Ecosystem Services Economics (ESE)

Working Paper Series

Division of Environmental Policy Implementation Paper N° 9

Environment for Development

European Forests and Carbon Sequestration Services: An Economic Assessment of Climate Change Impacts

Helen Ding, Paulo A.L.D. Nunes and Sonja Teelucksingh

January 2011

The United Nations Environment Programme

Design and Layout: Catherine K. Kimeu/UNON

Printing: Publishing Services Section, UNON, Nairobi-Kenya, ISO 14001:2004 certified

Ecosystem Services Economics

European Forests and Carbon Sequestration Services: An Economic Assessment of Climate Change Impacts

Helen Ding
Center for Environmental Economics and Management, Department of Economics, Ca' Foscari University of Venice, Italy
Fondazione Eni Enrico Mattei, Italy

Paulo A.L.D. Nunes
Center for Environmental Economics and Management, Department of Economics, Ca' Foscari University of Venice, Italy
Fondazione Eni Enrico Mattei, Italy

Sonja Teelucksingh
Fondazione Eni Enrico Mattei, Italy
University of the West Indies, Trinidad and Tobago

UNEP

January 2011

Table of contents

Preface

The paper presents an economic valuation of the impact of climate change on forest regulating services in Europe. It demonstrates the interdisciplinary nature of work to estimate the economic value of regulating services. Using Global Circulation Models (GCMs) and Integrated Assessment Models (IAMs), an economic assessment of the carbon sequestration in European forests is presented and future projections are made based on the four climate change scenarios that have been presented by the Intergovernmental Panel on Climate Change (IPCC).

Ibrahim Thiaw,
Director, Division of Environmental Policy Implementation (DEPI)
United Nations Environment Programme (UNEP)

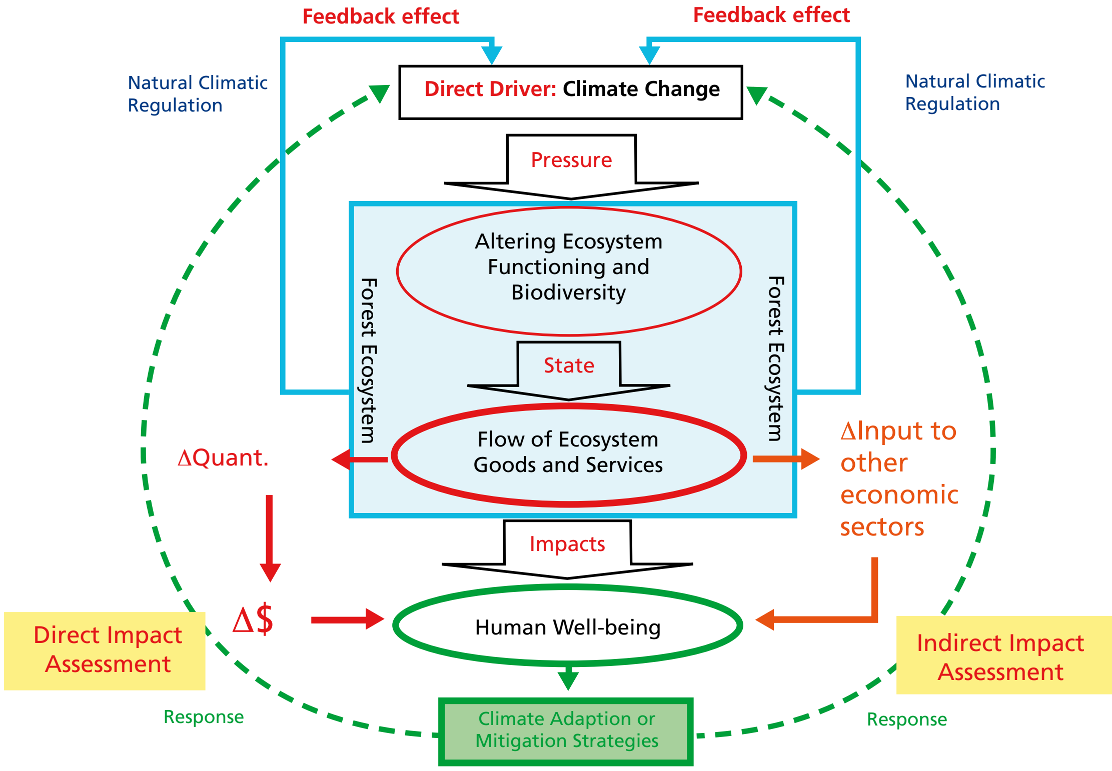
1. Introduction

It has been proven that climate change, has significant impacts on the natural environment and human health (MA, 2005). This, in turn, has led to an increasing number of scientific studies focusing on the mapping and identification of the scale of climate change impacts on ecosystem performance and the respective provisioning of ecosystem goods and services. More recently, accompanying studies on the assessment of the role of ecosystems with respect to their contribution to the economy and human wellbeing were made well-known by the Millennium Ecosystem Assessment (MA). However, to the authors' knowledge, few studies have put an emphasis on the estimation of human welfare losses related to climate-driven changes of biodiversity and ecosystem services. In fact, the costs of climate change impacts on biodiversity are not well mapped due to the complex (and not fully understood) interactions between climate change, ecosystems, and the respective impacts on human well-being (both in utility and productivity/employment terms). For this reason, the present paper attempts to contribute to this line of research by undertaking an empirical valuation of the European forest ecosystems, addressing the role of biodiversity as "the foundation of the vast array of ecosystem services that critically contribute to human well-being" (MA, 2005. p.p.18). More specifically, we propose a three-step approach to value the climate changes impacts on biodiversity and forest ecosystems. The first step is the characterisation of the climate role in the creation of relevant forest ecosystem services. The second step is the calculation of the reduced quantity and quality of these ecosystem services that result in a loss to human welfare under alternative IPCC scenarios. Finally, the third step is the (monetary) valuation of that loss.

We begin the analysis with a conceptual DPSIR (OECD, 1999) framework that has been applied to the capture of the causal relationship between climate change, biodiversity, forest ecosystems and human well-being (see Figure 1). Scientific evidence has demonstrated that climate change is one of the main drivers that directly alters ecosystem functioning and causes biodiversity loss. The shift of climate conditions can change species distribution, population sizes, the timing of reproduction or migration events, and can increase the frequency of pest and disease outbreaks (MA 2005, p.p. 10). As a consequence, increases in global temperature and greenhouse gases concentrations may be detrimental to the health of forest ecosystems and ultimately human well-being, both through the disturbance of existing biodiversity as well as through a negative influence on the ability of ecosystem to deliver goods and services. These damages are directly caused by climate change, and are therefore associated with particular costs to human society. Yet it is important to note that forest ecosystems also engender feedback effects to climate change due to their important contributions to the stock of CO2 emissions. These are important benefits that ecosystems provide to society. Therefore, monetizing the respective costs and benefits associated with climate change impacts on ecosystems has practical sense in guiding cost-effective climate-change policy. Finally, while mitigation and adaptation policy measures can reduce losses which are translated to a welfare gain, the policies themselves also imply economic costs. Therefore, both costs and benefits need to be considered in the specific valuation strategies.

