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Economic Assessment of Forest Ecosystem Services Losses: Cost of Policy Inaction

Aline Chiabai · Chiara M. Travisi · Anil Markandya · Helen Ding · Paulo A. L. D. Nunes

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Abstract This paper presents a bottom-up methodological framework for estimating some of the key ecosystem services provided by forests biomes worldwide. We consider the provision of wood and non-wood forest products, recreation and passive use services, and carbon sequestration. The valuation framework derives per hectare estimates by applying meta-analysis, value-transfer and scaling-up procedures in order to control for the existing heterogeneities across world regions and forest biomes. The first part of the study estimates stock values per hectare for each forest ecosystem service in the baseline year 2000 and in the year 2050. Results differ per geographical region and biome. Carbon stocks represent, on average, the highest value per hectare, followed by provisioning services, passive use and recreational values respectively. The second part provides an estimation of the welfare loss (or gain) associated with policy inaction in the period 2000–2050 leading to a change in the forest area. Welfare results are mixed and require a careful interpretation, ranging from a worldwide annual benefit of +0.03% of 2050 GDP to an annual loss of −0.13%. The highest

A. Chiabai (✉) · A. Markandya
Basque Centre for Climate Change (BC3), Bilbao, Spain
e-mail: aline.chiabai@bc3research.org

C. M. Travisi
Fondazione Eni Enrico Mattei FEEM, Milano, Italy
e-mail: chiara.travisi@gmail.com

A. Markandya
University of Bath, Bath, UK
e-mail: anil.markandya@bc3research.org

H. Ding
Department of Agriculture and Natural Resources, University of Padua, Padova, Italy
e-mail: helen.ding@unipd.it

P. A. L. D. Nunes
The Mediterranean Science Commission,
Principauté de Monaco; Department of Agriculture and Natural Resources,
University of Padua, Padova, Italy
e-mail: pnunes@ciesm.org

damage is expected in Brazil due to the increasing deforestation taking place in tropical natural forests, which is causing a considerable loss of carbon stocks.

Keywords Carbon · Cultural services · Forest ecosystem services · Market values · Meta-analysis · Millennium Ecosystem Assessment · Non-market values · Non-wood forest products · Value-transfer · Wood forest products

Abbreviations

CBD	Convention on Biological Diversity
COPI	Cost of policy inaction
ESs	Ecosystem services
EVRI	Environmental valuation reference inventory
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
IMAGE	Integrated Model to Assess the Global Environment
MEA	Millennium Ecosystem Assessment
NWFPs	Non-wood forests products
PPPGDP	Purchasing power parity GDP
TEV	Total economic value
IUCN	International union for conservation of nature
TEEB	The Economics of Ecosystems and Biodiversity
WFPs	Wood forests products
WITCH	World Induced Technical Change Hybrid model

1 Introduction

1.1 Where Do We Stand

In recent years we have been witnessing a major debate on the potential effects of biodiversity loss, which was in part driven by unsustainable economic activities in most world regions. Biodiversity contributes to human well-being in two ways. On the one hand, it contributes directly by providing raw materials and contributing to health; on the other hand, it is indirectly related to human well-being through its essential role in supporting ecosystem functioning and supplying ecosystem goods and services to humans. These have entailed ethical questions on the role of humans in the stewardship of the planet's natural resources. As biodiversity decreases, what are we losing in terms of goods and services to humans? And what is the impact on the welfare and wellbeing of the current and future population and societies?

Several studies have tried to provide economic estimates of the costs and benefits of land conversion and human activities inducing ecosystem services loss. However, the coverage of the available economic estimates of the costs of such a loss is partial, and the required research effort still massive. Amongst all ecosystems on earth, the present paper focuses on valuing the world's forest ecosystems services (ESs).

Forests not only provide timber but they also represent critically important habitats for the ecosystem services they supply (e.g. Miller and Tangley 1991; Mendelsohn and Balick 1995; Pearce 1996, 1998, 1999). They regulate local and global climate, enhance soil retention and water quality, ameliorate water events, facilitate pollination, improve landscape aesthetics, provide habitats for a vast store of species, and enclose invaluable genetic information yet to be uncovered.

At the current alarming level of deforestation of approximately 13 million hectares per year (FAO 2007), the loss of forest ecosystem services is expected to be serious. Evidence also suggests that ecosystem services loss could accelerate in the future as an effect of climate change (Pimm and Raven 2000; Thomas et al. 2004). The international research community is committed to support policy action towards a sustainable use of forest resources worldwide, and the forest economic evaluation challenge has gradually reached the international policy agenda.

The stabilization of Green House Gas emissions by forest conservation or prevention of deforestation—questions not originally included in the Kyoto Protocol—were addressed in COP13 in Bali on December 2007. Countries rich in forest resources, such as Brazil, asked for economic compensation for the ecosystem services that they can give to the planet by helping future conservation of millions of hectares of native woodland in the tropics. As the loss of forest ecosystem services is mainly due to the conversion of forests to agricultural land, paying farmers for the environmental services they may conserve or provide is generating growing interest worldwide, from policy makers to non-governmental and private decision-makers (FAO 2007). As such policy initiatives are currently being debated, the availability of a worldwide perspective on forest service values is becoming pivotal, and a common platform of analysis of forest services is needed.

Previous studies valuing biodiversity have mainly focused on single categories of forest ecosystem services, either market or non-market, and specific forest types (e.g. Chomitz et al. 2005; Portela et al. 2008). The CBD report (Secretariat of the Convention on Biological Diversity 2001) provided a comprehensive literature review of the market and non-market values for a vast array of forest services (from provisioning services to genetic information). Such estimates help us to understand the typologies and orders of magnitude of the services involved; however, they cannot be seen as representative of all forest areas, and they are not easily comparable at the global scale.

The total welfare contribution of ecosystem services has been estimated by Costanza et al. (1997) at USD33 trillion per year, but this approach has been criticized by economists for not being an incremental one (Toman 1998; Bockstael et al. 2000). There is little advantage in knowing the total value of an ecosystem unless there is a threat to eliminate it or a policy to reconstruct it in its entirety, which is rarely the case (Markandya et al. 2008). Regarding the valuation of non-market forest ecosystem services, criticisms also exist with respect to the nature of the value estimates being used in the valuation, which tend to be very site specific, and transfers to other forests and locations are difficult or often not credible (Markandya et al. 2008).

1.2 Moving Forward

Within the EU-funded project COPI "Cost of Policy Inaction: the case of not meeting the 2010 biodiversity target", the authors have developed an original framework based on a range of monetary valuation methods to assess forest provisioning, regulating and cultural ecosystem services across the globe (see Fig. 1). We consider the provision of wood and non-wood forest products (WFPs and NWFPs), cultural services (recreation, ecotourism and passive use), and carbon sequestration capacity. We thus create a common bottom-up estimation platform to monetize the value of the above mentioned ecosystems services, both market and non market ones, worldwide. Our approach looks at the global scale, but derives global estimations with meta-analysis, value-transfer and scaling-up procedures which are based on the largest possible set of regional and national data, in order to cover the highest

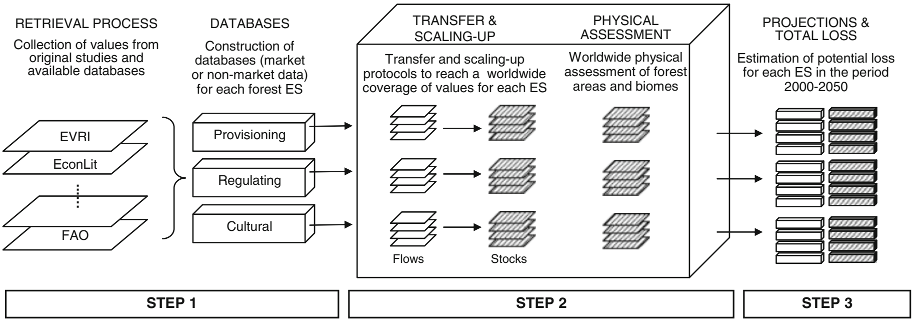


Fig. 1 A schematic illustration of the overall methodological approach

variability in terms of geographical and socio-economic regions, as well as forest biomes. To avoid the 'adding up' problem and potential related biases, we do not simply estimate the average values of forest ecosystem services, but we attempt to differentiate values by geographical location and forest biome. To do so, we rely on a thorough retrieval process that allows us to build, for each forest service analyzed, comprehensive databases gathering both estimates already available in the literature and data from national statistics to be used in the valuation procedure. Overall, the valuation methodological approach builds up on a three-step estimation process (see Fig. 1).

Step 1: Construction of databases and computation of annual flow values per hectare. For provisioning services we provide an original estimation based on FAO data available at a very disaggregated geographical level (country level). For cultural and regulating forest services, to reach worldwide coverage, we rely on meta-analysis and we transfer the values from study sites to unexplored geographical regions.

Step 2: Computation of stock values per hectare. As we want to compare different forest services and look at the corresponding change in the natural capital stock between 2000 and 2050 we convert flows into stock values per hectare.

Step 3: Projections of stock values per hectare from 2000 to 2050, and estimation of total welfare loss associated with the projected forest area changes.

All methodological details, merits and limitations, are presented and discussed in the following sections. In Sect. 2 we present the overall estimation platform, as well as the model projecting forest areas, while describing forest ecosystem services, forest biomes, world regions and land use data. The specific estimation method employed for each forest service, and the main results, are detailed in Sect. 3. Section 4 discusses the cost of policy inaction in year 2050, and finally Sect. 5 offers some conclusive remarks, while discussing future challenges.

2 Valuing Forest Ecosystem Services

2.1 A Worldwide Assessment of Forest Ecosystem Services

The forest ecosystem services considered in this study are selected according to data availability, world coverage, and relevance to decision making. This leads to the restricted set presented in Table 1. As defined by the Millennium Ecosystem Assessment (MEA), provisioning services are the goods obtained from ecosystems and they include food, fiber, fresh

Table 1 List of forest Ecosystem Services addressed for the monetary estimation

MEA category	Ecosystem services
Provisioning	Food, fiber, fuel: wood and non wood products
Regulating	Climate regulation: carbon storage
Cultural	Recreation and ecotourism
	Passive use

Source: Modified from MEA (2005)

water, and genetic resources. For forestry, we consider in particular wood and non-wood products (both plant and animal) extracted from natural or managed forested areas. Regulating services include benefits obtained from the regulation of ecosystem processes, such as air quality regulation, climate regulation, water regulation, erosion regulation, pollination and natural hazard regulation. As for regulating services, above all, deforestation is responsible for a huge amount of carbon emissions. We thus estimate the role of forests in climate regulation as important carbon storage reservoirs. Cultural services are the non-material benefits that people obtain from the ecosystem through aesthetic experience, reflection, recreation and spiritual enrichment. We refer to recreation/ecotourism and passive use of forests, these two dimensions being better covered by the economic valuation literature. The assessment provided is therefore not comprehensive of all forest ecosystem services, as not all instrumental values are covered. Besides, non-anthropocentric values (such as moral and spiritual values)—which should be taken into account in decision-making—do not lend themselves to this kind of quantification.

Several valuation methods can be applied to estimate the monetary value attached to each forest ecosystem service. By using the well-known notion of Total Economic Value (TEV), and depending on the nature of the good being valued, we can identify the best available valuation method to be employed for the monetary estimation of each ES of concern (see, e.g., Pearce and Moran 1994).

Broadly speaking, we employ market price data for the estimation of provisioning and regulating ESs while we rely on non-market (stated or revealed preference) valuation data to estimate cultural values. Greater uncertainty surrounds non-market values than market values, but given the global perspective of this exercise, it is essential to rely on the full body of knowledge already available in the environmental economics literature in order to gather estimates that cover, for each service to be valued, the highest variability in terms of countries and forest types (biomes). In this regard, a crucial role is played by the use of meta-analysis and value transfer, within the non-market valuation.

For each forest ES, we first perform a thorough retrieval process and gather the widest possible set of relevant market and non market data. In particular, for recreation and passive use values we carry out two meta-analyses. Second, we apply specific value transfer and scaling up protocols to adjust available values to new, unexplored, contexts, in order to provide worldwide estimates. By means of multivariate meta-regressions, meta-analysis enables us to explain the variance of the available Willingness-To-Pay figures as a function of a set of statistically significant explanatory variables. The literature retrieval process resulted in three different sets of data, one for each MEA service category. Several of these data, however, do not provide usable estimates. Thus, the stock values actually employed represent a subsample of the whole body of the literature. Still they are intended to provide the maximum coverage of the variety of forest biomes that populate forest areas worldwide.

