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Valuing climate change impacts on European forest ecosystems

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ABSTRACT

This paper presents one of the first attempts to perform a systematic assessment of the climate change impacts on European forests and its capacity to deliver ecosystem services by developing a hybrid economic valuation model. Different methods are combined to assess climate change impacts on forests by different latitudes, productivity in bio-physical terms and related economic consequences. Our computation shows that countries within the Mediterranean European geo-climatic zone will benefit from the highest welfare gain in moving towards an environmentally oriented scenario. The welfare gain has been estimated around 86% increase in the cultural values, 45% increase in the value of carbon sequestration and 24% increase in the values of wood forest products. The other countries show an intermediate state of affairs with mixed results. On the other hand, high welfare losses are always expected when moving to the more economically oriented scenarios, with the highest impacts among the Northern European countries. Results show that all storylines describe significant impacts on human wellbeing. These economic magnitudes contribute to a better understanding of the potential welfare loss across different regions and therefore will have important policy implications, such as developing the ecosystem-base adaption measures for Europe to cope with climate change.

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1. Introduction

Climate change is already impacting ecosystem and biodiversity in various world regions, in particular on the forest biomes located in the high-altitude and high-latitude regions (IPCC, 2001). These impacts can impose *pressure* on the forest ecosystem, and lead to the changes in the *state* of ecosystem functioning and biodiversity, which in turn affect the overall provision of forest ecosystem goods and services (EGS), such as wood forest products, carbon sequestration, forest recreation and passive use benefits, and ultimately have an *impact* on human-wellbeing – see Fig. 1. However, the economic assessment of these impacts is still a growing literature.

Tol (2008) has conducted a literature survey in 2008, which showed an exponential increase in the number of papers published in international peer reviewed journals on the topic of climate change, from 1,714 to 11,652 papers, respectively in 1995 and 2008. Among all the reviewed literature, only a very small proportion has centred within the economics literature (about 33 papers in 1995 and 218 papers in 2008), most of which have focused on market-related impacts of climate change (Tol, 2005). The use of a monetary metric to express economic impacts of climate change on forest and ecosystems services provision is not present in this review, mainly due to the mixed nature of ecosystem services and the lack of recorded market information (Pearce et al., 1996; Tol, 2005). Recent literature has moved forward to exploring methodologies that can examine the relationship between ecosystem services and climate change, in order to explain how changes in climate conditions may affect the provision of ecosystem services. In this regard, two remarkable studies should not be ignored. First of all, Ojea et al. (2010) developed a meta-transfer regression of worldwide forest ecosystem services values, whose architecture also introduced a climate change variable that aimed to capture the impact of climate change on ecosystem services. More recently, Ding and Nunes (2014) developed a 3 stage regression model to empirically estimate the relationship between climate change, biodiversity and the value of EGS provided by European forests, which constituted a first attempt of its kind.

In this setting, the present paper attempts to enrich the economics literature of climate change impacts on ecosystem services, by undertaking an empirical application of various economic valuation techniques to estimate the economic impacts of climate change on European forests and the corresponding provision of EGS. Different from the previous studies, the present study will

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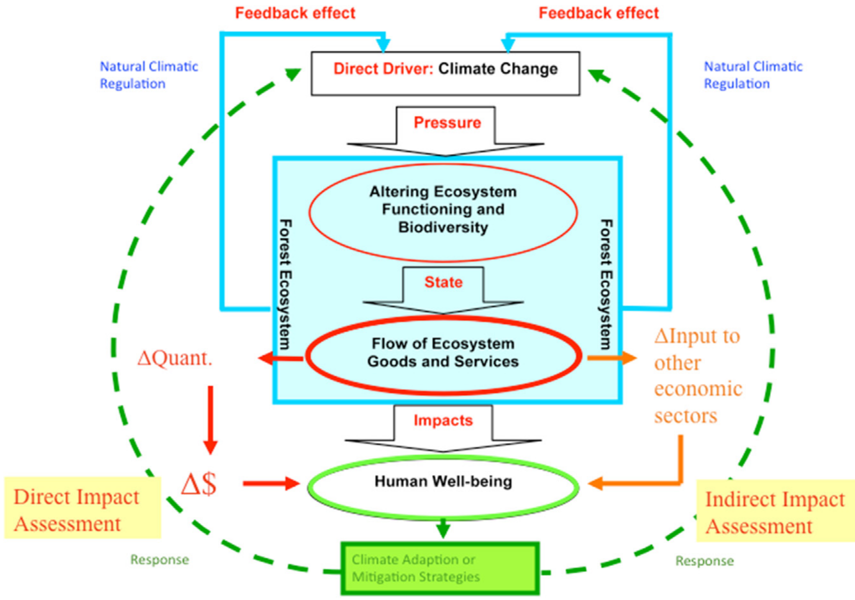

Fig. 1. Conceptual model for the climate change, forest biodiversity and human well-being interactions.

focus on the integration of climate science modelling and economic valuation techniques to first assess the magnitude of changes in the biophysical provision of ecosystem services due to potential impacts of climate change under different future scenarios, and then translate these biophysical impacts into economic values, accordingly. The results are therefore anchored in a solid interdisciplinary study covering the fields of natural sciences, socio-economics and climate change modelling, which can play a crucial role in better understanding the economic and environmental consequences of the chosen future development paths and exploring the potential of ecosystem-based mitigation and adaptation policies for fighting against global warming.

The paper is organised as follows. Section 2 analyses the climate change impacts on European forests. Section 3 presents the projections of the provision of EGS under different climate scenarios. Section 4 presents an integrated-hybrid economic valuation methodology that is applied to estimate, in monetary terms, the impacts on human welfare associated to the bio-physical changes in the provision of forest ecosystem services among all countries under consideration. Section 5 discusses the policy implementation of the results and Section 6 concludes.

2. Understanding the climate change impacts on European forest ecosystems

Over the last 30 years, the world has experienced significant temperature increases, particularly in the northern high latitudes, and this trend will continue into the future (IPCC, 2001). In Europe, the average temperature is projected to increase from 2.1 to 4.4 °C by 2050, with the strongest consistent increase in the higher latitudes (IPCC, 2001). Moreover, model simulations suggest a decrease in precipitation in the south of Europe, particularly in summer, but an increase in precipitation over much of northern Europe (Schöter et al., 2005). In the present study, the magnitude of climate change impacts on forest ecosystems, and the respective provision of EGS (in both physical and economic terms) will be estimated under future climate change scenarios. These scenarios are correspondent to different states of the world by 2050 following assumptions made by the IPCC (2000) on Emission Scenarios, namely A1, A2, B1 and B2 storylines. Each is an outcome of an integrated global atmosphere-ocean circulation modelling, including the Hadley Centre Couplet Model Version 3 (HadCM3), together with the coherent use of socio-economic storylines, including population and Gross Domestic Product (GDP) growth, land use, and CO_2 concentrations. (Gordon et al., 2000, Nakicenovic and Swart, 2000; Schöter et al., 2004, 2005) – see Table 1.

The four storylines are distinguished in terms of four future distinct development paths, i.e. 'global economic' oriented, 'regional economic' oriented, 'global environmental' oriented, and 'regional environmental' oriented, respectively. The two economic oriented scenarios (A1 and A2) focus on 'material consumption' and are characterized by a higher population and CO_2 concentration rates. The A1 scenarios also consider different combinations of

Table 1
The specifications of the four IPCC storylines.
(*Source:* adapted from Schöter et al. (2005) and IPCC (2001)).

