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The Economic Impacts of Biodiversity Policy for Improving the Climate Regulating Services Provided by EU Natura 2000 Habitats

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Abstract: We adopted the state-of-the-art methodologies to quantify the total carbon stocked by Natura 2000 habitats as well as to project the future changes of carbon stocks influenced by alternative policy options for the management of Natura 2000 habitats by 2020. Our results show that the N2K network currently stores around 9.6 billion tonnes of Carbon, equivalent to 35 billion tonnes of CO2, which is estimated to be worth between €607 billion and €1,130 billion (stock value in 2010), depending on the price attached to a ton of carbon. Of the different ecosystems the forest habitats contain the highest carbon value in the network, ranging between €318 and €610 billion in 2010. Furthermore, our results also show that in the future these carbon values can be increased. A policy scenario (Policy ON), where full Protected Area coverage (terrestrial PAs + fuller MPAs) with a move to full favourable conservation status is estimated to generate a gain of at least a total of 1.71-2.86% by 2020 compared to a policy inaction scenario (Policy OFF), where no additional action is taken to conserve the current Natura 2000 sites over the next decade.

Keywords: EU, Natura 2000 habitats, climate regulating services, economic assessment, conservation policies

JEL Classification: Q23, Q51, Q57

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1. Introduction

Climate regulating services provided by natural habitats and ecosystems refer to the sequestration of carbon from the atmosphere by plant tissue and the capacity of living biomass, litter and soil organic matter in terms of carbon storage in the course of time (IPCC, 2006). As far as the Natura 2000 habitats are concerned, an estimate of both total carbon stocks and the net changes of carbon associated with a particular habitat type may serve as an important indicator for evaluating the impacts of land-use and management practices in Europe, as these practices may have either immediate or long-term impacts on carbon stocked in ecosystems.

In the Natura 2000 network, many sites harbour several ecosystems that are important current storages of carbon and offer significant opportunities for further carbon sequestration, including sites located on forested lands, wetlands (e.g. peatlands) agricultural lands (especially croplands, grasslands, and range lands), biomass croplands, deserts and degraded lands and boreal wetlands and peatlands (Kettunen, et al., 2009). In particular, forests sequester the largest fraction of the terrestrial ecosystem carbon stocks on the planet, recently estimated at 1,640 PgC globally (equivalent to 1,640 Giga tons or billion tons of carbon) (Sabine et al., 2004). This suggests that forest ecosystems in the N2K network are of key importance in retaining already captured carbon and in this way reducing carbon emissions. Moreover, changes in forest ecosystems in terms of deforestation, afforestation, fertilization, tree harvesting, and natural disturbance on managed lands can significantly affect the existing carbon sinks and lead to release of CO_2 to the atmosphere (Paustian, 2006). For example, Parry *et al.* (2007) estimate annual global anthropogenic emissions of CO_2 at about 10Gt, of which about 1.5 Gt is from land use change (mostly deforestation, at a rate of about 13 million hectares per year), accounting for some 15% of global CO_2 emissions. In comparison, in non-forest ecosystems (such as cropland, grassland), net biomass carbon stocks are considered to remain roughly constant, although there could be some reduction in stocks over time if land degradation is occurring (Paustian, 2006). Land-use and management practices on Natura 2000 sites can influence ecosystems in a way that affects greenhouse gases (GHGs) fluxes1 over a period of several years to a few decades. This has been taken into account in the conservation measures of Natura 2000 network.

It should be also noted that in addition to terrestrial ecosystems, and their vegetation cover, marine ecosystems (including the marine protected areas) have an essential role in climate regulation via their effect on biogeochemical cycling and the biological 'pump' that moves carbon from the surface ocean and sequesters it in deep waters and sediments (MA 2005). However, our knowledge is rather limited in terms of the carbon capacity contained in the marine protected areas, and in terms of how conservation measures may affect the carbon stocked in the ocean. Therefore, although the objective of this study is to evaluate the role of carbon sequestration services provided by all Natura 2000 habitats as a way of mitigating GHGs in the atmosphere and regulating climate, we will focus particularly on the terrestrial ecosystems. Finally, in order to assist policymaking, we will evaluate the potential impacts of alternative policies and management practices on Natura 2000 sites on the changes of net carbon stocks in the above-and below-ground biomass

The paper is organized as follows. Section 2 discusses the spatial distribution of carbon storage in global ecosystems. Section 3 focuses on the development of a comprehensive valuation framework to estimate carbon benefits provided by ecosystems. Section 4 exercises the valuation

[1] CO2 fluxes between the atmosphere and ecosystems are primarily controlled by uptake through plant photosynthesis and release via respiration, decomposition and combustion of organic matter.

approach to estimate the total carbon currently stored in Natura habitats and their respective economic values. Section 5 estimates the economic gains and/or losses due to the net changes of carbon stocks in Natura 2000 habitats under future policy scenarios. Section 6 concludes and discusses the limitations of the study.

2. What and where are the benefits: spatial distribution of the service of carbon storage?

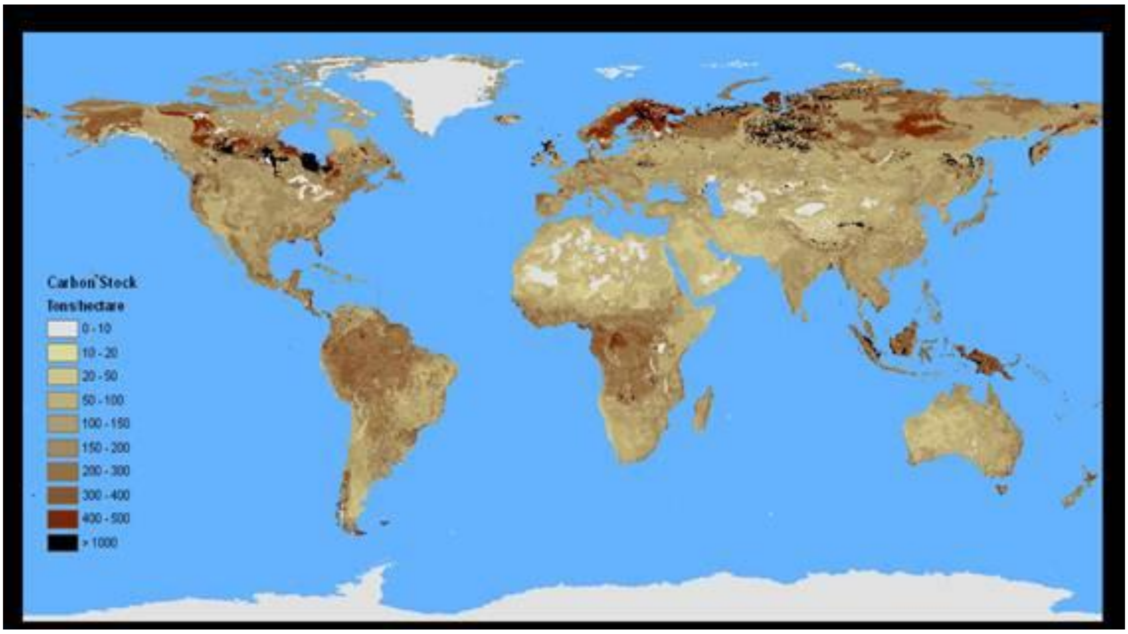
To better understand and evaluate the benefits of climate regulating services provided by natural habitats and ecosystems, it is important to clearly distinguish between *carbon sequestration* and *carbon storage*. The first refers to the process of carbon flow cycling that is captured from the atmosphere by trees and other plants through physical and biological processes, and is usually reported in terms of estimates per year of the tree growth. Instead, carbon storage refers to the amount of CO_2, or carbon equivalent that is stocked by above- and below- ground biomass, dead wood, litter and soil organic carbon[2]. This takes place in forest ecosystems and/or many other ecosystems such as grassland, cropland and peatland, throughout their entire vegetative cycle (Penman, et al. 2003).