Following these steps, the paper is organized as follows. Section 2 presents a systematic overview of current European forest ecosystem and its interaction with climate change impact through a new geo-climatic lens. Section 3 discusses the assessment of climate change impacts on forest regulating services using an ecosystem based valuation approach, which we adopt as the corner stone of the present valuation exercise. Section 4 presents the economic valuation exercise, and corresponding monetary estimation results of forest sequestration services in the context of climate change. Section 5 concludes.

Figure 1. A conceptual model for the climate change, forest biodiversity and human well-being interactions.



2. An overview of the regulating services of European forests

A Geo-Climatic Map of European Forests

This study covers 34 European countries[1] previously classified as Western Europe and Eastern Europe sub-regions in the European Forest Sector Outlook Study 1960-2000-2020 main report (UNECE/FAO, 2005). We regroup these countries into four geo-climatic groups in order to address the spatial effects of climate change impacts, i.e. (1) Mediterranean Europe (Latitude N35-45°), (2) Central-Northern Europe (Latitude N45-55°), (3) Northern Europe (Latitude N55-65°) and (4) Scandinavian Europe (Latitude N65-71°),. The new geographical groupings are presented in Table 1.

[1] Three EFSOS sub-regions are presented in the Appendix.

Table 1. Geographical groupings of the 34 European countries.

Geographical groupings	Latitude classification	Countries included
Mediterranean Europe	Latitude N35-45°	Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey, TFRY Macedonia
Central-Northern Europe	Latitude N45-55°	Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia
Northern Europe	Latitude N55-65°	Denmark, United Kingdom, Estonia, Latvia, Lithuania
Scandinavian Europe	Latitude N65-71°	Finland, Iceland, Norway, Sweden

We adopt this grouping on the basis of the assumption that each country's particular forest types are closely determined by the specific climate conditions. We are therefore able to identify the predominant tree species as well as the respective contributions to the local economy at both the national and the larger regional scales. From an ecological viewpoint, different tree species can play different roles in ecosystem regulation and life supporting functions, which will ultimately influence the provision of forest ecosystem goods and services. Alternatively, from an economic perspective, different tree species may deliver very different flows of ecosystem goods and services in terms of economic importance and related welfare impacts. Finally, from a geo-climatic perspective, this classification may also allow us to explore the sensitivity of different tree species to climate changes, in particular to increases in temperature and precipitation rates in the countries under consideration.

Forest areas and forest type distributions

Data collected from Food and Agriculture Organization (FAO) show a total forest coverage of 185 million hectare over the selected 34 European countries, accounting for about 32.7% of the territory (FAO, 2005) (see TableA1 in Appendix for more information). If we divide the forest areas by latitudes, we observe an uneven distribution of forest types across the four classified geo-climatic regions in Europe, as shown in Table 2. In Mediterranean Europe most of the forests are coniferous and broadleaved evergreen, which account for 30% of the total forest area in the region. The Central-Northern and Northern European regions are home to most of the temperate forests, which account for 35% and 19% of the total forests, respectively. Finally, in Scandinavian Europe, forest area accounts for the remaining 16% of total forest, in which the identical forest biomes are mainly boreal .

Table 2. Distribution of forest ecosystems in Europe.

Geographical groupings	Latitude classification	Major forest types
Mediterranean Europe	Latitude N35-45°	Coniferous and broadleaved evergreen forests
Central-Northern Europe	Latitude N45-55°	Temperate forests
Northern Europe	Latitude N55-65°	Temperate forests
Scandinavian Europe	Latitude N65-71°	Boreal forests

Due to the diverse climatic conditions across latitudes, species diversity and dynamics of forest ecosystems differ considerably throughout Europe, as reflected in the numbers and composition of tree species. For example, the Ministerial Conference on the Protection of Forests in Europe MCPFE (2007) reported that approximately 70% of the forests in Europe are dominated by mixed forest consisting of two or several tree species, with the remaining 30% dominated mainly by conifers. In addition to the natural conditions, forest species compositions of the current European forest structures have been heavily influenced by anthropophagic interventions such as past land use and management (Ellenberg, 1986). In particular, the forest protective management strategy in Europe has resulted in a 1.0 percent annual expansion in the area of mixed forests over the last 15-year period (MCPFE 2007); this may be partly due to the widely acknowledged scientific evidence that mixed forests composed of several tree species are usually richer in biodiversity than forests dominated by one tree species.

Climate change and European forests

With respect to the sensitivity of tree species to temperature changes, this has been studied in terms of specific forest types located in different geo-climatic regions in Europe. In Mediterranean Europe, most forests consist of sclerophyllous and some deciduous species that are adapted to summer soil water deficits. Temperature changes may allow the expansion of some thermophilous tree species (e.g. quercus pyrenaica) when water availability is sufficient (IPCC, 2001). Similarly, Garcia-Gonzalo et al. (2007) find that in Scandinavian Europe, where growth of boreal forests is currently limited by a short growing season, low summer temperature and short supply of nitrogen, climate change can be associated with an increase in forest productivity in terms of carbon stock. This is because an increase in temperature can prolong the growing season, enhance the decomposition of soil organic matter and thus increase the supply of nitrogen. In turn, these changes may have positive impacts on forest growth, timber yield and the accumulation of carbon in the boreal forests (Melillo et al. 1993; Lloyd and Taylor 1994; Giardian and Ryan 2000; Jarvis and Linder 2000; Luo et al. 2001).

Defining forest regulating services

A concise mapping of ecosystem goods and services (EGS) is the basis of high quality ecosystem assessment studies. For this reason, we adopt the MA approach (MA, 2003), which provides a practical, tractable, and sufficiently flexible classification for the categorisation of the various types of ecosystem goods and services (EGS). In this context, all EGS can be generally classified into four main categories, i.e. provisioning, regulating, cultural and supporting services – see Table 3.

Table 3. A general classification of ecosystem goods and services for European forests (Source: adapted from MA 2003).

Types of Ecosystem Services		Examples
Supporting Services	Provisioning Services	Food, Fiber (e.g. timber, wood fuel), ornamental resources.
	Regulating Services	Climate regulation, water regulation, erosion regulation.
	Cultural Services	Recreation and ecotourism, aesthetic values, spiritual and religious values, cultural heritage values.

According to the MA, products obtained from ecosystems are defined as provisioning services , these include food, fiber, fresh water, and genetic resources. . Cultural services are the nonmaterial benefits obtained from ecosystems through aesthetic experience, reflection, recreation and spiritual enrichment. Regulating services include benefits obtained from the regulation of ecosystem processes including air quality regulation, climate regulation, water regulation, erosion regulation, pollination and natural hazard regulation. Supporting services are those that are necessary for the production of all other ecosystem services, such as soil formation, photosynthesis, primary production, nutrient cycling and provisioning of habitat (MA, 2003). The present paper focuses on the economic valuation of European forests in terms of carbon regulating services. In particular, the valuation exercise will assess the magnitude of these services as carbon sinks. The methodologies adopted shall de discussed and elaborated in the following section.