Indicator	Climatic model–HadCM3 (Scenarios by 2050)			
	Storyline A1FI Global economic	Storyline A2 Regional economic	Storyline B1 Global environmental	Storyline B2 Regional environmental
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

fuel, including the A1 Fossil Intensive scenario (A1FI), which is the one selected for this study. On the contrary, the other two scenarios, B1 and B2, are environmental oriented scenarios and are characterized by the concepts of 'sustainability, equity and environment'. In this context, the A2 scenario, which describes the state of a heterogenic world that is characterized by the highest population growth, a regional oriented economic development, and a high CO_2 concentration, is often used by the European Commission as the reference scenario for interpreting the costs of policy inaction for relevant climate policies.

The present study includes 34 European countries.[1] Data on the state of forests are derived from the *European Forest Sector Outlook Study 1960-2000-2020 main report* (UNECE/FAO, 2005). Total forest area under consideration covers about 185 million ha in 2005 (FAO/FRA2005, 2006), accounting for 32.7% of the combined territories. The composition and distribution of forest biomes are distributed across Europe – see Fig. 2 below, in accordance with the type of soil, topography and, most importantly, regional climate conditions, including temperature and precipitation. Therefore, the respective magnitudes of climate change impacts are expected to be different.

For this reason, we classify the 34 European countries into four geo-climatic clusters to reflect the main types of forest biomes appeared in different latitudes. We refer to: (1) Mediterranean Europe (N35–45°)[2]; (2) Central Europe (N45–55°)[3]; (3) Northern Europe (N55–65°)[4]; and (4) Scandinavian Europe (N65–71°).[5] It shall be noted that the grouping is organised at country level, though this classification is expected to largely represent the predominated tree species in the country. The underlying idea of this grouping is based on the assumption that particular types of forests in each country are closely determined by country specific climate conditions, which are classified into four main latitudes. This way thus allows us to identify the predominant tree species as well as the respective contributions to the local economy at both national and larger regional scales. From an ecological view point, different tree species can play different roles in ecosystem regulating and life supporting functions, which will ultimately influence the provision of forest EGS. Whereas from an economic perspective, different tree species may deliver very different EGS, which thus refer to the various levels of economic importance and respective welfare impacts in different countries. This is also consistent with the economic valuation conducted later, which will use country as a smallest unit for scaling up valuation results to the level of geo-climatic regions. Finally, and from a geo-climatic perspective, this way of grouping may also allow us to explore how sensitive different tree species are when reacting to the changes of climate, including increase of temperature and precipitation rate in the countries under consideration.

Data show that forests in the Mediterranean Europe count for 30% of the total forest cover in Europe, predominated by Mediterranean, broadleaf and mixed forests. The Central and Northern Europe are home to most of the temperate conifer forests, representing 35% and 19% of the forest coverage in Europe, respectively. Finally, forests in the Scandinavian Europe are mainly boreal, accounting for the remaining 16% of European forests. The sensibilities of tree species in response to the changing temperature are considered to be different across the classified geo-climate regions. For instance, in the Mediterranean region, most forests consist of *sclerophyllous* and some deciduous species that have adapted to summer soil water deficit. Temperature changes may allow for an expansion of some *thermophilous* tree species (e.g. *Quercus pyrenaica*) when water availability is sufficient (IPCC, 2001).

3. Projecting changes in Ecosystem Goods and Services

3.1. Definition of Forest Ecosystem Goods and Services

Forest Ecosystem Goods and Services (EGS) are classified following a Millennium Ecosystem approach (MEA, 2003), including *provisioning, regulating, cultural* and *supporting services*. The MA classification with examples of forest EGS is presented in Table 2.

Forest *provisioning services* refer to wood forest products[6] (WFPs) (FAO, 1999), which contain seven product categories (as identified in FAOSTAT) representing different industrial sectors: industrial roundwood, wood pulp, recovered paper, sawnwood, wood-based panels, paper and paper board, and wood fuel. Another service included in the assessment is carbon regulation service (or carbon sequestration service), given the role of forest ecosystems in the mitigation of climate change and considering that soil carbon storage has also been largely studied in the literature (Ding et al. 2012). In the EU, the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project funded by the 5th Framework Programme of the European Commission has projected the carbon stocks in forest ecosystems for 17 EU countries under different IPCC scenarios in response to climate changes (Schöter et al., 2004). These simulations results have been directly adopted in the present study. Furthermore, for the remaining 17 EU countries that are not covered by ATEAM[7] model, the IMAGE 2.2 programme[8] has been used to model the respective changes in forest land and ecosystem services.

Cultural services provided by European forests consist of both recreational and passive uses. In particular, recreational services, include both Consumptive Recreational Use of forest (CRU) e.g. hunting and picking non-wood forest products (e.g. mushrooms), and Non-Consumptive Recreational Use of forest (NCRU) e.g. natural park visiting, forest landscape and other spiritual uses, both of which represent the most important value in this service category (MCPFE, 2007). Some activities refer to both consumptive and non-consumptive uses, such as fishing and hunting where the two components of enjoyment and use of resources are both present. The same applies to the gathering of non-wood forest products (NWFP). In this case it is impossible to separate the consumptive from the non-consumptive use of the resource. However, the inclusion of both values would result in double counting.[9] Therefore,

[1] Three EFSOS sub-regions are presented in the Annex. Note that in this paper, we exclude the CIS sub-region (i.e. Belarus, Republic of Moldova, Russian Federation and Ukraine) from our study for fear that the vast forest area and the relative low prices of forest products in these countries may bias our valuation result for the whole of Europe.

[2] Mediterranean Europe includes Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey, and The former Yugoslav Republic of Macedonia.

[3] Central Europe includes Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia.

[4] Northern Europe includes Denmark, United Kingdom, Ireland, Estonia, Latvia, Lithuania.

[5] Scandinavian Europe includes Finland, Iceland, Norway, Sweden.

[6] WFPs include industrial wood, wood fuel, small woods and other manufactured wood products.

[7] This project with a specific emphasis on assessing the vulnerability of human sectors relying on ecosystem services with respect to global change (Schöter et al., 2004), delivers projections in forest areas, wood products and carbon sequestration by forests across the four IPCC storylines for the EU-17.

[8] IMAGE (2001) version: http://themasites.pbl.nl/models/image/index.php/Download.

[9] The recreational value of forests usually involves both consumptive (e.g. consumption of animal meat) and non-consumptive (e.g. enjoyment derived from hunting activities and forest landscape) uses of forests and can be presented in different forms, such as entry fees to natural parks, travel costs for obtaining leisure enjoyment in the forests, and willingness to pay for enjoying the scenic value of forest, etc.

