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# Assessing the economic impacts of climate change. An updated CGE point of view

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**SUMMARY** The present research describes a climate change integrated impact assessment exercise, whose economic evaluation is based on a CGE approach and modeling effort. Input to the CGE model comes from a wide although still partial set of up-to-date bottom-up impact studies. Estimates indicate that a temperature increase of 1.92C compared to pre-industrial levels in 2050 could lead to global GDP losses of approximately 0.5% compared to a hypothetical scenario where no climate change is assumed to occur. Northern Europe is expected to benefit from the evaluated temperature increase (+0.18%), while Southern and Eastern Europe are expected to suffer from the climate change scenario under analysis (-0.15% and -0.21% respectively). Most vulnerable countries are the less developed regions, such as South Asia, South-East Asia, North Africa and Sub-Saharan Africa. In these regions the most exposed sector is agriculture, and the impact on crop productivity is by far the most important source of damages. It is worth noting that the general equilibrium estimates tend to be lower, in absolute terms, than the bottom-up, partial equilibrium estimates. The difference is to be attributed to the effect of market-driven adaptation. This partly reduces the direct impacts of temperature increases, leading to lower damage estimates. Nonetheless these remain positive and substantive in some regions. Accordingly, market-driven adaptation cannot be the solution to the climate change problem.

**Keywords:** Computable General Equilibrium Modeling, Impact Assessment, Climate Change

**JEL:** C68, Q51, Q54

## Table of Contents

# 1. Introduction

A key challenge today's policy makers are facing concerns the reduction of greenhouse gases emissions; the major cause of climate change. If emissions continue to grow as they have over the last century, the consequences on the ecologic and human systems could be daunting. This is the economic reasoning that underlines the search for economic efficient climate policies. More precisely, policy makers should base the choice of environmental regulations on analyses allowing reliable and robust comparisons of the costs and the benefits of a given policy.

In the context of climate change, this is very demanding. It means, preliminarily, to give a monetary value to actual and expected consequences of present and future climate change in different locations worldwide, all of which are affected, but in differentiated ways. Coupling climatic, environmental, and economic models can help to provide this type of information.

This research describes the methodology that has been used to economically assess climate change impacts, and the associated results. This exercise is the first phase of a wider research plan aiming to estimate updated region-specific, reduced-form, climate change damage functions. These should finally serve to perform policy cost-efficiency, cost-effectiveness exercises in a dynamic optimization framework. The regional scope of the study is global, but particular emphasis is given to Europe. The exercise starts from a detailed physical and economic assessment of specific climate change impacts, and then uses these new impact estimates to re-assess the full cost of carbon.

The logical steps followed in the research, which required a strong multidisciplinary effort are summarized in Figure 1 and described below:

- Identification and estimation of a wide set of climate change impacts related to the A1B IPCC SRES scenario through impact-specific bottom-up partial equilibrium studies.
- Joint macro-economic assessment of these climate change impacts occurring in 2050. The assessment is done by means of a top-down recursive-dynamic computable general equilibrium (CGE) model, ICES (Intertemporal General Equilibrium System). The aim is to capture the role of market driven mechanisms able to smooth or amplify the initial climate shocks to the economic system.
- Extrapolation, starting from these outputs, of a reduced-form damage function accounting for autonomous market adaptation.

- The updated damage function is embedded in an Integrated Assessment model WITCH (World Induced Technical Change model).
- The assessment of the social cost of carbon under different policy scenarios is performed using the augmented version of the WITCH model.

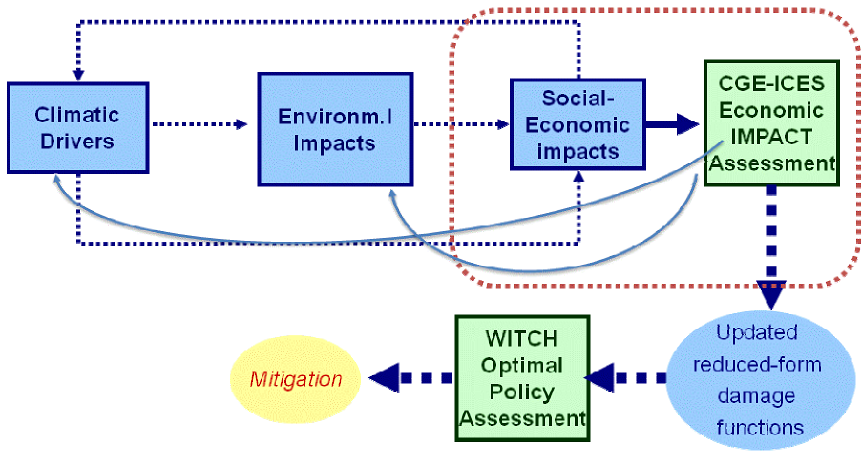


*Figure 1. The structure of the integrated impact assessment exercise*

The last three research steps are analyzed in a paper companion to this (Bosetti and De Cian, 2011) whereas the first two are described in what follows.

Section 2 introduces the ICES CGE model and benchmark calibration; section 3 briefly describes the impacts assessment provided by bottom-up studies; section 4 details the process of including impacts into the CGE model; section 5 introduces major results and section 6 concludes.

## 2. The ICES model and the baseline scenario

Computable General Equilibrium (CGE) models are increasingly used to assess costs and benefits associated with climate change impacts (for a partial list, see e.g. Deke *et al.* (2002), Darwin and Tol (2001), Bosello *et al.* (2007) on sea-level rise; Bosello *et al.* (2006) on health; Darwin (1999), Ronneberger *et al.* (2009) on agriculture; Berrittella *et al.* (2007), Calzadilla *et al.* (2008) on water scarcity; Bosello *et al.* (2009) on sea-level rise, agriculture, health, energy demand, tourism, forestry; Aaheim and Wey (2009) on sea-level rise, agriculture, health, energy demand, tourism, forestry, fisheries, extreme events, energy supply; Ciscar, (2009) on sea-level rise, agriculture, tourism, river floods).

The appeal of such tools is the explicit modeling of market interactions between sectors and regions (inter industry and international trade flows are accounted for by databases relying upon input output Social Accounting Matrices). This allows tracing adjustment mechanisms in the whole economic system triggered by a “shock” initially concerning just one part of it (region or sector). In other words,, not only direct costs but higher-order effects can also be determined.

Following this approach, we use the Intertemporal Computable Equilibrium System (ICES) model (Eboli *et al.*, 2010) to assess the economic consequences of a wide set of climate change impacts. ICES is a recursive-dynamic model improving upon the static structure of the GTAP-E model (Burniaux and Troung, 2002). The calibration year is 2001, data come from the GTAP6 database (Dimaranan, 2006) and the simulation time is 2001-2050.

Table 1 reports regional and sector aggregation for this study. A detailed description of the model can be found in Appendix I

*Table 1 - Regional and sector disaggregation of the ICES model*

| | |
|---|---|
| ***REGIONAL DISAGGREGATION OF THE ICES MODEL*** | |
| USA: | United States |
| MEUR: | Mediterranean Europe |
| NEUR: | Northern Europe |
| EEUR: | 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 |
| ***SECTORAL DISAGGREGATION OF THE ICES MODEL*** | |
| Rice | Gas |
| Wheat | Oil Products |
| Other Cereal Crops | Electricity |
| Vegetable Fruits | Industry |
| Animals | Transport |
| Forestry | Residential |
| Fishing | Market Services |
| Coal | Public Services |
| Oil | |

To be consistent with the work carried out in the reference bottom-up impact studies, the economic benchmark of the model replicates the A1B IPCC SRES scenario whose GDP growth rates are reported by Figure 2.