As for provisioning and regulating services, the estimation process is based on market data, actual and estimated, respectively. Data on forest products are drawn from the database on forests of the Food and Agriculture Organization (FAO) of the United Nations. Values are estimated with adjustments taking into account: product category or industrial sector; country of origin; forest biome; forest size designated to production; profitability of the forest sector. For carbon valuation, we refer to the WITCH (World Induced Technical Change Hybrid) model developed by FEEM[1] (Bosetti et al. 2007, 2009), providing price ranges for different future scenarios and we combine this information with data on carbon capacity per forest type and country.

As we want to evaluate changes in forest stocks and in the related provisioning, regulating and cultural services between 2000 and 2050, stock values have to be used. Flow values are thus converted into stock values under the assumption that flows remain constant over time t by using the perpetual revenue formula in Eq. 1, at the usual 3% discount rate, i, applied by the European Commission (see Gordon 1959).[2]

$$V = \frac{V(t)}{i} \tag{1}$$

where V is the stock value and $V(t)$ is the flow value over time t.

2.2 Forest Biomes, World Regions, Forest Areas and Land-Use Changes from 2000 to 2050

Projections of forest areas are based on IMAGE 2.4, an Integrated Model to Assess the Global Environment (Bouwman et al. 2006; Bakkes and Bosch 2008), providing a long-term assessment of the impacts of global changes (including climate change) on land uses up to the year 2100. This is an ecological-environmental model that simulates the impacts of human activities on natural resources worldwide, taking into account the interactions between economic, demographic, technological, social and political factors (http://www.pbl.nl/en/themasites/image/index.html).[3] The change in vegetation types is an important determinant of the changes in land uses. IMAGE 2.4 uses a modified version of the BIOME natural vegetation model (Prentice et al. 1992) to simulate changes in natural vegetation cover for 14 biomes taking into account climate characteristics.

The classification of forest biomes and world regions—employed in this study—distinguishes 6 main different forest biomes (boreal, tropical, warm-mixed, cool coniferous, temperate mixed and temperate deciduous), distributed across 12 world regions (see Table 2[4]). For the purpose of the COPI study the time frame 2000–2050 is used. IMAGE 2.4 model and

[1] Fondazione Eni Enrico Mattei, WITCH model version 2008. Available at: http://www.witchmodel.org/simulator.

[2] The choice of the appropriate discount rate is much debated in the scientific and policy community, especially for valuing losses of natural resources, involving long-time impacts, intergenerational issues and latent non-marginal impacts. Discount rates between 0 and 3% are usually used (Hope 2006). According to Weitzman (2001), a declining discount rate should be used for long term natural resource projects in order to account for intergenerational equity, while allowing for economic efficiency (Portney and Weyant 1999). Evans (2004) refers to 3% discount rate for the near future up to 25 years, 2% discount rate for the medium future, 26–75 years, and 1% discount rate for the distant future, 76–100 years. In our study we make the conservative choice of using the 3% discount rate as both market and non-market values are included in the assessment, and discounting timber value is less contentious than passive and recreation values.

[3] IMAGE 2.4 is a complex modelling framework which “establishes physical indicators for both the energy/industry system and the agriculture/land-use system for assessment of changes in land cover, climate, carbon and nitrogen cycles” (Bouwman et al. 2006).

[4] See Table 17 in the Annex for countries broken down.

Table 2 World regions used in COPI

World regions	Description
NAM	North America
EUR	OECD Europe
JPK	OECD Asia (Japan & Korea)
ANZ	OECD Pacific (Australia & New Zealand)
BRA	Brazil
RUS	Russia & Caucasus
SOA	South Asia (and India)
CHN	China Region
OAS	Other Asia
ECA	Eastern Europe & Central Asia
OLC	Other Latin America & Caribbean
AFR	Africa

Source: Braat and Ten Brink (2008)

COPI provides estimates of the spatial coverage and distribution of each forest biome, taking into account different drivers and pressures. Changes of forests over time are mainly driven by land use changes (see Table 3). In particular, agricultural land-use changes (i.e. forest areas converted into farmland) and forest management (i.e. natural forests versus managed forest) remain the greatest driving forces influencing forestry productivity. In this paper only two land uses of forests are considered, namely "natural forest" and "managed forest". The former includes primary forests (with minimal disturbance) as well as lightly used natural forests (partially employed for extractive use such as hunting and selective logging with long periods of re-growth).[5] The latter refers to the forest areas designated to timber plantations. The valuation of forest ecosystem services in this paper refers as much as possible to these forest varieties (biomes and land use types) and world regions.

The projection begins with some important assumptions for constructing the baseline, according to which the main economic, political and technological features will remain stable for the next 50 years, following the current evolution path (Braat and Ten Brink 2008; Bakkes and Bosch 2008). The major assumptions are summarized in Table 3. They include the absence of additional environmental policy to face existing pressure on natural resources, as well as no change in agricultural subsidies. The model projects an increase in population and income which influences in turn diet, mobility demand and consumption preferences, expected to increase in the same way as in the past. Under these conditions, without any policy intervention, forest biomes and natural stocks will deteriorate with the expansion of population and economy.

The COPI assessment presented in this paper is defined as the economic damage costs associated with a loss of EGSs due to loss of forest area, "occurring in the absence of additional policy or policy revision" (business-as-usual scenario) (Braat and Ten Brink 2008). The analysis does not include wider social costs related to forest land converted into other land uses, such as urban (infrastructures) or agricultural land.

One of the critical aspects of the IMAGE 2.4 model regards the underlying uncertainty of greenhouse gas emission sources and their relationship with human activities. Another uncertainty regards the use of historic trends to calculate the growth rate of economic activities. The national GDP per capita levels have been equally weighted in the period 1980–2000,

[5] Pristine areas, consisting of primary vegetation with minimal disturbance, are disappearing and represent only a small percentage of total forests.

Table 3 Major assumptions for forest change projections under the IMAGE 2.4 Model

Criteria	Major assumptions
Socio-economic and environmental criteria	
Population	Projected world population will be stabilized at around 9.1 billion inhabitants by 2050 (UN 2006), with almost all the increase expected in developing countries
GDP	Global average annual growth rate at 2.8% between 2005 and 2050; in China and India 5% growth rate per year averaged over the whole period
Biodiversity	It is assumed that increased GDP will increase the pressures on biodiversity
Energy consumption	Expected increase faster than historic trends, from 280 EJ to 2000 to 470 EJ in 2030, and ca 600 EJ in 2050
Agricultural production	The production will need to increase by more than 50% in order to feed a population more than 27% larger and roughly 83% wealthier than today's, with a 10% extension of agricultural area and continuous evolution of agricultural productivity
Major policy implications	
The "protected area" policy	Current trends will not substantially change
Climate change policy	No post-Kyoto regime other than the policies in place and instrumented by 2005; the existing trading scheme for emission credits is included
Policy for biodiversity conservation	The policies towards conservation of forests and sustainable use of biodiversity exist but there is a lack of enforceability and effectiveness

Source: Braat and Ten Brink (2008), Bakkes and Bosch (2008)

which leads to a conservative baseline. Indeed, if more weight would have been assigned to the year 2000, the per capita income of countries such as Brazil, Russia, India and China would have increased considerably (OECD 2008; Bakkes and Bosch 2008), with a higher expected pressure on natural ecosystems. These assumptions lead therefore to lower pressures on ecosystems in the model, resulting in an underestimation of the model impacts (Braat and Ten Brink 2008). More realistic scenarios would anticipate, instead, higher environmental pressures than those projected in the baseline.

Finally, the IMAGE-GLOBIO model does not consider that the loss of natural ecosystems would impact economic growth, which is expected to continue autonomously (Braat and Ten Brink 2008).

2.2.1 Results

The model provides projections of land-use changes across various forest biomes and world regions between 2000 and 2050, under the assumption that no additional policy or policy revision is adopted. The results of the projection are presented in Table 4, where the world's forest area is found to decrease by a further 117 million hectares by 2050 (corresponding to 3.2% of current worldwide forest area). The highest absolute loss is expected to occur in Russia (about 47 million hectares) and in Brazil (41 million hectares). As regards forest biomes, tropical forests reveal the highest absolute loss (most of which is registered in Brazil), followed by boreal forests (mainly in Russia).

Russian boreal forests, known as the Taiga, correspond to the largest forested area in the world, greater than the Amazon forest (see Table 12 in the Annex). Among the different

Table 4 Projected forest area changes in terms of forest biome and land use type across world regions 2000–2050 (1,000 hectare)

Forest biome and landuse	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	−4,031	1,867	27	−116	0	−35,674	−760	212	−1	−531	−723	0	−39,731
Natural	−24,301	−6,425	−590	−125	0	−36,080	−1,400	−4,526	−2	−1,238	−836	0	−75,523
Managed	20,270	8,293	618	8	0	406	639	4,738	0	707	112	0	35,791
Tropical	219	0	4	−24	−36,214	0	−39	19	−6,288	0	392	−3,282	−45,579
Natural	−10	0	6	−225	−41,638	0	−654	−236	−16,503	0	−2,905	−13,824	−75,989
Managed	229	0	−1	201	5,058	0	615	254	10,215	0	3,296	10,542	30,409
Warm mixed	17	282	102	−1,270	−4,476	−1	−3,730	243	−705	0	−4,194	−8,187	−21,553
Natural	−13,248	−1,335	207	−1,935	−5,146	−1	−10,089	−7,811	−2,018	0	−4,745	−10,181	−56,303
Managed	13,265	1,617	−105	665	1,036	0	6,359	8,053	1,313	0	552	1,994	34,750
Temp. mixed	303	1,870	1,666	−147	0	−6,252	−427	12	0	−5,584	−115	0	−8674
Natural	−14,299	−8,620	−864	−167	0	−6,231	−1,008	−759	0	−5,254	−147	0	−37,347
Managed	14,602	10,489	2,530	20	0	−21	580	771	0	−331	32	0	28,673
Cool coniferous	−1,252	−781	57	0	0	−4,621	−437	−5	0	−216	0	0	−7254
Natural	−5,257	−5,288	−981	0	0	−4,627	−869	−1,078	0	−671	0	0	−18,772
Managed	4,005	4,507	1,038	0	0	7	432	1,073	0	455	0	0	11,517
Temp. deciduous	200	5,673	1,366	−280	0	−426	−613	92	−25	−423	−19	−146	5,400
Natural	−8,342	−4,056	2,424	−449	0	−422	−4,092	−5,043	−83	−401	−40	−153	−20,657
Managed	8,542	9,729	−1,058	169	0	−4	3,479	5,135	58	−21	21	6	26,057
Total	−4,545	8,912	3,224	−1,836	−40,690	−46,974	−6,007	572	−7,019	−6,754	−4,659	−11,616	−117,392
% Δ(2000 base) TOTAL	−0.5	3.8	7.0	−3.3	−10.5	−4.2	−17.3	0.2	−3.4	−26.6	−1.6	−7.1	−3.2
% Δ (2000 base) NATURAL	−8.5	−15.2	0.5	−5.4	−12.2	−4.4	−70.5	−8.6	−9.8	−34.7	−3.1	−15.3	−8.4
% Δ (2000 base) MANAGED	73.7	53.9	49.5	66.3	117.7	0.8	133.1	92.7	74.5	22.7	53.1	180.8	61.6

eco-regions of the boreal forests in Russia, there is the Eastern-Siberian Taiga which is the greatest untouched boreal forest on the earth. The deforestation taking place in the Russian forests is around 20, 000 km^2 per year, which is comparable to the deforestation rate in the Amazon forest of Brazil. The major responsible are timber extraction and forestry activities, intensified by the demand for timber in China and Southeast Asia, as well as the demand for pulp in Europe. Other stressors for the Russian boreal forests are the illegal timber extraction which does not follow sustainable practices, and forest fires which particularly threaten the Siberian forests.

As regards deforestation in the Amazon forest of Brazil, this is historically associated with the unsustainable use of land for commercial pasture and exploitation of timber and other forest products. The major pressure is represented by cattle ranching and small-scale subsistence agriculture, while large-scale agriculture is more widespread outside the rainforest. Deforestation currently taking place in the tropical forests is a result of the recent economic growth which is causing increasing exploitation of forest resources. The impact of deforestation on tropical forests is more dramatic than for boreal and temperate forests. This is because boreal and temperate forests are more adapted to rapid regeneration (they regenerated between glaciations periods), and because their biodiversity level is much lower than that of tropical forests. These latter need much more time to regenerate, once deforested, and their loss entails a significant loss in terms of biological species. This conflict between economic development and protection of natural forest in developing countries can be solved only by undertaking sustainable forest management plans.