In addition, it is useful to distinguish between *total carbon stocks*, which refer to total carbon stored by ecosystems in a given year, and *net changes in carbon stocks*, derived from the expected carbon gains or losses (or annual *"carbon fluxes"* in other words) from land-use practices and management, as well as discrete disturbances on managed land (e.g. fires). Such a distinction can be applied to the calculations made for many ecosystems, including forests, croplands, grasslands, wetlands, and other land uses. The carbon stock is useful for providing us a general picture of ecosystems carbon capacity, whereas the carbon flux is essential to better understand the consequences of land-use changes and land management practices on the existing carbon sinks.

Where in nature is carbon being stored? Figure 1 shows a globally consistent map of carbon storage in terrestrial ecosystems, produced using globally consistent estimates for above- and below- ground biomass. It is estimated that earth's terrestrial ecosystems store an approximately 2,052 giga tons of carbon in their biomass and soil (Campbell, et al. 2008). Two distinct bands of high carbon density can be noted: in the northern latitudes and the tropics.

Figure 1: Global carbon stock density in terrestrial ecosystems (above and below ground biomass plus soil carbon)

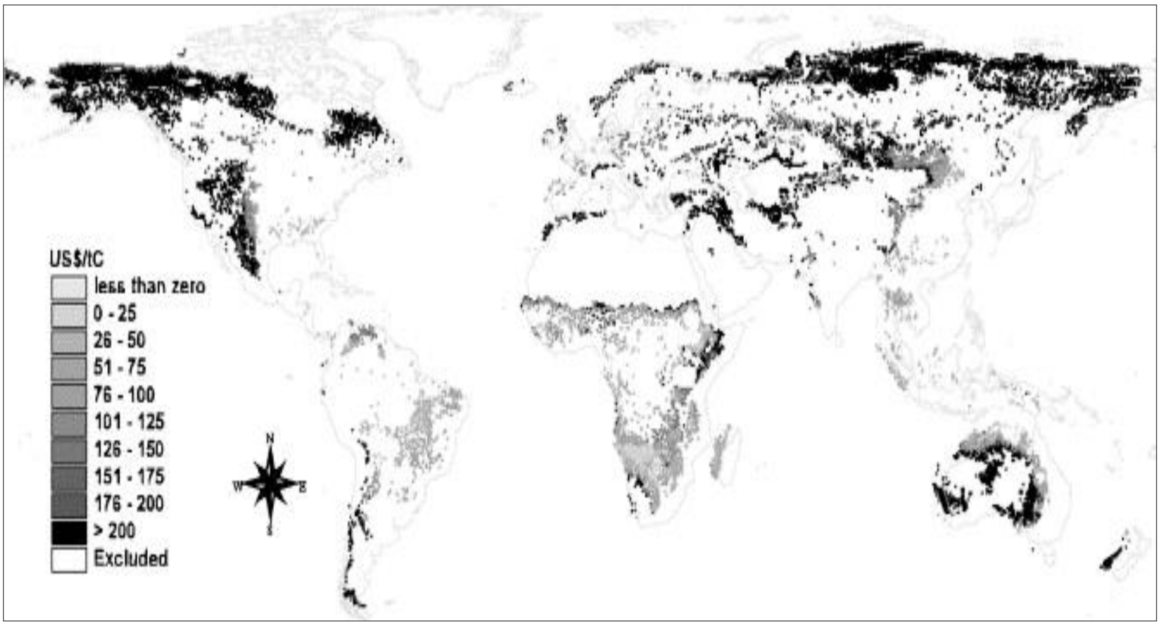
[2] Above- and below- ground biomass, dead wood, litter and soil organic carbon are known as the 5 Carbon pools.



Source: Campbell et al. 2008: pp6

In the context of Europe and the Natura 2000 sites, carbon stock density appears relatively high across Europe. In particular Northern European countries, where boreal forests are predominant, shows much higher carbon storage potential in terms of high carbon density in the soil and biomass (Figure 1). This suggests that conservation measures focusing on maintaining the existing carbon storage in, for example, forest ecosystems might be considered more cost-effective to meet the conservation objectives in those countries. This is particularly clear in the case of forest fires. In other words, by saving the same hectare of forest from burning down, we can gain higher carbon benefits from forests located in the Northern latitudes, as more carbon is prevented from being released to the atmosphere. Moreover, as far as cost is concerned, areas with the lowest costs involved in sequestering carbon are the most cost-effective locations. The map below (Figure 2) represents a geographic distribution of the costs involved in sequestering carbon (EUR/ton), calculated by combining the biological potential for carbon sequestration with estimated costs of reforestation (Kettunen, et al., 2009; Benitez et al. 2007). It shows that the costs of establishing forest areas appear to be higher, or in other words lower cost-effectiveness, in central and northern Europe, e.g. Italy, Austria, Scotland, Ireland and also around the Balkan area (as according to the Benitez et al. 2007, Figure 2).

