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The economic assessment of changes in ecosystem services: an application of the CGE methodology

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ABSTRACT: The present study integrates Computable General Equilibrium (CGE) modelling with biodiversity services, proposing a possible methodology for assessing climate-change impacts on ecosystems. The assessment focuses on climate change impacts on carbon sequestration services provided by European forest, cropland and grassland ecosystems and on provisioning services, but provided by forest and cropland ecosystems only. To do this via a CGE model it is necessary to identify first the role that these ecosystem services play in marketable transactions; then how climate change can impact these services; and finally how the economic system reacts to those changes by adjusting demand and supply across sectors, domestically and internationally.

KEYWORDS: Climate change, ecosystems services, integrated assessment, CGE.

JEL classification: C68, Q51, Q54, Q57.

La valoración económica de cambios en servicios del ecosistema: una aplicación de la metodología CGE

RESUMEN: El presente estudio integra en la modelización de Equilibrio General Computable (EGC) los servicios de la biodiversidad, proponiendo una metodología para la evaluación de impactos del cambio climático en los ecosistemas. La evaluación se centra en impactos del cambio climático sobre: los servicios de absorción de carbono proporcionados por la foresta, tierras agrícolas y praderas Europeas; y los servicios de aprovisionamiento ofrecidos por los ecosistemas de la foresta y tierras de cultivo. Para la evaluación con un modelo EGC es necesario identificar el papel que esos servicios juegan en las transacciones de mercado; establecer cómo el cambio climático puede afectar esos servicios; y finalmente, evaluar cómo el sistema económico reacciona a esas variaciones ajustando oferta y demanda en todos los sectores, doméstica e internacionalmente.

PALABRAS CLAVES: Cambio climático, servicios ecosistémicos, evaluación integrada, EGC.

Clasificación JEL: C68, Q51, Q54, Q57.

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1. Introduction

The present study proposes a methodology for integrating climate-change impacts on biodiversity services in a Computable General Equilibrium (CGE) economic assessment. Although it uses a general equilibrium model, the assessment is partial as we focus on the economic value transfer of a set of services provided by selected ecosystems restricted to the context of the European Union (EU). The tool proposed for the assessment is the recursive-dynamic CGE ICES (Intertemporal Computable Equilibrium System) model (Eboli *et al*., 2009). In its present version it represents economic development for 14 major world regions and 17 economic sectors from 2001 to 2050. The assessment performed is anchored on market transactions. Put differently, it depends upon the possibility of identifying changes in demand/supply for inputs and outputs, exchanged at a given price on a market represented within the model. Therefore, in order to proceed, a selection of ecosystem services is translated into marketable items and their changes are translated into changes in the corresponding economic variables within the CGE model. We assess climate change impacts on both the carbon sequestration services provided by European forest, cropland and grassland ecosystems and the provisioning services provided by forest and cropland ecosystems only. To do this via a CGE model it is necessary to identify first the role that these ecosystem services play in marketable transactions; then how climate change may impact these services; and finally how the economic system reacts to those changes by adjusting demand and supply across sectors, domestically and internationally. The difference in GDP between a reference scenario (in our case a situation that includes some climate change impacts but excludes those on ecosystem services) and the perturbed scenario (a situation with climate change impacts including those on ecosystems), isolates the economic consequences of climate change on ecosystem services. This value, expressed in monetary terms, embeds all of the macro economic adjustments involved in the system.

Section 2 below briefly introduces the main features of the model (further detail is provided in a dedicated appendix) and describes how climate change impacts are assessed, Section 3 discusses the quantification and inclusion of ecosystem services and their changes into the model, Section 4 presents major results and Section 5 concludes.

2. Assessing climate change impacts using a computable general equilibrium model

CGE models were initially developed to analyse international trade policies and, to a lesser extent, public sector policies. The peculiar feature of CGE models is market interdependence. All markets are linked, as factors of production are mobile between sectors and internationally. Each change in relative prices induces a cost-minimising input reallocation in the entire economic system. This is also true for the demand side: responding to a scarcity signal in one market, utility-maximising consumers readjust their entire consumption mix. As a consequence, CGE models can capture and describe the propagation mechanism induced by a localised shock in a global context via price and quantity changes, and vice versa. Moreover, they are able to assess the "systemic" effect of these shocks, or more specifically the final welfare or general equilibrium outcome which is determined after all the adjustments in the economic system have operated. The final impact on national GDPs summarises these "higher order" effects, which are usually very different from the initial impacts.

This feature of CGE models, coupled with their flexibility, has led recently to their increased application to the economic assessment of climate change impacts. A growing CGE literature assesses the costs of single impact categories, e.g., Deke *et al*. (2002), Darwin and Tol (2001), Bosello *et al*. (2007) on sea-level rise; Bosello *et al*. (2006) on health; Tzigas *et al*. (1997), Darwin (1999), Ronneberger *et al*. (2009) on agriculture; and Calzadilla *et al*. (2008) on water scarcity.

CGE models have been also used to investigate the interactions of multiple impacts, although the techniques are still in their infancy. For example, Bigano *et al*. (2008) analyse the joint effect of adverse climate impacts on sea-level rise and tourism activity for the 12 macro-regions into which the world is divided, showing that the interactions usually tend to exacerbate the negative effects. Eboli *et al*. (2009), Bosello *et al*. (2009), Aaheim *et al*. (2009), Aheim and Wey (2010), present the first combined assessment of an extended set of climate change impacts (health, tourism, agriculture, energy demand and sea-level rise). None of these exercises however addresses the issue of ecosystem services.

In this paper we apply ICES, a recursive dynamic CGE model, calibrated in 2001. The economic data are provided by GTAP database version 6 (Dimaranan, 2006). The regional and sectoral details adopted in this exercise are reported in Table 1.

TABLE 1

Regional and sectoral disaggregation of the ICES model

REGIONAL DISAGGREGATION OF THE ICES MODEL (this study)	
USA:	United States
Med_Europe:	Mediterranean Europe
North_Europe:	Northern Europe
East_Europe:	Eastern Europe
FSU:	Former Soviet Union
KOSAU:	Korea, S. Africa, Australia
CAJANZ:	Canada, Japan, New Zealand
NAF:	North Africa
MDE:	Middle East
SSA:	Sub Saharan Africa
SASIA:	India and South Asia
CHINA:	China
EASIA:	East Asia
LACA:	Latin and Central America

TABLE 1 (cont.)

Regional and sectoral disaggregation of the ICES model

SECTORAL DISAGGREGATION OF THE ICES MODEL (this study)	
Rice	Gas
Wheat	Oil Products
Other Cereal Crops	Electricity
Vegetable Fruits	Water
Animals	Energy Intensive industries
Forestry	Other industries
Fishing	Market Services
Coal	Non-Market Services
Oil	

First ICES is benchmarked to replicate regional GDP growth paths consistent with the A2 IPCC scenario. Then it is used to assess climate change economic impacts for 1.2 and 3.1 °C increases in 2050 wrt 2000, which is the likely temperature range associated with that scenario.

