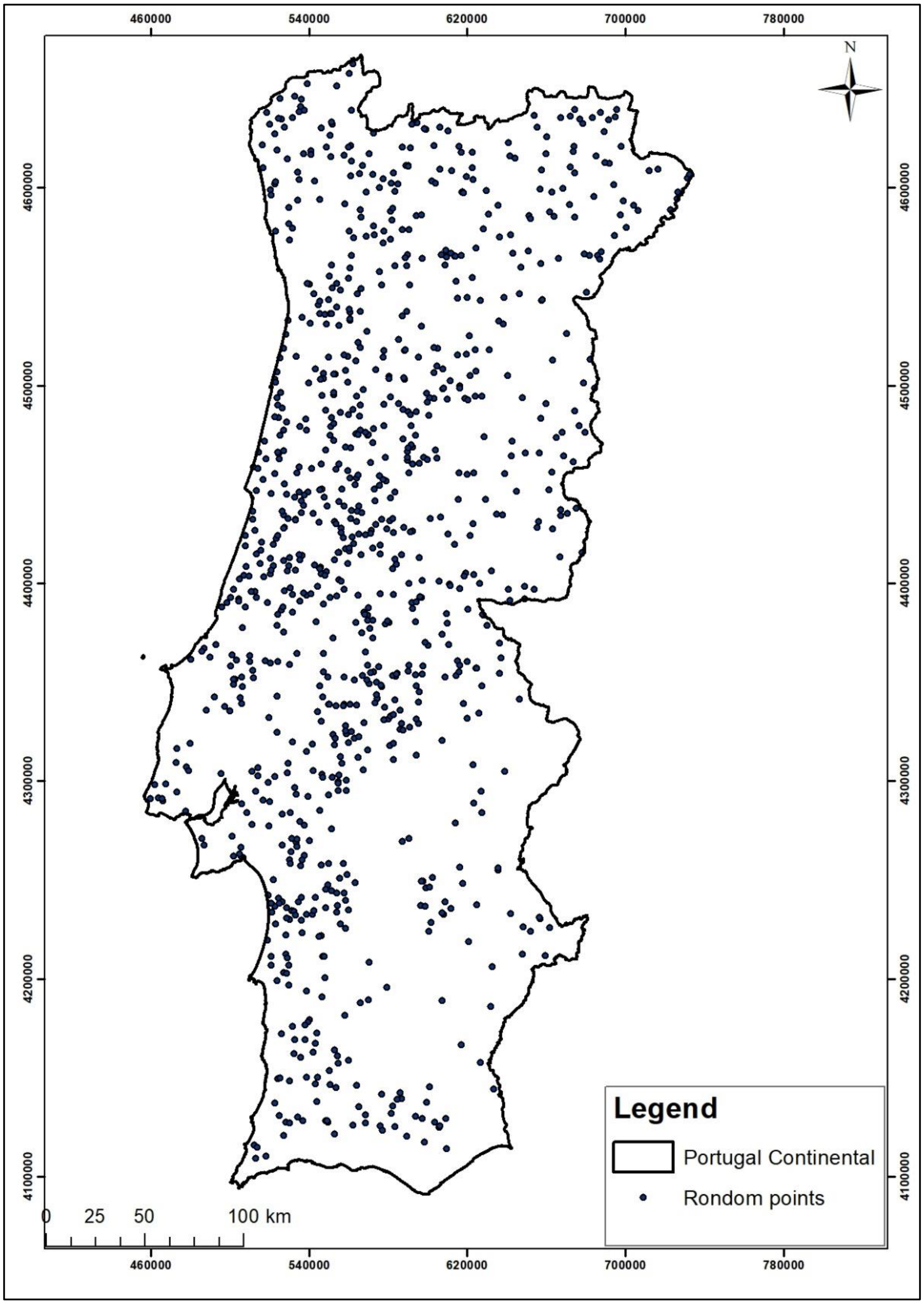
annex 23:the Minimum and the maximum of temperature average (degrees Celsius) in 31 climatic stations with its coordinates (Coordinate system:Lisboa Hayford Gauss GeoE)