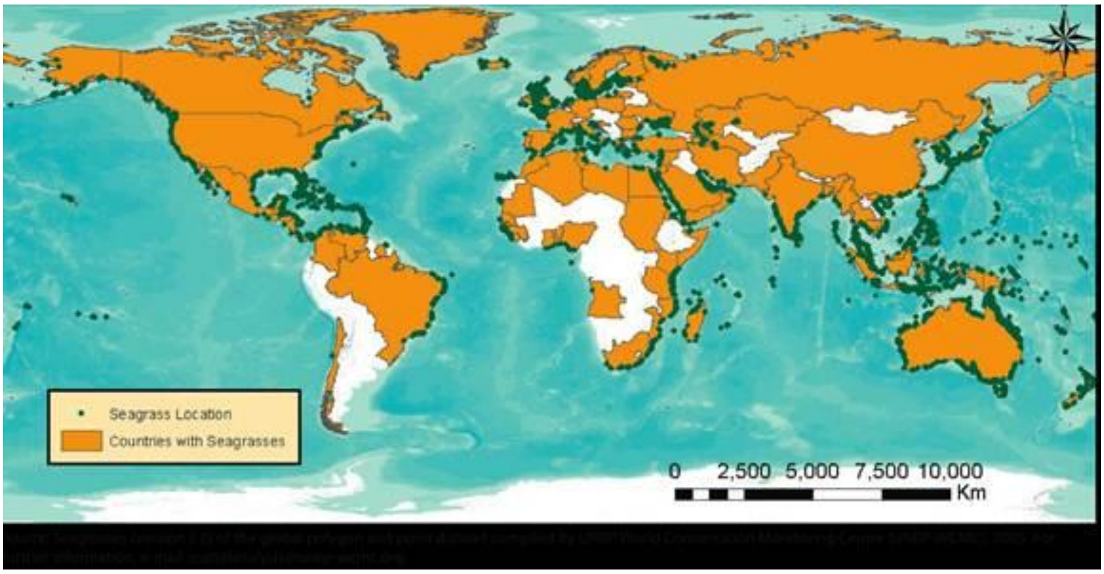
Figure 2: Geographical distribution of carbon costs



Source: Benitez et al. 2007

In addition to the terrestrial ecosystems, two types of coastal habitats in Europe appear to possess the greatest GHG mitigation potential, namely seagrass meadows and salt marshes3. The amount of carbon held in living biomass is much more variable among the habitat types: seagrasses contain 0.4–18.3 tCO2e per hectare, and salt marshes, on average, a few times higher than that at 12–60 tCO2e/ha (Murray et al. 2011). Figure 3 and 4 present two maps of the distribution of seagrass and salt marshes across the globe.

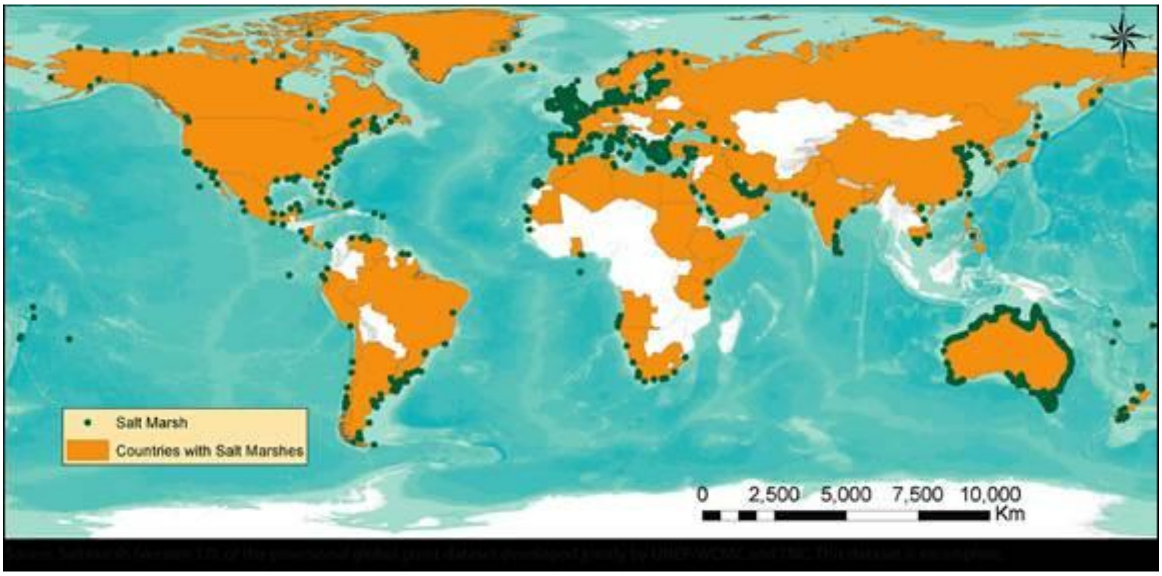
Figure 3: Global distribution of seagrasses



Source: Murray et al. 2011

Figure 4: Global distribution of salt marshes

[3] Although mangroves is among the coastal ecosystems with great potential as carbon sink, we do not this ecosystem in the present analysis as they are most abundant in the tropical and sub-tropical zone.



Source: Murray et al. 2011

3. Valuation framework: estimating the carbon benefits in a dynamic context

Land use policy and land management practices can have significant impacts on the carbon stocks in the soils of terrestrial ecosystems, including increasing the resistance of carbon sequestration in forest and agriculture soils. Therefore, it is necessary to estimate the carbon benefits in a dynamic context, so that the potential impacts of land use and management practices on stocked carbon and biodiversity can be evaluated and the possible multiple benefits of conservation activities on the protected areas, such as biodiversity benefits and carbon regulating benefits can be realized.

A comprehensive economic valuation of carbon benefits provided by Natura 2000 sites needs a solid scientific base. For this reason, the estimation of the carbon benefits in the present report will be conducted following the following 3 steps, strictly respecting the 2003 IPCC Good Practice Guidance (GPG) *for Land Use, Land Use Change, and Forestry*:

Step 1. Characterization of the Status Quo (SQ) or Baseline Scenario. This involves profiling the current carbon economic value provided by all N2K sites in Europe in a reference year. To do this, we need to estimate the biophysical-carbon stocks in the European Natura 2000 sites and combine these with a monetary metric unit, typically the social cost of carbon or the market price of carbon, which reflects the marginal abatement cost of carbon. These two measurements will allow us to calculate the economic, or welfare, value of carbon stocks.

Step 2. Characterization of a future scenario. This involves the study of policy driven land use changes and the assessment of their respective impacts in terms of changes in carbon stocks in the above ground biomass and below- ground soil organic matters. From an operative view point, we can proceed according to three main directions:

a. Trend analysis: by means of exploring the intertemporal analysis of land use changes and extrapolating these into future trends, typically within a 10 to 15 year time scale. Here we may also have specific information regarding the costs of land use degradation in the absence of policy or benefits from improved management on natural habitats;

b. Specific land-use policies: by means of working with well-defined land use changes as identified by policy makers or any other key stakeholder(s). Here we may have specific European policies on the use of land for bio-fuel, reforestation/afforestation as well as habitat de-fragmentation;

c. Spatial land use editor toolkit: this involves constructing an instrument in which the policy maker selects changes in land use to be sanctioned and the toolkit calculates the changes in carbon stocks and fluxes. The toolkit may be part of a decision support system characterized an explicit spatial dimension with information regarding land covers of specific habitats under consideration. (see for example, ARIES application in Mexico and US: http://www.ariesonline.org/case_studies.html).