To this end the physical implications of an extended set of climate change impacts are assessed through a comprehensive survey and meta-analysis of the relevant literature. Then they are transformed into appropriate changes in key economic variables, suitable for use as inputs to the ICES model. Climate impacts are represented as changes in productivity, supply or demand for different inputs and/or outputs of the model, as reported in Table 2.

TABLE 2

Climate change impacts analyzed within this assessment

Supply- side impacts
Impacts on labour quantity (change in mortality – health effect of climate change)
Impacts on labour productivity (change in morbidity – health effect of climate change)
Impacts on land quantity (land loss due to sea level rise)
Impacts on land productivity (Yield changes due to temperature and CO_2 concentration changes)
Impacts on net potential productivity of forest land (raw timber production changes due to temperature and CO_2 concentration changes)
Demand-side impacts
Impacts on energy demand (change in households energy consumption patterns for heating and cooling purposes)
Impacts on recreational services demand (change in tourism flows induced by changes in climatic conditions)
Impacts on health care expenditure

More specifically, land losses due to sea level rise are modelled as percentage decreases in the stock of productive land by region (Bosello *et al*., 2007); changes in mortality/morbidity are modelled as changes in regional labour productivity (Bosello *et al*., 2006); changes in land productivity by crop are already in a format suitable for input as ICES includes factor specific productivity as an exogenous parameter (following Tol, 2002a,b). Changes in expenditure by tourists are modelled as changes in demand addressing the “market services sector”, which includes recreational services (Bigano *et al*., 2008); changes in health care expenditure are translated into changes in the public and private demand for the "non market services" sector, which includes health services (Bosello *et al*., 2006); changes in regional demand for oil, gas and electricity are modelled as changes in the demand for the output of the respective industries (De Cian *et al*., 2007). Changes in net forest productivity are derived from Songhen *et al*. (2001)[1].

TABLE 3

Summarizes the results of the direct impact assessment exercises (we report only year 2050 for exemplification) once they have been translated into ICES inputs consistent with the desired temperature increases

TABLE 3a

Climate change impacts as inputs for the ICES model (% change wrt baseline, reference year 2050 reference temperature +1.2 °C wrt 2000)

Region	Health			Land Productivity			Sea-level rise
	Labour Prod.	Public Exp.	Private Exp.	Wheat	Rice	Cer Crops	Land Loss
USA	-0.06	-0.15	-0.02	-5.66	-6.19	-8.18	-0.03
Med_Europe	0.01	-0.10	0.00	-1.14	-4.62	-2.00	-0.01
North_Europe	0.06	-0.35	-0.01	1.50	-5.90	50.00	-0.02
East_Europe	0.09	-0.47	-0.01	-1.13	-2.64	-4.60	-0.02
FSU	0.16	-0.41	-0.01	-6.12	-7.47	-9.73	-0.01
KOSAU	-0.43	0.57	0.04	-7.78	-2.90	-3.11	-0.01
CAJANZ	0.09	0.03	0.00	-0.74	-1.87	-2.24	0.00
NAF	-0.28	2.02	0.10	-12.81	-10.78	-12.62	-0.02
MDE	-0.22	1.34	0.10	-8.40	-11.73	-13.60	0.00
SSA	-0.31	0.47	0.07	-9.89	-7.17	-8.81	-0.07
SASIA	-0.11	0.28	0.06	-2.96	-4.89	-6.61	-0.20
CHINA	0.14	0.65	0.06	0.93	0.50	-1.42	-0.05
EASIA	-0.11	1.05	0.06	2.45	0.34	-1.15	-0.32
LACA	-0.14	0.68	0.07	-6.69	-6.61	-8.25	-0.02

[1] For a detailed description of the impact assessments studies by category (see Bosello *et al.,* 2009).

TABLE 3a (Cont.)

Climate change impacts as inputs for the ICES model (% change wrt baseline, reference year 2050 reference temperature +1.2 °C wrt 2000)

Region	Tourism		Energy Demand			Forestry nat res. prod
	Mserv Demand	Expenditure flows*	Nat Gas	Oil Products	Electricity	
USA	-0.68	-0.11	-13,67	-18.52	0.76	16.61
Med_Europe	-1.86	-0.07	-12,68	-15.84	0.76	22.45
North_Europe	7.54	0.48	-13,75	-15.52	-2.20	22.45
East_Europe	-2.46	-0.02	-12,93	-17.39	0.76	22.45
FSU	0.00	0.00	-13,02	-17.39	0.75	51.49
KOSAU	-1.31	-0.02	0.00	-13.03	12.31	-15.72
CAJANZ	5.54	0.35	-5.05	-12.63	-4.80	16.61
NAF	-2.52	-0.01	-8.60	-13.25	5.95	36.04
MDE	-4.67	-0.13	-13.12	-17.39	0.74	28.28
SSA	-4.43	-0.02	Nss	-6.51	16.35	36.04
SASIA	-1.21	-0.02	Nss	Nss	20.38	43.77
CHINA	-4.99	-0.20	Nss	Nss	20.38	35.07
EASIA	-4.69	-0.07	Nss	Nss	20.38	28.28
LACA	-2.68	-0.16	Nss	Nss	21.37	44.74

Source: Own elaboration.

Notes: Nss: Not statistically significant.

*Expenditure flows in US$ trillions.

TABLE 3b

Climate change impacts as inputs for the ICES model (% change wrt baseline, reference year 2050 reference temperature +3.1 °C wrt 2000)

Region	Health			Land Productivity			Sea-level rise
	Labour Prod.	Public Exp.	Private Exp.	Wheat	Rice	Cer Crops	Land Loss
USA	-0.18	-0.28	-0.03	-18.89	-20.37	-25.15	-0.05
Med_Europe	0.01	-0.18	-0.01	-8.33	-18.94	-11.84	-0.01
North_Europe	0.16	-0.88	-0.03	-7.74	-26.01	107.82	-0.04
East_Europe	0.23	-1.18	-0.02	-10.50	-13.57	-18.35	-0.05
FSU	0.40	-1.03	-0.03	-21.92	-24.64	-30.10	-0.01
KOSAU	-1.14	1.62	0.11	-17.00	-7.41	-7.38	-0.01
CAJANZ	0.22	0.24	0.00	-12.33	-14.31	-15.17	-0.01
NAF	-0.69	4.42	0.23	-42.14	-41.00	-45.97	-0.04
MDE	-0.34	1.82	0.14	-32.40	-38.52	-43.12	-0.01
SSA	-0.84	1.34	0.19	-26.33	-21.43	-25.36	-0.14
SASIA	-0.30	0.76	0.17	-14.92	-18.89	-22.99	-0.43

TABLE 3b (Cont.)