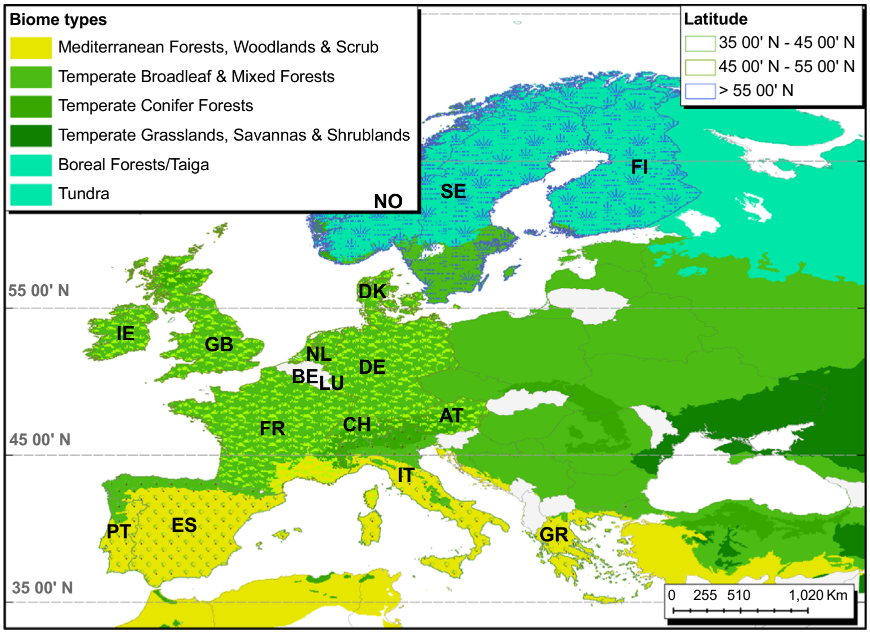

Fig. 2. Distribution of terrestrial biomes in Europe and classification of EU-17 countries in latitude categories.

Table 2
Adapted MA approach for forest EGS classification.
Source: adapted from MEA (2003).

Types of Forest EGS		Examples	Explanation of the data uses
Supporting Services	Provisioning Services	Industrial Roundwood, Wood pulp, recovered paper, sawnwood, wood-based panels, paper and paper board, and wood fuel	The data report from FAOSTAT does not provide sufficient data on non-wood forest products, for this reason, our figures on the forest provisioning services will not embed this service type. We acknowledge that our estimation is underestimated compared to other studies (e.g. Merlo and Croitoru, 2005) in the literature, as it is more difficult to estimate the provision of non-wood forest products under climate change scenarios.
	Regulating Services	Climate regulation, i.e. carbon sequestration	We focus only on the carbon sequestration other than watershed protection due to the limited studies for watershed protection in the climate change context. This caveat leaves the value of regulating services underestimated in this study.
	Cultural Services	Recreation and passive use of forest	As for cultural services, both recreational and passive uses of forests in Europe are considered. Note that our analysis is limited to the non-consumptive recreation, such as the enjoyment derived from hunting activities and forest landscape. And passive use of for

in our study we considered all recreational activities but we did not add the value of the goods obtained from fishing, hunting or gathering.

Notwithstanding some of the existing literature in general equilibrium modelling has made some considerable efforts to analyse the climate-driven changes in tourism demands (Berrittella et al., 2006; Bigano et al., 2008), it should be noted that the direct linkage of cultural services with climate change is rather too complex to convey. This link is more indirect in the sense that the use of natural environment does not depend directly on temperature increase but it is indirectly linked with climate variables. If climate varies and, for example, the frequency and duration of extreme events are changing, this will indirectly affect tourism flows and tourism demand in specific locations affected. The link is indirect as other socio-demographic and economic variables are in cause in this case. A direct link would be in the case of health impacts resulting from an increased incidence of flooding or heat waves. If the flood risk increases, this would directly affect health in terms of additional risk of mortality and injuries. Finally, passive use value of forests is considered in the cultural services category due to their important inter-temporal existence values to be passed onto future generations to come, yet will be greatly affected by the choice of future climate scenarios.

Although the authors acknowledge that many factors that may affect the provision of *carbon regulation and cultural services* by different forest biomes, we assume in this paper that the provided quantity of these two types of ecosystem services is positively correlated to the size of the forest area (i.e. the bigger is the forest, the more *regulating and cultural services* it provides).

With respect to the forest *supporting services*, indicators for measuring the respective forest ecosystem changes in response to climate change are not well developed and thus, quantity data to measure them are not readily available (MEA, 2005). For this reason, we will not tackle this service category directly. It is, however, important to realize that the value of supporting services is embedded in the value of other three MA ecosystem services, in terms of sustaining the healthy ecosystem functioning and the capability of delivering ecosystem services to human society. Therefore, taking into account this value category would also result in double counting.

Table 3
Projected European forest areas between 2005 and 2050 (Estimates in 1000 ha).
Source: Ding et al. (2010).

Geo-climatic region (Latitude)	2005	A1 2050	A2 2050	B1 2050	B2 2050
Mediterranean Europe (N35–45)	55,808	38,324	46,399	59,885	62,108
Central Europe (N45–55)	59,015	50,682	62,064	72,017	78,118
Northern Europe (N55–65)	10,669	7227	10,582	11,749	13,530
Scandinavian Europe (N65–71)	59,461	47,435	46,503	47,569	45,572

3.2. *Project ecosystem goods and services changes under future climate change scenarios*

In this paper, the baseline for the biophysical data for all EGS are extracted at country level from the FAOSTAT-Forestry database for a reference year 2005 and then aggregated to a geo-climatic region scale. The projection of quantitative changes of forest area, wood forest products and carbon stocks due to climate change by 2050 were derived with the use of ATEAM and the IMAGE 2.2 models, respectively. In particular, ATEAM model was used to derive the percentage changes in forest areas and wood products for the four IPCC storylines, for the EU-17. For the remaining 17 European countries, the respective forest areas are projected on the basis of the IMAGE 2.2 model. The projections of forest area, wood forest products and carbon sequestration services by 2050 are presented in Tables 3–5 below.

The detailed assessment of the implication of the biophysical changes on the delivery of EGS is discussed in Ding et al. (2010), which has provided a comprehensive and detailed discussion on the projections of biophysical changes of forest ecosystem ecosystems under future IPCC scenarios. These projected EGSs under different climate change scenarios are essential inputs to the economic valuation framework that we are developing in this paper.

Table 5
Projected carbon sequestration in European forests between 2005 and 2050 (Estimates in Mt/year).
Source: Ding et al. (2010).

Geo-climatic region (Latitude)	2005	A1 2050	A2 2050	B1 2050	B2 2050
Mediterranean Europe (N35–45)	4,601	3,334	4,106	5,970	5,704
Central Europe (N45–55)	11,345	10,513	14,298	17,105	17,068
Northern Europe (N55–65)	1,476	1,030	1,557	2,034	2,111
Scandinavian Europe (N65–71)	3,609	2,943	2,924	4,153	3,204

4. Economic valuation of forest ecosystems goods and services

4.1. *A Hybrid economic valuation approach*

From an economic viewpoint, wood forest products, carbon sequestration and cultural services represent different types of economics benefits. Therefore, different economic valuation methodologies need to be adapted and combined so as to respect the economic profile of the forest ecosystem services under consideration. In this context we propose to use a *hybrid economic valuation model* – see Fig. 3. The reasons of employing a *hybrid model* in the present study are twofold: (1). it requires the integration of the physical projects of changes in EGS with economic values under climate change scenarios; (2). it refers to a mixed-use of economic valuation techniques in a hybrid framework to evaluate EGS. In particular, depending on the type and nature of these goods and services under consideration, either market or non-market valuation techniques can be applied to estimate the economic value of the above-mentioned ecosystem services, i.e. wood forest products, carbon sequestration, and cultural services, respectively.

Table 4
Projected wood forest products between 2005 and 2050.
Source: Ding et al. (2010).