Step 3. Interpretation of policy impacts and associated losses/gains on carbon value by comparing the selected policy scenarios and the SQ scenario. Policy scenarios present a narrative description of the possible future paths regarding the Natura 2000 sites management in Europe. They are subjective and depend on the political preferences. In this regard, we consider mainly two realistic scenarios, i.e. (1) the policy ON scenario, where full Protected Area coverage (terrestrial PAs + fuller MPAs) with a move to full favourable conservation status will be evaluated; and (2) the policy OFF scenario, describing a narrative picture of the future in which some elements of degradation will occur across the Natura 2000 sites, with respect to the reference year 2010. In this report, year 2020 is defined as policy target for estimating the total changes.

4. Understanding the baseline: estimating the total carbon currently stored in Natura habitats and their economic value

The 2003 IPCC - GPG *for Land Use, Land Use Change, and Forestry* has developed a systematic approach to calculate the total carbon stocks in above-and below- ground biomass, dead wood, litter and soil organic carbon by six land-use categories, i.e. forest land, cropland, grassland, wetlands, settlements, and other land. Each land-use category is further subdivided into land remaining in that category (e.g., Forest Land Remaining Forest Land) and land converted from one category to another (e.g., Forest Land converted to Cropland) (Penman et al. 2003). Among all the land uses, forests are the most important terrestrial ecosystems in terms of providing carbon-regulating services. To estimate the stocked carbon in plant and woody biomass, national Forest Inventory Data (FID) with annual greenhouse gas (GHGs) inventories in the Agriculture, Forestry and Other Land Use (AFOLU) are commonly used. From these we can calculate not only the total carbon stocks under each land-use category but also the net carbon changes as a result of growing biomass and land conversion. Typically, carbon stocks are estimated by first estimating the total biomass stocks on land and then convert then to carbon stocks using a conversion factor. By dividing total stocked carbon by the area of the ecosystem or habitat which provides the service, we can approximate the carbon density (tC/ha) of this particular type of ecosystem or habitat. As for estimating the changes of carbon stocks, there are two methods can be used depending on data availability:

1. Gain-loss method (also known as 'default method'): the carbon stock changes are estimated by considering all relevant processes, and calculated as the difference between annual carbon gains (due to growth of tress) and carbon losses (due to harvest, fires and other natural loss and disturbance);
2. Stock change method: the carbon stocks changes are the difference of carbon stocks for a given forest area at two points in time. This method is relatively less data demanding compared to gain-loss method and therefore is preferred in the present study due to limited time and data availability.

The current calculation of carbon density (tC/ha) for the terrestrial ecosystems relies on field measurements, taking into account total carbon stored by each land-use category in aboveground biomass and soil organic carbon stored up to 1m depth belowground (World Bank, 2009). This type of research is often costly and time-consuming. As regards Natura 2000 sites, the simplest and most practical way of estimating carbon densities for all the habitats concerned would be a survey of the literature. In the present study, carbon density by habitat is selected from the studies that included habitat types most relevant to the Natura 2000 habitat classification. Table 2 summarizes the reviewed global average carbon density for a number of habitats, including temperate forest, boreal forest, temperate grass, desert/semi-deserts, tundra, wetlands, cropland, seagrass and salt marshes4.

Table 2: Selected average carbon density estimates in the literature

Habitat type	Average carbon density estimated (tC/ha)	Reference
Temperate forest	150	World Bank (2009)
Boreal forest	410	
Temperate grass	240	
Deserts/Semi-deserts	40	
Tundra	130	
Wetlands	690	
Cropland	80	
Seagrass	212	Murray et al. (2011)
Salt marsh	285	

Furthermore, the selected carbon density estimates are applied to corresponding Natura 2000 habitat types, as shown in Table 3. Thus, total carbon stocks by habitat can be calculated by multiplying carbon density of each habitat type by its total. Note that forest habitats in the Natura 2000 network are classified in terms of broad-leafed deciduous, coniferous, evergreen woodland and mixed forest, which is inconsistent with most of studies that we have found in the literature. These studies distinguish forests by biome classification, i.e. temperate, boreal and tropical forests. We are aware that carbon densities differ across forest biomes, but we are not able to disentangle different forest biomes from the Natura 2000 habitats. The problem of data inconsistency among studies forces us to apply an average estimate of the carbon densities derived from temperate and boreal forest biomes in the literature to all forest and other woodlands that are counted in the Natura 2000 sites.

[4] It shall be noted that for marine and coastal habitats, both carbon in the living biomass and soil organic carbon are counted for in the present calculation.

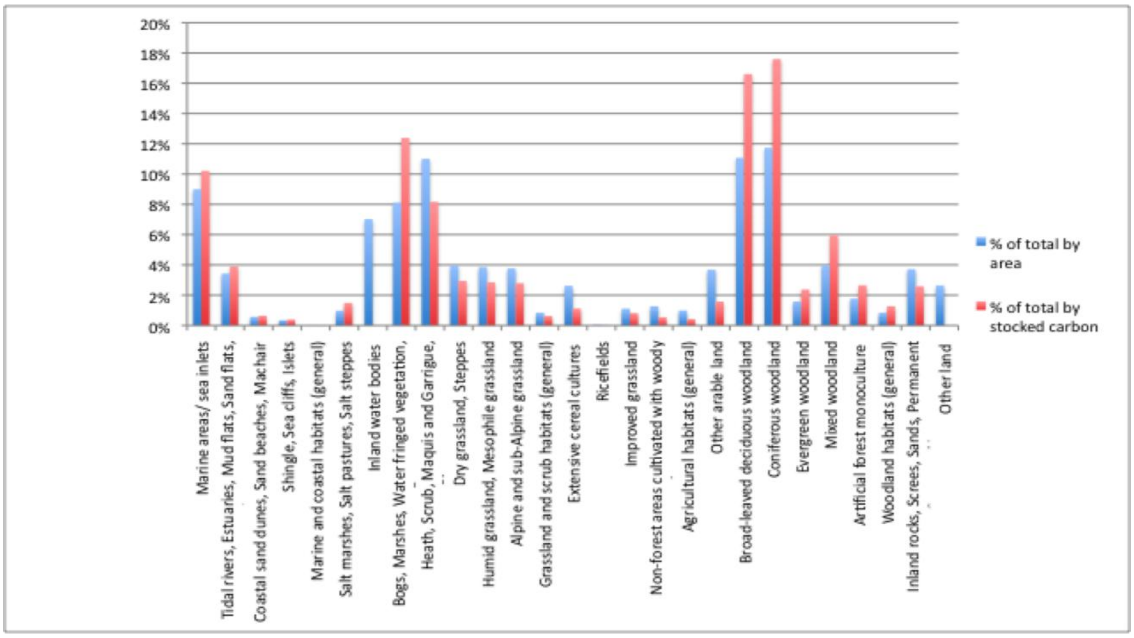
Table 3: selected estimates of carbon densities for Natura 2000 habitats