Climate change impacts as inputs for the ICES model (% change wrt baseline, reference year 2050 reference temperature +3.1 °C wrt 2000)

Region	Tourism		Energy Demand				Forestry nat res. Prod
	Mserv Demand	Expenditure flows *		Nat Gas	Oil Products	Electricity	
EASIA	-0.32	2.96	0.17	-0.54	-4.98	-8.50	-0.66
LACA	-0.39	1.98	0.19	-21.71	-23.38	-25.78	-0.05
USA	-1.76	-0.44		-35.31	-47.84	1.96	12.62
Med_Europe	-4.82	-0.26		-32.76	-40.91	1.96	17.06
North_Europe	19.47	1.86		-35.51	-40.09	-5.68	17.06
East_Europe	-6.37	-0.06		-33.41	-44.92	1.97	17.06
FSU	-0.01	0.00		-33.65	-44.92	1.94	38.39
KOSAU	-3.39	-0.07		0.00	-33.66	31.81	9.66
CAJANZ	14.30	1.36		-13.04	-32.63	-12.40	12.62
NAF	-6.52	-0.05		-22.22	-34.22	15.37	15.58
MDE	-12.07	-0.50		-33.89	-44.92	1.92	8.92
SSA	-11.46	-0.08		Nss	-16.83	42.23	15.58
SASIA	-3.12	-0.07		Nss	Nss	52.65	20.75
CHINA	-12.90	-0.76		Nss	Nss	52.65	28.12
EASIA	-12.11	-0.29		Nss	Nss	52.66	8.92
LACA	-6.92	-0.64		Nss	Nss	55.20	17.06

Source: Own elaboration.

Notes: Nss: Not statistically significant.
*Expenditure flows in US$ trillions.

As can be clearly seen, impacts differ greatly from region to region and type to type. First, except for the case of land losses to sea-level rise, they are not necessarily all negative. For instance labour and land productivity could decrease in some regions, but increase in others responding to regionally differentiated climate stimuli and to different health characteristics of the labour force or crop and land characteristics. From the consolidated literature, the consensus is that land productivity tends to increase in mid to high latitude countries and decrease in low latitude countries. Labour productivity decreases where vector-borne diseases dominate (the developing world), and tends to increase where reduced cold-related mortality more than offsets increased heat-related mortality. Second, impacts affect both the supply and the demand sides of the economic system. In the former they can be defined quite unambiguously as "good" or "bad" [2]: for instance decreases in labour productivity due to adverse health impact and decreases in the availability of productive land due to sea-level rise are sure initial losses for the economic system. In the latter case,

[2] In this statement we disregard distributional implications across income groups or classes within the same country.

when agents' preferences change, determining the "quality" of the impact is more difficult. Indeed, when the demand for a given good or service (e.g., energy demand) decreases, consumer expenditure is typically redirected towards other goods and services. Consequently, the final impact on utility cannot be determined a priori, but only at the end of a fully fledged general equilibrium exercise. As said, demand-side impacts involve changes in demand for market services, changes in household energy demand and changes in demand for public services. The first two are considerably larger than other impacts and affect sectors of the economy which generate high added value. Consistently with changes in tourism flows, the demand for market services increases in colder regions where the climate becomes more attractive. The aggregate result for Canada, Japan, Australia and New Zealand (CAJANZ) is dominated by the Canada effect. Elsewhere there are decreases: note particularly the negative impact on the "hotter" Mediterranean Europe. The use of gas and oil products drops everywhere as they become less necessary for heating purposes, while electricity demand increases especially in hotter regions reflecting increased use of air conditioning.

This general picture shows that negative impacts are clearly concentrated in developing countries. This highlights that they are more vulnerable to climate change than developed economies, due to a combination of greater exposure and greater sensitivity.

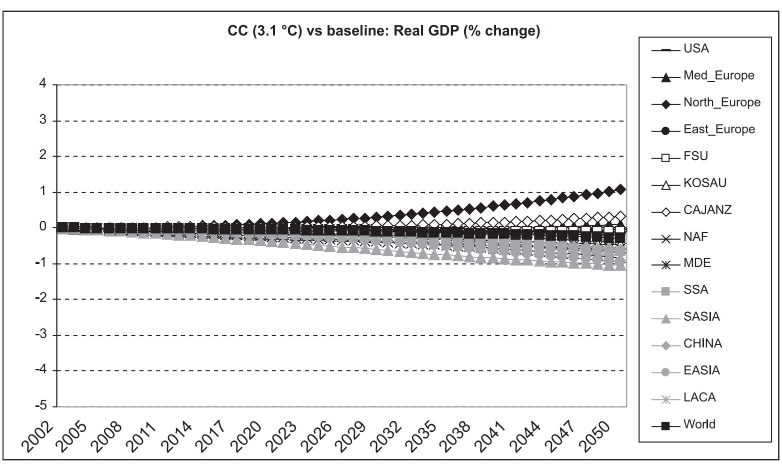
2.1. CGE assessment of climate change impacts. First results

Before turning to the effects of climate change on ecosystems we briefly discuss the results obtained so far.

The economic implications of the impacts calculated in Table 3 are reported in Figures 1 and 2 and summarised for 2050 in Figure 3, which also shows the significance of each individual impact category.

FIGURE 1

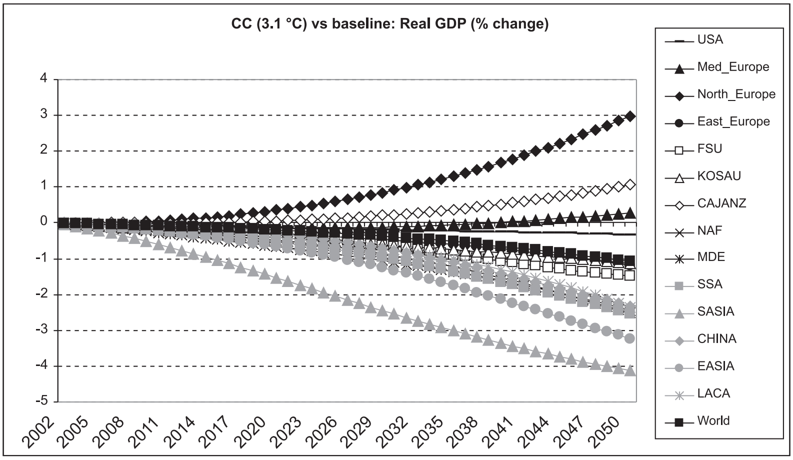
GDP impact of climate change: +1.2°C wrt 2000



Source: Own elaboration.

FIGURE 2

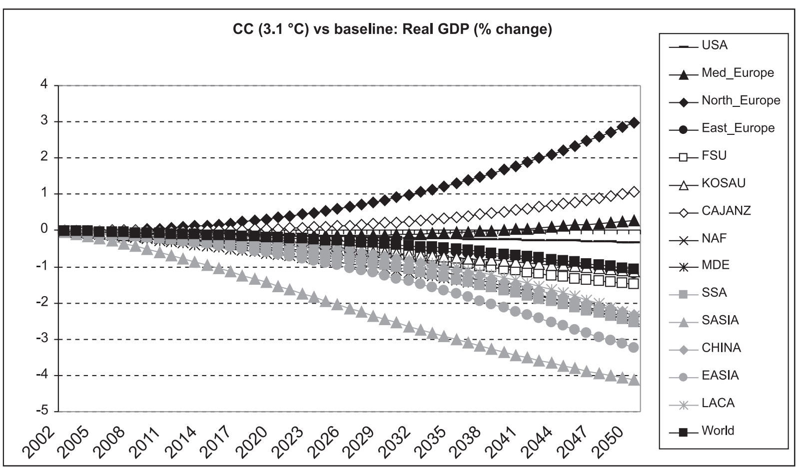
GDP impact of climate change: +3.1°C wrt 2000



Source: Own elaboration.