Type of products	Geo-climatic region (Latitude)	2005	A1 2050	A2 2050	B1 2050	B2 2050
Wood pulp (Estimates in Mt/yr)	Mediterranean Europe (N35–45)	4.82	3.68	3.92	4.97	5.27
	Central Europe (N45–55)	10.88	10.53	12.01	9.89	12.39
	Northern Europe (N55–65)	0.41	0.33	0.42	0.33	0.45
	Scandinavian Europe (N65–71)	25.70	25.14	24.00	22.51	22.60
Industrial roundwood (Estimates in million m3/year)	Mediterranean Europe (N35–45)	45.28	30.57	38.27	43.49	47.55
	Central Europe (N45–55)	176.58	154.13	190.23	151.69	194.81
	Northern Europe (N55–65)	31.60	24.04	40.26	27.89	33.71
	Scandinavian Europe (N65–71)	147.31	147.66	141.56	136.13	133.33
Recovered paper (Estimates in Mt/yr)	Mediterranean Europe (N35–45)	11.85	7.18	7.61	9.62	10.60
	Central Europe (N45–55)	30.69	25.76	29.68	25.80	31.42
	Northern Europe (N55–65)	8.38	6.78	8.31	6.78	9.06
	Scandinavian Europe (N65–71)	2.62	2.51	2.38	2.30	2.26
Sawnwood (Estimates in Mm3/yr)	Mediterranean Europe (N35–45)	15.38	10.11	13.75	15.05	16.70
	Central Europe (N45–55)	63.04	60.93	68.81	56.45	71.07
	Northern Europe (N55–65)	10.98	8.33	13.93	9.69	11.74
	Scandinavian Europe (N65–71)	32.60	32.36	30.97	29.44	29.16
Wood-based panels (Estimates in Mm3/yr)	Mediterranean Europe (N35–45)	17.86	10.87	13.06	15.29	16.88
	Central Europe (N45–55)	42.58	37.52	42.91	36.71	45.67
	Northern Europe (N55–65)	4.98	3.96	5.50	4.12	5.39
	Scandinavian Europe (N65–71)	3.31	3.09	2.92	2.62	2.75
Paper and paperboard (Estimates in Mt/yr)	Mediterranean Europe (N35–45)	19.60	11.58	12.30	15.45	16.98
	Central Europe (N45–55)	50.22	44.24	50.93	44.20	53.11
	Northern Europe (N55–65)	6.88	5.57	6.90	5.56	7.45
	Scandinavian Europe (N65–71)	26.35	25.84	24.70	23.03	23.22
Woodfuel (Estimates in Mm3/yr)	Mediterranean Europe (N35–45)	20.24	12.03	16.50	17.96	19.96
	Central Europe (N45–55)	26.50	25.07	31.09	24.07	31.03
	Northern Europe (N55–65)	4.96	3.87	7.24	4.16	5.53
	Scandinavian Europe (N65–71)	12.66	12.47	11.91	11.34	11.23

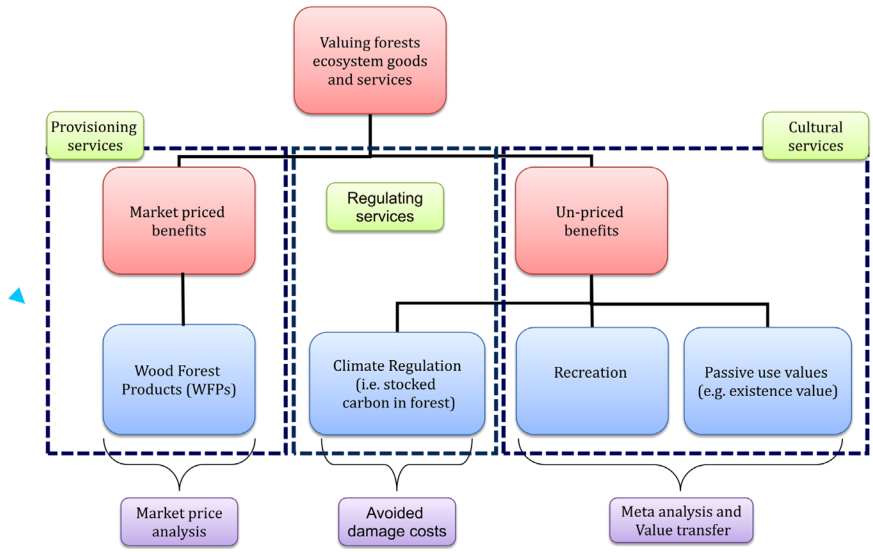

Fig. 3. A hybrid economic valuation methodology.

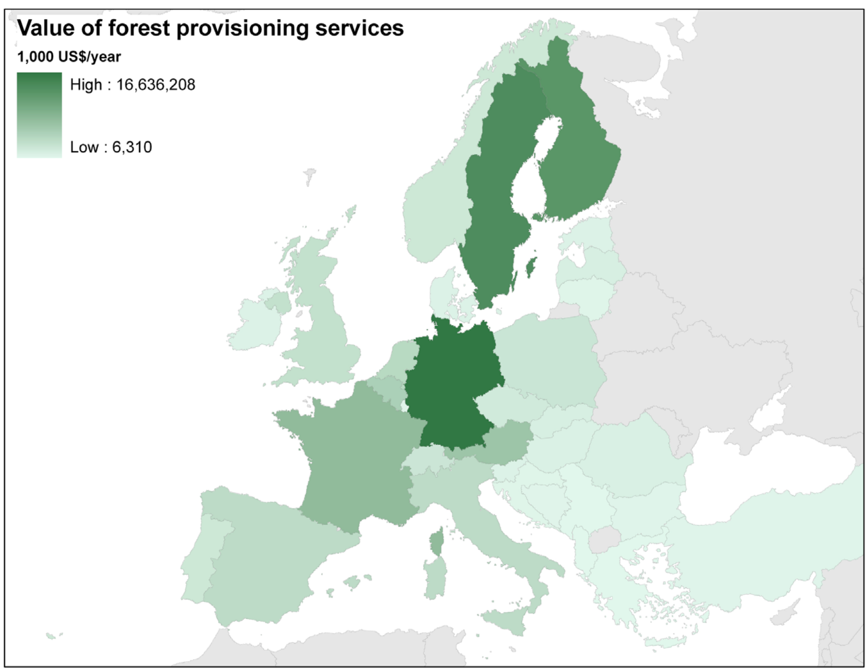

Fig. 4. The value of provisioning service by European forests in 2005.

Each economic valuation methodology used, and respective valuation results derived, are detailed and discussed in the following subsections.

4.2. The economic value of wood forest products

The economic valuation of the wood forest products (WFPs) is characterized by a two-step approach. The first step consists of calculating the total value of all forest products for each country. For this, we shall combine the use of the biophysical data, as provided in Section 3, together with the market price of each WFP, averaged at the country level. Market prices for WFPs are, in turn, derived from the export values and export quantities for year 2005, as reported at country level by FAOSTAT. Our economic valuation results show that Sweden, Norway, Germany and France are the most important WFPs producers in Europe, where the highest value of provisioning services are registered – see Fig. 4.

The second step is then to project the total value of WFPs to 2050. Based on the result of a literature survey[10] and observed historical data,[11] we assume that that real prices of wood products

[10] Clark (2001) offers a theoretical analysis and an empirical examination of wood prices, based on aggregated global wood market data over the last three decades. Hoover and Preston (2006) analyse trends of Indiana (USA) forest products prices using statistical data from 1957 to 2005. Although different in the spatial scale of the analyses, both papers lead to a similar conclusion: there is no evidence of increase in real prices for wood in the long term. This means that no global wood shortage is predicted, a result that can be explained by the technological development leading to an increase in resource productivity (less wood required in the production process and enhanced wood supply).