MA ecosystem classification	Natura 2000 habitat types	Applied value of carbon density (tC/ha)
Marine and costal ecosystem[1]	Marine areas/ sea inlets	212
	Tidal rivers, Estuaries, Mud flats, Sand flats, Lagoons (including saltwork basins)	212
	Coastal sand dunes, Sand beaches, Machair	212
	Shingle, Sea cliffs, Islets	212
	Marine and coastal habitats (general)	212
Inland water ecosystem[2]	Salt marshes, Salt pastures, Salt steppes	285
	Inland water bodies (Standing water, Running water)	
	Bogs, Marshes, Water fringed vegetation, Fens	285
Dryland ecosystem[2]	Heath, Scrub, Maquis and Garrigue, Phygrana	139
	Dry grassland, Steppes	139
	Humid grassland, Mesophile grassland	139
	Alpine and sub-Alpine grassland	139
	Grassland and scrub habitats (general)	139
Cultivated ecosystem[2]	Extensive cereal cultures (including Rotation cultures with regular fallowing)	80
	Ricefields	80
	Improved grassland	139
	Non-forest areas cultivated with woody plants (including Orchards, groves, Vineyards, Dehesas)	80
	Agricultural habitats (general)	80
	Other arable land	80
Forest and other woodland[2]	Broad-leaved deciduous woodland (NB = temperate deciduous forest)	280
	Coniferous woodland (NB: temperate forest)	280
	Evergreen woodland (NB: temperate forest)	280
	Mixed woodland (NB = temperate)	280
	Artificial forest monoculture (e.g. Plantations of poplar or Exotic trees)	280
	Woodland habitats (general)	280
Mountain[2]	Inland rocks, Screes, Sands, Permanent Snow and ice	130
urban settlement[2]	Other land (including Towns, Villages, Roads, Waste places, Mines, Industrial sites)	

Sources: 1. Murray et al. (2011); 2. World Bank (2009);

The areas of total 27 different types of habitat included in Natura 2000 network are reported by European Environmental Agency for total 20 Member States (national data is available on request). By multiplying the carbon density selected for each habitat type (as identified in Table 12) by the size of the habitat, we can obtain the total carbon stocks currently stored by a specific type of habitat at country level – Figure 5.

Figure 5: Percentage of habitats within the Natura 2000 network and the respective proportional contribution to carbon storage.



Source: own calculation (Note: detailed country data are available on request)

Our results show that total stocked carbon in all N2K sites is about 9.6 giga tons5. Of this total, forest and other woodlands present the most important carbon sinks, accounting for 52% of total carbon sequestrated (approximately 5.2 GtC). Second most important carbon sink is dryland ecosystems (including grasslands), amounting to 1.7 GtC of carbon stocks (or around 17% of the total carbon stocks), followed by marine/costal ecosystem (1.5 GtC or about 15% of total carbon stocks) and inland water systems (1.3 GtC or 14% of total carbon stocks). Although the current estimation is subject to high uncertainty and our current limited knowledge of carbon sequestrated by different nature habitats (in particular by marine/coastal ecosystems), our results may suggest that further investment in forested land conservation or sustainable forest management may enhance the overall carbon capacity of N2K sites and increase the future carbon credits. Finally, within the N2K network, cultivated lands that comprise croplands for cereal production, rice fields and grassland for cattle feeding account for a very small portion of the total N2K area. Therefore they make a limited contribution of 0.4 GtC carbon stocks (equivalent to 5% of total carbon stock). However, they are complex systems with great potential of increasing total carbon sequestration by improving cultivation activities, management practices and the use of machinery and fertilizers.

In order to value the carbon sequestration services of Natura 2000 habitats in monetary terms, a range of carbon prices are applied to reflect the damages caused by different degrees of climate change impacts. In the present report, a number of well recognized EU studies (EC, 2008; DECC, 2009 and Centre d'analyse stratégique, 2009) have been looked at to choose the most suitable value for carbon prices in 2020, taking into account the 2020 emission reduction target for Europe as well as the estimated social costs of carbon6. Finally, the team has chosen to use the European Commission

[5] Given that annual anthropogenic emissions of CO_2 are about 10 gigatons (Parry et al. 2007), all N2K sites store the equivalent of just under 4 years of global anthropogenic emissions.

[6] Social Cost of Carbon is the net present value of the impact over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. It is outcome of Integrated Assessment Models (IAM), which translate climate damages into monetary costs (or exernality) to a society.

values (EC, 2008 and DECC, 2009) as the lower values and the value of the French study (Centre d'analyse stratégique, 2009) as the higher values – See Table 4.

Table 4: Carbon value used in this study (€/t, 2010)

CO_2-eq or C-eq	*Range*	*2010*	*2020*
Carbon dioxide (CO_2) or CO_2 - equivalent	*Low*	*17.2*[1]	*39*[2]
	High	*32*[3]	*56*[3]
Carbon (C) or C-equivalent	*Low*	*63.12*	*143.13*
	High	*117.44*	*205.52*

Note: the conversion between Euro/tCO2eq and Euro/tC is: 1€/tCO_2=3.67€/tC, based on the conversion to CO_2 from C using the ratio of molecular weights (44/12).

Source: 1. DECC (2009), 2. EC (2008), and 3. Centre d'analyse stratégique (2009)

The upper- and lower- bounds of carbon value in 2010 are applied to estimate the total carbon value provided by Natura 2000 sites and to reflect other co-benefits that conservation and forestry provide. Results are shown in Figure 6. It is important to note that, the use of a range estimate of carbon prices also aims to account for uncertainties of climate change damages, respectively.