FIGURE 3

Final climate change impact: % change in regional GDP wrt no climate change baseline (ref. year 2050)



Source: Own elaboration.

For the world as a whole, all the impacts jointly considered may result in costs bill ranging from 0.3% to 1% of GDP in 2050 depending on the temperature increase scenario. However, these global figures hide important regional differences. While developed regions lose only slightly, or even gain (e.g., Europe, especially northern Europe), developing regions may lose considerably more. For a temperature increase of 3.1° C wrt 2000 for instance, South East Asia, South Asia, Sub Saharan Africa and Northern Africa may experience GDP contractions of 4%, 3%, 2.6% and 2.4% respectively. This final effect can be decomposed into its different determinants. For instance it is interesting to note that the bulk of losses in developing countries are due to negative impacts on GDP driven by the dynamics of the agriculture and tourism markets, while for developed countries the impacts of climate change on tourism, affecting the service sector, seem most significant. It is also interesting to note the time pattern of GDP impacts. In the case of Mediterranean Europe, where there may be gains from climate change, GDP performances with climate change are lower than those of the benchmark up to 2035. They are higher only after that year, when positive trade effects and international capital inflows counterbalance negative impacts. As can be seen, negative impacts on the region come primarily from agriculture and tourism. Decreases in land productivity and in tourism demand are however smaller in the Mediterranean EU than in other regions. Thus in the long term the area is partly favoured compared to others in terms of food exports and attracting tourism. Moreover, the decrease in worldwide GDP due to climate impacts tends to reduce energy prices, which also benefits the Mediterranean EU as it is a net energy importer.

Also worthy of note is the negligible impacts of land and capital losses due to sea level rise and health on GDP. This depends mainly on the fact that GDP measures the flow-value of goods and services produced within a region, and accordingly does not directly measure endowment (stock) losses. These are recorded only "indirectly" in GDP insofar as they change the region's ability to produce goods and services. That is why, for instance, catastrophic events affecting property values typically have negligible impacts measured in terms of GDP changes. In addition, our assessment cannot capture other important cost determinants such as, for instance, displacement costs (not to mention the value of human life). As said, these could, at least in principle, be evaluated by a direct costing approach. Thus the cost of climate-induced sea-level rise can be measured by multiplying the quantity loss in land (and/or capital and/or population "dwelling" on that land) by its "value"; the health impact of climate change can be economically assessed by multiplying disability-adjusted life years (DALY) by a "value" of life. With a general equilibrium assessment costs are instead quantified by the differences in the performance of the economic system that result from the initial losses.

As can be noted in Tables 2 and 3, climate-change impacts on ecosystem services are not included in this first assessment. This is the purpose of the next section.

3. Including ecosystem services in a CGE assessment

The present study focuses on three major services provided by EU forest and agricultural ecosystems: timber for commercial activities, agricultural products grown on croplands and carbon sequestration, though many other ecosystem services are also provided by forest and agricultural ecosystems in Europe, such as water regulation, erosion regulation and recreational uses. The ecosystem classification has been popularised by the publication of two recent reports: the Millennium Ecosystem Assessment (MA, 2003) and The Economics of Ecosystem and Biodiversity (TEEB, 2008, 2010a, 2010b) by the scientific community in Europe and the rest of the world.

In particular, the Millennium Ecosystem Assessment presents a practical, tractable and sufficiently flexible classification for categorising the various types of ecosystem services (ES), which can be grouped into four main categories: provisioning, regulating, cultural and supporting services. By way of example, Table 4 below shows more details about forest and cropland ecosystem services.

TABLE 4

A general classification of Ecosystem Services for European Forests and Croplands

Types of Ecosystem Services	Forest ecosystems	Cropland ecosystem
Provisioning Services	Food, Fiber (e.g., timber, wood fuel), ornamental resources, etc.	Food, fibre, latex, pharmaceuticals and agro-chemicals Different crop types for food production, for animal feeding and energy production
Regulating Services	Climate regulation, water regulation, erosion regulation, etc.	Nutrient cycling, regulation of water flow and storage, regulation of soil and sediment movement, regulation of biological population including diseases and pests
Cultural Services	Recreation and ecotourism, aesthetic values, spiritual and religious values, cultural heritage values, etc.	Agricultural landscape and eco-turism
Supporting Services	Biodiversity	Genetic library

Source: adapted from MA (2003) and Swift *et al.* (2004).

In this context, the specific choice of three ESs in the present study represents only a lower-bound of the total services that forests and croplands can provide. It is motivated by the availability of information and consistency with the ICES model.

Forest and cropland provisioning services

The quantification of forest and cropland ecosystems services is based on the use of a hybrid economic valuation method characterised by the use of multiple market and non-market economic valuation tools. Provisioning services refer to physical resources that ecosystems provide directly for human well-being (MA, 2003).

Timber and agricultural produce provision is quantified based on a bio-physical assessment which explores the application of land-use models, the underlying land cover typologies and the respective patterns in terms of ecosystem service productivity levels (Ding *et al.*, 2010; Palatnik and Nunes, 2010). We also explore the use of a market price analysis approach for estimating the economic value of timber and agricultural produce derived from European forests and agricultural ecosystems.

In this study, quantitative data on annual timber production and crop yields are derived from the FAOSTATA 2005 database (http://faostat.fao.org/). To associate productivity with land use changes, we assume a linear relationship between timber production and forest cover and between crops and cropland area. Thus future changes in timber and crops are simply interpreted as reflecting the changing pattern of land-use in the European countries under consideration. It is important to note that the figure for crops from a country's agricultural land is an aggregate that contains a variety of crop products. Crop yields are derived from the FAO database, which provides the weighted average yield (t/ha) harvested production (ton) per unit of harvested area (hectare) for the crop category mentioned above. By multiplying the weighted average yield of a crop product by the respective cropland area in a country, the total harvest of that specific crop for that country can be calculated. Finally, aggregation of all crop production in a country gives the total quantity of provisioning services provided by that country's agricultural land.

As mentioned above, projections of future production of timber and crops rely on projections of future changes in land use. In the present study, projections of changes in land use under the climate change scenario are taken from the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project, which was funded by the 5th Framework Programme of the European Commission with specific emphasis on assessing the vulnerability of human sectors relying on ecosystem services with respect to global change (Schröter *et al.*, 2004). In the software delivered, percentage changes in forest area, croplands, timber products and crop yields are projected for the four IPCC storylines, but only for EU-17. For the remaining European countries under consideration, the respective forest areas are projected on the basis of the IMAGE 2.2 program (IMAGE, 2001). The values are in reference to 2050.

Climate-change caused impacts in EU forest-timber production and consequent changes in forest ecosystem provisioning services, are modelled as one-on-one changes in the productivity of the natural resource inputs used by EU timber industries. Changes in agricultural productivity due to climate-change impacts on biodiversity are modelled as one-on-one changes in the productivity of the land input for EU agricultural industries. Both these factor-specific productivity levels are exogenous variables in the ICES model.