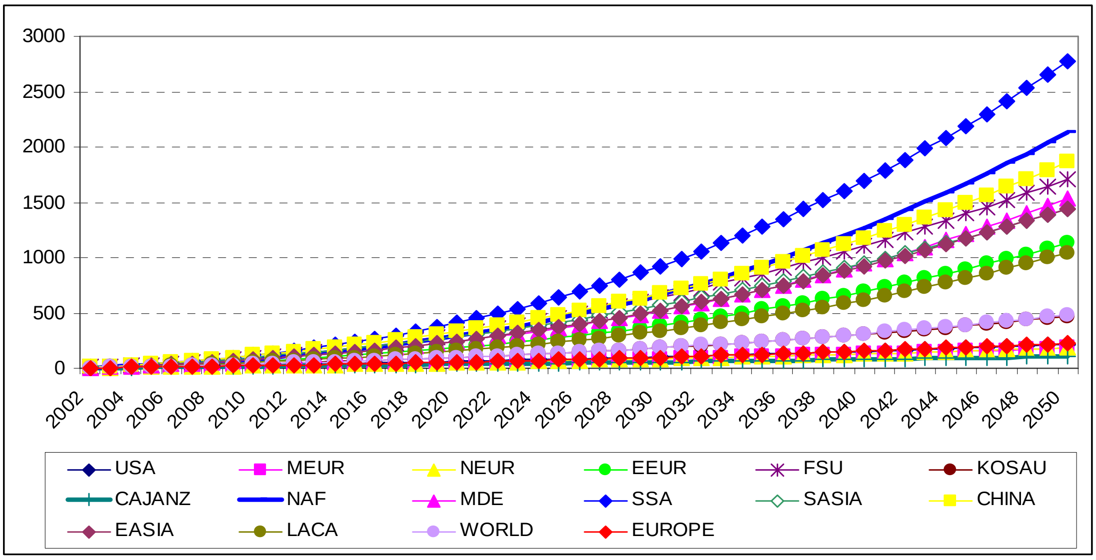


*Figure 2 - GDP growth rates by region (% change 2001-2050)*

The next sections report the impacts' categories considered and how they have been translated into suitable input for the ICES model.

## 3. Assessing climate change impacts by category

As anticipated, the initial inputs to the CGE exercise derive from the results of a set of bottom-up partial-equilibrium exercises.

These allow to physically quantify climate change consequences on sea-level rise, energy demand, agricultural productivity, tourism flows, net primary productivity of forests, floods, and reduced work capacity due to thermal discomfort ("health"). All the studies, except those on floods and health, have a global coverage. The last two focus on the EU. The majority of them are based on geo referenced grid datasets. When this is the case, results have been aggregated to match the geographical resolution of the CGE exercise.

The major characteristics of the individual studies are summarized below, while for a detailed description the interested reader is directly addressed to the specific impact studies.

Estimates of coastal land loss due to *sea-level rise*, are based upon the DIVA model outputs (Vafeidis *et al.*, 2008). DIVA (Dynamic Integrated Vulnerability Assessment) is an engineering model designed to address the vulnerability of coastal areas to sea-level rise. The model is based on a world database of natural system and socioeconomic factors for world coastal areas reported with a spatial resolution of 5°. The temporal resolution is 5-year time steps until 2100 and 100-year time steps from 2100 to 2500. Changes in natural as well as socio-economic conditions of possible future scenarios are implemented through a set of impact-adaptation algorithms. Impacts are then assessed both in physical (i.e. sq. Km of land lost) and economic (i.e. value of land lost and adaptation costs) terms.

Changes in *tourism flows* induced by climate change are derived from simulations based on the Hamburg Tourism Model (HTM) (Bigano *et al.*, 2007). HTM is an econometric simulation model, estimating the number of domestic and international tourists by country, the share of international tourists in total tourists, and tourism flows between countries. The model runs in 5-year time steps of. First, it estimates the total tourists in each country, depending on the size of the population and of average income per capita; then it divides tourists between those that travel abroad and those that stay within the country of origin. In this way, the model provides the total number of holidays as well as the trade-off between holidays at home and abroad. The share of domestic tourists in total tourism depends on the climate in the home country and on per capita income. International tourists are finally allocated to all other countries based on a general attractiveness index, climate, per capita income in the destination countries, and the distance between origin and destination.

Changes in average *crops' productivity* per world region derive from the ClimateCrop model (Iglesias *et al.*, 2009; Iglesias *et al.*, 2010). Crop response depends on temperature, $CO_2$ fertilization, and extremes. Water management practices are also taken into account. Spatially integrating all these elements, the model estimates climate change impacts and the effect of the implementation of different adaptation strategies.

Responses of *residential energy demand* to increasing temperatures derive from the POLES model (Criqui, 2001; Criqui *et al.*, 2009). It is a bottom-up partial-equilibrium model of the world energy system extended within ClimateCost to include information on water resource availability and adaptation measures. It determines future energy demand and supply according to energy price trends , technological innovation, climate impacts, and alternative mitigation policy schemes. The present version of the model considers both heating and cooling degree-days in order to determine the evolution of demand for different energy sources (coal, oil, natural gas, electricity) over the time-horizon considered.

Data on changes in *forest net primary productivity (NPP)* are provided by the LPJmL Dynamic Global Vegetation Model developed at the PIK – (Boundeau *et al.*, 2007; Tietjen *et al.*, 2009). The LPJ model, endogenously determines spatially explicit transient vegetation composition and the associated carbon and water budgets for different land-uses including forestry. It estimates the effects of climate change on forest (NPP) for all world countries in the world, with or without carbon fertilization effects on vegetation and the role of forest fires.

Data on climate change impacts on *river floods* are based on results from the LISFLOOD model (Van der Knijff *et al.*, 2009; Feyen, 2009). This is a spatially distributed hydrological model embedded within a GIS environment. It simulates river discharges in drainage basins as a function of spatial information on topography, soils, land cover, and precipitation. This model has been developed for operational flood forecasting at the European scale and it is a combination of a grid-based water balance model and a 1-dimensional hydrodynamic channel flow routing model. The LISFLOOD model can assess the economic loss in the EU27 countries per different macro-sectors: residential, agriculture, industry, transport and commerce along with the number of people affected. The role of climate change, and of economic growth in determining the final losses can be disentangled. Differently from other impact studies, LISFLOOD is an EU model, thus the Non-EU regions remain outside the scope of its investigation.

Finally, climate change impacts on *“on the job performance” in Europe* are derived from Kovats and Lloyd (2011). They assess the change in working conditions due to heat stress produced by the increase in temperature and their effects on labor productivity. By linking climate data, a combined measure of heat and humidity (the “Wet Bulbe Globe Temperature”) and effects on the human body (Kjellstrom *et al.*, 2009), they are able to estimate the expected decrease in labor productivity for four European macro-regions (Western, Eastern, Northern and Southern). Authors also consider sectoral impacts taking into account future changes in distribution of labor force across sectors.

*Table 2 Bottom-up studies and reference models.*

| IMPACT | MODEL | Geographical Scope | Reference |
|---|---|---|---|
| ***sea-level rise*** | DIVA (Dynamic Integrated Vulnerability Assessment) | Global | Vafeidis *et al.*, 2008 |
| ***tourism flows*** | Hamburg Tourism Model | Global | Bigano *et al.*, 2007 |
| ***crops' productivity*** | ClimateCrop | Global | Iglesias *et al.*, 2009; Iglesias *et al.*, 2010 |
| ***residential energy demand*** | POLES | Global | Criqui, 2001; Criqui *et al.*, 2009 |
| ***forest net primary productivity*** | LPJmL Dynamic Global Vegetation Model | Global | Boundeau *et al.*, 2007; Tietjen *et al.*, 2009 |
| ***river floods*** | LISFLOOD | EU27 | Van der Knijff *et al.*, 2009; Feyen, 2009 |
| ***job performance*** | n.a. | Europe | Kjellstrom *et al.*, 2009, Kovats and Lloyd (2011) |

## 4. ICES: modeling and estimation of impacts

To determine with a CGE model the economic consequences of the different impacts assessed, first they need to be translated into changes in economic variables existing within the model.