From Table 4, we can observe an obvious trend of land-use changes in the next 50 years in which a large decline of natural forests will be substituted by an increase in managed forests. This can be seen also by analyzing the share of managed forest compared to natural forest in the two tables in the Annex (Tables 12, 13), according to which the percent of forest designated to plantation is expected to increase by 2050 for almost all the world regions, while the proportion of natural forest is decreasing.

In some world regions, the depletion of natural forests in absolute terms is much lower than the corresponding increase of managed forests, which leads to an increase in the total forest area in these regions by 2050 (Europe and China). In Japan and Korea (JPK) an increase is expected in both natural and managed forests. Yet in all the other regions, the loss of natural forests is much higher than the expected increase in managed forests, which leads to a total loss of hectares. The increase in managed forests, even if expected to be quite high in percentage terms (62% increase on worldwide forests by 2050), cannot therefore compensate the loss of natural areas (8% decrease worldwide by 2050). In addition, the increase in managed forest area is generally accompanied by a rapid deterioration of the quality of the forests. European forests, in particular, are endangered by air pollution, extreme weather events, droughts and infestations. In developing countries major pressures are represented by the overexploitation of fuelwood, overgrazing, fires and pests, which lead to gradual degradation of forests.

It can be noticed that a dramatic depletion of natural forests is observed in the Eastern European and Central Asia (ECA) (35% loss compared with year 2000), where it is estimated that 100,000 hectares of forests were lost in the last 20 years because of forest damage (FAO 2007).

Table 5 Provisioning services provided by forest ecosystems

Wood forest products (WFPs)	Non-wood forest products (NWFPs)	
	Plant products	Animal products
Industrial Roundwood	Food	Living animals
Wood pulp	Fodder	Hides, skins and trophies
Recovered paper	Raw material for medicine and aromatic products	Wild honey and beeswax
Sawnwood	Raw material for colorants and dyes	Bush meat
Wood-based panels	Raw material for utensils, crafts & Construction	Other edible animal products
Paper and paper board	Ornamental plants	
Wood fuel	Exudates	
	Other plant products	

Sources: FAOSTAT and FAO (2005)

3 Estimation Approach: From Site-Specific Values to Worldwide Estimates

3.1 Provisioning Services

3.1.1 Methodology

Forest provisioning services have been classified into two main categories, following the FAO recommendation: wood forest products (WFPs) and non-wood forest products (NWFPs) (FAO 1999). Wood forest products include industrial wood, wood fuel, small woods and other manufactured wood products. In our study we refer to seven product categories, as identified in FAOSTAT,[6] representing different industrial sectors: industrial roundwood, wood pulp, recovered paper, sawnwood, wood-based panels, paper and paper board, and wood fuel (see Table 5). Non-wood forest products are defined as "all goods of biological origin, as well as services, derived from forest or any land under similar use, excluding wood in all its forms" (FAO 1999). They can be gathered from the wild or produced in forest plantations, agro-forestry land or from trees outside the forest. NWFPs include for example food and food additives (e.g. fruits, nuts, mushrooms, herbs), fibers (raw material for utensils and construction), resins, plant and animal products used as medicinal or cosmetics (Table 5).

The economic value of forest provisioning services is a direct use value and is estimated using market data based on current quantities and prices available from Food and Agriculture Organization (FAO) of the United Nations database on forests for year 2005 as specified below.[7]

3.1.2 Wood Forest Products

For WFPs, in the absence of data about prices of forest stocks, one commonly used method is to estimate the sum of the discounted future earnings flows from timber production (net

[6] http://www.faostat.fao.org/.

[7] http://www.faostat.fao.org/site/626/default.aspx#ancor/.

present value method); however, the data needed for this calculation are not easy to obtain, especially when they have to be consistent and cover all regions. The theoretically correct measure for estimating the flows is the stumpage price, which is the price paid by the logging companies to the owners of the forests for getting the right to harvest standing timber. It can be estimated by deducting the unit cost of logging and transportation from the trading price of the timber product, i.e. the felling price in the market.

In the present study, the methodological approach builds up on a three-step estimation process: (i) computation of the annual net value (NV) per hectare (flow), (ii) computation of the net present value (NPV) per hectare (stock), and (iii) projections of stock values to year 2050. Projections of stock values are estimated in order to compute the total welfare loss due to policy inaction (see Sect. 4).

The first step consists of calculating the total value of all forest products for each country, taking into account export values, domestic production and export quantities for year the 2005, available at the country level from FAOSTAT. Results are reported in Table 14 in the Annex (total values are summed-up at world region level for the purpose of the study). Subsequently, total values are adjusted according to forest net rents, also available at the country level (Bolt et al. 2002),[8] in order to get a net value (NV) of wood forest products, which approximate the stumpage price (Eq. 2):

$$NV_{i,j} = \left[EV_{i,j} \times \frac{Pq_{i,j}}{Eq_{i,j}} \right] \times r_i \tag{2}$$

$NV_{i,j}$ represents the net value of WFPs by country i and product j, $EV_{i,j}$ is the export value, $Pq_{i,j}$ is the domestic production quantity, $Eq_{i,j}$ denotes the export quantity, and r the rent rate.

The net values estimated in Eq. 2 are computed in US$2005. For simplicity of calculations, we assume that the net values for year 2005 are constant over time, following past historical trends,[9] which allows us to consider them as an annual flow of WFPs. The second estimation step consists of converting this annual flow into a net present value NPV (stock values) using the formula for the present value of a perpetual annuity, as follows:

$$NPV_{i,j} = \frac{NV_{i,j}}{d} \tag{3}$$

$NPV_{i,j}$ is the net present value (or stock value), $NV_{i,j}$ is the net value (or flow value) and d is the discount rate.

In order to compute an average value per hectare, NVs and NPVs of all forest products are firstly aggregated by world region, and then divided by the forest area designated to plantation in each region and forest biome in the baseline year using a weighted mean (see Eq. 4).[10] The main underlying assumption is that each hectare of managed forest has the same productivity and profitability, regardless the forest type and the tree species.

$$AV_{wr,f} = \frac{\sum_{i \in wr} \sum_j NPV_{i,j} \times S_i}{\sum_i S_{wr,f}} \tag{4}$$

[8] The forest net rents of world countries are taken from World Bank database, available online at: http://www.tahoe-is-walking-on.blogspot.com/2010/01/world-banks-ans-adjusted-net-saving.html.

[9] This is confirmed by an analysis we have performed on the World Bank time series data (http://www.tahoe-is-walking-on.blogspot.com/2010/01/world-banks-ans-adjusted-net-saving.html), according to which the average prices for timber in the last 30 years (1971–2002) appears to follow a constant trend.

[10] In this study, following Braat and Ten Brink (2008), productive forest areas are referred to as "managed forest".

$AV_{wr,f}$ represents the average NPV of WFPs per hectare by world region wr and forest biome f, and $S_{wr,f}$ is the forest area designated to plantation.

The third step consists of projecting the net stock values per hectare for the year 2050. For this purpose, we refer to two studies (Clark 2001; Hoover and Preston 2006) that analyze long-term historical data. 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) analyze 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 expected technological development leading to an increase in resource productivity (less wood required in the production process and enhanced wood supply). This statement is also corroborated by the World Bank time series data[11] which provide estimates of the average prices for total produced roundwood (Bolt et al. 2002). The analysis of the database shows that the trend in real prices remained relatively constant in the 30-year period 1971–2006. We therefore assume that real prices of wood products will remain stable in the long run, while allowing prices to vary across countries and continents.

3.1.3 Non-Wood Forest Products

Non-Wood Forest Products (NWFPs) play a crucial role in developing countries, where they contribute to poverty alleviation and local development. They are particularly important for indigenous people who gather them for food and medicines (Bodeker et al. 1997). Despite their relevance, however, a systematic monitoring and evaluation of NWFPs products is still missing in many countries (Donoghue et al. 2004), leading to difficulties in the estimation. Most of the current knowledge about NWFPs comes from traditional practices of indigenous people. More information is therefore required to evaluate the economic relevance of these products, in terms of quantities, economic values (prices) and product status. Notwithstanding this difficulty, we decided to include NWFPs in our analysis, taking into account the available information from FAO (2005) for year 2005. The economic values of NWFPs are estimated based on the export values of the total removals at the country level, when available, and then aggregated by COPI region. These values represent flows of NWFPs and have been then translated into stock values or NPV. Finally, average values per hectare per region are computed by dividing the total value of NWFP by the total hectares of forests in the baseline year 2005. It was not possible to project these values in future scenarios due to the lack of statistical data on price trends in this context. The contribution of NWFPs to the overall economic value provided by forest provisioning services is, however, expected to be quite low if compared with WFPs. Therefore the inclusion of these products in the analysis, even if underestimated, will probably not significantly affect the overall valuation of provisioning services.

3.1.4 Limitations

There are several limitations and weaknesses surrounding the methodology used for estimating WFPs and NWFPs. The first regards the assumption that each forest hectare has the same productivity for the computation of an average value per hectare of WFPs. Productivity of

[11] World Bank database, available online at: http://www.tahoe-is-walking-on.blogspot.com/2010/01/world-banks-ans-adjusted-net-saving.html.

Table 6 NPV per hectare of WFPs by world region and forest biome, stock values (2005 US$/ha)

World Region	Boreal	Tropical	Warm-mixed	Temperate mixed	Cool coniferous	Temperate deciduous
NAM	166,987	1,612	39,882	68,561	35,612	35,056
EUR	27,734	–	1,543	11,137	12,100	15,996
JPK	86,895	271	5,721	106,366	168,131	71,228
ANZ	199,179	22,710	93,262	7,519	–	28,407
BRA	–	57,124	15,224	–	–	–
RUS	10,793	–	15	8,270	1,487	555
SOA	98,651	8,345	62,113	6,294	41,918	26,108
CHN	128,005	2,408	52,917	6,261	24,444	48,639
OAS	190,036	126,590	9,948	–	–	263
ECA	15,785	–	–	17,026	9,702	1,321
OLC	69,883	46,556	15,530	720	–	198
AFR	–	159,637	55,522	–	–	2,051

WFPs is instead expected to vary according to the forest type and the tree species (within the same forest type). It was nevertheless not possible to take into account this dimension in a worldwide study, mainly because of the lack of data. The results presented are therefore able to capture only the geographical variation at the national level, as values are constructed using a bottom-up approach at the country level. They are not capturing the difference in value due to forest type and tree species, as well as differences at sub-national level due to socio-economic factors.

Another limitation regards the projection of stock values to the year 2050, which are expected to remain constant, compared to the year 2005. Even if the overall trend is expected to remain constant, there might be geographical variations, as confirmed by an analysis of the World Bank time series data about prices of roundwood (Bolt et al. 2002). These variations are not considered in our study, and productivity is assumed to remain constant over time at the country level.

As regards NWFPs, the estimation is constrained by lack of data, as already specified. It must be said, however, that the benefits of NWFPs are not totally captured by the economic value, because a small amount of the population are making use of them (mostly indigenous people), which results in small economic values per hectare. Their importance could be better evaluated considering the value of NWFPs in terms of contribution to the household incomes (Kramer et al. 1995; Bahuguna 2000; Cavendish 1999).

An additional limitation to the overall methodology is that spatial and temporal variation in the level of use and the number of beneficiaries of forest products is not accounted for.

3.1.5 Results

Estimates of NPVs (stocks) per hectare, for both WFPs and NWFPs, are provided in Table 6, per world region and forest biome. The values are reported in US$ 2005. Differences in NPVs per hectare result from the combined effect of total production values by forest products, distribution of forest area across regions and incidence of forest area designated to plantation in each region.