TABLE 5

ummarizes the impact of different scenarios of temperature increase on European croplands and forest timber productivity due to biodiversity/ecosystem effects

Climate change impacts on ecosystem services (% change wrt, reference year 2050 consistent with the IPCC A2 scenario)

	+1.2°C T wrt 2000		+3.1°C T wrt 2000	
	Agricultural Land Productivity	Forest productivity (timber)	Agricultural Land Productivity	Forest productivity (timber)
Med_Europe	-2.30	-6.08	-5.94	-15.70
North_Europe	-0.93	15.09	-2.39	38.97
East_Europe	-1.42	4.48	-3.67	11.56

Source: Own elaboration.

Land productivity declines for Europe as a whole because of soil biodiversity loss, while forest timber productivity declines in the Mediterranean but increases elsewhere in the EU, in particular in the Northern area. These data are used to revise the original CGE input information regarding changes in land and forest productivity in the EU contained in Table 3.

The updated estimates are reported in Table 6 together with the percentage difference with respect to the original baseline values.

TABLE 6

Climate change impacts on agricultural land and forest productivity inclusive of effects on ecosystem services (% change wrt 2000, reference year 2050 consistent with the IPCC A2 scenario)

	+ 1.2°C T wrt 2000				+ 3.1°C T wrt 2000			
	Agricultural land productivity			Forest productivity	Agricultural land productivity			Forest productivity
	Wheat	Rice	Cer Crops	Raw Timber	Wheat	Rice	Ce Crops	Raw Timber
Med_Europe	-3.44	-6.92	-4.30	16.38	-14.28	-24.89	-17.78	1.36
% ch wrt Table 3	201.9	49.7	115.1	-27.1	71.3	31.4	50.2	-92.0
North_Europe	0.57	-6.83	49.07	37.54	-10.13	-28.41	105.43	56.03
% ch wrt Table 3	-61.8	15.7	-1.9	67.2	31.0	9.2	-2.2	228.4
East_Europe	-2.55	-4.06	-6.02	26.93	-14.17	-17.23	-22.02	28.62
% ch wrt Table 3	125.2	53.8	30.9	19.9	34.9	27.0	20.0	67.8

Source: Own elaboration.

Finally, the ICES model is re-run and the new results are compared with the old ones.

Forest, cropland and grassland sequestration services

In the general equilibrium assessment of changes in carbon sequestration services by European forests, croplands and grasslands we follow a different integration strategy. Changes in forest/ cropland/grassland based carbon sequestration alter the balance of GHGs between land sinks and the atmosphere that can be defined over a period of time.

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

Carbon regulation in cropland soil corresponds to two opposite processes: climate effects, in terms of soil temperature and moisture, tend to (1) speed up decomposition; and (2) cause a decrease/release of carbon soil, while net primary production increases carbon storage (Brussard *et al*., 2007). The total carbon stocked in European cropland can be found in results already published by the ATEAM project, referring to the quantity of carbon stored in the soil to a depth of 30 cm. We aggregate carbon values in terms of latitudes and show that agriculture land in the higher latitude countries (+N65) shows a greater capacity for carbon sequestration than that in Central or Mediterranean Europe (accounting for a mean 500 tC to 30 cm depth in cropland and about 140 tC in grassland). This argument needs to be supported by further scientific evidence, but it indicates that different types of soil may have different carbon sequestration capacities. This result may provide some additional insights for policy makers who seek to factor agricultural land into their decision-making in combating climate change. As for future projections, the estimates of the carbon stocked in the soil in 2050 (tons/ha) are again based on the results of the ATEAM model for the 17 most economically developed European countries. To include the other 17 countries of interest to us, we use latitude as a proxy to extend the calculation from the 17 advanced economies (for which we have full data) to the other countries located on the same latitude.

With a carbon cycle simulator it is in theory possible to compute the changes over time in temperature in an additional scenario where the carbon sequestration services from European forests are affected by climate change. Taking 2050 as the reference point and applying the reduced-form carbon cycle module of the Nordhaus RICE 99 model (Nordhaus and Boyer, 2000), the reduced ability of EU forests to sequester carbon implies a world temperature which is 0.018°C higher. The change in the temperature, in turn, impacts on the economy at various levels. Therefore, we re-estimate all the climate change impacts considered in Table 2, re-calculating new macro-regional GDP effects. Finally, as before, we measure general equilibrium economic implications by comparing the old GDP calculations with the new ones that factor in the respective effects of climate change on sequestration service. These results are discussed in the next section.

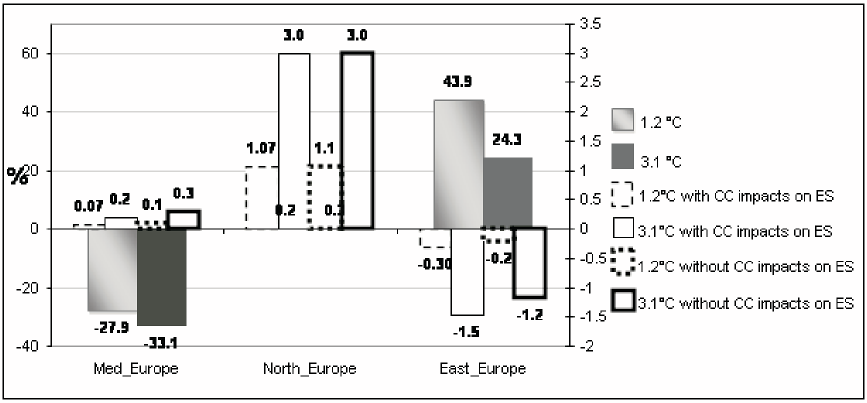
4. Valuation results

Forest and cropland provisioning services

Figure 4 reports the general equilibrium (GDP) implications of changes in agriculture and forest ecosystem-driven productivity compared to the performances reported in Section 2 measured for the year 2050. The Mediterranean EU still gains from climate change because of positive terms of trade effects and decreased energy imports. Nonetheless, these gains are lower (by 30 or 33% depending on the temperature scenario) than without accounting for ecosystem effects. Eastern Europe experiences higher GDP losses (40%, 23% depending on the temperature scenario) in the scenario where impacts on biodiversity and ecosystem services are embedded into the general equilibrium model. Finally, in Northern Europe, GDP is nearly unaffected as gains for the timber industry more or less offset losses in agriculture.

FIGURE 4

Climate change impact on GDP with and without ecosystem/biodiversity effects (ref. year 2050)



Source: Own elaboration.

Notes: % change with vs without ecosystem services effects, filled bars left axis; % change wrt no climate change baseline of both with and without climate change impacts on ecosystem services empty bars right axis.

The "snapshot" discussed aboverefers only to the welfare impacts for 2050. If the inter-temporal welfare impacts registered between now and 2050 are to be taken into account, the net present value (NPV) of GDP losses between the simulations with and without climate change impacts on biodiversity/ecosystem services throughout the simulation period must be assessed. These estimates are presented in Table 6. Over the fifty years the NPV of losses for the Mediterranean EU now ranges from US$ -43.7 to -97.6 billion, depending on the temperature scenario. Therefore, this implies as NPV GDP loss ranging from US$ 9.7 to 32.5 billion more than in the original welfare computations. A qualitatively similar result is reported for the Eastern EU, however, with higher losses ranging from US$ 7.2 to 22 billion.