We discuss the procedure adopted below.

*Land losses to sea-level rise* have been modeled as percent decreases in the stock of productive land and capital by region. Both modifications concern variables, land and capital stocks, which are exogenous to the model and therefore can be /directly implemented. As information on capital losses is not available, we assume that they accurately match land losses[1].

Changes in regional *households' demand for oil, gas, and electricity* are modeled as changes in households' demand for the output of the respective industries.

Changes in *tourists' flows* are modeled as changes in (re-scaled) households' demand addressing the market services sector, which includes recreational services. In addition, changes in monetary flows due to variations in tourism demand are simulated through a direct correction of the regional incomes.

Impacts on *agriculture* are modeled through exogenous changes in land productivity. Due to the nature of source data, land productivity varies by region, but is uniform across all crop types present in ICES.

[1] Although we could have avoided including capital losses, they are an important part of sea-level rise costs. Therefore, we prefer to have a rough, even though arbitrary estimation of this component rather than none. We are not including displacement costs.

Climate change impacts on *forest NPP* are implemented in ICES via an exogenous change in the productivity of the natural resource endowment of the timber sector, assuming that the available stock of forest for commercial purposes remains constant with respect to the baseline scenario.

With reference to *river floods*, to account for economic damages affecting the agricultural sector we impose an equal-value reduction in regional land stock. When other sectors are involved, there is an equal-value reduction in sectoral capital productivity. Regarding people affected, this is accommodated in the model by reduction in labor productivity. It is computed relating people affected to the total regional population and assuming that the average loss of working days is one week.

Reduction in labor productivity is also the channel to account for *on the job performance effects of temperature increases*. Figures derived from Kovats and Lloyd (2011) are directly used to modify ICES sector-specific labor productivity.

As can be noted, two broad categories of impacts can be distinguished in the abovementioned list. The first relates to the supply-side of the economic system, affects exogenous variables in the model - stock or productivity of primary factors - and thus can be easily accommodated. Impacts on sea-level rise, agriculture, forestry, floods, and human health belong to this category and they do not require any substantial change in the basic structure of the model.

The second affects changes on the demand side. Impacts on tourism and energy consumption are of this kind. This implies to intervene on variables, which are endogenous to the model. In this case the technicality involved is more complex. The computed percentage variations in the demands have been imposed as exogenous shifts in the respective demand equations. The implicit assumption is that the starting information refers to partial equilibrium assessment thus with *all prices and income levels constant*. The model is then left free to determine the *final* demand adjustments. Modification in demand structure imposes to comply with the budget constraint; therefore, we have compensated the changed consumption of energy and tourism services with opposite changes in expenditure for all the other commodities.

Table 3 summarizes the results of all this procedure presenting the computed inputs for the ICES CGE model necessary to run the climate-change simulation.

The computations performed refer to year 2050 and are consistent with the A1B IPCC SRES emission scenario or a temperature increase of roughly +1.9℃ with respect to preindustrial levels (Christensen *et al.*, 2010).

*Table 3 - Climate change impacts: inputs for the ICES model (% change wrt baseline, reference year 2050, A1B IPCC SRES Scenario)*

| | **Demand-side Impacts** | | | | |
|---|---|---|---|---|---|
| | *Energy* | | | *Tourism* | |
| | *Gas* | *Oil Products* | *Electricity* | *Mserv Demand* | *Regional Income** |
| **USA** | 0.83 | 1.78 | 7.25 | 2.99 | 0.067 |
| **MEUR** | 0.15 | 0.79 | 6.91 | -1.18 | -0.008 |
| **NEUR** | -0.55 | 0.15 | 0.33 | 1.57 | 0.012 |
| **EEUR** | 0.41 | 1.30 | 0.15 | 0.13 | 0.0007 |
| **FSU** | 0.17 | 2.18 | -2.94 | 5.15 | 0.061 |
| **KOSAU** | 0.80 | 1.63 | 3.60 | 0.20 | 0.004 |
| **CAJANZ** | 0.43 | 1.10 | 8.05 | 8.29 | 0.038 |
| **NAF** | -0.26 | 0.77 | 7.38 | -3.78 | -0.018 |
| **MDE** | 1.00 | 2.66 | 5.86 | -2.71 | -0.001 |
| **SSA** | -0.14 | 0.91 | 4.53 | -2.93 | -0.002 |
| **SASIA** | 1.94 | 3.06 | 9.46 | 0.01 | 0.0002 |
| **CHINA** | -0.59 | 0.96 | 5.22 | -3.32 | -0.005 |
| **EASIA** | -1.25 | 0.29 | 12.68 | -3.28 | -0.027 |
| **LACA** | -0.54 | 0.23 | 11.95 | -2.28 | -0.122 |

* Trillion $

| | **Supply-side Impacts (1)** | | | |
|---|---|---|---|---|
| | *SLR* | *Forestry* | *Agriculture* | *Health* |
| | *Land and K Stock* | *NPP* | *Land productivity* | *Labour productivity* |
| **USA** | -0.082 | -10.73 | -7.54 | *n.a. -> 0* |
| **MEUR** | -0.008 | -17.78 | -12.60 | -0.31 |
| **NEUR** | -0.258 | -10.71 | 11.41 | -0.004 |
| **EEUR** | -0.003 | -9.88 | -0.94 | -0.14 |
| **FSU** | -0.080 | 0.31 | 4.17 | *n.a. -> 0* |
| **KOSAU** | -0.013 | -15.72 | -4.01 | *n.a. -> 0* |
| **CAJANZ** | -0.332 | 0.29 | 5.30 | *n.a. -> 0* |
| **NAF** | -0.005 | 28.57 | -21.63 | *n.a. -> 0* |
| **MDE** | -0.272 | -20.29 | -6.53 | *n.a. -> 0* |
| **SSA** | -0.034 | -13.30 | -8.60 | *n.a. -> 0* |
| **SASIA** | -0.660 | -10.07 | -14.22 | *n.a. -> 0* |
| **CHINA** | -0.0004 | -5.87 | 4.07 | *n.a. -> 0* |
| **EASIA** | -0.140 | -14.37 | -16.03 | *n.a. -> 0* |
| **LACA** | -0.027 | -13.87 | -3.23 | *n.a. -> 0* |

n.a.: not available

| | **Supply-side Impacts (2)** | | | | | |
|---|---|---|---|---|---|---|
| | *Floodings* | | | | | |
| | *Lab Prod.* | *Agriculture (land stock)* | *Industry (K prod.)* | *Transport (K prod.)* | *Residential (K prod.)* | *Commerce (K prod.)* |
| **USA** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **MEUR** | -0.0003 | -0.014 | -0.004 | -0.003 | -0.044 | -0.001 |
| **NEUR** | -0.0004 | -0.013 | -0.008 | -0.006 | -0.115 | -0.002 |
| **EEUR** | -0.0004 | -0.008 | -0.010 | -0.010 | -0.697 | -0.004 |
| **FSU** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **KOSAU** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **CAJANZ** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **NAF** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **MDE** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **SSA** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **SASIA** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **CHINA** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **EASIA** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |
| **LACA** | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* | *n.a. -> 0* |

n.a.: not available

## 5. Macroeconomic consequences of climate change impacts and the role of market-driven adaptation

When implemented, the climate change impacts summarized in table 3, imply that in 2050, there will be a worldwide GDP loss of -0.5% (Figure 2). This is mainly driven by decreases in crop productivity, followed by the redistribution of tourism flows and land loss to sea-level rise. Other impacts are negligible; however, it is worth recalling that flooding and health in particular are computed for the EU only. In addition, “health”, only addresses thermal discomfort on “on the job” performance.