3. An ecosystem based economic valuation of global climate change

Climate change and the IPCC storylines

Over the last 30 years, the world has experienced significant temperature increases, particularly in the northern high latitudes (IPCC, 2001). The research results of the International Panel on Climate Change (IPCC) show that the average temperature in Europe will increase from 2.1 to 4.4°C by 2050, varying across latitudes, with the strongest warming consistently in the higher latitudes. In addition, model simulations also suggest a decrease in precipitation in the south of Europe, particularly in the summer, and an increase in precipitation over much of northern Europe (Schöter et al., 2005). In order to quantify the climate change impacts on forest ecosystems, both quantitative and qualitative data are needed to describe the ability of the ecosystems to provide the necessary goods and services, both in the present time period and in future scenarios of climate change. Moreover, to specify these scenarios, we adopt the four major storylines that are developed by the IPCC, coupling the global circulation models (e.g HadCM3[2]) with socio-economic storylines (Nakicenovic and Swart 2000; Schöter et al. 2004; Schöter et al. 2005). This enables us to describe the change of flows of ecosystem services under future states of the world or scenarios.

A special report published by the IPCC in 2000 provided a narrative description of four alternative futures each associated with specific attributes in terms of population growth, CO2 concentration, degree of temperature changes, and change of precipitation. These attributes are the major elements driving future climate changes (Nakicenovic and Swart, 2000) – see a synthesis in Table 4.

Table 4. The specifications of the four IPCC storylines (Source: Schröter *et al.*, 2005; IPCC, 2001).

Indicator	Climatic model - HadCM3 (Scenarios by 2050)			
	Storyline A1FI	**Storyline A2**	**Storyline B1**	**Storyline B2**
Population (10^6)	376	419	376	398
CO_2 concentration (ppm)	779	709	518	567
Δ Temperature (°C)	4,4	2,8	3,1	2,1
Δ Precipitation Europe (%)	-0,5	0,5	4,8	2,7
Socio-economic dimensions	High savings and high rate of investments and innovation	Uneven economic growth, high per capita income	High investment in resource efficiency	Human welfare, equality, and environmental protection

More importantly, efforts have been placed on the development of a general circulation model – HadCM3 – so as to directly relate socioeconomic changes to both climatic changes and land use changes through climatic drivers (Schröter D. et al. 2004). As a consequence, the IPCC presents four brief "future stories" that differ in economic, technical, environmental and social dimensions (Nakicenovic and Swart, 2000). According to the IPCC

2 HadCM3, Hadley Centre Couplet Model Version 3 is a coupled atmosphere-ocean GCM developed at the Hadley Centre and described by Gordon et al. (2000).

specifications, A1FI, A2, B1 and B2 storylines are distinguished in terms of four future development paths, i.e. 'global economic' oriented, 'regional economic' oriented, 'global environmental' oriented, and 'regional environmental' oriented, respectively. The two economic oriented scenarios (A1FI and A2) focus on 'material consumption', but A1 scenarios also consider different combinations of fuel, expressed as A1FI. The two environmental oriented scenarios (B1 and B2) mainly concentrate on the concepts of 'sustainability, equity and environment'. It is important to point out that, among all others, the storyline A2 describes a very heterogeneous world which is characterized by high population growth, regional oriented economic development, and fragmented and slow per capita economic growth and technology, (in fact mirroring current socio-economic development patterns). For this reason, A2 is frequently used by the European Commission as the baseline scenario, with the remaining scenario analyses conducted relative to this storyline. In particular, our focus is mainly on the comparison of A1 vs. A2, in an assessment of the movement to a more economically focused world. Alternatively, we may also consider B1, and B2, vs. A2, in an assessment of the movement to a more sustainably oriented world.

Estimation of the physical changes of ecosystem services due to climate change

As previously discussed, climate plays a significant role in influencing the provision of forest carbon sequestration services., The magnitude of the impact is, however, dependent upon the forest type as well its distribution across Europe. We shall quantify the potential reduction of carbon stocked in European forests under possible climate change scenarios proposed by IPCC. It is important to note that our work heavily relies on the previous research results derived from the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project[3] in terms of its projections of quantitative changes in both forest area and carbon stocks due to climate change. This project provided percentage changes of forest area and stocked carbon for each of the EU-17 countries under four IPCC storylines. For the remaining 17 countries of interest, the changes of forest areas and carbon stocks in the future climate change scenarios are calculated based on the results delivered by an IMAGE 2.2 program (IMAGE 2001). The projection delivers point estimates for the years 2005 and 2050.

Changes in forest area

In the A1FI and A2 scenarios, forest areas decrease by approximately 21% and 9% by 2050, respectively - see Table A1 in the Appendix for more details. The A1FI scenario shows the strongest impact due both to the most severe climate change assumption (Δ temperature (C°) of 4.4 degrees) as well as the no-migration assumption, (Thuiller et al., 2005). By contrast, scenarios B1 and B2 demonstrate 6% and 10% increases in forest area, respectively. The higher increasing rate of forest area in the B2 scenario may benefit from both a hypothetical afforestation as well as an assumed higher level of precipitation (Schöter et al., 2005). In addition, we can also observe a significant spatial effect of climate change impacts on the forest land-use pattern across latitudes. For example, Mediterranean Europe (N35-45°) is facing a general negative forest growth in scenario A1FI and A2, but a significant expansion in scenario B1 and B2. Central-Northern Europe (N45-55°) and Northern Europe (N55-65°) regions face negative growth only in the A1FI scenario, in correspondence with the more severe climatic conditions. One should note that the projections for these regions in the A2 scenario are also embedded in a historical trend of forest area increases. Finally, Scandinavian Europe (N+65°) always experiences a decrease in forest growth which implies a shrinking forest extension under both current conditions and future scenarios.

[3] ATEAM's main objective is to assess the vulnerability of human sectors relying on ecosystem services with respect to global change.. For more information see : http://www.pik-potsdam.de/ateam/