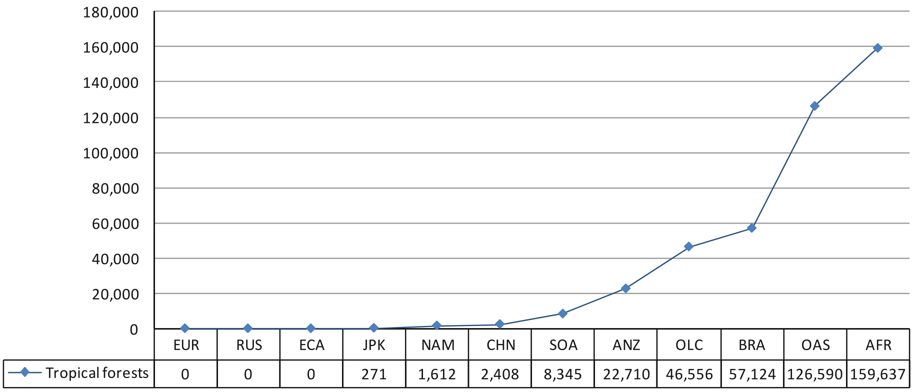


Fig. 2 NPV per hectare of WFPs by world region for tropical forests, stock values (2005 US$/ha)

The contribution of NWFPs appears to be quite small if compared to WFPs, with percentages in developed countries ranging from 0.02% for North America (NAM) to 1.9% for Europe (EUR), and in developing countries from 0.02% for Russia and Caucasus (RUS) to 1.2% for "other Asia region" (OAS) (see Table 14 in the Annex). Despite their small contribution, specific attention has been recently given to NWFPs, since they can play a significant role in strengthening local economies and in the conservation of ecological systems by adopting sustainable forest management practices.

In tropical forests (Table 6; Fig. 2) the highest NPVs are registered in Africa (AFR), other Asia (OAS), Brazil (BRA), Latin America and Caribbean regions (OLC). As regards specifically Africa, the reason for these high values seems to be related to the fact that the last decades have seen a large expansion of forestry with high yields and large-scale plantations. The expansion of planted forests in Africa, especially tropical forests (See Table 4), over the last years is due to a combination of many factors, including an increased exploitation of natural forests, an increasing demand for wood products engendered by population growth and urbanization, an intensification of industrialization and an increase in exports of timber and wood forest products (Chamshama and Nwonwu 2004). At the same time natural forests are characterized by low growth rates, while afforestation rates are much lower than the corresponding loss of indigenous forests. As regards the financial returns of planted forests, they depend heavily on the ownership of the plantations, i.e. whether publically or privately owned forests. Profitability in public forests is quite low due to inefficiencies in management and low productivity levels. The private sector, on the contrary, especially in South Africa, is characterized by high profitability and viable financial returns. Between 1980 and 2000, the forest industry in South Africa presented a very high increase in the value of sales (1460%) (Chamshama and Nwonwu 2004). These factors might explain the high net value per hectare of forest stocks estimated for plantations in Africa. The forest products which contribute more to the high values are specifically wood fuels, followed by industrial roundwood.

In the boreal and warm-mixed forest biomes (see Fig. 3), Australia and New Zealand (ANZ) show the highest NPV per hectare. Not surprisingly, in Australia, the forest industry adds significantly to the national economy, contributing to around 0.6% to the Gross Domestic Product and 6.7% to the manufacturing output (data 2009[12]). The forestry sector in Australia is characterized by high quality products and competitive supporting infrastructures, which

[12] ABARE's Australian Forest and Wood Products Statistics, http://www.abare.gov.au/publications_html/forestry/forestry_09/forestry_09.html.

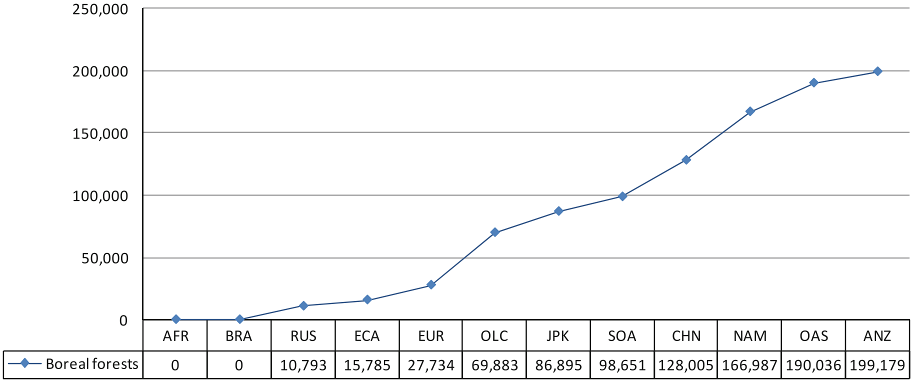


Fig. 3 NPV per hectare of WFPs by world region for boreal forests, stock values (2005 US$/ha)

attract investment opportunities in the sector, with strategies put in place to endorse the export segment.

The results obtained for the average NPV per hectare might be slightly overestimated. We assume in fact that harvesting is taking place only in managed forests, while some portions of natural areas that might be used for timber extraction are excluded from the present computation due to a lack of official statistics on logging in natural forests. In particular, problems associated with illegal logging[13] are severe in many countries (Amazon forests, Central Africa, Southeast Asia and Russia), which makes it difficult to calculate the correct forest areas being exploited for timber production. It is estimated that around 50% of timber from tropical forests and 20% of timber from boreal forests come from illegal activities (Taiga Rescue Network, Sweden.[14])

3.2 Regulating Services

3.2.1 Methodology

Regulating services in forests include a vast array of services such as climate regulation (through carbon sequestration), water regulation (runoff control, aquifer recharge) and purification, erosion control, natural hazard control, pollination, and biological pest control. In this study we focus only on the role of carbon services provided by forest biomes as a way of mitigating greenhouse gases in the atmosphere. In this context it is important to distinguish between carbon sequestration and carbon storage. The first is the process of carbon cycling which is captured from the atmosphere by trees through physical and biological processes, and is usually estimated during one year of the tree growth. Instead, the latter refers to the amount of CO_2 that is stocked by forest biomass, above and below-ground throughout their entire vegetative cycle.

The approach used in this study analyzes the carbon currently stocked in the forest biomes and evaluates the changes that would occur in year 2050. The methodological framework for valuing carbon stocks is built on two phases. First, we identify the biomass carbon capacity by forest type and world region (measured as tonne of C stocked per hectare, tC/ha). Secondly,

[13] Illegalities may result in extraction of timber without permission or from protected areas, extraction of protected species or exceeding the agreed limits, misdeclaration to customs, etc.

[14] Taiga Rescue Network, Sweden, www.taigarescue.org.

Table 7 Biomass carbon capacity in forests (tC/ha)

World region	Boreal	Tropical	Warm-mixed	Temperate mixed	Cool coniferous	Temperate deciduous
NAM	37.37*	92**	92**	51*	37.37**	51*
EUR	37.37*	–	92**	59.4*	37.37**	59.4*
JPK	37.37**	149**	100**	47.35*	37.37**	47.35*
ANZ	37.37**	149**	134**	51**	–	51**
BRA	–	186*	168*	–	–	–
RUS	37.37*	–	92**	37.98*	37.37**	37.98*
SOA	59.4**	225*	180*	168**	59.4**	168**
CHN	25.77*	96**	78**	25.77*	25.77**	25.77*
OAS	59.4**	92*	78**	–	–	59.4*
ECA	37.98*	–	–	59.4*	37.98**	59.4*
OLC	34**	149*	134*	59.4**	–	34.88*
AFR	–	200*	168**	–	–	59.4**

* Directly reported from the original studies by forest type and geographical region
** Transferred from the original studies to similar world regions
Source: Myneni et al. (2001), Gibbs et al. (2007)

we compute a value of carbon stocked per hectare for a future scenario in 2050, based on different assumptions on climate change mitigation strategies.

Quantities of carbon stocks (above- and below-ground biomass) are drawn from two studies, Myneni et al. (2001) and Gibbs et al. (2007). Myneni et al. (2001) provides estimates of carbon stocks for temperate and boreal forest in Canada, Northern America, China, Japan, Russia, Finland, Sweden, Eurasia and South Eastern Asia. Gibbs et al. (2007) provides estimates of carbon stocks for tropical and warm-mixed forests in Brazilian Amazon, Latin America, Sub-Saharan Africa and Tropical Asia (Table 7).

For world regions not directly covered by these two studies, their forests' capacity for storing carbon is assumed to be equal to the countries that are located in the same geographical regions and covered by the literature. In our framework, carbon stocks vary mainly according to two factors: forest type (tree species having different biomass) and forest area. Tropical and warm mixed forests show the highest carbon capacity, as expected, with the maximum levels being registered in Africa (AFR), South Asia and India (SOA), and Brazil (BRA).

As regards the economic valuation, for the price of carbon, we refer to the WITCH model (World Induced Technical Change Hybrid model) developed by FEEM (Bosetti et al. 2009, 2007).[15] This is an Integrated Assessment Model (IAM) built to assess the impacts of climate policies on the global and regional economy. The model provides, for different future scenarios, the price of carbon permits, the GDP loss, the consumption loss and the total GHG abetment. The carbon market shows the evolution over time of the market price of emissions permits traded in a global market. In the present analysis we use a scenario where all technologies and policies are available, including a broad range of mitigation strategies with immediate and global collaborative action on climate change mitigation. Within this scenario two settings are used to compute the price of carbon for 2050: 640 ppm CO_2 equivalent and 535 ppm CO_2 equivalent, the former providing a lower-bound price of permits at 136 US$

[15] Fondazione Eni Enrico Mattei, WITCH model version 2008. Available at: http://www.witchmodel.org/simulator.

per tonne of CO_2, and the latter corresponding to an upper-bound price of 417 US$ per tonne of CO_2. Prices per tonne of CO_2 are stock values, which have been converted into prices per tonne of carbon (tC)[16] and lastly translated into average values per hectare:

$$V_{wr,b} = \left(tC/ha_{wr,b}\right) * \$/tC \tag{5}$$

$V_{wr,b}$ is the value per hectare by world region wr and forest biome b, $tC/ha_{wr,b}$ denotes the tonnes of carbon stocked per hectare, and *\$/tC* is the estimated price per tonne of carbon stocked.

3.2.2 Results

Results about the projected stock values per hectare of carbon for the year 2050 are reported in Table 8. As expected, the highest values are registered for tropical and warm mixed forests in Africa (AFR), South Asia and India (SOA) and Brazil (BRA), due to the high capacity of carbon sequestration in these forest biomes. This is also confirmed by a study conducted by Lewis et al. (2006) showing that 18% of the carbon dioxide is actually absorbed by tropical forests in Africa, Asia and South America.[17]

Biomes represent the most important factor explaining the variation in forest carbon stocks, as they correspond to different bioclimatic factors, such as temperature, geological features and precipitation patterns. The average stock values may vary within the same forest biome, according to the carbon capacity, as reported in Table 7, which depends mainly on the specific tree species present in the biome, having different biomass.

The values presented are nevertheless subject to a number of limitations, as forest carbon stocks vary within each biome according to many factors not considered in the studies of Myneni et al. (2001) and Gibbs et al. (2007). These latter provide instead an average value for the biomass carbon capacity using the biome-average datasets.[18] The factors not considered in this approach include slope, elevation, drainage, soil and land-use type. Furthermore, the studies used to compute a biome average value refer to mature stands and to specific forest patches. This value has therefore some limitation in representing adequately the variation within a forest biome and a country. Nevertheless, biome average values are routinely used to estimate carbon stocks as they are commonly available and because they represent the only consistent source of information about forest carbon (Gibbs et al. 2007). A further limitation of this analysis is that it does not account for different land uses of forests which could be associated with lower carbon stocks, such as forest plantations. Finally, the studies of Myneni et al. (2001) and Gibbs et al. (2007) do not cover all the geographical regions, so that the available figures have been transferred from the original study sites to regions with similar forest types, assuming for the latter the same carbon capacity.

Lastly, it is important to note that the carbon storage capacity of forests is a complex and dynamic process. This capacity depends also on the forest location. Furthermore, the maximum storage capacity of a forest is attained after a long period of time. The current knowledge of the dynamic nature of carbon storage in forests is very limited. To simplify the issue, we assume that the projected stocked carbon in forest biomes in the future scenario of policy inaction is linearly related to the changes of forest extension. We acknowledge that

[16] One tonne of carbon is equal to 3.66 tonnes of CO_2.

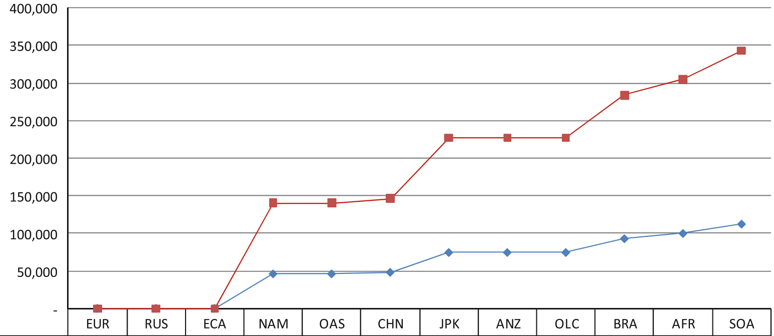
[17] University of Leeds (2009, February 19). "One-fifth Of Fossil-fuel Emissions Absorbed By Threatened Forests". *ScienceDaily*. http://www.sciencedaily.com/releases/2009/02/090218135031.htm.