Regional differences are more interesting. In the EU as a whole (Figure 4), the overall effect on Gross Domestic Product is slightly positive (+0.01%). Gains in Northern Europe (+0.18%) slightly overcompensate losses in the Mediterranean (-0.15%) and Eastern Europe (-0.21%). Northern Europe mainly benefits from positive impacts on crop productivity and an increase in its tourism attractiveness. Mediterranean Europe experiences major adverse effects from decreases in labor productivity from worsened “on the job” performance, and increases in energy demand due to the prevalence of a cooling effect. The latter exerts its negative impacts on the trade balance in a region already heavily dependent on international energy imports. Note also the positive GDP effects of impacts on agriculture and tourism. These may appear counterintuitive, as the direct impacts are negative. However, secondary effects in international markets can explain these positive effects. The higher agricultural commodity prices, induced by the negative shocks on productivity (see Figure 7), tend to favor food exporters. When agriculture contributes with a low share to total regional value added, this effect can dominate the production loss. This applies not only to the Mediterranean EU, but also to the USA (more on this below). Tourism is different. The market service sector is unambiguously affected negatively (see below Table 4), but a lower demand of recreational services induces a whole re-composition of the demand structure (all other goods and services increase their demand) with a slight overcompensating effect on GDP. Note also that these gains are a long-term phenomenon as until 2035 the Mediterranean Europe is a net looser (Figure 2).

In the Eastern EU, adverse consequences are mostly due to a decrease in crop productivity and flooding.

In the USA and China (Figure 5), climate change net effect on GDP is positive. In the former the tourism effect dominates, while in the latter, the major driver is the increase in crops' productivity.

The research also confirms the higher vulnerability of least developed regions (Figure 6). The drivers of negative GDP performance (ranging from -1.5% in Sub Saharan Africa to -3.1% in South Asia) are clearly the adverse impacts on crops' productivity, even reinforced by lower tourism attractiveness and land loss to sea-level rise. Both factors play a detectable role in North Africa and South Asia, respectively. It is interesting to note that the initial impact on developing countries agricultural sector is in magnitude comparable or smaller than that affecting Mediterranean Europe. The implications are much more negative though. This is the result of the higher dependence of developing economies on agriculture and of their lower possibility to substitute land stock with capital stock.

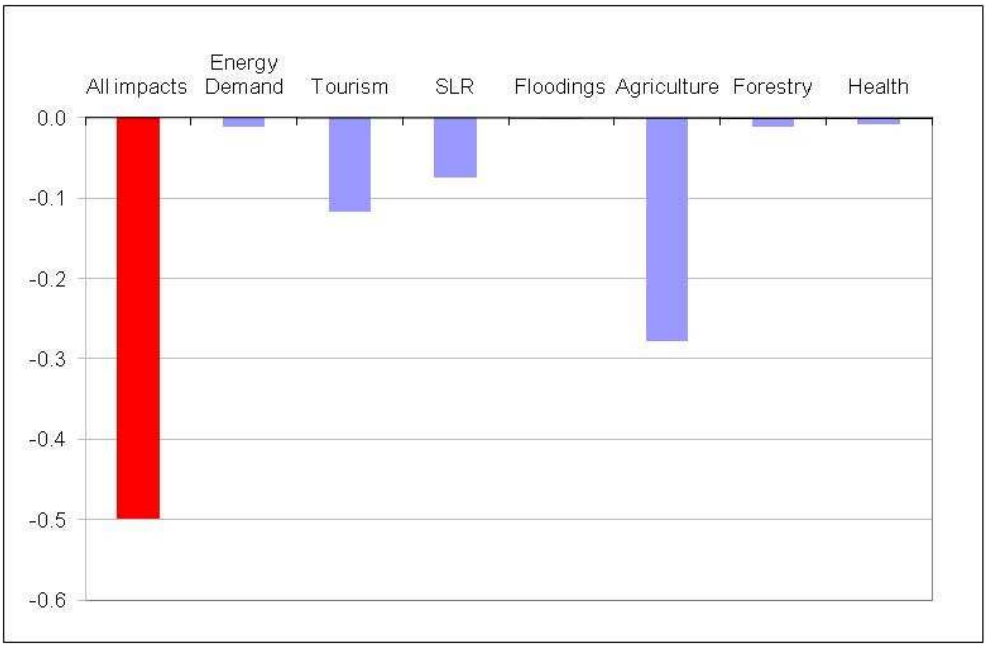


*Figure 2. Real world GDP: % change w.r.t. no climate change (ref. +1.92℃ in 2050)*

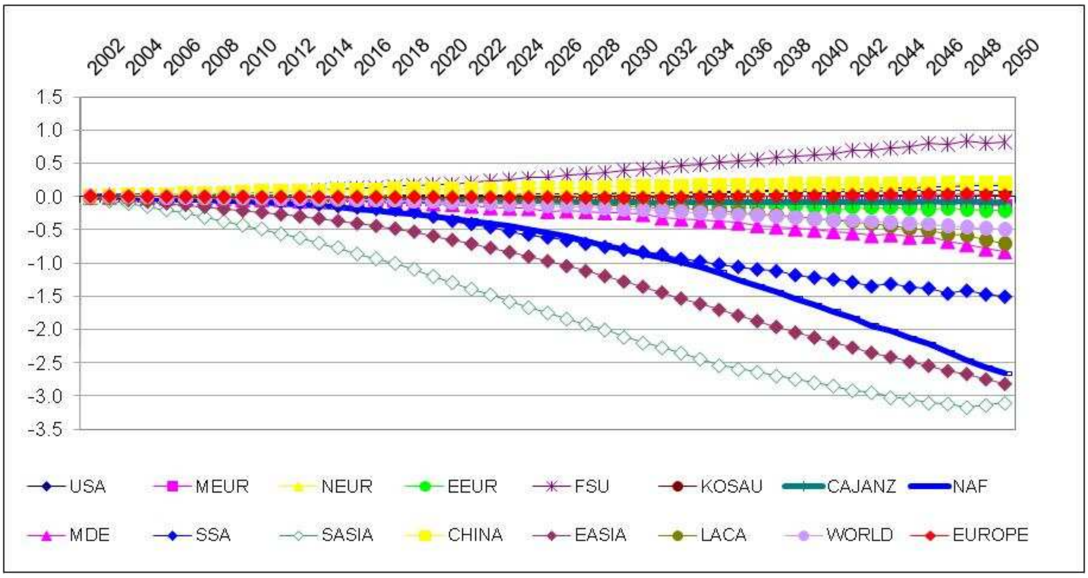


*Figure 3. Real regional GDPs: % change w.r.t. no climate change (ref. +1.92℃ in 2050)*