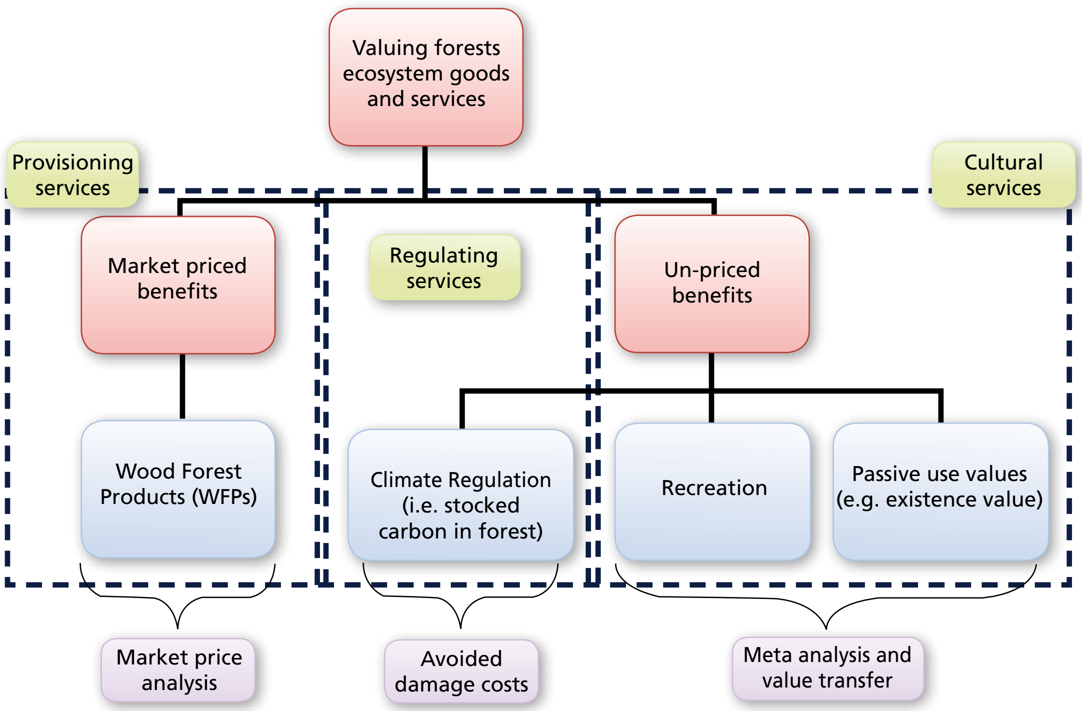
Changes of carbon stock

The carbon cycle connects forests and climate change. Total carbon stored in forests has a very important role in determining any climate stabilization path. In fact, the quantity of carbon stocked in trees biomass approximately corresponds to 77% of the carbon contained in the global vegetation, while forest soil stores 42% of the global 1m top soil carbon (Bolin et al., 2000). Forests exchange large quantities of carbon in photosynthesis and respiration, contributing to the global carbon cycle as a source of carbon when they are disturbed, and as a sink when in recovery and regrowth after disturbances. In turn, climate changes may also influence the future carbon-storage capacity of forest ecosystems., We therefore construct projections for carbon sequestration in forests for all the European countries across the four IPCC storylines – see Table A2 in the Appendix for more details. Our findings show that the average carbon stock tends to increase in all scenarios, but the respective magnitudes differ. For example, in the A1FI scenario, representing a world oriented towards 'global economic' growth together with the highest CO2 concentration and temperature, the total carbon sequestrated by forests appears to be the lowest.. This result is consistent with results reported by Schröter et al. (2005), who highlighted that for most ecosystem services the A1FI produces the strongest negative impacts. On the other hand, B-type storylines, which are sustainable development oriented, contribute to an increase in forest area and a consequently large quantity of carbon stock. These figures, in turn, will be at the basis of the economic valuation exercise, which shall be discussed in detail in the following sub-section.

The monetization of climate change impacts: The application of a hybrid economic valuation method

In the context of the MA classification of provisioning, regulating and cultural ecosystem goods and services, – see Table 4 – it is not difficult to agree that no single valuation method will deliver a full range of the forest value components under consideration,. A flexible, systematic and integrated straightforward approach is therefore needed to estimate the costs of climate change through each of the value components. In Figure 2, we summarize all valuation techniques, both market and non-market, used for the assessment of the value of forest ecosystem goods and services, these include market price analysis methods, cost assessment methods and valuation methods based on meta-analysis. These techniques are most appropriately applied in the context of regional or national scale climate change impacts, disaggregated by sector or market. .In the present paper, we shall focus on the monetary value assessment of forest regulating services.

Figure 2. A hybrid economic valuation methodology.



4. Economic valuation of stocked carbon in European forests under future IPCC scenarios

The integrated assessment models and the marginal value of carbon

Despite significant scientific investigation, the economics of climate change is still not well understood due to the high uncertainties of climate change impacts in the long run (Kelly and Kolstad, 1999). More ambitious and controversial approaches of cost-benefit analysis require additional information about the monetized value of climate impacts, which is necessary to calculate the "optimal" policy, or to determine whether a particular policy is "worthwhile." – Ackerman and Finlayson (2005). Moreover, another major drawback of the existing literature on climate change impacts is that most of the impact studies take a static approach (Tol, 2002a; Watson et al., 1996; Pearce et al., 1996; Tol et al., 2000), whereas climate change is rather a long-term dynamic process, involving the complexity of interface between physical and economic dynamics, such as the increasing CO2 concentration, the growing world population and economy, and the evolving technologies and institutions (Tol, 2002b). More precisely, the consequences of climate instability and rapid large-scale shifts in global climate may interfere in the economic production function in many sectors (e.g. forestry, and tourism), whereas the socio-economic development is always the embedded driving force behind climate change.

Current literature provides a significant quantity of research on the application of economic modelling to the estimation of socio-economic damage costs of climate change., also known as Integrated Assessment Models - IAMs. These models, developed primarily for the purpose of assessing policy options for climate change control, by definition combine the socio-economic aspects of global economic growth with the scientific aspects of geophysical climate dynamics. economists have been putting more effects on moving the state of the art IAMs towards a dynamic approach (e.g. Tol, 2002b). Well-known IAMs in the literature include MERGE[4], IMAGE[5], FUND[6], and DICE[7], with a focus on global estimates of carbon stocks. These models are characterised by significant differences that can all affect these final estimates including levels of modelling detail,, in their respective capacities to deal with climate-economic-atmospheric complexity and the economic modelling strategy, in their capacities to deal with uncertainty and in their abilities to incorporate economic responses.

The marginal value of carbon storage or carbon price refers to the benefits from avoided damages caused by incremental CO2 or CO2-equivalent GHG emissions in the atmosphere due to the carbon sequestration functions of forest ecosystems. The avoided damage costs assessment method has been widely used in the literature (see Cline, 1992; Nordhaus, 1993a,b; Merlo&Croitoru, 2005; CASES, 2008) to indirectly calculate the benefits from carbon sequestrated in forests. However it is important to note that the concept is different from the market price of carbon (obtained via emission trading scheme) and the marginal abatement cost (involves the costs of technological R&D for facilitating the emission abatement), under certain restrictive assumptions the three measures would be broadly equal, (DEFRA, 2007).. The estimation of carbon price in our paper is built upon an existing project, "Cost Assessment for Sustainable Energy Systems" - CASES[8], a worldwide study funded by the EU. One of the main features of CASES is that it is built upon the IAMs, to estimate the cost of GHG emissions under different energy evolution paths in 2020, 2030 and 2050. The CASES study adopted the estimates of UK's Department for Environment, Food and Rural Affairs (DEFRA 2005) with respect to the social costs of carbon. As a consequence, the CASES project was able to obtain three levels of estimates of marginal damage costs, i.e. lower, upper and

---

4 MERGE - the Model for Estimating the Regional and Global Effects of GHG policies
5 IMAGE - the Integrated Model to Assess the Greenhouse Effect
6 FUND - the Climate Framework for Uncertainty Negotiation and Distribution model
7 DICE - the Dynamic Integrated Climate Economy model
8 CASES, Project No.518294 SES6, (2006-2008). Project official website: http://www.feem-Project.net/cases/

central estimates[9], respectively. For example, as reported in the CASES final report, the lower estimates of marginal damage costs range from € 4/tCO2 in 2000 to € 8/tCO2 in 2030; the upper estimates range from € 53/tCO2 in 2000 to € 110/tCO2 in 2030; and the central estimate ranges from € 23/tCO2 in 2000 to € 41/tCO2 in 2030.