By contrast, a different welfare pattern is reported for Northern European countries. Unlike the others, this group experiences welfare gains due to climate change effects and those gains become even larger when ecosystem/biodiversity services provided by European ecosystems are taken into account, amounting to US$ 2 to 5.6 billion. All in all, the total net discounted loss for the three regions ranges from US$ 15 to 49 billion. These results can be interpreted as the general equilibrium cost associated with the decreased ability of forest and agricultural systems to produce provisioning services as a consequence of climate change.

TABLE 6

Climate change impact on GDP with and without ecosystem/biodiversity effects

Region	Climate Change indirect impact NPV 2001-2050 (dr=3%) Million US$					
	+ 1.2°C T wrt 2000			+ 3.1°C T wrt 2000		
	Without CC impacts on ES (1)	With CC impacts on ES (2)	Difference (ES effect) (2) – (1)	Without CC impacts on ES (1)	With CC impacts on ES (2)	Difference (ES effect) (2) – (1)
Med_Europe	-33,979	-43,733	-9,754	-65,084	-97,631	-32,548
North_Europe	488,420	490,350	1,929	1,360,399	1,366,058	5,659
East_Europe	-20,808	-28,046	-7,238	-101,529	-123,787	-22,258

Source: Own elaboration.

Forest, cropland and grassland sequestration services

When carbon sequestration services from the European forests, croplands and grasslands is reduced by climate change, climate change impacts themselves become larger. This information is shown by estimation results presented in Table 7, see Column ‘Part I + Part II’ which now denotes a world scenario with the temperature increase discussed above (+0.018°C). In particular, Table 7 shows that at a global level, and depending upon the climate change scenario, the damage imposed by climate change on carbon sequestration services provided by EU ecosystems can cost on average 553 to 1736 million US$ per year. These figures monetize the negative GDP performances of all the economies considered due to the higher temperature increases consequent upon the lower CO_2 sequestered by EU forests.

TABLE 7

General equilibrium economic assessment of EU forests carbon sequestration service

Region	*+ 1.2°C T wrt 2000*				*+ 3.1°C T wrt 2000*			
	Climate Change indirect impact NPV 2001-2050 (dr=3%) Million US$			Annuitized (2001-2050)	Climate Change indirect impact NPV 2001-2050 (dr=3%) Million US$			Annuitized (2001-2050)
	Without CC impacts on ES (1)	With CC impacts on ES (2)	Difference (2) – (1)		Without CC impacts on ES (1)	With CC impacts on ES (2)	Difference (2) – (1)	
USA	-266,294	-270,566	-4,273	-87	-631,392	-635,746	-4,354	-89
Med_Europe	-33,979	-34,476	-497	-10	-65,084	-63,792	1,292	26
North_Europe	488,420	496,059	7,639	156	1,360,399	1,372,541	12,142	248
East_Europe	-20,808	-21,189	-381	-8	-101,529	-103,035	-1,506	-31
FSU	-21,482	-22,422	-941	-19	-214,426	-222,225	-7,799	-159
KOSAU	-71,135	-72,260	-1,125	-23	-172,240	-173,401	-1,160	-24
CAJANZ	102,803	104,473	1,670	34	361,249	366,294	5,044	103
NAF	-50,229	-51,229	-1,001	-20	-210,749	-215,451	-4,702	-96
MDE	-221,033	-224,571	-3,537	-72	-620,101	-626,561	-6,460	-132
SSA	-52,729	-53,895	-1,167	-24	-218,737	-222,748	-4,010	-82
SASIA	-368,147	-375,246	-7,099	-145	-1,474,608	-1,503,348	-28,740	-587
CHINA	-431,586	-438,733	-7,147	-146	-1,863,000	-1,887,020	-24,020	-490
EASIA	-212,334	-215,812	-3,478	-71	-730,920	-739,675	-8,755	-179
LACA	-332,006	-337,790	-5,784	-118	-995,229	-1,007,254	-12,025	-245
Europe	433,633	440,394	6,761	138	1,193,786	1,205,714	11,928	243
World	-1,490,538	-1,517,658	-27,120	-553	-5,576,367	-5,661,421	-85,054	-1,736

Source: Own elaboration.

Focussing on Europe, Table 7 shows that a reduced carbon sequestration service by EU ecosystems implies a welfare gain that ranges from US$ 138 to 243 million on a yearly basis. For Mediterranean and Eastern Europe the net welfare effect of the carbon sequestration services provided by ecosystems is positive as higher temperature are “bad” for them, but it is negative for Northern Europe, which ultimately gains from climate change.

5. Conclusions

The present study proposes a methodology for assessing climate change impacts on ecosystem services in economic terms within a CGE approach. The use of this research tool enables us to quantify the higher order economic consequences of those impacts. In other words, we can determine the final changes in EU GDP performance, the output of the CGE model, summarising all the market driven adjustments (in prices, demand and supply) triggered by climate change via effects on ecosystems. The analysis thus captures the role of macroeconomic feedback at the domestic and the international levels in determining the final outcome.

In the first step of the research, a broad-ranging set of climate change impacts were assessed that fif not include ecosystem effects. This involved translating each of them into meaningful economic input for the CGE model and then imposing them jointly to determine their overall economic impact.

In the second phase, climate change impacts on ecosystem services were physically quantified, translated into changes in market activities and used to enrich the previous impact assessment. The differences in model results between the two simulations clarified the incremental relevance of climate-induced changes in ecosystem services.

Our valuation focuses on the provisioning services provided by European forest and cropland ecosystems and on the carbon sequestration services provided by European forest, cropland and grassland ecosystems.

For provisioning services, we show first that agricultural land productivity in the EU is expected to decline in the next 50 years (-6% in the Med EU in 2050 for a temperature increase of 3.1°C with respect to 2000 is the biggest decrease) as a result of soil biodiversity loss, while forest timber productivity may decline in the Mediterranean but increase in other EU areas, in particular the north.

In economic terms, this means that the Mediterranean EU may experience an NPV GDP loss ranging from US$ 9.7 to 32.5 billion and the Eastern EU a loss ranging from US$ 7.2 to 22 billion in the next fifty years depending on the climate scenario.

However climate change has a positive net effect on ecosystem provisioning services in Northern European countries, which may experience an NPV GDP gain ranging from US$ 2 to 5.6 billion. All in all, the total net discounted loss for the three regions ranges from US$ 15 to 49 billion. These results can be interpreted as the general equilibrium cost associated with the decreased ability of forest and agricultural systems to produce provisioning services as a consequence of climate change.

The value of EU forest, grassland and cropland carbon sequestration services is assessed by estimating the environmental damages that the world as a whole avoids because of the benefits of those services. According to our estimates, the service could provide a cooling effect of 0.018°C over fifty years. This would imply lower accumulated, discounted (at 3%) GDP losses, ranging from US$ 27 to 85 billion, or from US$ 0.55 to 1.7 billion in annuitised terms. Note that not all world regions are actually damaged by climate change. In our exercise Northern Europe and the Canada, Japan and New Zealand aggregates actually benefit from it. For these regions, the carbon sequestration service which reduces climate change is in fact welfare decreasing.