All in all, our valuation estimates indicate that the total carbon value of all N2K habitats as a whole lay between 607and 1,130 billion Euro in 2010, depending on the choice of carbon prices. Among all others, the forest habitats contain the highest carbon value in the network, ranging between 318 and 610 billion Euro in 2010. The second highest carbon value is contained in the dryland (grassland) system, ranging between 106 and 197 billion Euro in 2010, followed by Marine and inland water ecosystem, which account for 92 to 171 billion Euro and 84 to157 billion Euro, respectively.

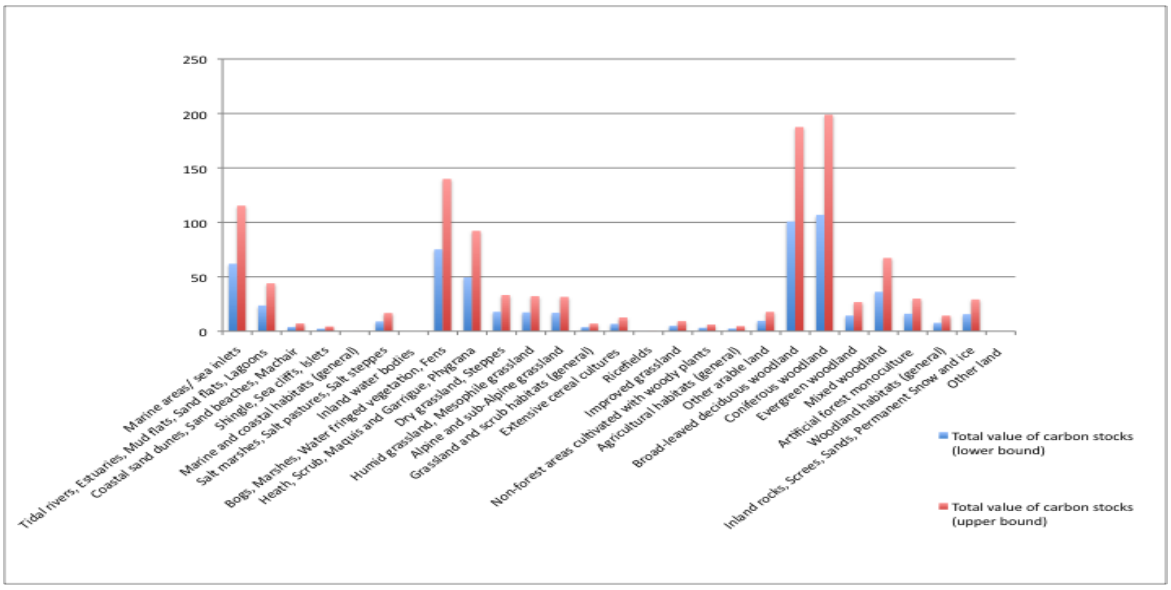


Figure 6: Total economic value of carbon stocks by N2K habitats (Billion Euro, 2010)

Source: own estimation (Note: detailed country data are available on request)

5. Estimating the net changes of carbon stocks in Natura 2000 habitats under future policy scenarios

Assessing, measuring and accounting for net changes in carbon stocks in natural ecosystems are particularly challenging tasks for two reasons. First, ecosystems display a natural variability in terms of carbon flows and fluctuations that are difficult to estimate (Eisbrenner and Gilbert, 2009). For example, the carbon uptake of the Earth's land and oceans has varied naturally over time (IPCC, 2000). Second, difficulties arise when we attempt to quantify the anthropogenic influences on carbon stocks in ecosystems, through large-scale changes of land use, particularly deforestation urbanisation and land-use conversions, as well the use and regulation of fertilisers, air pollution or waste deposits (Eisbrenner and Gilbert, 2009). Evidence has shown that past land-use conversions from forest land to crop production, wetland, grassland, and other land uses have resulted in substantial loss of carbon from the biomass and *vice versa.* Given that CO_2, the most common GHG, is sequestered in biomass and soils in forests, wetlands and grasslands at higher rates than in cropping systems, we can therefore expect a number of management practices that can result in an increase in soil organic carbon and carbon sequestrated by biomass, including the restoration of wetlands, the improvement of grassland and the establishment of agroforestry ecosystems and so on. On the other hand, policies that passively manage the existing protected areas or encourage land conversions from grassland to croplands will cause the release of stocked CO_2 to the atmosphere and reduce carbon stored in the ecosystems.

In this section, we focus on analysing and evaluating different impacts of potential EU policy options regarding the ambitions and targets of N2K management by 2020. In particular, we consider two different dimensions of policy impacts on the N2K habitats, namely policy ON and OFF scenarios. With respect to the policy ON scenario, we consider the positive impacts of land-use practices and management that: (1) improve the current status or quality of forest, grassland and cropland habitats without extending the conservation area (i.e. **qualitative aspects** of the policy), and (2) encourage the enlargement of conservation areas for certain habitats (i.e. the **quantitative aspects** of the policy). On the contrary, the policy OFF scenario refers to a Business-As-Usual scenario (or policy inaction scenario), in which we assume that the EU will not provide any future investments in the N2K habitats protection and management. As a consequence, certain degrees of natural degradation may occur on many N2K sites and thus result in the release of CO_2 to the atmosphere or loss of carbon value. However, it is scientifically uncertain, to what extent, the N2K habitats may degrade in the context of policy inaction. To simply the problem, we assume a zero rate of degradation to ease the current calculation, meaning that by 2020 the total quantity of carbon stocked in N2K habitats will remain the same as in 2010 (Status Quo). Nevertheless, it is necessary that future research shall shed light on this direction so as to improve the economic estimation.

(1) Assessing the carbon value under the Policy ON and OFF scenarios:

To assess the impacts of "policy ON" scenario on carbon stocks, we separately evaluate (a) the **quality improvement** of the existing N2K sites, based on the net annual change of C-stock (tC/ha/yr) due to improved land-use management (IPCC, 2000) – see Table 5 for details; and (b) the **quantitative changes** of N2K site in terms of changing in land-use composition and conversions between different land uses.

Table 5: A review of the relative potential in 2010 for net change in carbon stocks through some improved management

Activity	Global net annual change of C-stock (tC/ha/yr)	Global total net change of C-stock (MtC/yr)
Forest Management	+0.5	+100

Cropland Management	+0.3	+75
Grazing Land Management	+0.5	+70
Source: data are derived directly from the ECCP-Working Group on Forest Sinks final report, originally estimated by IPCC (2000)		

First of all, to estimate the economic gains of carbon stocks from the qualitative improvement of N2K sites, the annual change of C-stocks for three main habitat categories: forest, grazing lands and croplands, are estimated over a 10-year period of time to estimate the total stocked carbon in those habitats by 2020. This is done using the estimated net annual changes of carbon stocks under improved management practices given in Table 5. Furthermore, total carbon value provided by N2K sites in 2020 can be estimated by multiplying the estimated total carbon stocks in 2020 by the carbon price of that year. The gains of carbon value due to improved habitat management between the period of 2010 and 2020 are the difference of carbon values between the two points of time.