In the present paper, we adopt the CASES central estimate and calculate the respective economic values in 2050. The future values are then converted to 2005US$ using Purchasing Power Parity (PPP) and the necessary time adjustments. Final economic valuation results are presented and discussed in the following sub-section.

Estimation results

Table 5 presents the economic valuation of stocked carbon in European forests under future IPCC scenarios . These estimation results depend not only on the IPCC scenarions under consideration but also on the European geographical areas under consideration. For example, the forests in Central Europe contribute to the largest portion of benefits from the carbon regulating services in Europe, but this result depends both on acreage as well as the type of forests present.

Table 5. Projection of total benefits of carbon storage in European forests (million$, 2005).

Scenarios	Mediterranean Europe	Central-Northern Europe	Northern Europe	Scandinavian Europe	Europe
A1 2050	37,176	117,241	11,489	32,817	198,722
A2 2050	45,790	159,453	17,362	32,605	255,210
B1 2050	66,575	190,755	22,679	46,310	326,320
B2 2050	63,609	190,341	23,546	35,733	313,229

In addition, the productivity value of climate regulating services ($/ha) is also calculated based on the projected forest areas under different future scenarios (See Table 6 and/or Appendix-TableA3 for disaggregated data). The results clearly show the marginal benefit of carbon regulating services provided by different forest lands. Moreover, different forest management schemes may also influence these values. For instance, *ceteris paribus*, the B1 scenario shows the highest marginal value of regulating services provided by European forests.

Table 6. Projection of the productivity value of carbon sequestration (US$/ha/yr, measured in 2005).

Scenarios	Mediterranean Europe	Central-Northern Europe	Northern Europe	Scandinavian Europe	Europe
A1 2050	927	2,712	1,563	748	927
A2 2050	950	2,795	1,625	763	950
B1 2050	1,093	2,879	1,913	992	1,093
B2 2050	990	2,684	1,720	836	990

[4] The values are based on full Monte Carlo runs of the FUND and PAGE models, in which all parameters are varied to reflect the uncertainty surrounding the central parameter values in both models. The lower and upper bounds are the 5% and 95% probability values of the PAGE model, while the central guidance value is based on the average of the mean values of the FUND and PAGE models. A declining discount rate is used as suggested by the UK Government 'Green Book'. The equity weighting of damages in different regions is applied to an aggregation of the regional damage costs to global damages; in other words, lower and higher weights are applied to damages in richer and poorer regions respectively.

To better interpret the results, we undertake a comparative study among all four IPCC scenarios. Table 7 shows the comparative results of three IPCC scenarios (i.e. A1, B1 and B2) with respect to the A2 (BAU) storyline, which is characterized by a high population, strong economic growth and high income per capita. This scenario is today interpreted by the European Commission as the benchmark scenario, so as a reference point in the evaluation of the (comparative) welfare changes due to climate change.

Table 7. Projection of total benefits of carbon storage in European forests.

Benchmark A2 Scenario		Mediterranean Europe	Central-Northern Europe	Northern Europe	Scandinavian Europe	Europe
Absolute value difference (Million$, 2005)	A1vs.A2	-8,614	-42,212	-5,874	212	-56,489
	B1vs.A2	20,785	31,303	5,317	13,705	71,109
	B2vs.A2	17,819	30,888	6,183	3,128	58,018
Percentage Change	A1vs.A2	-18.8%	-26.5%	-33.8%	0.6%	-22.1%
	B1vs.A2	45.4%	19.6%	30.6%	42.0%	27.9%
	B2vs.A2	38.9%	19.4%	35.6%	9.6%	22.7%

From these results, one can clearly see that the countries within Mediterranean Europe (Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey and Yugoslav) will benefit from the highest welfare gain in a movement towards the B1 or B2 storyline. In fact, this geo-climatic zone can experience welfare gains with increases in the value of the carbon sequestration services of up to 45%. In other words, the "no adoption" of a B2 storyline, and a movement towards an A2 scenario, will be associated with a high welfare loss in Mediterranean Europe due to the reduced quantity and quality of the forest ecosystem services under consideration.

Alternatively, moving from an A2 towards an A1 scenario will always involve a welfare loss for Mediterranean Europe. In short, for Mediterranean Europe the 'A' scenarios will always be associated with reduced quantity and quality of forest ecosystem services and the resultant lowering of human welfare levels. On the other hand, storyline B1 is ranked as the most preferred scenario for this geo-climatic area. The region of Scandinavian Europe (including Finland, Norway and Sweden) presents mixed results. Firstly, moving from an A2 towards an A1 scenario will not involve any welfare loss; on the contrary small welfare gains can be registered. Furthermore, in a movement towards a B type scenario, Scandinavian Europe will also experience significant welfare gains in the provision of carbon sequestration services. The respective welfare gains are, however, much lower when compared to Mediterranean Europe, ceteris paribus. If we consider Mediterranean and Scandinavian Europe as two 'corner situations' in terms of the respective welfare change magnitudes, we can observe that Central Europe and Northern Europe each present an intermediate state of affairs. In any case, it is important to note that a movement from an A2 to an A1 scenario will be always associated with high welfare losses in regulating services, with the highest losses registered among the Northern Europe countries (Denmark, United Kingdom, Estonia, Latvia and Lithuania). Finally, both Central Europe and Northern Europe show a similar profile in terms of carbon sequestration values: any B type scenario is characterized by a welfare gain, results that are in accordance with what is also registered in Mediterranean and Scandinavian Europe.