[11] The World Bank time series data providing estimates of the average prices for total produced round wood (Bolt et al. 2002), according to which the trend in real prices remained relatively constant in the 30-years period 1971–2006. The

Table 6
Projection of Total Productivity Value of WFPs (US$/ha/yr, measured in 2005)

Scenarios	Mediterranean Europe (N35–45)	Central Europe (N45–55)	Northern Europe (N55–65)	Scandinavian Europe (N65–71)
A1 2050	168 (+5.3%)	824 (+0.6%)	749 (+60.8%)	749 (+64.2%)
A2 2050	139 (−12.8%)	777 (−5.1%)	682 (+46.4%)	730 (+60.0%)
B1 2050	134 (−16.1%)	584 (−28.7%)	401 (−13.9%)	668 (+46.4%)
B2 2050	141 (−11.9%)	633 (−22.7%)	503 (+8.0%)	701(+53.6%)

NB: Percentage changes from initial benchmark in 2005 are showed in parentheses.

welfare gains can then be interpreted as the costs of policy inaction as no actions are taken for climate mitigation. However, it shall also be noted that, if the future state of the world is characterized by the A1FI scenario, and therefore by the highest CO_2 concentrations scenario, this will bring along with it an additional welfare loss of 40 million dollars for the Mediterranean Europe, with respect to the A2 scenario. Moreover, the A1FI scenario might represent a “worst case” scenario, as it also brings significant welfare losses to all the regions, with an aggregated effect estimated up to 6.5 billion dollars for Europe as a whole. Among all others, the Northern Europe loses the most, depicting a reduction of 25% when comparing to the A2 scenario. An exception of this welfare pattern is registered in the Scandinavian Europe where moving from a A2 towards a A1 scenario does not involve any welfare loss, but rather a minor increase.

Table 7
Comparison of total value of WFPs for European forests.

Benchmark A2 scenario		**Mediterranean Europe (N35–45)**	**Central Europe (N45–55)**	**Northern Europe (N55–65)**	**Scandinavian Europe (N65–71)**	**Europe**
Absolute value difference (Million$, 2005)	A1vs.A2	−40	−6,306	−1,802	1,597	−6,551
	B1vs.A2	1,565	−6,115	−2,503	−2,171	−9,223
	B2vs.A2	2,283	1,186	−405	−1,999	1,065
Percentage change	A1vs.A2	−0.6%	−13.3%	−25.0%	4.7%	−6.9%
	B1vs.A2	24.3%	−12.9%	−34.7%	−6.4%	−9.7%
	B2vs.A2	35.4%	2.5%	−5.6%	−5.9%	1.1%

will remain stable in the next 50 years, while allowing different prices to exist across countries (Clark, 2001; Hoover and Preston, 2006; Bolt et al. 2002). Thus, the projection of total value of each type of WFPs depends only on the total quantity produced by a country under different future scenarios. The computation is expressed by Eq. (1).

$$TV_n^S = \sum_{i=1}^{7} \frac{ExportValue_{i,n}}{ExportQuantity_{i,n}} \cdot Q_{i,n}^S, \text{ with } S = \text{A1FI, A2, } B1 \text{ and } B2 \text{ storylines} \quad (1)$$

where *TV* is the total value of WFPs (*i* type of WFP) in Country *n* under IPCC scenario *S*. Furthermore, we scale up WFPs values for each of the geo-climatic groups in order to investigate the presence of geographic specific climate change induced impacts on this ecosystem services. Finally, by aggregating values over all of the involved wood forest commodities and countries, we can get a regional total value of WFPs for all the 2050 climate change scenarios. Furthermore, these values are divided by the forest size located in the same area, and gives rise to productivity values (measured in $/ha) of forest biomes in terms of providing WFPs– see Table 6 for the computation results.

As we can observe, the WFPs productive values vary among the four geographical groupings. The Mediterranean Europe reveals the lowest productivity values of WFPs. However, from a perspective of vulnerability to climate change, highest economic productivity values of WFPs in the Mediterranean Europe may also reveal the highest vulnerability of the local community to the threats of climate change. In fact B1 and B2 climate change scenarios, when compared to A2 – here interpreted as our reference scenario for policy discussion – are characterized by the highest perceptual changes, respectively 24.3 and 35.4 – see Table 7.

The results suggest that moving the future development path away from A2 towards the B-type scenario involves significant welfare gains, ranging up to 2.28 billion dollars. On the contrary, if the future state of the world holds on to the A2 scenario, this

(*footnote continued*)
forest net rents of world countries are taken from World Bank database, available online at: http://tahoe-is-walking-on.blogspot.com/2010/01/world-banks-ans-adjusted-net-saving.html.

Finally, in the context of a sustainable development future, the climate change impacts are found un-unified across regions. Regional sustainable developing plans may have significant positive impacts on the Mediterranean region as shown in Scenarios B2. The total economic value of WFPs in the region is projected so high that it can offset the loss in rest of Europe and lead to an average welfare gain in Europe. Thus our results suggest that sustainable developing plans may be more economically cost-effective in the Mediterranean countries, compared to the Northern and Scandinavian European countries, where sustainable forest management has already been well established and effectively implemented.

4.3. The economic value of climate regulating services

Forest conservation or prevention of deforestation in order to stabilize Greenhouse Gas (GHG) emissions – questions not originally included in the Kyoto Protocol – have been officially recognized in COP16 in Cancun in December 2010 as one of the most important options to the post-Kyoto climate policies for combating climate change. The estimation of the economic value of carbon sequestration services provided by forest ecosystem is therefore considered to have a very important impact on policymaking for CO_2 stabilization in Europe. We acknowledge that the economic value estimates reported for regulating services in the present paper are underestimated, as we do not undertake a valuation of the other regulating services, e.g. watershed protection and soil nutrient cycling, due to the limited knowledge about how to quantify those services in physical terms. As previously shown, carbon stocks in European forests are projected to increase over the next 50 years under all 4 IPCC storylines, therefore we may expect to obtain more benefits from forest regulating services. However, the magnitudes of those benefits may vary across different forest biomes.

The methodological framework for the valuation of regulating services consists of two steps: we first compute the marginal value of per tonne of carbon stored in forests (2005 US$/tC), and then use it to estimate the total carbon benefits in different geo-climate regions under the IPCC scenarios.

First of all, the marginal value of carbon storage refers to the benefits from avoided damages[12] caused by incremental CO_2 or CO_2-equivalent GHG emissions in the atmosphere due to the carbon sequestration functions of forest ecosystems. In the present paper, we build our analysis upon an existing project, "Cost Assessment for Sustainable Energy Systems"-CASES,[13] a worldwide study funded by the EU.

One of the main features of CASES is that it is built upon the Integrated Assessment Models (IAMs), which by definition combine the dynamics of global economic growth with the dynamics of geophysical climate dynamics, to estimate the cost of GHG emissions under different energy evolution paths in 2020, 2030 and 2050. The CASES project was able to obtain three levels of estimates of marginal damage costs, i.e. lower, upper and central estimates,[14] respectively.

In the present study, we adopt a value estimate of 96.1 Euro/tC from the CASES report, referring to the central estimate of the avoided cost of one tonne of carbon in 2080. The value is first adjusted for our analysis by discounting to the real Euro value in 2005, using a 3% discount rate, and then converted to 2005 US$ taking into account the real exchange rate and the Purchasing Power Parity (PPP). Finally, future economic benefits (measured in 2005 US$) of carbon stocks in each country's forests are calculated by multiplying the US$/tC value by the projected quantity of carbon totally stored in the same forests in 2050 (see Section 3) for each of the IPCC storylines, and then aggregated to compute the regional total benefits for the four large geo-climatic groupings.