This calculation is expressed in Equation 1 below:

$$\begin{aligned}\Delta V_H &= V_H^{2020} - V_H^{2010} \\ &= p_{2020} \times \left\lfloor C_{2010} + A_H^{2010} \times \sum_{n=1}^{10} \Delta netC_H \right\rfloor - p_{2010} \times C_{2010}\end{aligned} \qquad \text{Eq (1)}$$

: the estimated changes in carbon value by habitat types (*H*) (economic gains) between 2010 (V_H^{2020}) and 2020 (V_H^{2010}) (in 2010 Euro)

p: applied carbon prices for 2020 and 2010, respectively (in 2010 Euro)

A_H: The total area of the habitat in year 2010 (in *ha*)

: net annual change of carbon stocks (in tC/ha/yr)

C: total carbon stocked in N2K sites in year 2020 and 2010, respectively

n: a period of 10 years between 2010 and 2020

Second, the quantitative changes of N2K habitats in terms of changes in the total area and land-use composition by 2020 are projected based on the identified possible conversions between different land-uses in N2K networks – see Table 15. Note that In the case of Natura 2000 sites, since most of the sites are protected areas (PAs), it is unlikely that natural forest will be converted to cropland, grassland and other land uses. However, we shall note that the opposite conversion may happen if for example policy objective is to enlarge the coverage of forest areas and to restore wetlands. In Table 6, we summarize the potential conversion between N2K terrestrial habitats as well as the associated impacts on carbon storage.

Table 6: Possible conversion between different land-uses in N2K networks

From	**To**	**Impacts on carbon storage**
Cropland	Forest	+
Cropland	Grassland	+
Grassland	Forest	+
Grassland	Cropland	-

Grassland	Settlements	-
Wetland (e.g. peatland)	Cropland	-
Cropland	Settlements	-
Source: The table is summarized based on the global evidence reported by IPCC-GPG (2006)		

In practice, annual net changes of carbon stocks due to the land uses change are estimated using the **stock change method**, measuring the carbon stocks changes as the difference of carbon stocks for a given forest or other habitats at two points in time i.e. 2010 and 2020. **More specifically, to provide a comprehensive example, we assume that the European Commission will implement a policy of increasing at least 10 percent of forest-protected area in all the Member States by 2020, with respect to their national forest coverage in 2010.** This objective can be achieved in two ways. First, national environmental policy can set aside marginal farmland (or grassland which is already high in tree coverage and rich in biodiversity) to protect forest habitats close-by. Second, local policymakers can also decide to abandon some croplands and convert them to grassland to generate additional carbon credits.

In Table 7, we illustrate how to calculate the total area of habitats after land conversions have occurred. Bearing in mind the policy target of a 10 percent increase in total forest area, 80 hectare of forest habitat in 2010 will extend to 88 hectare by 2020, accounting for 8-hectare of total increase, of which 50% is assumed due to conversion of cropland to forest and the other 50% is converted from grassland. This land-conversion matrix will be constructed at country level and then aggregated for the EU. It is important to note that the total area of N2K sites remains constant overtime.

Table 7: Example of land conversion matrix used for analysing the N2K sites (for illustration only)

Time 1 (2010)	Time 2 (2020)	Net land-use conversion between Time 1 and Time 2
F = 80	F = 88 (10% increase)	F = +8
G = 60	G = 56	G = -4
C = 70	C = 66	C = -4
Sum = 210	Sum = 210	Sum = 0
Note: F = Forest land, G = Grassland, C = Cropland		

As a consequence, we will be able to calculate the total carbon stocks in 2020 after the expected land-use changes. To keep it simple, we assume that the carbon densities for all habitat types remain unchanged by 2020, although it is crucially important to apply the estimated carbon densities to the new areas of the changed habitat. Finally, the annual change in carbon stocks in biomass for the same land-use category can be estimated using Equation 2 below (see Table A9 in Annex 2 for the estimated net changes of carbon after land conversions).

$$\Delta netC_H = \frac{(C_H^{2020} - C_H^{2010})}{(t_{2020} - t_{2010})} = \frac{(A_H^{2020} - A_H^{2010}) \times D_H}{10} \quad \text{Eq (2)}$$

$\Delta netC_H$: net annual change of carbon stocks by habitats (in tC/ha/yr)

D_H: estimated carbon densities by habitat type

A_H : The total area of the habitat in year 2010 (in *ha*)

C: total carbon stocked in N2K sites in year 2020 and 2010, respectively

t: year 2010 and 2020, respectively

Finally, the economic gains of carbon value as a result of the land use changes, they can be estimated following Equation 3.

$$\Delta V_H = p_{2020} \times (A_H^{2020} \times D_H) - p_{2010} \times (A_H^{2010} \times D_H) \qquad \text{Eq (3)}$$

(2) Results: estimated carbon value under the two Policy ON and Policy OFF scenarios

The results derived from both qualitative and quantitative evaluation of potential policy ON impacts can be integrated in cost-benefits analysis of the policy alternatives and provide important insights on cost-effectiveness of these polices. In Table 8 and Table 9, we summarize the estimated total carbon stocks and the respective economic values by N2K habitats.

Table 8: Estimated total carbon stocks by N2K habitats (GtC)

Scenarios	**otal**	**arine Total**	**nland Water Total**	**Dryland Ecosystem Total**	**Cultivated Ecosystem Total**	**Forest and Other Wood Land Total**	**Inland rocks, Screes, Sands, Permanent Snow and ice**	**ther land**
Policy OFF Scenario in 2020	.61	.46	1.33	1.67	0.43	4.47	0.25	.00
Scenario Policy ON-1 in 2020	.78	.46	1.33	1.74	0.45	4.55	0.25	.00
Scenario Policy ON-2 in 2020	.89	.46	1.33	1.55	0.39	4.92	0.25	.00

Note: see Table A4 in Annex 2 for detailed results

Table 9: Total Economic value of carbon services provided by N2K habitats (Billion Euro, 2010)						
General habitats	**Policy OFF – 2020**		**Policy ON_1: qualitative improvement - 2020**		**Policy ON_2: quantitative land-use changes – 2020**	
	Lower bound	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
Marine Total	208.6	299.6	208.6	299.6	208.6	299.6
Inland Water Total	191.0	274.3	191.0	274.3	191.0	274.3
Dryland Ecosystem Total	239.5	343.9	248.7	357.1	221.5	318.1
Cultivated Ecosystem Total	62.2	89.3	64.5	92.6	55.6	79.8
Forest and Other Wood Land Total	639.7	918.6	651.8	936.0	703.7	1010.4
Inland rocks, Screes, Sands, Permanent Snow and ice	35.6	51.1	35.6	51.1	35.6	51.1
Other land	0.0	0.0	0.0	0.0	0.0	0.0
Total	1376.7	1976.8	1400.3	2010.6	1416.0	2033.3
Δ wrt Policy OFF	**-**	**-**	+23.6	+33.8	+39.3	+56.5
Note: see Table A6, A7 and A8 in Annex 2 for detailed results						