5. Conclusions

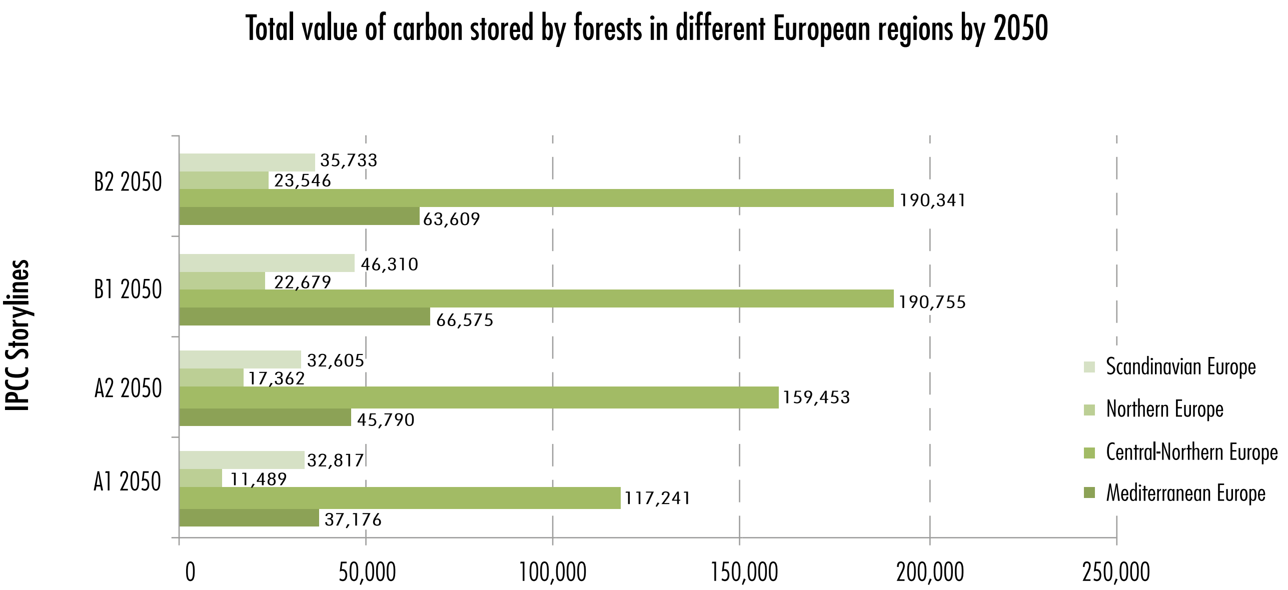
This paper reports an original economic valuation of the impact of climate change on the provision of forest regulating services in Europe. To the authors' knowledge the current paper represents the first systematic attempt to estimate human well-being losses with respect to changes in biodiversity and forest regulating services that are directly driven by climate change. The valuation exercise is anchored in an ecosystem service based approach, involving the use of general circulation models and integrated assessment models. The modelling and economic assessment is performed in the context of climate change, with a particular focus on the carbon sequestration services provided by European forests.

In order to value climate change impacts, we first identify four different climate scenarios, corresponding to the four IPCC storylines, referred to as A1FI, A2, B1 and B2 scenarios. . Secondly, we proceed with the analysis and evaluation of climate change impacts on the total forest area (for each country) as well as on the quantities of carbon stored in forests (in bio-physical terms). We project future trends of forest areas and stocked carbon in 2050 for the four IPCC scenarios, through the construction and simulation of global circulation models such as HADMC3.

Moreover, considerable impacts of differentiated latitudes on the variability of forest EGS are taken into account by regrouping the 34 selected countries by their different latitude intervals. As a consequence, we are able to identify the dominant forest types, assess their respective efficiency in terms of carbon sequestration and compare their sensitivities to climate change impacts. Finally, we apply a central estimate of carbon price derived from CASES, to combine the dynamics of global economic growth with the dynamics of geophysical climate dynamics .

Figures 3 summarizes the economic valuation of regulating services provided by forest ecosystem in Europe across the four IPCC scenarios. As we can see, the value of stocked carbon in the Mediterranean European region varies from 37.2 in the A1 scenario to 45.8 billion in A2 scenario, to 63.6 billion in the B2 scenario, and 66.6 billion in the B1 scenario. Therefore, the B1 scenario is ranked as the one with the highest level of provision. The same ranking holds also for the Central-Northern Europe and the Scandinavian Europe, where the B1 scenario is associated with the provision of 190.3 billion dollars and 46.3 billion dollars, respectively. Finally, for the Northern European countries, the highest benefits from carbon sequestration services are again registered in the 'B' scenarios, but with the B2 scenario corresponding to 23.5 billion dollars of benefits, slightly higher than those in the B1 scenario.

Figure 3. Forest carbon sequestration values.



In summary, we address two dimensions in the evaluation of climate impacts on European forests:

- Firstly, future projections yield different states of the world depending upon the IPCC scenario adopted. In particular, our results suggest a loss of benefits of carbon stocks from forests to all Europe in the A1 scenario, when compared to the A2 scenario. This may be the result of intensive harvesting of forest products to meet the rapid progress of economic development path, represented by the A1 scenario. In contrast, a focus on sustainable development and environmental protection in the B-type scenarios may lead to the extension of protected forest area and thus consequent welfare gains from carbon sequestration in most of the geo-climatic regions.

- Secondly, spatial issues matter in an assessment of the distributional impacts of climate change, as these impacts are not distributed in a uniform way across the European countries under consideration. With carbon sequestration defined as a global public good, an analysis of the distributional aspects of welfare gains and losses is crucial in signalling the potential for international negotiations. The implied transaction costs are beyond the scope of the present analysis but are an important direction for future research.

Acknowledgements

The current research is part of the ongoing University Research Sponsorship Programme financed by the European Investment Bank. The authors are grateful for its financial support. The authors also thank Carlo Carraro, Francesco Bosello, Ramiro Parrado, Renato Rosa, Mateu Turrò, and Peter Carter for their valuable comments and suggestions on a previous version of this paper. In addition, the authors thank Silvia Silvestri for valuable research assistance, data management and suggestions on an earlier version of this manuscript. Finally, the authors thank the research group, Advanced Terrestrial Ecosystem Analysis and Modelling – Potsdam Institute for Climate Impact Research (PIK), Germany – and in particular to Dagmar Schröter, scientific coordinator. Finally, the authors also thank Jeannette Eggers at the European Forest Institute.

References

Ackerman, F. and I. Finlayson (2005) "Monetized Impacts of Climate Change: Why are the Numbers So Small?", evidence submitted to the Stern Review, December 8, 2005

Bolin B., Sukumar R. et al., (2000_. Global perspective. Land use, land-use change, and forestry. In: Watson, R. T. et al. (Eds.). A Special Report of the IPCC. Cambridge University Press, 23-51.

CASES (2008) CASES Project No.518294 SES6, (2006-2008). Project official website: http://www.feem-Project.net/cases/

Cline, W.R. (1992) "The Economics of Global Warming", Institute for International Economics, Washington, DC.

DEFRA (2005) "The Social Cost of Carbon Review – Methodological Approaches for Using SCC Estimates in Policy Assessment", AEA Technology Environment, London.

DEFRA (2007) "The Social Cost of Carbon and The Shadow Price of Carbon: What They Are, and How to Use Then in Economic Appraisal in the UK", Economics Group of the Department for Environment, Food and Rural Affairs, UK. Available online at:

Ellenberg, H., (1986): Vegetation Mitteleuropas mit den Alpen. Ulmer, Stuttgart, Germany, 4th ed., 989 pp.

Garcia-Gonzalo J., Peltoa H., Gerendiain A. Z., Kellomäki S., (2007). Impacts of forest landscape structure and management on timber production and carbon stocks in the boreal forest ecosystem under changing climate, Forest Ecology and Management, 241: 243-257.