In addition to the forest area the predominant tree species may play a significant role in the determination of the carbon sequestration capacity in a geographical region, and therefore on the value of the forest's climate regulating services. For example, the forests in Central Europe contribute to the largest portion of benefits from the carbon regulating services in Europe. But this does not only depend on the fact that this area occupies the largest forest areas in Europe, but also because the type of forests in this area may have larger tolerance and capacity in terms of carbon sequestration.

The productivity value of climate regulating services provided by per unit of land ($/ha) is calculated based on the projected forest areas under different future scenarios (See Table 8). The results show clearly the marginal benefit of carbon regulating services provided by different forestlands. Moreover, different forest management scheme may also influence these values. For instance, *ceteris paribus*, the B1 scenario shows the highest marginal value of regulating services provided by European forests.

To better interpret the results, we undertake a comparative analysis among all four IPCC scenarios. Table 9 shows the comparative results of three IPCC scenarios (i.e. A1, B1 and B2) with respect to the A2 (BAU) storyline.

Table 8
Projection of the productivity value of carbon sequestration (US$/ha/yr, measured in 2005).

Scenarios	Mediterranean Europe (N35–45)	Central Europe (N45–55)	Northern Europe (N55–65)	Scandinavian Europe (N65–71)	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

From these results, one can clearly see that the countries within Mediterranean Europe[15] 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 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 carbon sequestration 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. In a movement towards a B type scenario, Scandinavian Europe would 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 both 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, i.e., any B type scenario is characterized by a welfare gain, which are in accordance with what is also registered in Mediterranean and Scandinavian Europe.

4.4. The economic value of cultural services

The cultural services provided by forest ecosystems consist of two components in our analysis: recreational use (e.g. nature-based *tourism* in forests) and passive use (e.g. existence and bequest value of forests and biodiversity). These services are not traded in regular markets and no market price is therefore available from national statistics to be used in the economic valuation exercise. This requires the use of specific techniques, as referenced in the literature, the so-called "non-market valuation approaches", either stated or revealed preferences (Braden and Kolstad, 1991; Cropper and Freeman 1991; Hanley et al., 1998; Scarpa et al., 2000;

[12] The avoided damage costs assessment method has been widely used in the literature (see Cline (1992), Nordhaus (1993a), (1993b), Merlo and Croitoru (2005), CASES, 2008) to calculate indirectly the benefits from carbon sequestrated in forests, but 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), although under certain restrictive assumptions the three measures would be broadly equal, at the margin (DEFRA, 2007).

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

[14] The values are based on full *Monte Carlo* runs of the *FUND* and *PAGE* models, in which all parameters 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 rates is use as suggested by the UK Government'Green Book'. The equity weighting of damages in different regions is applied to aggregate the regional damage costs to global damages, in other words, damages in richer regions receive lower weights and damages in poorer regions receive higher weights.

[15] Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey and Yugoslav.

Table 9
Projection of total benefits of carbon sequestration in European forests.

Benchmark A2 Scenario		Mediterranean Europe (N35–45)	Central Europe (N45–55)	Northern Europe (N55–65)	Scandinavian Europe (N65–71)	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%

CBD (Secretariat of the Convention on Biological Diversity), 2001; Bateman et al., 2002; Horton et al., 2003; TEEB, 2009). These approaches assess the individual willingness to pay (WTP) for using and enjoying the resource. In our study, we did not conduct original revealed or stated preference surveys to assess the economic value of cultural services, but we used a value transfer approach based on meta-analysis (Woodward and Wui, 2001; Ghermandi et al., 2010). This is a statistical method combining a set of individual case studies (gathered from the existing literature, mainly primary valuation studies) to build a regression function which relates the monetary value of the ecosystem service (in terms of WTP collected from original studies) with a number of explanatory variables meant to influence their value.

Our approach is based on three main methodological steps. The first consists of estimating a meta-regression function as explained above, while in the second step the beta coefficients estimated in the previous step are used to transfer the monetary values in each geo-climatic region and to project these values in a future time (year 2050) under the different climate change scenarios. As a final step, we multiply the values obtained in the previous steps by the forest areas under different climate change scenarios to assess the projected total value in 2050 and calculate what would be the benefit or cost by moving from one scenario to another.

4.4.1. The meta-regression function

According to previous literature reviews on cultural values, an expected utility specification can be used to describe how individuals are willing to trade income for increases or decreases in forest cultural services, under the assumption that the marginal value decreases with an increase in the forest size, and increases with an increase of the income in the country where the forest is located (e.g. Hammitt, 2000; Chiabai et al., 2011).

The meta-analysis enables us to explain the variance of the available WTPs (Willingness-To-Pay) as a function of a few statistically significant explanatory variables. In particular, the main explanatory factors for forest recreation and passive use are the forest size designated to recreation or to biodiversity conservation (S), and the income level of the study area (I, measured as PPPGDP), according to the regression model expressed by Eq. (2):

$$\log V = \alpha + \beta \log S + \gamma \log I \tag{2}$$

Where V is the marginal value of a given forest site designated to recreation or conservation of biodiversity.

By running the regression, we can estimate the marginal effect on V of the forest size (β) and the income level of the country where the site is located (γ). The WTP figures included in the regression are selected from the literature focusing on a number of valuable studies carried out in Europe (the case studies used in the analysis are reported in Table 10).

The results of the meta-analysis are shown in Table 11. The β coefficient on forest recreation size (logSIZE) is negative and significant for both recreation and passive use, showing that the marginal value of these services decreases with a marginal increase in forest area. The coefficient on income γ (logINCOME) is positive and significant, revealing a positive correlation of marginal values and income. The coefficients on passive use values are higher compared to those of recreation, showing a higher sensitivity of forest size and income on marginal values.

4.4.2. Value transfer to geo-climatic zones

The estimated coefficients from the meta-analysis above (reported in Table 11) are first used to adjust the WTP values of recreational and cultural services estimated in selected original studies for each of the geo-climatic regions. Next, these WTP value estimates from site-specific studies can then be transferred or scaled up to the specific geo-climatic regions that these studies represent under different future IPCC scenarios. Tables 12 and 13

Table 10
Studies used in the meta-analysis.

N.	Reference Study (Authors and year)	Country	World region	Forest biome	Forest services	N. obs
1	Bellu and Cistulli (1997)	Italy	EUR	Temperate broadleaf and mixed forests	Recreation	14
2	Campos and Riera (1996)	Spain	EUR	Boreal forest	Recreation	2
3	Bateman et al. (1996)	UK	EUR	Boreal forest	Recreation	2
4	Scarpa et al. (2000)	UK	EUR	Mediterranean forest	Recreation	8
5	Scarpa et al. (2000)	Ireland	EUR	Temperate broadleaf and mixed forests	Recreation	11
6	Bostedt and Mattsson (2006)	Sweden	EUR	Boreal forest	Recreation	4
7	Zandersen et al. (2005)	Denmark	EUR	Temperate broadleaf and mixed forests	Recreation	1
8	Van der Heide et al. (2005)	Netherlands	EUR	Temp. Conif. and Temp. Broadleaf	Recreation	1
9	Mogas et al. (2006)	Spain	EUR	Mediterranean forest	Recreation	2
10	Kniivila et al. (2002)	Finland	EUR	Temp. Conif.	Recreation/passive	2
11	Hanley et al. (1998)	UK	EUR	Temp. Conif.	Recreation	3
12	Gurluk (2006)	Turkey	EUR	–	Recreation	1
13	Siikamaki and Layton (2007)	Finland	EUR	Boreal	Passive	2
14	ERM (Environmental Resources Management) (1996)	UK	EUR	Conifer forest	Passive	2
15	Hanley et al. (2002)	UK	EUR	Temperate, conifer and broadleaved woodland	Passive	6
16	Garrod and Willis (1997)	UK	EUR	Temperate, conifer and broadleaved	Passive	6
17	Mogas et al. (2006)	Spain	EUR	Mediterranean	Passive	1