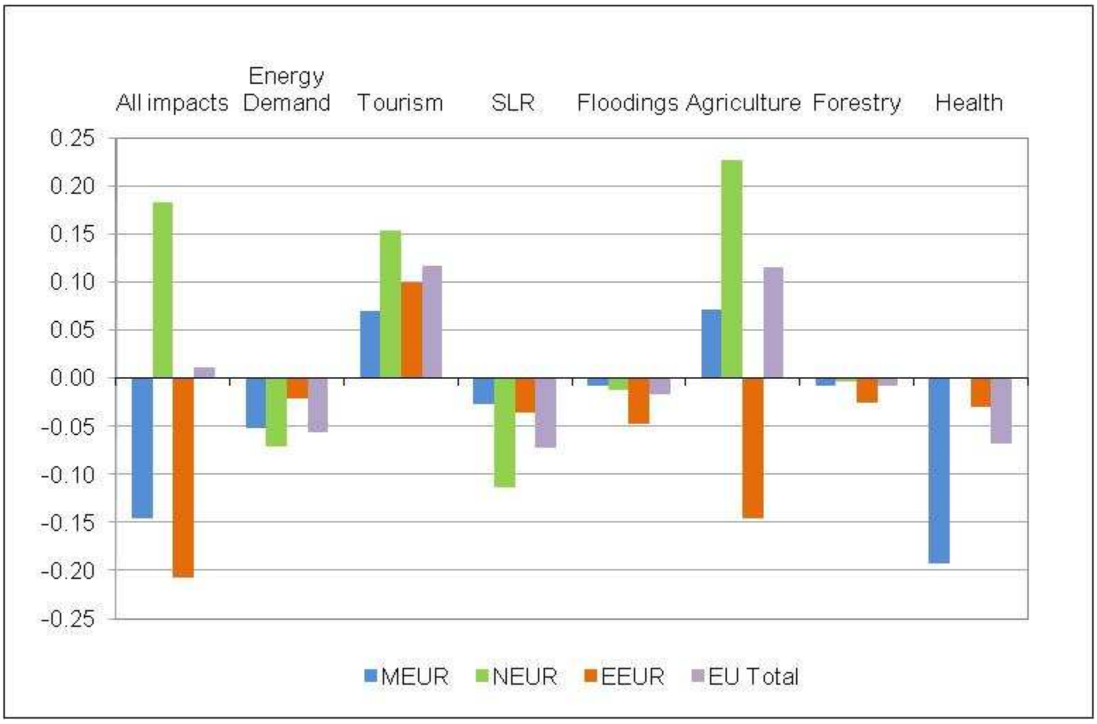


*Figure 4. Real EU GDP: % change w.r.t. no climate change (ref. +1.92℃ in 2050)*

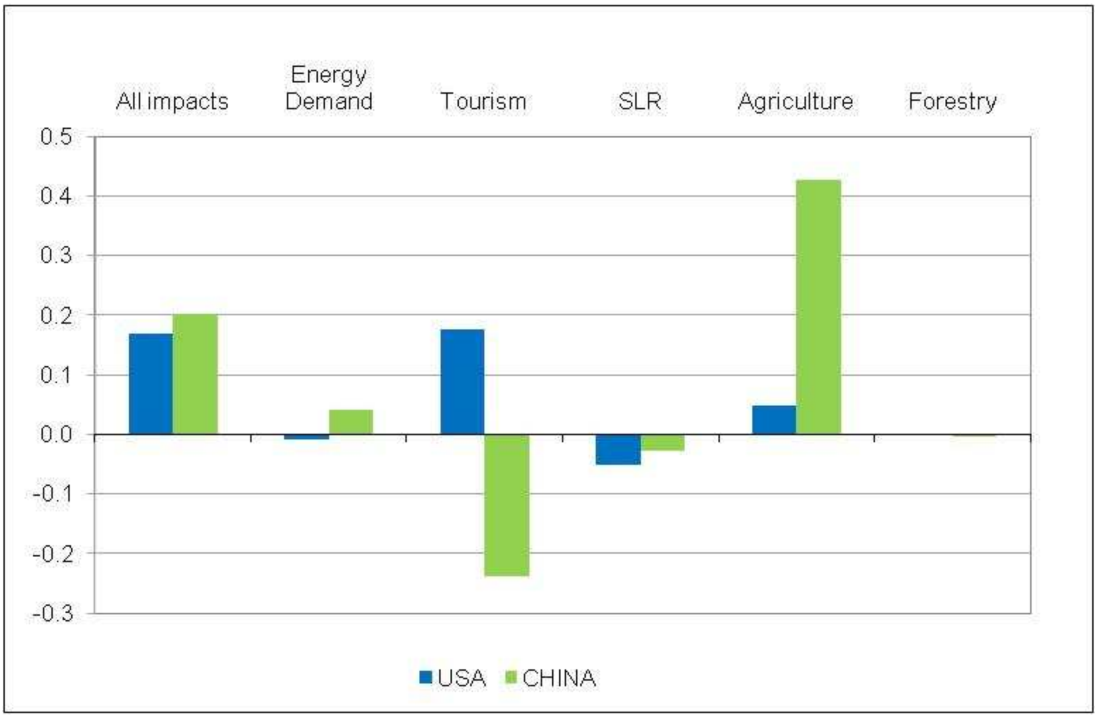


*Figure 5. Real USA and China GDPs: % change w.r.t. no climate change (ref. +1.92℃ in 2050)*

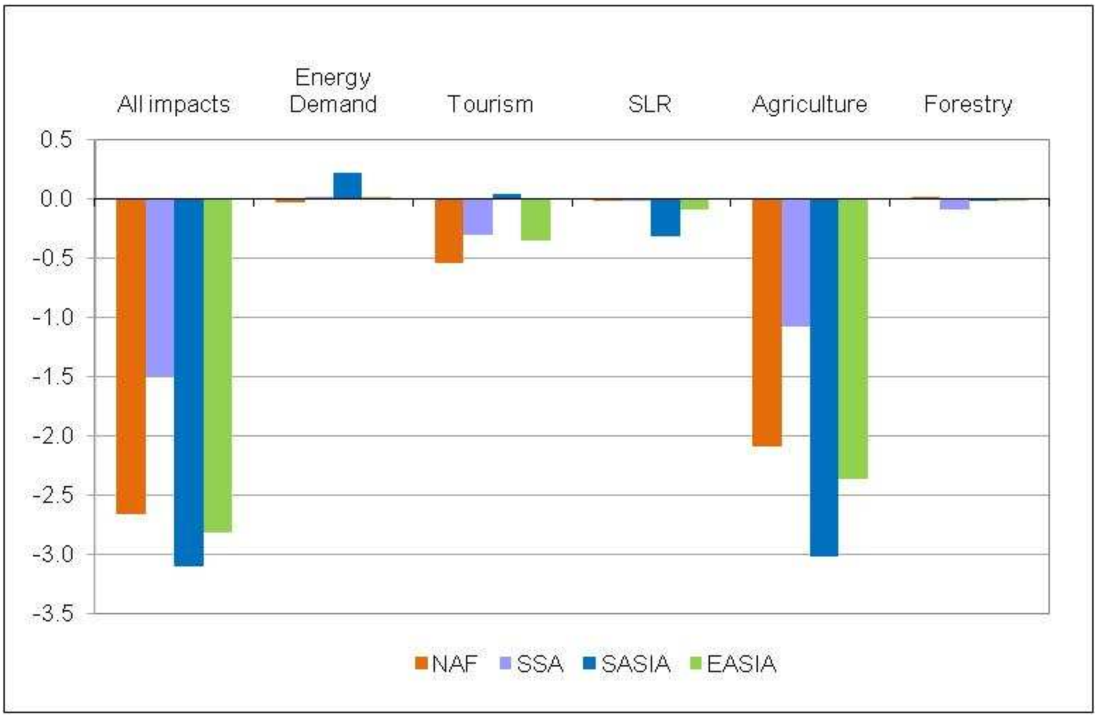


*Figure 6. Real North Africa, Sub Saharan Africa, South Asia and East Asia GDPs: % change w.r.t. no climate change (ref. +1.92℃ in 20 50)*