[18] The estimates are based on biome-average datasets where a single representative value of forest carbon per hectare is applied to broad forest categories or biomes (Gibbs et al. 2007).

Table 8 Projected stock values per hectare of carbon sequestered by world region and forest biome (2050 US$/ha)

World region	Boreal		Tropical		Warm-mixed		Temperate mixed		Cool coniferous		Temperate deciduous	
	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
NAM	18,707	57,038	46,053	140,419	46,053	140,419	25,529	77,841	18,707	57,038	25,529	77,841
EUR	18,707	57,038	–	–	46,053	140,419	29,734	90,662	18,707	57,038	29,734	90,662
JPK	18,707	57,038	74,586	227,418	50,058	152,629	23,702	72,270	18,707	57,038	23,702	72,270
ANZ	18,707	57,038	74,586	227,418	67,077	204,523	25,529	77,841	–	–	25,529	77,841
BRA	–	–	93,108	283,891	84,097	256,417	–	–	–	–	–	–
RUS	18,707	57,038	–	–	46,053	140,419	19,012	57,969	18,707	57,038	19,012	57,969
SOA	29,734	90,662	112,630	343,416	90,104	274,733	84,097	256,417	29,734	90,662	84,097	256,417
CHN	12,900	39,333	48,056	146,524	39,045	119,051	12,900	39,333	12,900	39,333	12,900	39,333
OAS	29,734	90,662	46,053	140,419	39,045	119,051	–	–	–	–	29,734	90,662
EC A	19,012	57,969	–	–	–	–	29,734	90,662	19,012	57,969	29,734	90,662
OLC	17,020	51,894	74,586	227,418	67,077	204,523	29,734	90,662	–	–	17,460	53,237
AFR	–	–	100,116	305,259	84,097	256,417	–	–	–	–	29,734	90,662

LB Lower bound (640 ppm CO_2 equivalent), *UB* upper bound (535 ppm CO_2 equivalent)



	EUR	RUS	ECA	NAM	OAS	CHN	JPK	ANZ	OLC	BRA	AFR	SOA
Lower bound, 2050US$/ha	-	-	-	46,053	46,053	48,056	74,586	74,586	74,586	93,108	100,116	112,630
Upper bound, 2050US$/ha	-	-	-	140,419	140,419	146,524	227,418	227,418	227,418	283,891	305,259	343,416

Fig. 4 Projected stock values per hectare of carbon sequestered in tropical forests by world regions (2050 US$/ha) (LB = 640 ppm CO_2 equivalent, UP = 535 ppm CO2 equivalent)

future advancement of such kind of knowledge is essential to improve the preciseness of economic valuation results.

Figure 4 presents the variation among world regions in projected stock values of carbon in 2050 for tropical forests, characterized by the highest stocks of carbon.

3.3 Cultural Services: Recreation and Passive Use

3.3.1 The Meta Value-Transfer Model

Not being traded in regular markets, forest recreation and passive use values can nevertheless be captured by the concept of Willingness To Pay (WTP)[19] using non-market valuation approaches, either stated or revealed methods. In this paper, in order to assure a worldwide perspective, the estimation of cultural services relies on the body of evidence providing WTP estimates of forest recreation and passive use values, currently available from the environmental valuation literature.

The literature retrieval process[20] comprised checking several economic databases (among others EconLit, EVRI database and IUCN database for forest studies), reference chasing, and approaching key scholars in the field. This resulted in two sets of 22 and 21 studies providing 59 and 27 usable estimates of forest recreational and passive use values, respectively (see Table 15 in Annex for the complete list of studies). The WTP figures selected from the literature refer only to annual values or flows, which are converted into stock values in a second step.

Available WTP estimates refer to a range of forest biomes—temperate, warm-mixed, tropical and boreal forests—but cover only a part of the world regions, with the majority of case studies and estimates referring to Europe (EUR) and North America (NAM). Since available

[19] WTP is a measure of non-market environmental dimensions now widely accepted by the research community. We are, however, fully aware that it has often raised ethical objections. For this reason we have included in our meta-analysis dataset only estimates from published papers assuring a high level of analysis.

[20] Part of the literature review and computations of standardized marginal values per hectare per year in US$2000 has been conducted within Ojea et al. (2009). Further details are available upon request to the authors.

Table 9 List of variables used in the meta-regression models

Dependent variable	
WTP	Value per hectare per year [US$ 2000]
Explanatory variables	
INCOME	Purchasing power parity GDP per capita in the country of the study site [PPP GDP per capita]
POP	Population in the country of the study site [million]
SIZE	Size of the forest area designated to recreation or conservation [hectares] in the study site
Forest type	Type of forest in the study site
TEMP	Temperate forest: takes on value 0,1
WARM	Warm-mixed forest: takes on value 0,1
BOREAL	Boreal forest: takes on value 0,1
TROP	Tropical forest: takes on value 0,1

forest cultural value estimates are site-specific, a three-step meta value-transfer approach is applied in order to provide a worldwide estimation. Firstly, we employ meta-regressions to detect statistically significant variables explaining the variance of WTPs estimates for forest recreational and passive use values in the literature. Secondly, we apply value-transfer techniques to transfer available estimates to unstudied countries and sites, and scale them up from the country to the world region level. Finally, worldwide estimates for the year 2000 are projected to 2050. Below we provide a detailed methodological description.

3.3.2 The Meta-Regression Model

Following equation Eq. 6,[21] two meta-regression functions—one for recreation and one for passive use values—are estimated. To our knowledge, these are the first meta-regressions in the literature providing a synthesis of specific forest ecosystem services worldwide. A recent meta-regression by Ojea et al. (2010) has studied interactions between forest ecosystem values and the various ecosystem services they provide. However it has the theoretical limitation of synthesizing both market and non-market forest valuation data, for any type of MEA service category (provisioning, regulating and cultural), thus mixing pure market prices with implicit prices. Our exercise considers only WTP values. Original reported values per year (per household or per visit) are converted to value per hectare per year when necessary with simple calculations by employing the forest area and/or the households' number referring to the study.

$$V = \alpha + \beta_{site} \log X_{site} + \beta_{forest} X_{forest} + u \qquad (6)$$

V is the forest value (either recreational or passive use) per hectare per year (the so-called *effect size*), a is the constant term, the *betas* represent the vectors of the coefficients associated with the following types of explanatory variables: forest specific (*Xforest*), and context specific (*Xsite*), while u represents a vector of residuals. Explanatory variables are presented in Table 9. Context specific variables reflect the income level (measured as purchasing power parity GDP per capita) and the population in the country of the study site. Forest specific variables reflect the size of the forest area and the type of forest, both measured in the study site.

[21] This functional form proved to be the best specification in terms of statistical performance.

Table 10 Meta-regressions results for the recreational and passive use values datasets[a]

Variables	Forest recreational use Coefficients	Forest passive use Coefficients
Dependent		
logWTP		
Explanatory		
logINCOME	0.6252*	0.7455*
logSIZE	−0.4265***	−0.3935**
logPOP	0.3876	0.6388*
TEMP	–	−1.0082
BOREAL	0.0908	–
WARM	0.2200	1.5206
Constant	−1.6837	5.4694
Obs. number	59	27
R-squared	0.4707	0.8298
Adj R-squared	0.4208	0.7893

* Means $p < 0.05$, ** means $p < 0.01$, *** means $p < 0.001$

The results of the meta-regressions are presented in Table 10.[22] Both for forest recreational and passive use values, results show that WTP estimates increase as the level of income increases, according to economic theory. Similarly, population has a positive effect on WTPs, though is only statistically significant for passive use values. Passive values (such as forest pure existence) are indeed not linked to a direct personal experience of forest ecosystems (visitors), and we can thus expect to notice a positive correlation with the country population.

As expected, the size of forest area in the study site affects WTPs in a statistically significant way, showing a negative coefficient for both cultural values. The bigger the forest area in the study site, the lower the WTP it provides in per hectare terms. This result confirms what was found in previous meta-analyses of ecosystem values such as Ojea et al. (2010); Ghermandi et al. (2010) or Woodward and Wui (2001) for wetlands, as well as in the non-market valuation literature (Loomis and Ekstrand 1998). On the other hand, forest types do not lend themselves to be statistically significant explanatory factors. The meta-analysis of forest ecosystem services by Ojea et al. (2009) also reports mixed results on the effect of the type of forest biome.

3.3.3 The Value-Transfer and Scaling-Up Model

In the second estimation step, using statistically significant coefficients of the meta-regressions, we apply the value transfer model presented in Eq. 7 to estimate, respectively, forest recreational and passive use values for each world region. Prior to this, all annual cultural values have been converted into stock values following Eq. 1, in order to allow a direct comparison with the estimations of provisioning and regulating services.

In value transfer, already available estimates (known as *study site values*) are adjusted and transferred to unexplored policy contexts (known as *policy sites*) (see e.g. Florax et al. 2002).

[22] We report both the R-squared and the Adjusted R-squared for both models, as the number of predictors is important considering the small sample size. By adding predictors to the model, the R-squared tends to increase, but some of this increase might be due to chance variation, which could lead one to think that a model has a higher fit than in actuality. In these cases, the use of the Adjusted R-squared allows to adjust for the number of predictors. Therefore, when a new predictor is added, it increases only if this latter improves really the model. In our results, there is not much difference between the two indicators.

In this paper, *study site* values are those of Europe, for which the majority of studies are available. The adjustments consider the effects on WTP's magnitude of the following elements, whenever statistically significant: (i) size of the forested area, σ, (ii) income level measured as PPP GDP per capita, γ; and (iii) population, δ, in the world region. The δ coefficient is applied only to the passive use dataset.

$$V_{WR} = V_{Eu}^{*} \left(\frac{N_{WR}}{N_{Eu}}\right)^{\delta} \left(\frac{S_{Eu}}{S_{WR}}\right)^{\sigma} \left(\frac{PPPGDP_{WR}}{PPPGDP_{Eu}}\right)^{\gamma} \quad (7)$$

The notations WR and Eu denote figures referring to, respectively, the WR_{-th} world region and the *study site* Europe region. V_{WR} is the estimated WTP stock value per hectare (either recreational or passive use) in the WR_{-th} Europe. V_{Eu}^{*} is the WTP stock value per hectare (either recreational or passive use) in the *study site* Europe. S denotes the forest area designated to recreation or conservation in the world region. N denotes the population, and *PPPGDP* indicates the GDP per capita adjusted using Purchasing Power Parity (PPP) taken from World Bank *World Development Indicators*. The source of data on forest areas is the IMAGE 2.4 model used in the COPI study, while percentages of forest areas designated to recreation or conservation for each world region are taken from FAO (2005).

The transfer exercise is applied to the Europe mean and median WTP stock values (for recreational and passive use), estimated by averaging mean and median WTP figures available for each forest biomes in Europe. The value-transfer exercise is also referred to as a scaling-up in this study, because values are transferred from study sites to larger geographical areas (world regions).

3.3.4 Projections to Year 2050

Lastly, following the inter-temporal transfer in Eq. 8, values are projected from 2000 to 2050, using the 2050 projections on population, *PPPGDP* per capita and forest areas provided by the COPI study and IMAGE 2.4[23]:

$$V_{WR,T_1} = V_{WR,T_0} \left(\frac{N_{WR,T_1}}{N_{WR,T_0}}\right)^{\delta} \left(\frac{S_{WR,T_0}}{S_{WR,T_1}}\right)^{\sigma} \left(\frac{PPPGDP_{WR,T_1}}{PPPGDP_{WR,T_0}}\right)^{\gamma} \quad (8)$$

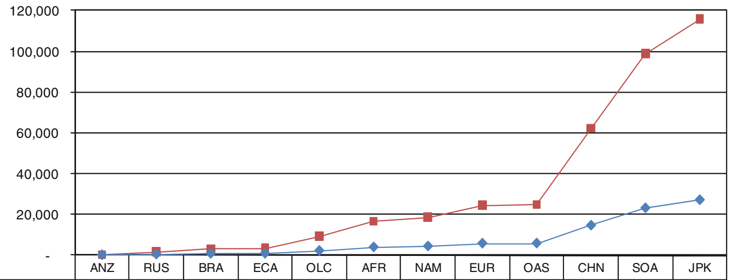
where T_0 is the baseline year 2000 and T_1 is the projection year 2050.