Table 11
Results of the meta-regression function for recreational and passive use values

Dependent variable	***Recreation use***		***Passive use***	
	Coefficient (std. error)	T-value	Coefficient (std. error)	T-value
LogWTP				
Explanatory factors:				
constant	3.274 (3.698)	0.89	3. 972 (2.835)	1.40
LogSIZE	−0.445 (0.073)	−6.14	−0.603 (0.079)	−7.58
LogINCOME	0.599 (0.352)	1.70	0.889 (0.255)	3.49
Nobs	59		23	
R^2	0.452		0.797	
Adj R^2	0.433		0.797	

summarize the selected non-market valuation studies on recreational and passive use values of forests in each geo-climatic region, respectively.

More specifically, for each geo-climatic region, we assume that one major forest biome can be identified as a representative forest type which survives the local climate. Once the major forest biome is identified for each geo-climatic region, we then select original non-market valuation studies that focus on recreational and passive use values of forests in this specific biome in any country located in the region to perform the within region value transfer.

The WTP figures selected from these studies[16] are transferred or scaled up to the corresponding geo-climatic region and forest biome, by taking into account the effect of the size of forest area under valuation, β, according to Eq. (3):

$$V_{EU,l}=V_{i,l}\left(\frac{S_{i,l}}{S_{EU,l}}\right)^{\beta} \tag{3}$$

where.

$V_{EU,l}$ is the estimated WTP/ha for Europe by geo-climatic region l, $V_{i,l}$ is the WTP/ha of country i by geo-climatic l (from representative case studies), $S_{i,l}$ is the forest area designated to recreation or conservation in country i by geo-climatic region l, and $S_{EU,l}$ is the forest area designated to recreation or conservation in Europe by geo-climatic region l

Data on forest areas designated to recreation and biodiversity conservation by country are taken from FAO/FRA2005 (2006).

4.4.3. Inter-temporal value transfer: projections under climate change scenarios for 2050

For the inter-temporal value transfer, the estimated marginal values in 2005 are projected to 2050 using population and PPPGDP growth rates, and by taking into account the effect of forest size,[17] under different IPCC scenario, as illustrated in Eq. (4) below:

$$V_{i,T_1}=V_{i,T_0}\left(\frac{H_{i,T_1}}{H_{i,T_0}}\right)\left(\frac{S_{i,T_0}}{S_{i,T_1}}\right)^{\beta}\left(\frac{PPPGDP_{i,T_1}}{PPPGDP_{i,T_0}}\right)^{\gamma} \tag{4}$$

where:

$V_{i,T1}$ is the estimated value/ha/year for country i in year T,
$V^{*}_{i,0}$ is the estimated value/ha/year for country i in year T_0, T_1 is year 2050, while T_0 is the baseline year 2005.

[16] When several representative case studies and values are available, the mean marginal value is used.

[17] We assume no variation over time in the percentage of forest area designated to recreation or conservation.

4.4.4. Estimation of total values under climate change scenarios

Finally, by multiplying the WTP estimates V(US$/ha) for recreational or passive use of forests with the sizes of forest area S that have been designated for recreation or conservation following the different climate change scenarios, we can obtain the total recreational or passive use value for each region under each IPCC storyline, and compare these results across different scenarios.

Final results on cultural services show that marginal values may widely differ depending on the latitude (or geo-climatic region) where the forest is located (see Tables 14 and 15). For recreational values, the highest value estimates are found in Northern Europe followed by Central-Northern Europe, which is in part due to already developed forest recreational facilities and services in these countries. For passive use values, the highest value estimates are registered in the Mediterranean countries instead, is known for its rich biodiversity and high conservation potential.

Finally, we compare the total values of forest cultural services among the different IPCC scenarios, using scenario A2 as a benchmark for the analysis (Table 16).

Results show that A1 scenario is worse off when comparing it to the A2 scenarios, a conflicting result compared to those obtained for the provisioning service. This may be caused by the fact that harvesting forest resources for WFPs production may result in reduced forest resources available for other uses, such as recreational or educational uses. On the contrary, in all B-type scenarios climate change has led to positive impacts on the social economy as the management efforts in sustainable development and environmental production may halt or compensate the negative impacts of climate change.

5. Discussions

Notwithstanding the uncertainties related to climate change, our assessment of the climate change impacts has shown some interesting results that are potentially useful for policy implications. Existing studies have shown that ecosystem management can maximizes co-benefits of mitigation of climate change by reducing emissions and storing carbon through implementation of good practices in Land Use, Land Use Change and Forestry (LULUCF) activities and the reduction of the loss of natural habitat and deforestation as well as the increase or the maintenance of carbon stocks through Reduced Carbon Emissions from Deforestation and Forest Degradation (REDD) (Munang et al., 2013). The development of ecosystem-based mitigation measures through improved land uses to reduce carbon emissions is gaining momentum (Lal, 2004 and Albrecht et al., 2003), whereas better managed ecosystem can increase the ability of forest ecosystems to sequester and store carbon by improving overall ecosystem health and resilience to climate change. This latter refers to Ecosystem-based Adaptation (EbA) interventions.

The comparison of the different future scenarios (A1, B1 & B2) against a BAU (A2) (see Table 16) allows us to better understand the changes in EbA capacity of European forest ecosystems in response to the future IPCC scenarios, considering the underlying assumptions of the GHG emission levels, the economic and demographic characteristics and the emphasis of future global and regional economic and environmental policies embedded in the chosen developing paths. Yet it can stimulate policy innovations to help maintain the sustainability of forest ecosystem interventions for adaptation in Europe.

Furthermore, in terms of the recreational use value of forest ecosystems in Europe, EbA interventions do not directly aim to increase recreation opportunities. However, by using green or nature infrastructures instead of built infrastructure for climate

Table 12
Selected studies on recreational use for geographical value-transfer.

Country	Reference study	Forest biome	Geo-climatic region
United Kingdom	Scarpa et al. (2000)	Temperate broadleaf and mixed forests	Northern Europe
The Netherlands	Scarpa et al. (2000)	Temperate broadleaf and mixed forests	Central-Northern Europe
Finland	Bostedt and Mattsson (2006)	Boreal	Scandinavian Europe
Italy	Bellu and Cistulli (1997)	Mediterranean and Temperate Broadleaf	Mediterranean Europe

Table 13
Selected studies on passive use for geographical value-transfer.

Country	Reference study	Forest biome	Geo-climatic region
United Kingdom	Garrod and Willis (1997) Hanley et al. (2002) ERM (Environmental Resources Management) (1996)	Temperate	Northern and central-northern Europe
Finland	Kniivila et al. (2002) Siikamaki and Layton (2007)	Boreal	Scandinavian Europe
Spain	Mogas et al. (2006)	Mediterranean	Mediterranean Europe

Table 14
Projections of marginal recreational values of European forests (US$/ha/yr, measured in 2005).