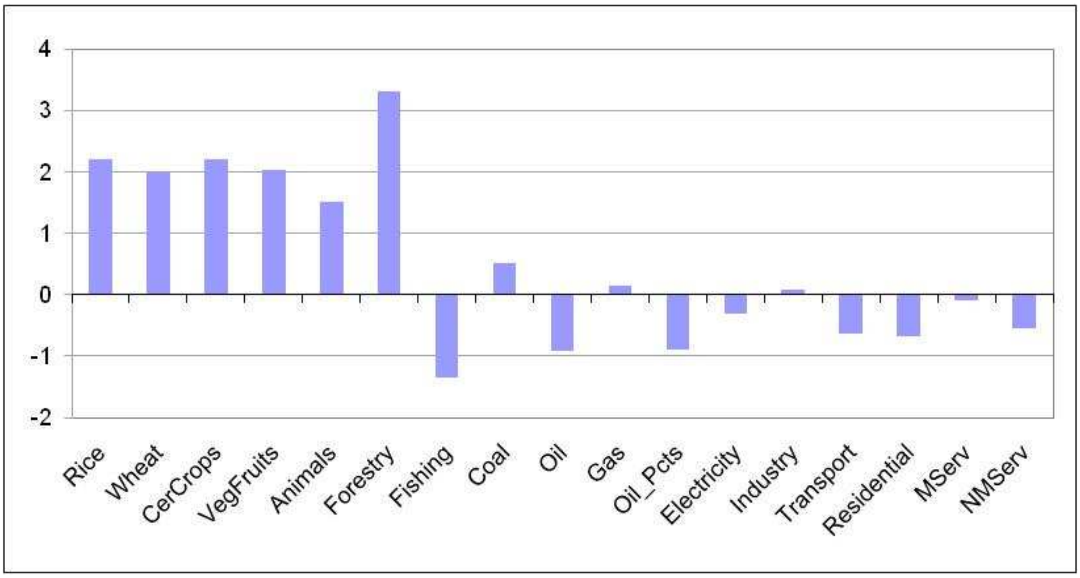


*Figure 7. World prices: Real USA and China GDPs: % change w.r.t. no climate change (ref. +1.92°C in 2050)*

Table 4 reports the effects climate change impacts can exert on sectoral production. Comments focus on the EU regions.

In the Mediterranean EU, the market service sector is most adversely affected , hit by the decrease in the recreational service demand, and partly the agricultural sectors. However, the latter as already mentioned, are not uniformly concerned and some, particularly cereal crops and rice, experience an increase in production fostered by higher agricultural prices. The demand for cooling increases, boosting electricity consumption, and thus production. In Northern Europe the positive signs prevail in the agriculture and the market service sectors. Interestingly, fossil fuel production declines. This is driven by the heating effect that compresses the gas-driven heating demand. Eastern EU is somewhat in between, showing positive production performances in the agricultural sectors, but negative ones in the market service one.

*Table 4. Sectoral production: % change w.r.t. no climate change (ref. +1.92°C in 2050)*

| | USA | MEUR | NEUR | EEUR | FSU | KOSAU | CAJANZ | NAF | MDE | SSA | SASIA | CHINA | EASIA | LACA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rice** | 3.31 | 4.16 | 7.04 | 0.87 | -0.85 | 2.74 | -0.28 | -0.32 | 2.35 | -0.32 | 1.01 | 0.00 | 0.79 | 4.49 |
| **Wheat** | -0.52 | -3.62 | 8.02 | 0.82 | -0.07 | 2.18 | 4.71 | 1.20 | 2.41 | 0.59 | 0.46 | 0.95 | -0.89 | 3.04 |
| **CerCrops** | 0.59 | 0.70 | 6.93 | 0.89 | 0.45 | 1.98 | 3.00 | 0.57 | 2.00 | 0.98 | 0.45 | 2.80 | -0.66 | 2.91 |
| **VegFruits** | -0.64 | -0.75 | 7.98 | 2.05 | 0.05 | 2.04 | 2.88 | 2.60 | 2.81 | 0.86 | 0.78 | 1.47 | 0.11 | 2.31 |
| **Animals** | 0.28 | 2.91 | 1.17 | 0.61 | 0.08 | 0.58 | 0.48 | 1.53 | 1.85 | -0.29 | -0.53 | 0.63 | -0.29 | 3.17 |
| **Forestry** | 2.01 | 3.76 | 2.71 | 3.06 | 2.48 | 2.86 | -1.16 | -4.59 | 7.92 | 0.52 | -3.44 | 2.11 | -0.06 | 4.39 |
| **Fishing** | -2.63 | 0.13 | -0.55 | -0.39 | 2.62 | -0.68 | -4.94 | -7.90 | 0.33 | -4.65 | -9.93 | 1.01 | -7.41 | -1.33 |
| **Coal** | 1.12 | 1.21 | 0.12 | 0.11 | 1.10 | 0.41 | 0.54 | -0.06 | 0.88 | -1.96 | -2.55 | 0.85 | 0.15 | 1.03 |
| **Oil** | -1.06 | -0.76 | -0.87 | -0.07 | 0.14 | -1.06 | -1.11 | -1.69 | -0.96 | -1.03 | -2.22 | -0.62 | -1.54 | -1.28 |
| **Gas** | -0.11 | 0.12 | -0.39 | 0.28 | 1.52 | -0.25 | -0.61 | -3.53 | 0.51 | -0.70 | -5.50 | 0.28 | -1.48 | -0.07 |
| **Oil_Pcts** | -0.99 | -0.69 | -1.00 | -0.40 | 1.61 | -0.70 | -1.14 | -3.34 | 0.08 | -1.78 | -3.68 | -0.21 | -3.10 | -1.04 |
| **Electricity** | 1.29 | 1.11 | -0.41 | -0.21 | 0.56 | 0.31 | 0.92 | -4.28 | 0.98 | -0.97 | -3.29 | 1.06 | -1.38 | 1.34 |
| **Industry** | -0.78 | 0.58 | -0.09 | -0.17 | 0.48 | -0.21 | -1.80 | -2.60 | 0.08 | -1.58 | -3.20 | 0.44 | -3.19 | 0.22 |
| **Transport** | -1.08 | -0.73 | -1.10 | -0.85 | 0.91 | -0.73 | -1.26 | -2.60 | -0.76 | -2.02 | -4.89 | -0.71 | -2.48 | -2.04 |
| **Residential** | -2.35 | -0.08 | -1.63 | -0.27 | 2.43 | -0.15 | -4.93 | -6.52 | -0.50 | -2.41 | -4.50 | 0.61 | -4.90 | -3.12 |
| **MServ** | 1.58 | -1.32 | 0.76 | -0.34 | 3.59 | 0.13 | 3.59 | -6.58 | -3.41 | -2.72 | -3.32 | -0.71 | -4.29 | -4.44 |
| **NMServ** | -1.19 | -0.91 | -0.22 | -0.28 | 2.26 | 0.05 | 0.36 | -4.74 | -1.13 | -1.11 | -2.26 | 0.13 | -3.54 | -3.28 |

To conclude, it is interesting to emphasize the difference between direct impacts and final consequences on GDP. Figures 8, 9, and 10 do so respectively in the cases of tourism demand, sea-level rise and land productivity. Generally, but not always, direct effects are larger than final effects. In fact, market-driven adaptation, primarily the possibility to substitute a scarcer production factor or consumption item with a cheaper one, provides a partial buffer against initial negative shocks. However, this general mechanism is more evident when primary factors of productions are concerned (see land losses to sea-level rise or decrease in land productivity)[2]. It is more ambiguous when demand re-composition effects are involved. In the latter case, substitution mechanisms are less clear and it may well happen that a decrease in demand in a sector drives negative impacts in other related sectors with a multiplicative effect that a direct costing approach cannot capture. This is, for instance, the case of the decreasing tourism demand in China, Middle East, and Sub Saharan Africa and of the increasing one in the USA, Eastern Europe, Korea and South Africa (KOSAU). It is also not unusual to detect changes in sign between direct costs and impacts on GDP. Examples of this is the Canada, Japan, New Zealand aggregate (CAJANZ), where tourism demand increases and GDP impact is negative or Mediterranean Europe where the opposite happens. In these cases domestic sectoral re-composition, price, and terms of trade effects in the international markets can interact producing these outcomes.