Giardina, C.P., and M.G., Ryan (2000), 'Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature', Nature 404: 858-861

Gordon, C., Cooper, C., Senior, C.A., Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F.B. and Wood, R.A., (2000): The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics 16, 147-168

IMAGE (2001) Integrated Model to Assess the Global Environment, Netherlands Environmental Assessment Agency – RIVM, available at http://www.rivm.nl/image/

IPCC (2001). Intergovernmental Panel on Climate Change, Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK, pp. 881

Jarvis, P.G. and S., Linder (2000), 'Botany-constraints to growth of boreal forests', Nature 405: 904-905

Karjalainen, T., Pussinen, A., Liski, J., Nabuurs, G.J., Eggers, T., Lapvetelainen, T., Kaipainen, T. (2003). Scenario analysis of the impacts of forest management and climate change on the European forest sector carbon budget. Forest Policy and Economics 5: 141-155.

Kelly, D. L. and C. D. Kolstad (1999) "Integrated Assessment Models for Climate Change Control", in Henk Flmer and Tom Tietenberg (eds), International Yearbook of Environmental and Resource Economics 1999/2000: A Survey of Current Issues (Cheltenham, UK-Edward Elgar, 1999)

Lloyd, J. and J.A. Taylor (1994), 'On the temperature dependence of soil respiration', Funct.Ecol.8: 315-323

Luo, Y.Q., Wan, S.Q., Hui, D.F., Wallance, L.L. (2001), 'Acclimatization of soil respiration to warming in a tall grass prairie', Nature 413: 622-625

MCPFE (2007), State of Europe's forests 2007: The MCPFE report on sustainable forest management in Europe, Ministerial Conference on the Protection of Forests in Europe, Liaison Unit Warsaw, Poland. ISBN: 83-922396-8-7 or 978-83-922396-8-0

MA (2003) "Ecosystems and Human Well-being: A Framework for Assessment", World Resources Institute, Washington, D.C.

MA (2005) "Ecosystems and Human Well-being: Biodiversity Synthesis", World Resources Institute, Ashington, D.C.

Melillo, J.M., McGuire, A.D,, Kicklighter,D.W., Moore III, B., Vorosmarty, C.J., Schloss, A.L. (1993), 'Global climate change and terrestrial net primary production', Nature 363: 234-239

Merlo, M. and L. Croitoru (2005) Valuing Mediterranean Forests: Towards Total Economic Value, CABI Publishing-CAB International, Wallingford, Oxfordshire, UK.

Nakicenovic N., and R. Swart (2000). IPCC Special Report on Emission Scenarios (Cambridge University Press, Cambridge.

Nordhaus, W.D (1993a) "Optimal Greenhouse Gas Reductions and Tax Policy in the 'DICE' model", American Economic Review, Papers and Proceedings 83: 313-317.

Nordhaus, W.D (1993b) "Rolling the 'DICE': an Optimal Transition Path for Controlling Greenhouse Gases", Resources and Energy Economics 15: 27-50.

OECD (1999) "Environmental Indicators for Agriculture: Volume 1 Concepts and Frameworks", Organization for Economic Co-operation and Development, Pairs.

Pearce, D. W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and P. Vellinga (1996) "The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control", in J.P. Burce, H.Lee and E.F. Haites, eds., Climate Change 1995: Economic and Social Dimensions – Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, pp179-224;

Schöter D. et al., (2004). ATEAM (Advanced Terrestrial Ecosystem Analyses and Modelling) final report (Potsdam Institute for Climate Impact Research, 2004).

Schöter D., Cramer W., Leemans R., Prentice I. C., Araùjo M. B., Arnell N. W., Bondeau A., Bugmann H., Carter T. R., Gracia C. A.,. de la Vega-Leinert A. C, Erhard M., Ewert F., Glendining M., House J. I., Kankaanpää S., Klein R. J. T., Lavorel S., Lindner M., Metzger M. J., Meyer J., Mitchell T. D., Reginster I., Rounsevell M., Sabaté S., Sitch S., Smith B., Smith J., Smith P., Sykes M. T., Thonicke K., Thuiller W., Tuck G., Sönke Zaehle, Bärbel Z., 2005. Ecosystem Service Supply and Vulnerability to global change in Europe. Science, 310: 1333-1337.

Thuiller W., Lavorel S., Araùjo M. B., Sykes M. T., Prentice I. C., (2005). Climate change threats to plant diversity in Europe. PNAS, vol. 102, n° 23: 8245-8250.

Tol, R.S.J. (2002a) "New Estimates of the Damage Costs of Climate Change: Part I. Benchmark Estimates", Environmental and Resource Economics 21 (1): 47- 73.

Tol, R.S.J. (2002b) "New Estimates of the Damage Costs of Climate Change: Part II. Dynamic Estimates", Environmental and Resource Economics 21 (1): 135 – 160

Tol, R.S.J., Frankhauser, S., Richels, R.G. and J.B. Smith (2000) "How Much Damage Will Climate Change Do? Recent Estimates", World Economics 1(4): 179-206.

UNECE/FAO, (2005). European Forest Sector Outlook Study, 1960 – 2000 – 2020, Main report, United Nation Publications, pp. 265

Watson, R.T., Zinyowera, M.C. and R.H.Moss, eds. (1996) "Climate Change 1995: Imacts, Adaptation, and Mitigation of Climate Change – Scientific – Technical Analysis – Contribution of Working Group II to the Second Assessment Report of the Integovernmental Panel on Climate Change." Cambridge: Cambridge University Press.

Appendix – Projections of the forest EGS in 2050 in both physical and monetary terms

Table 1. Projection of European forest area (estimates in 1000 ha).

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	3 ,752	2,292	2,360	3,762	3,598
	Italy	9,979	8,346	8,253	11,677	11,893
	Portugal	3,783	2,170	2,174	3,254	3,283
	Spain	17,915	12,052	11,969	17,389	17,633
	Albania	794	519	835	918	991
	Bosnia and Herzegovina	2,185	1,476	2,372	2,609	2,817
	Bulgaria	3,625	2,279	3,664	4,030	4,351
	Serbia and Montenegro	2,694	1,789	2,876	3,163	3,415
	Turkey	10,175	6,788	10,912	12,002	12,959
	TFRY Macedonia	906	612	984	1,082	1,168
	Regional Total	55,808	38,324	46,399	59,885	62,108
45 to 55	Austria	3,862	5,298	5,177	5,199	5,471
	Belgium	667	526	545	698	842
	France	15,554	15,094	16,056	20,080	21,926
	Germany	11,076	10,049	10,075	12,696	14,033
	Ireland	669	442	379	638	656
	Luxembourg	87	80	78	103	94
	Netherlands	365	151	421	333	413
	Switzerland	1,221	1,985	1,913	2,113	2,121
	Croatia	2,135	1,438	2,311	2,542	2,745
	Czech Republic	2,648	1,781	2,863	3,149	3,400
	Hungary	1,976	1,288	2,070	2,277	2,458
	Poland	9,192	6,118	9,834	10,816	11,679
	Romania	6,370	4,299	6,911	7,601	8,207
	Slovakia	1,929	1,297	2,085	2,294	2,477
	Slovenia	1,264	837	1,345	1,479	1,597
	Regional Total	59,015	50,682	62,064	72,017	78,118
55 to 65	Denmark	500	414	677	434	839
	UK	2,845	1,986	2,145	2,780	3,476
	Estonia	2,284	1,515	2,435	2,678	2,892
	Latvia	2,941	1,948	3,132	3,445	3,719
	Lithuania	2,099	1,364	2,193	2,412	2,604
	Regional Total	10,669	7,227	10,582	11,749	13,530

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
65 to 71	Finland	22,500	18,224	17,999	16,517	17,079
	Iceland	46	30	29	28	28
	Norway	9,387	6,478	6,277	5,141	5,761
	Sweden	27,528	22,704	22,198	25,884	22,704
	Regional Total	59,461	47,435	46,503	47,569	45,572

Notes: a data from FAO; b projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; c interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table 2. Projection of carbon stock in European forest (estimates in mt/year).