Scenarios	Mediterranean Europe (N35–45)	Central Europe (N45–55)	Northern Europe (N55–65)	Scandinavian Europe (N65–71)
Initial 2000	1.06–3.06	0.43–2.61	1.88–7.10	0.16–1.05
A1 2050	1.25–7.87	1.07–8.15	4.17–99.92	0.23–0.53
A2 2050	1.26–7.91	0.68–5.17	4.03–96.55	0.23–0.54
B1 2050	1.20–9.24	0.81–8.08	3.97–124.34	0.27–0.73
B2 2050	1.03–6.77	0.65–4.83	2.97–62.55	0.22–0.44

Table 15
Projections of marginal passive use values of European forests (US$/ha/yr, measured in 2005).

Scenarios	Mediterranean Europe	Northern and Central-Northern Europe	Scandinavian Europe
Initial 2000	356–615	123–182	123–255
A1 2050	898–1552	361–534	219–454
A2 2050	902–1558	344–509	220–457
B1 2050	748–1292	342–506	262–543
B2 2050	678–1171	230–340	203–421

adaptation, e.g. green roofs, positive co-benefits in term of visual impact and attractiveness might occur (Foster et al., 2011). Due to cultural differences and preferences in how forest aesthetics are considered, it is difficult to determine how adaptation measures can help maintain or increase the aesthetic value associated with landscapes. Nevertheless, a loss of habitat and diversity and the consequent simplification of landscapes often can have a major impact on the attractiveness of many places in terms of recreational use of forests, including in the most important mountain areas in Europe. The valuation of recreational value of forest ecosystems presented in this study does not only show the respective value increase or decrease under different future scenarios, but also distinguish the regional effects thanks to the geo-climatic classifications. From the economics point of view, identifying the economic gains and losses as a result of climate change impacts in different regions can help EU policy makers better understand which regions are more vulnerable to climate change and design targeted policy interventions to conserve the most valuable ecosystem services at regional level.

In Europe, there is a need of developing optimal forest management strategies to cope with climatic shocks on the regional ecosystems and to promote the sustainable use of forest resources for satisfying long-term human demand. However, as suggested by this research, the design and implementation of these policies should respect the specific local environmental, economic and political contexts of each country. In other words, there are no *silver bullet* policies that can be applied to the European context as a whole. This refers to a bottom-up management approach to effectively manage forest resources at country level. On the other hand, by comparing the welfare gains/losses of climate change impact occurred in different geo-climatic regions, the EU will be able to evaluate the cost-efficiency of policy alternatives across all of the member countries. Therefore, the countries that suffer the most losses from climate change may be compensated through other supplementary policy package imposed by the EU. This infers a top-down approach to improve the overall efficiency of resource management in Europe.

6. Conclusions

This paper reports on an original economic valuation of potential climate change impacts on forest EGS under different future climate change scenarios. On the one hand, we provide a comprehensive classification and mapping of the different European countries according to their contribution in the supply of forest goods and services. The proposed analysis is anchored to the well-known classification proposed by the MA Approach. On the other hand, we investigate the role of each country in detail, providing

Table 16
Comparison of total value of cultural values for European forests.

Benchmark A2 Scenario		Mediterranean Europe (N35–45)	Central Europe (N45–55)	Northern Europe (N55–65)	Scandinavian Europe (N65–71)	Europe
Absolute value difference (Million$, 2005)	A1vs.A2	−862	−352	−121	18	−1,317
	B1vs.A2	4,156	1,795	393	1,808	8,152
	B2vs.A2	3,607	633	182	1,038	5,460
Change in %	A1vs.A2	−17.8%	−14.2%	−28.3%	1.5%	−14.7%
	B1vs.A2	85.7%	72.5%	92.3%	152.5%	91.2%
	B2vs.A2	74.4%	25.6%	42.9%	87.5%	61.1%

the valuation of forest provisioning services, carbon regulation services and cultural services.

In order to value the climate change impacts, we first identified four different climate scenarios, which we refer to as the A1FI, A2, B1 and B2 scenarios, corresponding to the four IPCC storylines, and evaluated here to the year 2050. 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 provisioning quantities (in bio-physical terms) across all forest goods and services under consideration. The projections of future trends of forest areas and the provision of wood forest products in 2050 were derived from the ATEAM and IMAGE 2.2 models, which simulate the response of the global climate system to increase greenhouse gas concentrations as projected in HADCM3 in terms of four IPCC storylines. Moreover, considerable impacts of differentiated latitudes on the variability of forest EGS were taken into account by carefully regrouping the 34 selected countries located in different latitude intervals. As a consequence, it enabled us not only to identify the respective forest productivity related to predominant forest types situated in each latitude interval, but also to assess and compare the sensitivity of the differentiated forest types in response to climate change impacts. Both of these aspects have been considered when projecting the future trends of forest area and forest goods and services flows by 2050, in terms of the four IPCC storylines.

Finally, we applied various economic valuation methods (including market valuation methods for marketed forest products, and meta-analysis and value transfer methods for non-marketed forest ecosystem services) to estimate the values of the three MA service categories provided by European forests, i.e. the provisioning services, regulating services and cultural services, under four possible future climate change pathways. Our results show that climate change will continue to impact different forest biomes in Europe in an uneven pattern. However the magnitude of the values of forest ecosystem goods and services varies according to the nature of service under consideration, with the carbon sequestration being ranked among the most valuable services. Furthermore, the impact of climate change on ecosystems and its welfare evaluation in terms of the respective changes on the provision of forest EGS is multi-dimensioned, depending on both the nature of EGS and the geo-climatic regions under consideration. By comparing the welfare gains/losses of climate change impact occurred in different geo-climatic regions, we can clearly identify the regions that are more vulnerable to future climate change. Thus, the economic analysis can help EU policymakers better understand the potential policy impacts and improve the cost-efficiency of policies to mitigate climate change impacts across member states. In particular, the countries that suffer the most losses from climate change may be compensated through other supplementary policy package imposed by the EU. This infers a top-down approach to improve the overall efficiency of resource management in Europe.

In conclusion, and to the best of our knowledge, the current paper represents the first systematic attempt to estimate human well-being losses with respect to changes in biodiversity and forest ecosystem services which are directly driven by climate change. However, we acknowledge the complexity in mapping, modelling and estimating the relationships between climate change, biodiversity, ecosystem functioning, ecosystems services and human welfare. Against this background, we support the ongoing 'Potsdam Initiative',[18] for biodiversity, also suggesting that it is imperative to continue further with a global study so as to have a better understanding of the linkages between biodiversity and human well-being, especially in the context of global change. Finally, as the first of its kind, our research also indicate the lack of the scientific and data oriented foundation to report trends in ecosystem services provision and value (PCAST (President's Council of Advisors on Science and Technology), 2011), which therefore calls for future policy actions in the EU to construct a monitoring and reporting system for ecosystem services at both national and EU level, e.g. a dynamic “ecosystem service balance sheet” that will allow the timely registration and map of the ecosystem services provided by natural capital and natural assets, as well as the potential forecasts of their conditions an provision in the future (Nelson et al., 2013).

[18] At the meeting of the environment ministers of the G8 countries and the five major newly industrializing countries that took place in Potsdam in March 2007, the German government proposed a study on 'The economic significance of the global loss of biological diversity' as part of the so-called 'Potsdam Initiative' for biodiversity. The following was agreed at Potsdam: 'In a global study we will initiate the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation.'.

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