3.3.5 Results

Results in the baseline year 2000 are presented in Figs. 5 and 6, and discussed below. Overall, the positioning of world regions in terms of mean and median stock values of recreational and passive use services show a rather similar pattern, with the six highest estimates always including Japan and Korea (JPK), Europe (EUR), North America (NAM) and China (CHN). Brazil (BRA) and other Asian Countries (OAS) show the highest variability between recreational and passive use values, which is mainly attributable to the difference in forest area size dedicated to recreation and conservation, respectively.

For passive use, estimates go from 4,711 to 87,948 US\$2000 per hectare. The highest values signal a population effect for China (CHN), and an income effect combined with a scarce presence of conservation areas in respect to Europe (EUR) for Japan and Korea (JPK),

[23] Projections of population and *PPPGDP* per capita for year 2050 are provided by the COPI project for each world region, based on World Development Indicators (see Table 16 in the Annex) (Braat and Ten Brink 2008).



	ANZ	RUS	BRA	ECA	OLC	AFR	NAM	EUR	OAS	CHN	SOA	JPK
Transfered mean WTP [USD 2000/ha]	230	1,675	3,037	3,461	9,240	16,764	18,646	24,575	24,810	62,421	98,909	115,895
Transfered median WTP [USD 2000/ha]	54	395	716	816	2,179	3,954	4,398	5,796	5,852	14,723	23,329	27,336

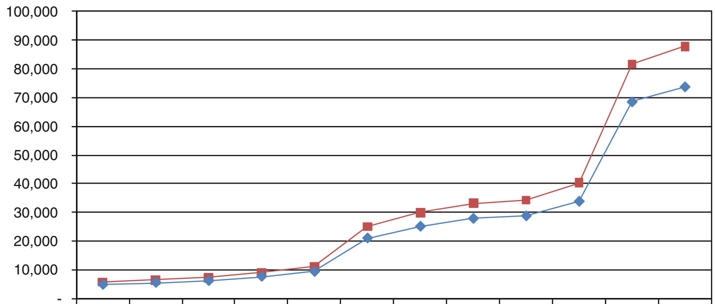
Fig. 5 Results of the meta-value transfer for recreational forest use. Upper and lower bound estimates of WTP stock values per world region (2000 US$/ha)

and North America (NAM). Low values for Russia and Caucasus (RUS), as well as Australia and New Zealand (ANZ), are mainly due to the low population, while low values for other Asian Countries (OAS), and other Latin American and Caribbean countries (OLC) can be explained by the low per capita income.

For recreation, the range goes from 54 to 115,895 US$2000 per hectare. Similarly to what discussed for passive use, highest estimates derive from an income effect, in accordance to the theoretical assumption—and empirical evidences—that higher per capita income is associated with higher WTP estimates. For other Asian Countries (OAS), the high marginal value is influenced by the high income level and by the very small forest size of Singapore. For South Asia and India (SOA), the high value can be explained as a result of the small forest recreational size registered in Bangladesh and Pakistan; while the low marginal values in North America (NAM) are due to the large forest recreational areas available.

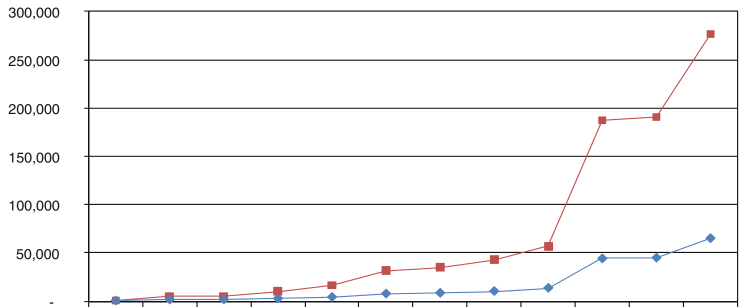
Regarding Brazil (BRA), whose forests are at the center of a heated debate, recreational values are kept low by the vast area currently dedicated to recreation, while passive use values are high due to the scarce presence of conservation areas and the low population density.

Results projected to the year 2050 are presented in Figs. 7 and 8. Given the assumption used to derive the 2050 forest areas and socio-economic scenarios in the IMAGE 2.4 model—which assume that many aspects of today's world will remain the same for the next 50 years (see Sect. 2)—the relative positioning of world regions do not vary significantly neither for recreational nor for passive use values. However, the rate of increase of cultural values from 2000 to 2050 is not the same for all world regions, and it also varies between recreation and passive use estimates. For recreation the rates range from 1.6 to 3. The highest increase is expected in Russia-Caucasian countries (RUS), China (CHN), South Asia-India (SOA), and Eastern Europe–Central Asia (ECA), which will triplicate values by 2050, followed by other Asian Countries (OAS) and Africa (AFR), which will duplicate them. With the only exception of China, such a trend will mainly be driven by the increasing scarcity of forest areas in tropical and boreal world regions that will push their recreational value up. Differently, the case of China reflects a slight future increase in forest areas in combination with the effect of an increase of both income level and population. Regarding passive use, the rate of increase in the period 2000–2050 is expected to be even higher (ranging from 1.9 to 4.4) and distributed rather homogeneously across all world regions. This is due to the significant reduction of natural forest areas that will affect almost all forest biomes (tropical, boreal, warm mixed and temperate mixed, temperate deciduous).



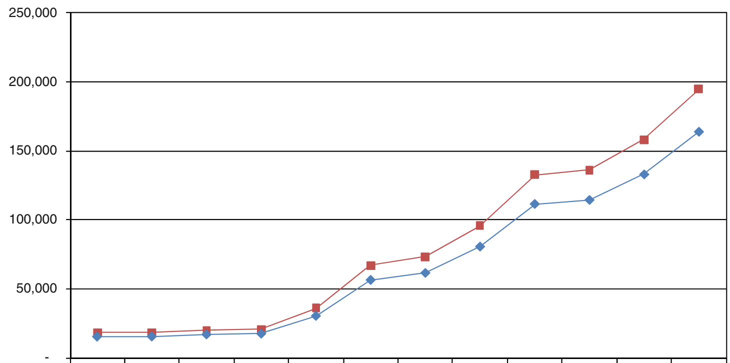
	RUS	OAS	OLC	ANZ	ECA	AFR	SOA	BRA	EUR	CHN	JPK	NAM
Transfered mean WTP [USD 2000/ha]	5,605	6,421	7,220	8,983	11,009	24,976	29,849	33,129	34,205	40,255	81,675	87,948
Transfered median WTP [USD 2000/ha]	4,711	5,396	6,068	7,550	9,252	20,990	25,085	27,842	28,746	33,830	68,640	73,912

Fig. 6 Results of the meta-value transfer for passive forest use. Upper and lower bound estimates of WTP stock values per world region (2000 US$/ha)



	ANZ	BRA	RUS	ECA	OLC	NAM	AFR	EUR	OAS	JPK	CHN	SOA
Transfered mean WTP [USD 2050/ha]	384	5,008	5,145	9,919	16,434	31,362	34,782	42,730	56,776	187,368	190,657	276,777
Transfered median WTP [USD 2050/ha]	91	1,181	1,214	2,339	3,876	7, 397	8,204	10,079	13, 392	44,194	44,970	65,283

Fig. 7 Results of projections to 2050 for recreational forest use. Upper and lower bound estimates of WTP stock values per world region (2050 US$/ha)



	RUS	OLC	ANZ	OAS	ECA	EUR	BRA	AFR	SOA	JPK	CHN	NAM
Transfered mean WTP [USD 2050/ha]	18,150	18,225	20,012	20,700	36,041	67,076	73,131	95,854	132,631	136,084	158,131	194,952
Transfered median WTP [USD 2050/ha]	15,253	15,316	16,818	17,396	30,289	56,371	61,460	80,556	111,464	114,365	132,894	163,838

Fig. 8 Results of projections to 2050 for passive forest use. Upper and lower bound estimates of WTP stock values per world region (2050 US$/ha)

4 Welfare Change Associated with Ecosystem Services Loss

In order to estimate the economic value associated with the welfare loss (or gain) of forest EGSs from the year 2000 to the year 2050, the change in forest area projected for that period (from IMAGE2.4) is multiplied by the stock values per hectare projected for 2050 for the selected EGSs, by world region and forest biome. This approach allows us to compute changes in the stock values for the selected EGSs, according to three main dimensions: ecosystem service, forest biome and geographical region. The underlying assumption is that the wellbeing of forest ecosystems, which is supported by biodiversity, does not vary as forest areas change. This assumption implies a direct proportional relationship between loss of forest areas and provision of ecosystem services. In case of threatened ecological areas, however, ecosystem services might be more sensitive to loss of area and the relationship might not be linear.

As discussed in Sect. 2.2, the IMAGE 2.4 model provides projections for natural (relatively untouched) and managed forest (plantations). For wood forest products, we use the projected change in the managed forest, while for non-wood forest products we refer to the change in the total forest area (natural and managed). Carbon sequestration is expected to occur in both natural and managed forests, so all the forest areas are considered for the final computation of loss. As regards the cultural services, these are provided by natural forests, but not all the natural forest area can be considered in valuing the economic loss associated with these services. We use therefore the percentage of forest area designated to recreation (for recreational services) or conservation (for passive use), available from FAO for the year 2005 (FAO 2005). We do not have, however, information about the variation over time in these data for all the world regions. Therefore, for projections in 2050 we make the simplistic assumption of no variation in the proportion of forest land used for cultural purposes.

Table 11 shows the estimated economic values associated with a change in forest areas in the year 2050, resulting from the business-as-usual scenario in the way forests are managed and exploited. We should note that the results refer to a subset of ecosystem services: we could not value for example, most of the regulating services (such as air quality maintenance, soil quality, water and temperature regulation, natural hazard control), and other provisioning services (such as pharmaceutics and fresh water), due to the difficulties in finding reliable data. As the figures show, however, the quantified losses are significant for the four services analyzed: carbon, wood and non-wood forest products, recreation/ecotourism and passive use services. The table reports, for each world region, the lower- and upper-bound economic loss or gain (in billion US$ 2050) for each service, the total welfare impact for the four services together, the annual welfare impact from 2000 to 2050, and the corresponding percentage of 2050 GDP.

At a global level, and for the four services under analysis, the estimates show an economic benefit (equal to 2,700 billion US$2050) when using the lower bound figures, and an economic loss with the upper bound figures (equal to 11,800 billion US$2050). This corresponds to a variation in the 2050 world GDP,[24] ranging from a benefit of +0.03% to a loss of −0.13% per year. The world regions that are expected to gain from the business as usual policy in both scenarios (lower and upper bound), include mostly developed countries such as North America (NAM), Europe (EUR), Japan and Korea (JPK), Australia and New Zealand (ANZ), but also regions like China (CHN) and other Asian Countries (OAS). This can be explained mainly by the positive value change engendered by provisioning services

[24] GDP projections in 2050 taken from COPI project for each world region, based on World Development Indicators (see Table 16 in the Annex) (Braat and Ten Brink 2008).