Latitude	Country	1990[a]	2005[b]	2050[d] A1FI	2050[d] A2	2050[d] B1	2050[d] B2
35 to 45	Greece	293.23	305.53	190.46	201.11	368.57	319.44
	Italy	1,315.59	1,389.67	1,186.02	1,200.24	1,826.60	1,770.73
	Portugal	161.08	170.08	99.55	101.92	218.21	169.31
	Spain	987.42	1,076.28	738.83	758.43	1,224.48	1,162.31
	Albania	62.62	64.66	43.15	71.14	89.95	88.03
	Bosnia and Herzegovina	177.93	177.93	122.61	202.14	255.58	250.11
	Bulgaria	274.83	295.19	189.39	312.23	394.78	386.33
	Serbia and Montenegro	215.71	219.38	148.65	245.07	309.86	303.23
	Turkey	818.55	828.57	564.07	929.94	1,175.81	1,150.64
	TFRY Macedonia	73.78	73.78	50.84	83.82	105.98	103.71
	Regional Total	4,380.75	4,601.05	3,333.57	4,106.03	5,969.82	5,703.84
45 to 55	Austria	937.51	943.37	1,454.04	1,440.26	1,549.25	1,562.36
	Belgium	72.87	72.87	64.56	67.19	97.03	103.55
	France	1,702.22	1,724.73	1,880.61	2,135.35	3,134.30	3,099.40
	Germany	1,257.57	1,257.57	1,281.98	1,395.33	2,233.45	2,130.37
	Ireland	71.30	78.33	58.13	51.71	99.80	94.39
	Luxembourg	23.50	23.50	24.40	24.53	31.68	27.03
	Netherlands	52.10	52.82	24.57	69.80	61.58	71.22
	Switzerland	294.63	300.04	547.99	540.40	653.70	620.48
	Croatia	575.06	576.68	436.35	722.68	779.21	788.89
	Czech Republic	712.27	715.24	540.47	895.12	965.14	977.12
	Hungary	515.09	533.73	390.85	647.32	697.96	706.63
	Poland	2,446.89	2,482.82	1,856.69	3,075.03	3,315.58	3,356.76
	Romania	1,719.50	1,720.58	1,304.75	2,160.91	2,329.95	2,358.88
	Slovakia	518.87	521.03	393.72	652.07	703.08	711.81
	Slovenia	334.66	341.41	253.94	420.57	453.47	459.10
	Regional Total	11,234.04	11,344.72	10,513.04	14,298.25	17,105.17	17,068.00
55 to 65	Denmark	60.92	62.68	53.44	91.68	71.13	121.77
	United Kingdom	409.39	417.01	300.10	334.64	498.37	568.02
	Estonia	304.98	310.55	212.33	354.77	459.44	446.08
	Latvia	392.27	399.88	273.10	456.31	590.95	573.76
	Lithuania	274.66	285.40	191.22	319.50	413.77	401.73
	Regional Total	1,442.21	1,475.52	1,030.20	1,556.89	2,033.65	2,111.36
65 to 71	Finland	1,040.16	1,041.32	869.50	903.69	1,219.41	991.76
	Norway	786.34	793.61	564.61	560.76	511.91	535.89
	Sweden	1,770.79	1,774.27	1,508.58	1,459.27	2,421.32	1,676.58
	Regional Total	3,597.29	3,609.20	2,942.69	2,923.71	4,152.64	3,204.23

Notes: a data from Karjalainen et al. (2003) and Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM), PIK; b EIBURS projections ; c projections by Karjalainen et al. (2003); d projections by ATEAM and EIBURS need to add the Finland study.

Table 3. Economic value of carbon sequestration (estimates in $/ha/year, $2005).

Latitude	Country	2005	2050 A1FI [b]	2050 A2 [b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	1,629	927	950	1,093	990
	Italy	2,785	1,585	1,622	1,744	1,660
	Portugal	899	512	523	748	575
	Spain	1,202	684	707	785	735
	Albania	1,629	927	950	1,093	990
	Bosnia and Herzegovina	1,321	927	950	1,093	990
	Bulgaria	1,629	927	950	1,093	990
	Serbia and Montenegro	1,629	927	950	1,093	990
	Turkey	1,629	927	950	1,093	990
	TFRY Macedonia	407	927	950	1,093	990
	Regional Average	1,476	927	950	1,093	990
45 to 55	Austria	4,885	3,061	3,102	3,323	3,185
	Belgium	2,185	1,369	1,374	1,551	1,371
	France	2,218	1,389	1,483	1,741	1,576
	Germany	2,271	1,423	1,544	1,962	1,693
	Ireland	2,342	1,467	1,523	1,744	1,605
	Luxembourg	5,402	3,385	3,487	3,418	3,205
	Netherlands	2,894	1,813	1,851	2,065	1,923
	Switzerland	4,915	3,079	3,150	3,450	3,263
	Croatia	5,402	3,384	3,487	3,418	3,205
	Czech Republic	5,402	3,384	3,487	3,418	3,205
	Hungary	5,402	3,385	3,487	3,418	3,205
	Poland	5,402	3,384	3,487	3,418	3,205
	Romania	5,402	3,384	3,487	3,418	3,205
	Slovakia	5,402	3,384	3,487	3,418	3,205
	Slovenia	5,402	3,385	3,487	3,418	3,205
	Regional Average	4,328	2,712	2,795	2,879	2,684
55 to 65	Denmark	2,507	1,441	1,510	1,827	1,618
	United Kingdom	2,932	1,685	1,740	1,999	1,822
	Estonia	2,719	1,563	1,625	1,913	1,720
	Latvia	2,719	1,563	1,625	1,913	1,720
	Lithuania	2,719	1,563	1,625	1,913	1,720
	Regional Average	2,719	1,563	1,625	1,913	1,720
65 to 71	Finland	926	532	560	823	648
	Norway	1,691	972	996	1,111	1,037
	Sweden	1,289	741	733	1,043	824
	Regional Average	1,302	748	763	992	836

Notes: a projections by CLIBIO based on CASES (reference)