This exercise is just a first attempt to determine the significance of ecosystem services in a market based economic assessment, and it could be extended in several directions. Firstly, the CGE world model is fed only with EU micro-economic valuation data on ecosystem services. This means that the current analysis is not able to pick out other potentially significant interactions triggered by climate-change impacts on ecosystem services that occur outside the EU. A potential next step is thus to design a full general equilibrium assessment that covers worldwide climate-change impacts on biodiversity and ecosystem services.

Secondly, from the point of view of technical design, the model faces significant limitations in the capture of certain values of ecosystems services. For instance, changes in timber production per hectare do not necessarily entail productivity changes to the same extent in commercial raw wood input for the timber industry. Similarly, changes in land productivity are not necessarily equal to changes in cultivated land productivity as considered here. Input information is aggregated at a higher level of geographical detail and is assumed to be uniform across sectors: this may hide significant feedbacks. Irreversibilities and thresholds in ecosystem functioning are not considered. Therefore, further work should be done in order to explore with greater detail these different aspects of valuation transmission mechanisms of ecosystem services.

Thirdly, it is highly recommended that the present analysis be extended beyond provisioning and regulating services to consider also cultural values provided by ecosystem services. This will be a challenging exercise due to the significant non-market nature of these valuation benefits.

Notwithstanding these gaps, the present analysis constitutes a significant benchmark in the valuation of ecosystem services in the context of global climate change.

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Annex I: Description of the ICES model

ICES is a recursive-dynamic CGE model for the world economy.

Its general equilibrium structure - in which all markets are interlinked - is tailored to capture and highlight the production and consumption substitution processes at play in the social-economic system as a response to economic shocks. In doing so, the final equilibrium determined explicitly takes into account "market-driven adaptation" of economic systems.

The main features of the model are:

- Top-down recursive growth model: a sequence of static equilibria are intertemporally connected by endogenous investment decisions.
- Detailed regional and sectoral disaggregation (up to 113 regions and 57 sectors).
- Inter-sectoral factor mobility and international trade. International investment flows.
- Representation of emissions of main GHG gases: CO2, CH4, N2O.

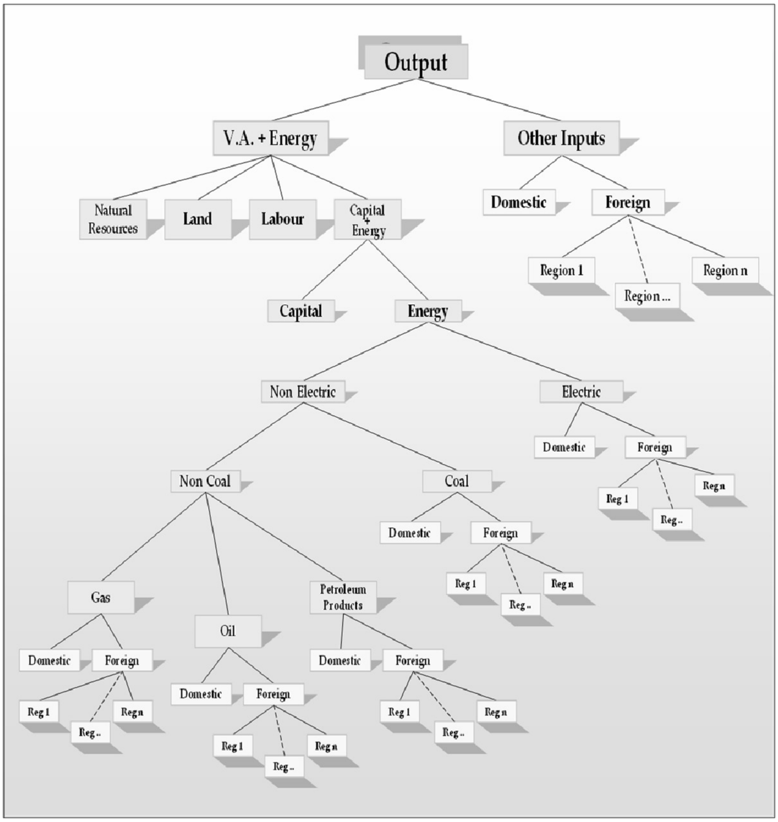
ICES solves recursively a sequence of static equilibria linked by endogenous investment determining the growth of capital stock from 2001 to 2050. The present version of ICES is calibrated in 2001 and replicates regional GDP growth paths consistent with IPCC scenarios. It incorporates assumptions on changes over time in population, energy efficiency, GHG emission and major fossil fuel prices taken from the latest available literature.

As in all CGE models, ICES makes use of the Walrasian perfect competition paradigm to simulate adjustment processes, although some elements of imperfect competition can also be included.

Industries are modelled through a representative firm, minimising costs while taking prices as given. In turn, output prices are given by average production costs. The production functions are specified via a series of nested CES functions. Domestic and foreign inputs are not perfect substitutes, according to the so-called "Armington" assumption (Figure A1).

FIGURE A1

Nested tree structure for industrial production processes



A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically but immobile internationally. Land and natural resources, on the other hand, are industry-specific.

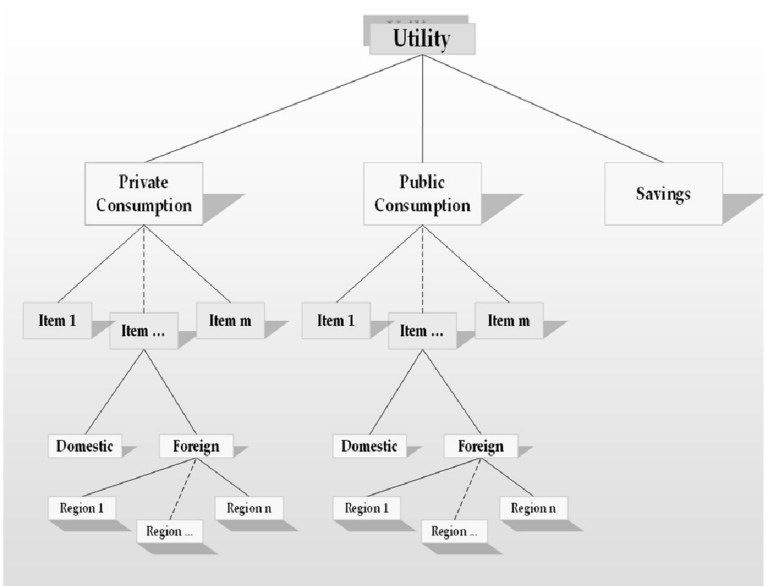
This income is used to finance three classes of expenditure: aggregate household consumption, public consumption and savings. The expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification.

Public consumption is split into a series of alternative consumption items, again according to a Cobb-Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: Non-market Services.

Private consumption is analogously split into a series of alternative composite Armington aggregates. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function which is used to account for possible differences in income elasticities for the various consumer goods.

FIGURE A2

Nested tree structure for final demand



Investment is internationally mobile: savings from all regions are pooled and then investment is allocated so as to achieve equality of expected rates of return to capital.