Table 11 Changes in stock values of forests, by world region and forest biome, projected to 2050 (bn US$, 2050)

World Region	Carbon		WFPs & NWFPs	Recreation		Passive use		Total		Δ value per year		2050 GDP (bn.$)	% of 2050 GDP	
	LB	UP	PE	LB	UP	LB	UP	LB	UP	LB	UP		LB	UP
NAM	−75	−229	5,357	−23	−96	−1,126	−1,340	4,133	3,692	92	82	35,700	0.26	0.23
EUR	258	785	559	−14	−52	−152	−181	651	1,112	14	25	28,500	0.05	0.09
JPK	79	241	421	1	2	2	3	504	667	11	15	8,200	0.14	0.18
ANZ	−100	−305	73	0	0	−5	−6	−32	−238	−1	−5	1,800	−0.04	−0.29
BRA	−3,605	−10,993	220	−13	−56	−233	−277	−3,631	−11,105	−81	−247	3,900	−2.07	−6.33
RUS	−881	−2,686	4	−8	−11	−76	−90	−961	−2,783	−21	−62	6,400	−0.33	−0.97
SOA	−464	−1,414	576	−52	−227	−212	−252	−152	−1,317	−3	−29	26,600	−0.01	−0.11
CHN	14	44	1,314	−34	−174	−271	−323	1,023	861	23	19	45,000	0.05	0.04
OAS	−318	−969	1,306	−12	−50	−34	−40	943	247	21	5	10,600	0.20	0.05
ECA	−193	−588	10	−1	−4	−24	−29	−208	−610	−5	−14	2,200	−0.21	−0.62
OLC	−268	−818	170	−1	−7	−14	−17	−114	−671	−3	−15	6,000	−0.04	−0.25
AFR	−1,021	−3,115	1,794	−9	−39	−204	−243	558	−1,604	12	−36	14,000	0.09	−0.25
TOT	−6,574	−20,045	11,806	−167	−714	−2,350	−2,796	2,715	−11,749	60	−261	195,000	0.03	−0.13
Δ value per year	−146.09	−445.45	262.35	−3.71	−15.88	−52.21	−62.13	60.34	−261.10	–	–	–	–	–
% of 2050 world GDP	−0.07	−0.23	0.13	−0.002	−0.01	−0.027	−0.032	0.03	−0.13	–	–	–	–	–

LB Lower bound, *UB* upper bound, *PE* point estimate. For Carbon: LB refers to 640 ppm CO_2 equivalent, UP to 535 ppm CO_2 equivalent. For cultural services: LB refers to median values, UP to mean values. For timber no range is available, only point estimates

(WFPs and NWFPs). For countries like Europe (EUR), Japan and Korea (JPK), and China (CHN), a benefit (even if lower compared to provisioning) is expected also from increased carbon stocks due to an expansion in total forest area projected in these regions (natural and managed). All the other world regions show an economic loss due to policy inaction, with the highest annual loss expected in Brazil, ranging from 2% to 6% of 2050 GDP (3,600–11,000 billion US$2050 from 2000 to 2050). This economic loss is attributable to a reduction in the forest area estimated around 12% in natural forests (and 10% in total forest area). This result is mainly explained by the projected loss of carbon due to deforestation in tropical forests, which present a high value of carbon stocks. For the other world regions, the annual loss ranges from 0.01 to 0.97% of 2050 GDP. Russia and Caucasus (RUS) present, after Brazil (BRA), the highest annual loss (0.33–0.97% of 2050 GDP) attributable to a 4.2% decrease in forest area, followed by Eastern Europe and Central Asia (ECA) (0.21–0.62%), where the forest area is expected to decrease by 27%. For both of them, the major costs are attributable to carbon loss.

In terms of the specific services under analysis, carbon shows the major economic loss, ranging from 6,500 to 20,000 billion US$2050 in the timeframe 2000–2050. The damage is expected mainly in Brazil, as already mentioned, followed by Africa (AFR), Russia and Caucasus (RUS), and South Asia and India (SOA). Passive use (conservation values) and recreational services follow with a loss of respective 2,300–2,800 billion US$ 2050, and 170–700 billion US$2050. The major losses for passive use services are expected in North America (NAM), China (CHN), Brazil (BRA), and South Asia and India (SOA), while for recreational services the most important losses are registered in South Asia (SOA) and China (CHN), followed by North America (NAM). Provisioning services (mainly WFPs) present always an economic gain, due to the projected increase in managed forests, with the highest benefits registered in North America (NAM), Africa (AFR), China (CHN) and other Asian countries (OAS).

5 Discussion and Conclusions

The paper reports on the methodology and the estimation of some of the services provided by forest biomes in different world areas, by applying consolidated methods for the monetary valuation of market and non-market goods. The study provides a methodological framework for assessing values per hectare for flows and stocks of different forest ecosystem services and the related economic loss due to policy inaction by 2050, together with an outline on how to use value-transfer techniques.

The valuation framework is applied to forest biomes, and specifically to some key ecosystem services identified following the Millennium Ecosystem Assessment (MEA 2005) taxonomy, provisioning services (wood forest products and non-wood forest products), carbon services and cultural services (recreation and passive use values). This selection is based on the availability of data and on their relevance to decision-making. The estimation of such services, although not covering the full range of forest instrumental values, allows the quantification of those values which are expected to be quite relevant to contexts where it is necessary to make decisions and trade one value against the other. Both market and non-market valuation techniques are applied, depending on the nature of the service under concern. As regards specifically non-market valuation, however, the present study mainly relies on the existing body of knowledge already available in the literature to draw suitable values for forest services, to be scaled up at the global (world regions) level using proper transfer protocols.

The first part of the study estimates stock values per hectare for the four EGSs under analysis, for the baseline year and for the year 2050. Carbon stocks present, in general, the highest value per hectare, followed by provisioning services, passive use and recreational values. It must be said, however, that values per hectare differ widely according to the world region and the forest biome analyzed.

The second part provides an estimation of the welfare loss (or gain) associated with a change in the forest area projected for the period 2000–2050, estimated in terms of change in total stock values, for the four EGSs analyzed. Final results show that using lower bound or upper bound values per hectare can lead to different welfare impacts. Using the lower bound values leads to a total economic benefit equal to 2,700 billion US$2050, while upper bound values produce a loss of around 11,800 billion US$2050. This corresponds to a variation in the 2050 world GDP ranging from a benefit of +0.03% to a loss of −0.13% per year. The greatest negative impact is projected for Brazil, showing an annual loss of 2–6% (2050 GDP), or 3,600–11,000 billion US$2050 for the EGSs analyzed. This is attributable to a large reduction in the Amazonian forest area, estimated around 12% in natural forest. The increase in managed forest in the same area, even if quite impressive in percent terms, is not compensating the huge deforestation which is taking place, and the associated degradation of forest ecosystems and related carbon services. Some regions, however, are expected to gain from the policy inaction. These include mainly developed countries (North America, Europe, Japan and Korea, Australia and New Zealand), and also some developing countries like China and other Asian countries (OAS). The economic benefit, ranging from 0.05 to 0.23% of 2050 GDP, is mainly due to the revenues generated by WFPs, considering that managed forest is projected to rise in all the world regions by 2050. The other world regions are expected to face an annual loss ranging from 0.01 to 0.97% (2050 GDP), mostly attributable to a loss of carbon stocks.

Provisioning services (represented mainly by WFPs) always show an economic benefit, due to the expected increase in managed forests. When using the lower bound estimates, the economic benefits emerging from provisioning services exceed the loss of the other services. However, the economic benefits associated with provisioning services do not reflect a monetary compensation for the expected loss of the other ecosystem services. This is because managed forest areas designated to WFPs (being the dominant part of provisioning in this analysis), especially those consisting in large-scale monoculture tree plantations, have many negative environmental and social impacts, which we were not able to value. These include destruction of native forests in many countries (such as Australia, Brazil, Indonesia and Chile) which is a major cause of biodiversity loss; soil contamination and deterioration caused by the use of agrochemical products; negative impacts on water supply and purification; violation of land rights of indigenous peoples which causes social conflicts in several countries (due to rural unemployment, poor work conditions and migration to cities). The most affected by these impacts are indigenous people, women and children. In addition, expansion of forest plantations might have a negative impact on climate change mitigation, due to a possible increase in greenhouse gas emissions caused by the development of pulp and biomass industry. Plantations, especially if monoculture, increase the stress on natural forests instead of reducing it, as they create little employment per each hectare, which encourages exploitation of remaining forest land. Expansion of managed forest should not therefore be seen as a policy to reduce emissions from forest degradation and deforestation. Another important issue to consider in this context is illegal logging which is quite frequent, even in countries with well established forest laws. The problem has been considered in the past as particularly relevant in tropical forests, but is increasingly gaining attention for boreal forests of Russia. This means on the one hand that available statistics on logging are not entirely reliable, and on the other hand that deterioration of forests, related EGSs and biodiversity levels might be more alarming than expected. Appropriate action is therefore required to limit this global trend.

Although useful, the figures provided in this paper represent, in our view, an underestimate of the total social cost that would result from the business-as-usual scenario. First, many important services are excluded from the analysis, such as most of the regulating services (water, soil quality, flood prevention) and other provisioning services such as pharmaceutical products and fresh water. These services are usually estimated by non-market valuation studies which provide site-specific values in local contexts. In order to perform a worldwide estimation of the welfare loss, these local values have to be transferred and scaled-up from the study-sites to the policy-sites. This requires, however, a substantial number of original studies, which are more difficult to find for the above services.

A second limitation is related to the estimation of the stock value per hectare. While for provisioning services we use net present values, for the other services we do not consider the related costs (such as conservation or recreational costs), as this information is very difficult to obtain at a worldwide level taking into account the geographical differences. A further weakness is that the study does not consider land use type as an additional factor influencing the capacity of the ecosystem to supply EGSs. Conversion of natural forests to plantations generates higher profits with immediate positive impacts on human well-being, but in the long run the provision of other services, such as regulating and supporting services (climate, flood control, water, soil formation, biomass production, nutrient cycling), can be durably compromised by the loss of pristine forests. This has not been taken into account in this paper, due to the many scientific uncertainties still surrounding the ecosystem functioning, and the associated relationship between ecosystem degradation and level of service provision. Third, threshold effects are not taken into account and a proportional relationship is assumed between forest stock areas and the stock of EGS provided. Finally, even if the estimation process is based on a bottom-up approach where data are taken at the country or study site level, the final estimates in our study are aggregated at regional levels and these latter are used to calculate the welfare change. As a result, geographical variation within countries and among sites is not accounted for, whereas ecosystem values should ideally be as site specific as possible.

Our work suggests that any attempt to provide a monetary estimation of ecosystem services still represents a very challenging task for researchers. On the one hand this task is made difficult due to the partial lack of original valuation studies providing reliable estimates of the WTP for forest values. On the other hand, the worldwide approach adopted here will need to be reinforced by taking into consideration the lack of information on the local ecosystem conditions that are expected to influence the results of the valuation.

Despite these limitations, the methodological framework provided in this study is an attempt to consider both market and non-market values in the valuation of natural resources. As highlighted in The Economics of Ecosystems and Biodiversity (TEEB 2009), most of the services provided by the ecosystems are not captured by conventional macro-economic indicators (such as the GDP), due to the fact that they are not traded in markets. It is therefore important to measure these un-priced benefits, which at the current state of the art, are not taken into account in conventional accounting systems such as the SEEA (System of Economic and Environmental Accounting), except for the Philippine Environment and Natural Resources Accounting Project (ENRAP).

Future research developments should go in the direction of understanding if the renewable natural capital stocks are consumed in a sustainable way in the long run, i.e. not exceeding the natural regeneration of the stocks. The net present value is the theoretically correct measure to use to value an asset and its depreciation, but it requires numerous assumptions, especially as regards the appropriate discount rate to use. In this perspective further work is also needed to analyze the existing trade-off between competing services, such as timber and regulating or cultural services.

Acknowledgments This research was initially developed within the EU funded project COPI "Cost of Policy Inaction. The case of not meeting the 2010 biodiversity target", aiming at valuing the total costs of no policy initiatives to modify the current paths of dynamics, by combining ecosystem service values and land use changes. The 2010 Biodiversity policy target was to "significantly reduce the rate of biodiversity loss by 2010", as agreed at World Summit on Sustainable Development in 2002 and adopted by the parties to the Convention on Biological Diversity. The authors thank the whole COPI research team. The updated results about the estimated values per hectare will contribute to the follow-up of the EU funded project on The Economics of Ecosystems and Biodiversity (TEEB).

Annex

See Tables 12, 13, 14, 15, 16 and 17.