Station ID	Local	X	Y	Tn	Tx
0	Viana do Castelo	144328,599	518614,72	9,74	20,04
1	Braga	173364,735	512060,952	8,17	23,03
2	Vila Real	234756,385	478593,028	9,13	20,98
3	Bragança	315444,507	538275,806	6,87	21,08
4	Porto/P. Rubras	154973,884	474546,062	10,18	19,71
5	Aveiro	156167,328	407468,395	12,04	20,96
6	Viseu	219270,833	410634,147	9,13	21,30
7	Guarda	273311,861	396594,192	8,06	18,14
8	Coimbra	171474,835	353721,144	11,03	22,44
9	Castelo Branco	255917,282	319393,653	11,25	23,72
10	Leiria	140976,948	312876,141	8,80	20,11
11	Santarém	148044,979	248359,804	11,51	25,10
12	Portalegre	261296,017	258880,109	12,23	22,62
13	Lisboa/G. Coutinho	113266,756	202032,93	13,13	22,71
14	Setúbal	133852,675	176129,685	10,59	24,84
15	Évora	221674,682	174206,075	10,31	25,15
16	Beja	223209,094	117863,139	11,28	24,93
17	Faro	214708,899	3997,12306	12,83	21,68
18	PONTE DA BARCA	176097,408	537278,802	13,04	17,95
19	RIO TORTO	271043,077	508156,987	12,19	17,63
20	FOLGARES	271113,933	482084,887	7,97	18,58
21	BARRAGEM DE CASTELO BURGÃES	179146,24	431725,253	11,37	18,56
22	CELA	119563,076	289984,571	11,75	16,84
23	ABRANTES	202579,128	276394,189	13,98	19,10
24	BARRAGEM DE MAGOS	151265,235	225005,262	13,61	19,19
25	ALBUFEIRA DO CAIA	285223,175	227070,273	13,27	20,10
26	MOINHOLA	157779,511	179922,408	13,40	19,05
27	VIANA DO ALENTEJO	210955,067	151442,699	11,84	20,59
28	GRÂNDOLA	162560,625	134060,462	14,48	19,27
29	ALBUFEIRA DO ROXO	204595,203	107091,958	14,41	20,39
30	ALBUFEIRA DA BRAVURA	149566,11	26757,4325	14,16	20,47

annex 24:Prediction model used in Tx and Tn interpolations (Semivariogram models: Spherical model)

Minimum temperature average (Tn)	Regression function	0,263820858331736 * x + 8,45432796898026	
	Prediction Errors		
	Samples	31 of 31	
	Mean	0,006	
	Root-Mean-Square	1,361	
	Mean Standardized	0,002	
	Root-Mean-Square Standardized	1,025	
	Average Standard Error	1,807	
Maximum temperature average (Tx)	Regression function	0,159003713061683 * x + 17,4333763999938	
	Prediction Errors		
	Samples	31 of 31	
	Mean	-0,018	
	Root-Mean-Square	2,019	
	Mean Standardized	-0,001	
	Root-Mean-Square Standardized	0,994	
	Average Standard Error	2,070	

annex 25: Random points used to study the NPP and biophysical factors relationship:



annex 26:ciritria of linear regression used to interpolate precipitation data for all Continental Portugal

Correlation and determination Coefficients (Precipitations model)							
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		Durbin-Watson
					R Square Change	Sig. F Change	
1	0,811[a]	0,66	0,64	137,56	0,658	0	1,209

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2006182,85	4	501545,712	26,505	0,000[b]
	Residual	1040733,16	55	18922,421		
	Total	3046916,01	59			

coefficients of the Linear model used in Precipitation interpolation

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-169,806	93,409		-1,818	0,075
	tan(a)	257,796	38,134	0,963	6,76	0
	distance (d)	-0,001	0	-0,439	-2,606	0,012
	Elevation (E)	0,423	0,098	0,537	4,294	0
	Ci (Climate index)	747,78	100,824	0,627	7,417	0

a. Predictors: (Constant), Ci (Climate index), Elevation, tan(a), distance (d)

b. Dependent Variable: Precipitation