As one can see, both future policy ON alternatives in terms of improving land-use management on terrestrial ecosystems, i.e. dryland, cultivated ecosystem and forests, and of enlarging protected area will have positive impacts on the total carbon storage and thus total economic gains to the society by 2020, with respect to the policy OFF scenario, namely policy inaction scenario. Excluding the costs of policy implementation, our results also suggest that in the short run, efforts in terms of enlarging the total area of protected forest habitats (i.e. Policy ON 2 involving a 10% increase in forestland) may generate at least 16 to 23 billion Euro more immediate benefits than the policy that focus only on the improvement of on-site quality (i.e. Policy ON 1). This is because setting aside croplands and grassland as "buffer zone" for forest conservation or regeneration can lead to higher growth rate of aboveground biomass and therefore increasing carbon density on those lands. However, it is uncertain which of two policy options may generate higher benefits in the long run, if the entire carbon cycle and decay under different scenarios will also be counted for, as sustainable forest management practices may help ecosystems to reduce or slow down the process of releasing CO_2 to the atmosphere. On the contrary, if neither of the policy options were undertaken, we then place ourselves in a Policy OFF - "policy inaction" scenario, where all the economic gains from improved policies on Natura 2000 sites are lost. Thus, a total of 1.71-2.86% of economic gains from scenarios ON1 and ON2 by 2020 can be intercepted as lower-bound estimates of the costs of policy inaction. If we take into account also the released carbon from degraded habitats (if a non-zero rate of degradation were applied instead), the total costs will be much higher.

6. Conclusions

In the present study, we adopted the state-of-the-art methodologies to quantify the total carbon stocked by Natura 2000 habitats as well as to project the future changes of carbon stocks influenced by alternative policy options for the management of Natura 2000 habitats by 2020. Furthermore, in order to estimate the economic value of N2K habitats, we used a range of carbon prices derived from the most recently EU studies, rather than a central estimate to count for uncertainty issues.

Our results show that the N2K network currently stores around 9.6 billion tonnes of Carbon, equivalent to 35 billion tonnes of CO2, which is estimated to be worth between €607 billion and €1,130 billion (stock value in 2010), depending on the price attached to a ton of carbon.

Of the different ecosystems the forest habitats contain the highest carbon value in the network, ranging between €318 and €610 billion in 2010. The second highest carbon value is contained in the dryland (grassland) system, ranging between €106 and €197 billion in 2010, followed by marine and inland water ecosystem, which account for €92 - €171 billion and €84 -157 billion, respectively.

In the future these carbon values can be increased. A policy scenario (Policy ON), where full Protected Area coverage (terrestrial PAs + fuller MPAs) with a move to full favourable conservation status is estimated to generate a gain of at least a total of 1.71-2.86% by 2020 compared to a policy inaction scenario (Policy OFF), where no additional action is taken to conserve the current Natura 2000 sites over the next decade.

Overall the increase in carbon storage benefits between 2010 and 2020 amounts to around €793 to €881 billion (lower and upper bound estimates for increase in value of carbon stock), partly due to the improved land management measures and partly due to the increase in the value of carbon itself which applies to both existing stock in 2010 and gains over the period to 2020 from land management measures. The underlying values of carbon used were 17 EUR/t CO2 to 32 EUR/tCO2 in 2010 to 39 EUR/tCO2 to 59EUR/tCO2 in 2020.

In addition it is estimated that efforts in terms of enlarging the total area of protected forest habitats (i.e. a version of the Policy ON scenario that leads to **quantity improvement of the N2K sites**) could generate at least €16 to 23 billion more in immediate benefits than the policy that focuses only on the improvement of on-site quality (for the period to 2020). The enlargement considered in the analysis was a 10 percent increase in forest-protected areas in all member states by 2020 with respect to their national forest coverage in 2010.

Nevertheless the reported economic valuation exercise is conducted based on the best information and knowledge available regarding the Natura 2000 sites, the authors are aware of a number of limitations in the estimation and suggest that the users should be cautious when interpreting and implementing the presented results for any policymaking. In particular, we highlight a number of issues that shall be particularly considered.

1. Time issue. In this study, we consider a short-term policy scenario to evaluate the impacts of N2K management on carbon stocks by 2020. Despite the fact that the focus of our study is not on climate policy only, It however shall be noted that a 10-year period is rather short to evaluate precisely the policy impacts on changes in carbon stocks, knowing that the time it takes for a carbon atom to complete its cycle between atmosphere-biosphere systems is about

100 years7 (CDIAC - Carbon Dioxide Information Analysis Centre: http://cdiac.ornl.gov/faq.html#Q16). Therefore, one should be cautious when using the present value estimates for any long-term policymaking debate.

2. The applied carbon density rates are estimated based on global evidence, rather than EU evidence, which means that our estimation of carbon stocks by the N2K sites may refer to a lower-bound estimate, as the carbon density in protected natural reserves are usually higher than average.
3. The present assessment focuses only on terrestrial ecosystems, subject to our limited knowledge about carbon sequestration capacity by many essential ecosystems, such as marine and costal ecosystems. Therefore, future efforts should be placed on improving our understanding, particularly on 'blue carbon' issues – i.e. those relating to marine ecosystems.
4. The policy assumptions on future land-use changes and their respective consequences are far too simple from the reality. A better understanding of the interface between CO2 and other GHGs, especially in the case of agricultural land management, is essential for improving the overall estimation of land-use change impacts on net carbon changes.
5. The analysis of Policy OFF scenario is very conservative in the present study. In particular, the assumption of a zero degradation rate for all N2K habitats in the context of policy inaction is illustrative rather than realistic. However, it is scientifically uncertain, to what extent, the N2K habitats may degrade in the context of policy inaction and how this degradation may affect the stocked carbon (which refers most likely to a non-linear relationship). This is a direction on which future research shall focus.
6. The costs of policy action are not tackled here, but shall be addressed in future research. In particular, a hypotheses that this cost is spatially explicit shall be tested, as the results may shed light on the distributional dimension of the policy action and therefore shall be brought into the policy discussions.

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