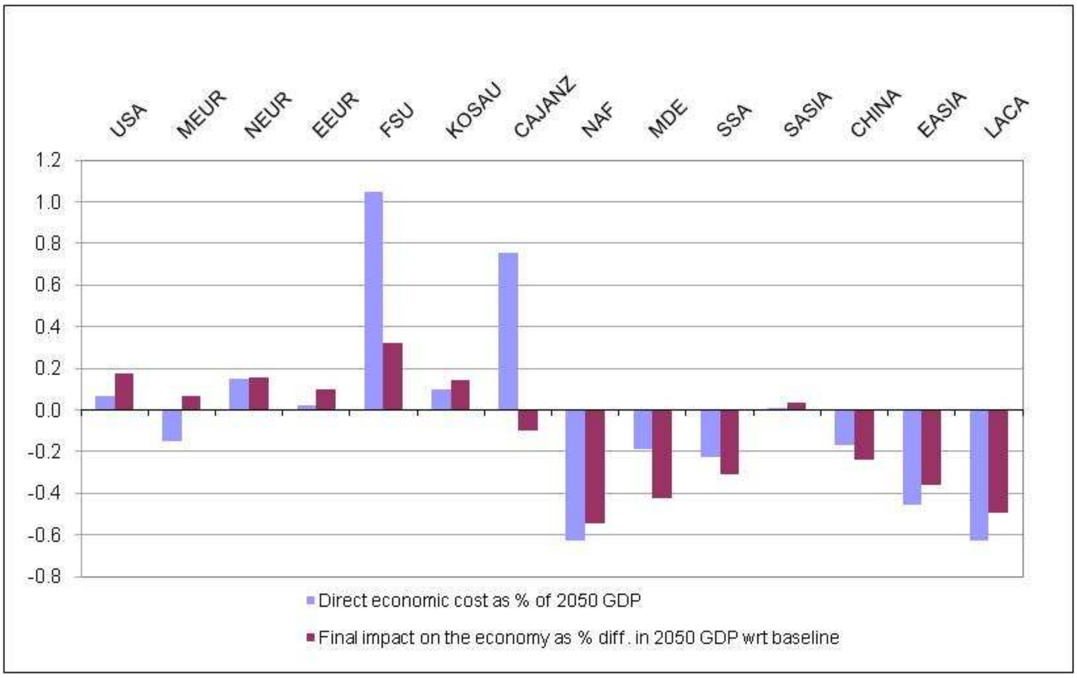


*Figure 8. Direct vs Indirect impacts in 2050: Tourism demand*

[2] An additional motivation of the prevalence of direct costs on GDP costs when primary factor of production are affected, is that GDP itself is a flow measure. Therefore, large stock losses, like for instance those on land, not to mention those on labour, are only marginally reflected by the ability of a country to produce flows of goods and services, which is GDP.

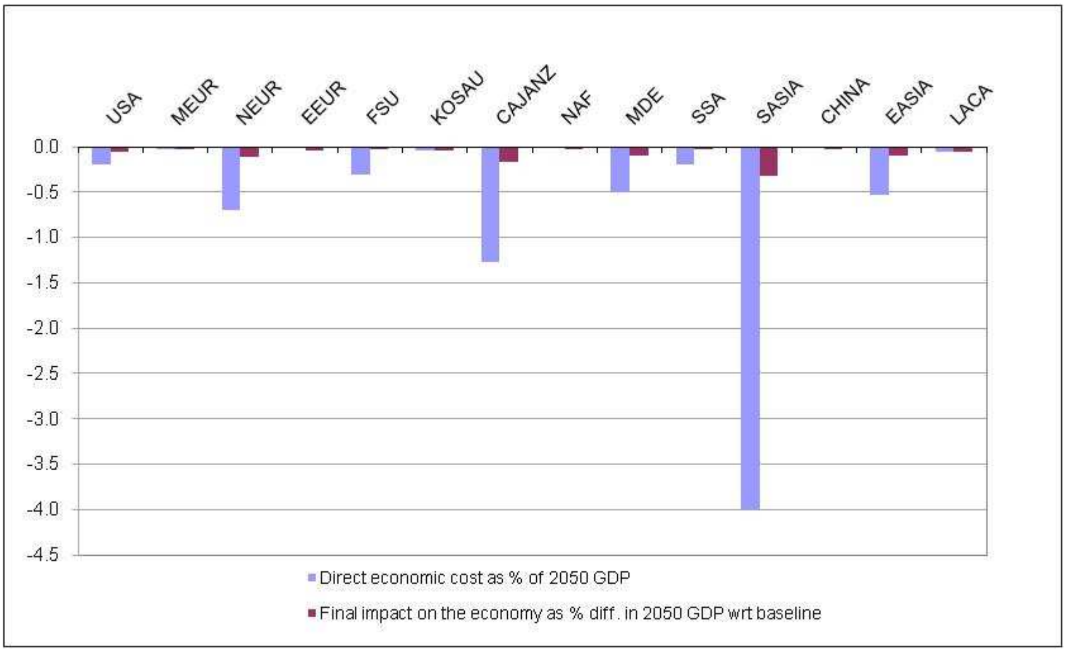


*Figure 9. Direct vs Indirect impacts in 2050: Sea-Level Rise*

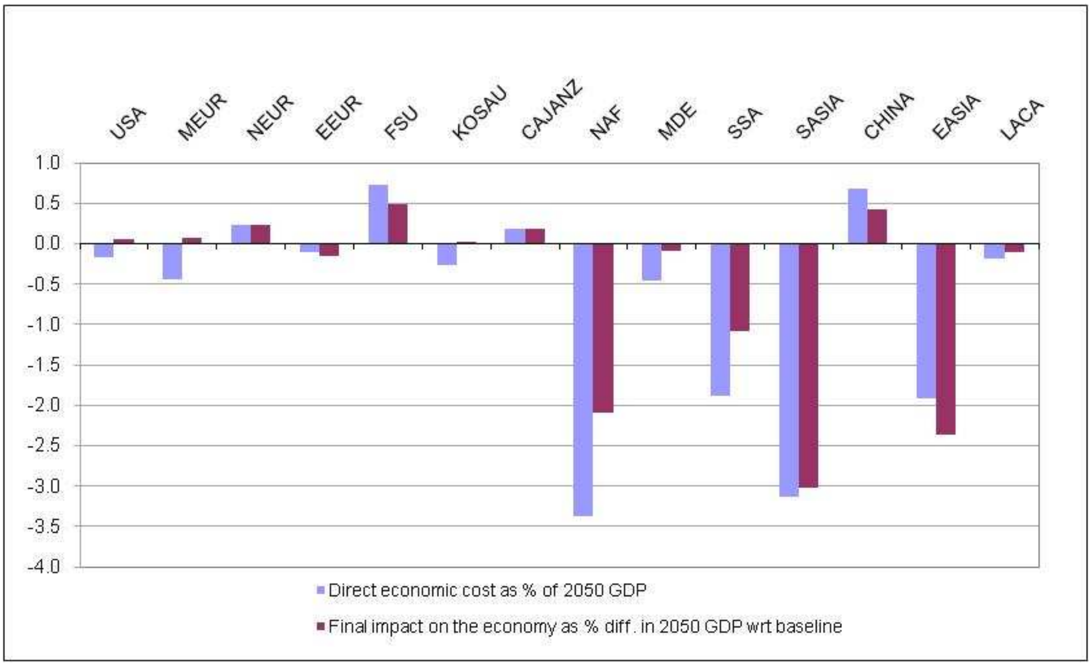


*Figure 10. Direct vs Indirect impacts in 2050: Crop productivity*

## 6. Conclusions

The present research describes a climate change integrated impact assessment exercise, of which economic evaluation is based on a CGE approach and modeling effort.