In this way, savings and investments are equalised at world level but not at regional level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

Annex II: Quantification of Impacts

Agriculture

To assess climate change impacts on agriculture we fed our temperature scenarios into a simple agricultural productivity module developed by Tol (2002a,b). This module calibrates a reduced-form function linking temperature, CO_2 concentration and yield from a meta analysis of the relevant literature in which data from Rosenzweig and Hillel (1998) are particularly important.

This last study is somewhat outdated, but it remains one of the few which report detailed results from an internally consistent set of crop modelling studies for 12 world regions and 6 crop varieties, allowing a reasonable degree of comparability.

We partly update the figures from Rosenzweig and Hillel, (1998) using more recent and detailed information from Bindi and Moriondo (2005) for the North African and Mediterranean Europe regions . The role of the CO_2 fertilisation effect is explicitly taken into account, but we do not consider the role of farm-level adaptation. Impacts on yields are then attributed to the model as exogenous changes in land productivity.

Tourism

To estimate climate change impacts on the tourism sector, tourism flows per region were obtained from the Hamburg Tourism Model (HTM), (Bigano *et al*., 2006a,b and Hamilton *et al*., 2005a,b), an econometric simulation model of tourism flows in and between 207 countries. Climate is represented by the annual mean temperature. A number of other variables, such as country size, are included in the estimation, but these factors are held constant in the simulation. International tourists are allocated to the different countries on the basis of a general attractiveness index, climate, per capita income in the destination countries and the distance between origin and destination. Again, other explanatory variables are included in the regression for reasons of estimation efficiency, but these are held constant in the simulation. The number of international tourists travelling to a country is the sum of international tourists from the other 206 countries. See Bigano *et al*., (2006a) for further details. Total expenditure is calculated by multiplying the number of tourists times an estimated value of the average individual expenditure. Changes in tourism attractiveness are implemented as changes in regional demand addressing market service sectors. This is done by rescaling the change in tourism and recreational service demand (expenditures) to the wider market service demand, which includes tourism services.

Energy demand

Climate-change impacts on energy demand are derived from De Cian *et al*. (2007). This study estimates household energy demand on a macro dynamic panel dataset spanning from 1978 to 2000, for 31 countries. Then it computes the demand elasticity to temperature of different energy vectors for cold, mild and hot countries. A cluster analysis places Mediterranean economies within the mild region. For this area, the study highlights the presence of a cooling and heating effect. Summer temperature leads to higher annual electricity demand (an almost uniform 0.7% in the Mediterranean area) to power increased use of air conditioners. By contrast demand for gas and oil products, mainly used to address heating needs, responds negatively to temperature increases, especially in autumn, spring and winter (-12% on an annual basis). Changes in regional demand for oil, gas and electricity are factored into ICES as exogenous shifts in demand by the different economic sectors for the output of the oil, gas and electricity industries. As demands are endogenous variables for the model, a final demand adjustment is then determined by the model itself.

Sea-level rise

The starting point for obtaining land losses is Bijlsma *et al*. (1996), which reports this information for 18 selected countries. Then the exponent of the geometric mean of the ratio between area-at-risk and land loss for the 18 countries is used to derive land loss for all other countries. Combined, these data specify the amount of land lost per country due to a sea level rise of one metre. Land loss is assumed to be linear in sea level rise, so results can be parameterised to any other sea-level rise scenario. This oversimplified procedure clearly introduces imprecision in land loss estimates, however better estimates would require the use of complex land elevation maps at global level, which is not feasible within the present exercise.

Land losses to sea-level rise are modelled as percentage decreases in the stock of productive land per region. In this case, the modification concerns a variable – land stock – which is exogenous to the model.

Health

We evaluate the impacts in terms of human health changes (in mortality and morbidity associated with malaria, schistosomiasis, dengue, diarrhoea, cardiovascular and respiratory diseases) in the thirteen regions of the ICES by applying the same methodology as Bosello *et al*. (2006). Estimates of the change in mortality due to vector-borne diseases (e.g., malaria, schistosomiasis, dengue fever) as a result of a one degree increase in the global mean temperature are taken from Tol (2002a). The estimates result from overlaying the model studies of Martens *et al*. (1995, 1997), Martin and Lefebvre (1995), and Morita *et al*. (1994) with mortality and morbidity figures from the WHO (Murray and Lopez, 1996). These studies suggest that the relationship between global warming and malaria is linear. This relationship is assumed to apply also to schistosomiasis and dengue fever.

To account for changes in vulnerability possibly induced by improved access to health care facilities associated with improvement in living standards (read GDP growth) we use the relationship between per capita income and disease incidence developed by Tol and Dowlatabadi (2001)[3], using the projected per capita income growth of the ICES regions for the countries within those regions.

For diarrhoea we follow Link and Tol (2004), who report the estimated relationship between mortality and morbidity on the one hand and temperature and per capita income on the other, using the WHO Global Burden of Disease data (Murray and Lopez, 1996).

Martens (1997) reports the results of a meta-analysis of changes in cardiovascular and respiratory mortality for 17 countries. Tol (2002a) extrapolates these findings to all other countries, using the current climate as the main predictor. Cold-related cardiovascular, heat-related cardiovascular and (heat-related) respiratory mortality are

[3] Vulnerability to vector-borne diseases strongly depends on basic health care and the ability to purchase medicine. Tol and Dowlatabadi (2001) suggest a linear relationship between per capita income and health. In this analysis, vector-borne diseases have an income elasticity of –2.7

specified separately, as are the cardiovascular impacts on the population aged under and over 65. Heat-related mortality is assumed only to affect the urban population. We use this model directly on a country basis then aggregate to the ICES regions.

Besides the changes in labour productivity, changes in health care expenditures are also estimated. The literature on the costs of diseases is scant and there are few papers that can be used as references. The costs of vector-borne diseases are taken from Chima *et al*. (2003), who report the expenditure on prevention and treatment costs per person per month.

The resulting changes in national mortality and morbidity aggregated to the ICES regions are reported in Table A1.

TABLE A1

Additional number of deceases due to climate change (1000 people, reference year 2050)

	Vector borne and enteric diseases		Cardio Vascular diseases		Respiratory diseases		Total	
	1.2°C	3.1°C	1.2°C	3.1°C	1.2°C	3.1°C	1.2°C	3.1°C
USA	12	31	-170	-431	4	15	-154	-385
Med_Europe	2	5	-73	-183	3	10	-67	-167
North_Europe	2	6	-115	-292	0	0	-113	-286
East_Europe	0	1	-54	-136	0	0	-53	-135
FSU	1	3	-281	-718	5	13	-275	-702
KOSAU	173	450	-21	-53	7	20	159	417
CAJANZ	0	0	-95	-240	5	15	-90	-225
NAF	16	41	-19	-48	30	73	27	67
MDE	5	12	-50	-126	48	79	2	-34
SSA	782	2029	-19	-40	99	271	861	2260
SASIA	54	141	-142	-345	204	557	116	353
CHINA	2	5	-966	-2463	4	12	-960	-2446
EASIA	14	36	-26	-60	46	129	33	106
LACA	37	97	-18	-37	42	120	62	180

Source: Own elaboration