Table 12 Forest area by forest biome and landuse type across world regions, year 2000 (1,000 ha)

Forest biome and landuse	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	489,618	55,531	1,990	3,475	0	917,443	3,726	71,354	269	2,645	17,648	0	1,563,701
Natural	461,611	39,581	1,936	3,468	0	879,865	3,234	66,357	269	2,645	17,429	0	1,476,396
Managed	28,007	15,950	54	8	0	37,578	492	4,997	0	0	220	0	87,305
Tropical	3,614	0	48	5,964	345,477	0	1,554	3,195	186,765	0	211,012	145,529	903,157
Natural	3,381	0	45	5,683	340,870	0	1,119	2,920	173,008	0	204,836	139,530	871,392
Managed	233	0	2	282	4,296	0	435	275	13,757	0	6,176	5,999	31,455
Warm mixed	86,804	9,746	1,172	32,450	42,699	160	18,153	88,032	17,433	0	53,288	18,963	368,899
Natural	68,452	6,894	973	31,404	42,130	154	13,371	79,285	15,711	0	52,235	18,028	328,635
Managed	18,352	2,852	199	1,046	880	6	4,782	8,747	1,722	0	1,053	935	40,575
Temperate mixed	120,630	67,370	24,021	3,171	0	86,269	1,656	9,194	0	20,445	4,609	0	337,365
Natural	101,591	48,009	21,179	3,142	0	82,144	1,216	8,357	0	16,971	4,546	0	287,154
Managed	19,039	19,361	2,842	29	0	4,125	440	837	0	3,474	63	0	50,211
Cool coniferous	89,170	25,755	3,722	0	0	113,047	1,831	13,296	0	1,449	0	0	248,270
Natural	83,749	16,022	3,523	0	0	107,377	1,489	12,132	0	1,419	0	0	225,711
Managed	5,421	9,733	199	0	0	5,670	342	1,164	0	30	0	0	22,560
Temperate decid.	64,635	75,262	15,399	10,269	0	3,532	7,858	63,535	466	815	1,270	265	243,307
Natural	53,046	58,956	12,591	10,029	0	3,421	5,257	57,962	389	747	1,229	261	203,887
Managed	11,589	16,306	2,809	240	0	112	2,602	5,572	77	68	41	4	39,420
Total	854,471	233,664	46,353	55,329	388,176	1,120,451	34,778	248,605	204,933	25,355	287,827	164,757	3,664,699
% on total	23.3	6.4	1.3	1.5	10.6	30.6	0.9	6.8	5.6	0.7	7.9	4.5	100
Total natural	771,830	169,462	40,247	53,724	383,000	1,072,961	25,685	227,013	189,377	21,782	280,274	157,819	3,393,174
% on total	21.1	4.6	1.1	1.5	10.5	29.3	0.7	6.2	5.2	0.6	7.6	4.3	92.6
Total managed	82,642	64,202	6,106	1,605	5,176	47,490	9,093	21,592	15,556	3,573	7,553	6,939	271,525
% on total	2.3	1.8	0.2	0.04	0.1	1.3	0.2	0.6	0.4	0.1	0.2	0.2	7.4

Table 13 Projections of forest area by forest biome and landuse type across world regions, year 2050 (1,000 ha)

Forest biome and landuse	NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	OAS	ECA	OLC	AFR	Total
Boreal	485,587	57,399	2,018	3,359	0	881,769	2,966	71,565	268	2,115	16,925	0	1,523,969
Natural	437,310	33,156	1,346	3,343	0	843,785	1,834	61,831	268	1,407	16,593	0	1,400,873
Managed	48,277	24,242	672	16	0	37,984	1,131	9,735	0	707	332	0	123,097
Tropical	3,833	0	52	5,941	309,263	0	1,515	3,214	180,477	0	211,403	142,247	857,944
Natural	3,371	0	51	5,458	299,232	0	465	2,684	156,505	0	201,931	125,706	795,403
Managed	461	0	1	483	9,354	0	1,050	529	23,972	0	9,473	16,541	61,864
Warm mixed	86,821	10,028	1,274	31,180	38,223	159	14,423	88,275	16,728	0	49,094	10,776	346,981
Natural	55,204	5,559	1,180	29,469	36,984	153	3,281	71,474	13,692	0	47,490	7,846	272,331
Managed	31,617	4,469	94	1,712	1,916	6	11,142	16,800	3,036	0	1,605	2,930	75,326
Temperate mixed	120,933	69,240	25,687	3,024	0	80,017	1,229	9,206	0	14,861	4,494	0	328,691
Natural	87,292	39,389	20,315	2,975	0	75,913	208	7,599	0	11,718	4,399	0	249,807
Managed	33,642	29,851	5,372	49	0	4,104	1,021	1,608	0	3,144	94	0	78,884
Cool coniferous	87,918	24,974	3,780	0	0	108,426	1,394	13,291	0	1,233	0	0	241,016
Natural	78,491	10,734	2,542	0	0	102,750	620	11,054	0	747	0	0	206,939
Managed	9,426	14,241	1,237	0	0	5,676	774	2,237	0	486	0	0	34,077
Temperate decid.	64,835	80,935	16,766	9,989	0	3,106	7,245	63,626	440	393	1,251	119	248,706
Natural	44,704	54,900	15,015	9,580	0	2,999	1,164	52,919	305	346	1,189	108	183,230
Managed	20,131	26,035	1,751	409	0	107	6,081	10,707	135	47	62	11	65,477
Total	849,927	242,576	49,577	53,493	347,486	1,073,477	28,771	249,177	197,913	18,601	283,168	153,142	3,547,307
% on total	24.0	6.8	1.4	1.5	9.8	30.3	0.8	7.0	5.6	0.5	8.0	4.3	100
Total natural	706,371	143,738	40,449	50,825	336,216	1,025,600	7,573	207,561	170,771	14,218	271,602	133,661	3,108,583
% on total	19.9	4.1	1.1	1.4	9.5	28.9	0.2	5.9	4.8	0.4	7.7	3.8	87.6
Total managed	143,555	98,838	9,129	2,668	11,270	47,877	21,198	41,616	27,142	4,384	11,566	19,481	438,724
% on total	4.0	2.8	0.3	0.1	0.3	1.3	0.6	1.2	0.8	0.1	0.3	0.5	12.4

Table 14 Total economic value for WFPs and NWFPs (million US$, 2005)

World region	Ind roundwood	Wood pulp	Recovered paper	Sawnwood	Wood based panels	Paper & paperboard	Wood fuel	Total WFPs	% on TOT	NWFPs	% on TOT	Total
NAM	83,343	42,861	5,631	56,949	27,362	80,416	3,328	299,891	100	66	0.02	299,957
EUR	2,256	6,164	2,157	11,660	12,024	55,230	374	89,865	98	1,770	1.93	91,635
JPK	1,779	5,139	3,475	7,379	5,167	31,880	–	54,820	98	972	1.74	55,792
ANZ	3,579	1,055	306	2,605	1,360	2,239	289	11,433	100	19	0.16	11,452
BRA	7,720	4,636	891	5,595	2,606	5,741	0	27,189	99	193	0.71	27,382
RUS	8,226	2,740	237	2,879	2,561	3,508	739	20,890	100	5	0.02	20,895
SOA	2,765	1,492	115	4,983	993	4,085	30,939	45,372	99	428	0.93	45,800
CHN	18,608	2,215	5,422	3,487	20,101	37,472	30,638	117,943	100	–	0.00	117,943
OAS	9,934	2,637	405	3,471	4,985	10,005	53,956	85,392	99	1,075	1.24	86,467
ECA	656	5	41	710	605	1,082	306	3,405	99	30	0.86	3,434
OLC	3,285	2,045	305	2,614	1,374	3,615	5,665	18,903	100	9	0.05	18,912
AFR	10,789	1,353	168	4,697	1,247	2,653	67,937	88,845	99	897	1.00	89,742
TOT	152,940	72,342	19,154	107,031	80,383	237,927	194,170	863,947	99	5,465	0.63	869,411
% on TOT	18	8	2	12	9	27	22	99		1		

Table 15 Studies used in the meta-analysis

No.	References study	Country	World region	Forest biome	Forest services	No. of obs.
1	Chase et al. (1998)	Costa Rica	OLC	Temperate coniferous	Recreation	3
2	Walsh et al. (1984)	USA	NAM	Temperate coniferous	Recreation	4
3	Bellu and Cistulli (1997)	Italy	EUR	Temperate broadleaf and mixed forests	Recreation	14
4	Campos and Riera (1996)	Spain	EUR	Boreal forest	Recreation	2
5	Bateman et al. (1996)	UK	EUR	Boreal forest	Recreation	2
6	Scarpa et al. (2000)	UK	EUR	Mediterranean forest	Recreation	8
7	Scarpa et al. (2000)	Ireland	EUR	Temperate broadleaf and mixed forests	Recreation	11
8	Bostedt and Mattsson (2006)	Sweden	EUR	Boreal forest	Recreation	4
9	Zandersen et al. (2005)	Denmark	EUR	Temperate broadleaf and mixed forests	Recreation	1
10	Verma (2000)	India	SOA	Tropical moist, Tropical dry and Montane grassland	Recreation	1
11	van der Heide et al. (2005)	Netherlands	EUR	Temp. Conif. and Temp. Broadleaf	Recreation	1
12	Van Beukering et al. (2003)	Indonesia	OAS	Tropical moist	Recreation	2
13	Phillips and Silverman (2008)	USA	NAM	Temp. Conif.	Recreation/passive	3
14	Naidoo and Adamowicz (2005)	Uganda	AFR	–	Recreation	2
15	Mogas et al. (2006)	Spain	EUR	Mediterranean forest	Recreation	2
16	Kramer et al. (1995)	Madagascar	AFR	–	Recreation and passive use	2
17	Kniivila et al. (2002)	Finland	EUR	Temp. Conif.	Recreation/passive	2
18	Hanley et al. (1998)	UK	EUR	Temp. Conif.	Recreation	3
19	Gurluk (2006)	Turkey	EUR	–	Recreation	1
20	Emerton (1999)	Kenya	AFR	Tropical moist and Montane grassland	Recreation	1

Table 15 continued

No.	Reference study	Country	World region	Forest biome	Forest services	No. of obs.
21	Shechter et al. (1998)	Israel	MEA	Mediterranean	Passive	1
22	Walsh et al. (1984)	USA	NAM	Temperate	Passive	4
23	Horton et al. (2003)	Brazil	EUR	Tropical forest	Passive	1
24	Kontoleon and Swanson (2003)	China	CHN	Coniferous and deciduous forest	Passive	1
25	Siikamaki and Layton (2007)	Finland	EUR	Boreal	Passive	2
26	ERM Report to UK Forestry Commission (1996)	UK	EUR	Conifer forest	Passive	2
27	Hanley et al. (2002)	UK	EUR	Temperate, conifer and broadleaved woodland	Passive	6
26	Garrod and Willis (1997)	UK	EUR	Temperate, conifer and broadleaved	Passive	6
27	Mogas et al. (2006)	Spain	EUR	Mediterranean	Passive	1

Table 16 Projections of PPP GDP per capita (US$) and population for year 2050 per world region

World regions	Description	GDP PPP Per capita 2050 (US$)	Population 2050 (millions)
NAM	North America	63,128	565
EUR	OECD Europe	46,963	607
JPK	OECD Asia (Japan & Korea)	46,221	177
ANZ	OECD Pacific (Australia & New Zealand)	52,292	34
BRA	Brasil	15,962	243
RUS	Russia & Caucasus	49,756	128
SOA	South Asia (India+)	11,452	2,321
CHN	China Region	32,174	1,404
MEA	Middle East	17,392	370
OAS	Other Asia	14,106	755
ECA	Eastern Europe & Central Asia	19,030	118
OLC	Other Latin America & Caribbean	15,648	385
AFR	Africa	6,932	2,014
WORLD	WORLD	21,430	9,122

Source: Braat and Ten Brink (2008)

Table 17 Description of world regions

World regions	Description	Countries included
NAM	North America	Canada, Mexico, United States
EUR	OECD Europe	Albania, Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Channel Islands, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Faeroe Islands, Finland, France, Germany, Gibraltar, Greece, Holy See, Hungary, Iceland, Ireland, Isle of Man, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia, Republic of Former Yugoslav, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
JPK	OECD Asia (Japan & Korea)	Japan, Korea, Democratic People's Republic of Korea
ANZ	OECD Pacific (Australia & New Zealand)	American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Island, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna Islands
BRA	Brasil	Brazil
RUS	Russia & Caucasus	Armenia, Azerbaijan, Georgia, Russia
SOA	South Asia (and India	Rep. of. Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
CHN	China Region	China, Hong Kong SAR, Taiwan Province of China
OAS	Other Asia	Mongolia, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Dem. Republic of Timor-Leste, Vietnam

Table 17 continued

World regions	Description	Countries included
ECA	Eastern Europe & Central Asia	Belarus, Moldova, Occupied Palestinian Territory, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Kazakhstan, Kyrgyz Republic
OLC	Other Latin America & Caribbean	Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Bermuda, British,Virgin Islands, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Guyana, Haiti, Jamaica, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, South Georgia and the South Sandwich Islands, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Turks and Caicos Islands, United States Virgin Islands, Argentina, Belize, Bolivia, Costa Rica, Chile, Colombia,Ecuador, El Salvador, Falkland Islands, French Guiana, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Peru, Suriname, St. Pierre and Miquelon, Trinidad and Tobago, Uruguay,Venezuela
AFR	Africa	Angola, Botswana, British Indian Ocean, Territory, Comoros, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mayotte, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Réunion, Seychelles, South Africa, Swazilan, Uganda, Tanzania, Zambia, Zimbabwe, Algeria, Burkina Faso, Burundi, Benin, Chad, Djibouti, Egypt, Eritrea, Ethiopia, Libya, Somalia, Sudan, Tunisia, Western Sahara, Cameroon, Cape Verde, Central African Republic, Congo, Democratic Republic of Congo, Republic of Côte d'Ivoire, Equatorial Guinea, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Rwanda, St. Helena, São Tomé and Príncipe, Senegal, Sierra Leone, Togo

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