The impact assessment is partial because it only focuses on some of the market impacts, , and only on one point temperature increase. Still it represents a first step toward the development of a methodology that integrates impact assessments based on CGEs and policy analysis based on IAMs. Moreover, it makes use of the most recent available information.

ICES estimates indicate that a temperature increase of 1.92℃ compared to pre-industrial levels in 2050 could lead to global GDP losses of about 0.5% compared to a hypothetical scenario where no climate change is assumed to occur. Northern Europe is expected to benefit from the evaluated temperature increase (+0.18%), while Southern and Eastern Europe are expected to suffer from the climate change scenario under analysis (-0.15% and -0.21% respectively).

The most vulnerable countries are the less developed regions, such as South Asia, South-East Asia, North Africa and Sub-Saharan Africa. In these regions the most exposed sector is agriculture, and the impact on crop productivity is by far the most important source of damages. Agriculture impacts strongly affect low-latitude regions, even at relatively low temperature increases because of their greater physical vulnerability and of the higher importance of this sector in their economy. Again agriculture and infrastructures are adversely affected by sea-level rise, which with its land and capital induced losses, is the third major driver of economic impacts at the world level. The tourism sector experiences the second highest losses, given the market impacts analyzed. Tourism flows will be gradually re-directed away from warmer regions, becoming increasingly too hot, towards more moderate, high-latitude regions. This trend produces important distributional effects across regions. Other impacts (on energy demand, on forest primary productivity, on river floods, and on the on-the-job performance) are generally of lower importance, but there are several exceptions. For instance, in Mediterranean Europe, the reduction of "on the job" performance due to higher temperatures leads to important productivity and then economic losses.

It is worth noting that the general equilibrium estimates tend to be lower, in absolute terms, than the bottom-up, partial equilibrium estimates. The difference is to be attributed to the effect of market-driven adaptation. Markets react to climate change impacts with changes in commodity and primary factor prices that allow for adjustments in consumption and production. This induced adaptation partly reduces the direct impacts of temperature increases, leading to lower estimates. However, this general mechanism is more evident when primary factors of productions are concerned (see land losses to sea-level rise or decrease in land productivity). It is more ambiguous when demand re-composition effects are involved. In this last case substitution mechanism are less clear and it well may happen that a decrease in demand in a sector drives negative impacts in other related sectors with a multiplicative effect that a direct costing approach cannot capture.

Therefore the final message we would like to convey is that, albeit its impact smoothing potential, market-driven adaptation cannot be the solution to the climate change problem: its distributional and scale consequences need to be addressed with proactive policy-driven mitigation and adaptation strategies.

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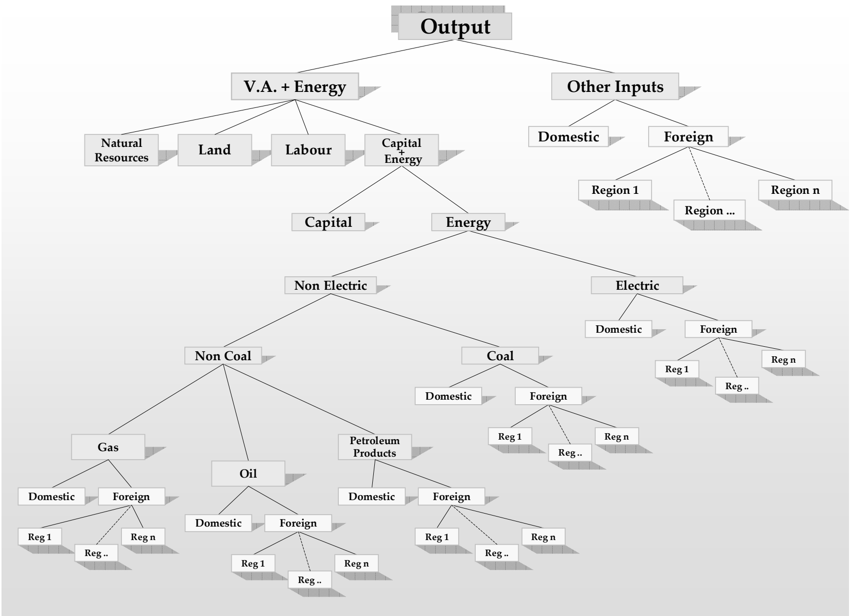
## Appendix. The ICES model

As in all CGE models, ICES makes use of the Walrasian perfect competition paradigm to simulate market adjustment processes, although the inclusion of some elements of imperfect competition is also possible. Industries are modeled through a representative firm, minimizing 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 of the ICES model*

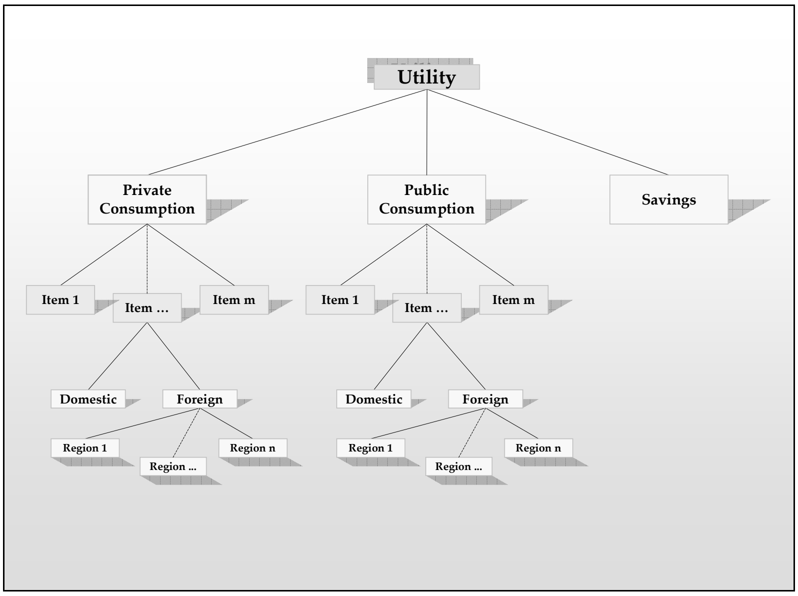



A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labor, capital). Capital and labor are perfectly mobile domestically, but immobile internationally. Land and natural resources, on the other hand, are industry-specific. 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 in 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 in 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 consumption goods (Figure A2).

*Figure A2. Nested tree structure for final demand of the ICES model*




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

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

The recursive-dynamic engine for the model can replicate dynamic economic growths based on endogenous investment decisions. As standard in the CGE literature the dynamic is recursive. It consists of a sequence of static equilibria (one for each simulation period which in the present exercise is the year) linked by the process of capital accumulation. As investment decisions, which build regional capital stocks are taken one year to the other, i.e. not taking into account the whole simulation period, the planning procedure is “myopic”. Two factors endogenously drive investment and its international allocation: the equalization of the expected rate of return to capital and the international GDP differentials. In other words, a country can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of its competitors.