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GLOBAL IQ

Impacts Quantification of global changes

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential , only for members of the consortium (including the Commission Services)	

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Executive Summary

The GLOBAL-IQ objectives are to provide assessments of the ongoing global changes at the national, EU and world levels until 2050 and 2100 and to explore policy relevant key sectors and issues with respect to the global changes challenge. Key findings of the project are:

- **Energy:** World energy demand grows by 89% until 2050 but stabilizes in the EU. EU imports rise to 80% for oil and 90% for gas in 2050, China and EU being the largest importers. With enough fossil fuels, gas dominates electricity production in the EU by 2030. With less fossils, coal consumption increases in Europe. Renewables increase at a 2% rate. Non- conventional oil and gas have a moderate impact on world GDP (between – 0.68% and +0.35% in 2050). Banning non-conventional oil reduces warming by 0.3°C by 2100 but at a very high cost. CSP (concentrated solar power) becomes attractive after 2050 and can expand significantly in case of nuclear generation constraints.
- **Climate change:** Meeting the RCP2.6 and RCP4.5 climate objectives requires high carbon prices: (between 143 to 519 US$/tCO2 for RCP2.6 and 21 to 53 US$/tCO2 by 2050). The RCP2.6 implies replacing fossil fuels by nuclear, hydro and other renewables in large proportions while decreasing by 20% EU energy consumption. This has large impacts on exporting countries: Russia and Middle East lose between 8% and 12% GDP. RCP4.5 requires much less adaptation until 2050. Climate impacts on agricultural yields are highly uncertain and heterogeneous (from -7% to + 7% on average worldwide, comparable to the EU). Food prices are projected to remain stable until 2050. In the RCP2.6 scenario, GDP loss amounts to 0.6% by 2100 without considering extreme events. Catastrophic losses represent 1% GDP in 2100. This average hides large regional differences: India and South Asia lose 4%GDP, Sub Saharan Africa 2%. EU suffers little form climate change, mainly through catastrophic events. The RCP2.6 scenario does not pass the cost-benefit test, even without discounting. The cost-benefit line is located in between RCP4.5 and RCP6.0 depending on the models.
- **Environment:** Deforestation amounts to 1% in the baseline with huge regional differences. Biodiversity protection opposes strongly with food security. Banning agriculture from biodiversity hot spots means land conversion of less productive areas with high impacts: +8% intake/cap in Africa instead of + 18% in the baseline scenario and + 36% food prices levels in Africa rather than -2% in the baseline.
- **Growth, competitiveness and trade:** The US and EU share of world GDP fall from 55% today to 40% by 2050, China share doubles from 8% to 16%. Projections show a slow income convergence with high disparities remaining. GDP/cap rises at 4% per year in China and India and at 2.5% in Northern Africa and Middle East. EU continues to deindustrialize (less strongly in CEE countries) with a general move toward services in western EU. The working force share of the population drops from 60% to less than 50% in OECD countries while Africa gains 3.8 more billion people by 2100, anticipating large relocation of the world labor force after 2050. Skills improvements in Asia and Latin America favour EU trade in value added goods but implies large skills acquisition by the EU labor force to remain competitive. Trade barriers to stop EU deindustrialization are clearly beneficial for the EU but outweighed in a 2:1 ratio by losses of trade partners. Trade blocks policies show little positive impacts with respect to overall free trade because the world GDP becomes less concentrated. The opening of a Northern Seas route could drop by 1 half the trade cost between Asia and EU, promoting EU growth significantly.
- **Analysis of key sectors:** CEE countries face significantly more stringent productivity constraints than western EU with double energy/output ratios. Redistributive effects favour electricity subsidization for poor households. Water and energy households conservation behavior are quite similar, they reflect a general concern for climate change but not to the exposure to actual climate conditions in EU countries. A case study on air pollution in Beijing, China, show high figures for air quality. Total cost of illness amounts to 1 average wage month while the value of statistical life (VSL) approximates 16.8 million yuan (: 2.8 million US$). A VSL computation for the Czech Republic concludes to a 2.4 million € magnitude. A meta-analysis on forest recreation benefits in the EU conclude to an average value of 92€/km2 with strong heterogeneities: northern and Baltic EU states value much more forests than central Europe countries. Land use estimates on US data show long run land prices elasticities around 0.3, 10 times larger than the short run estimates usually used in assessment studies. The result is a 160% larger conversion of land to biofuels than current figures.
- **Risk and uncertainty management:** Long term uncertainty requires using declining over time discount rates converging down to 1% by 2100. Ambiguity aversion reinforces this result promoting the need for early mitigation action against global warming. Ambiguity also leads to restraints on insurance possibilities against long term risks while enlarging the space of agreement for international cooperation. In food production, imposing strict biofuels mandates increases the price volatility. An insurance fund at a volume around 0.2% GDP can cut one fifth of welfare costs for the most impact countries by climate change.

SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND OBJECTIVES

The main objectives of the GLOBAL-IQ project are:

- To provide new insights on the main drivers of socioeconomic trends in the context of global changes at the regional, EU and world level.
- To produce quantitative investigations of the main aspects of global changes and provide assessment of the potential dynamics of global changes up to 2100.
- To summarize and enhance the present state-of-the-art in socioeconomic analyses of global changes both on conceptual and empirical grounds.

'Global changes' is a shortcut way to embrace a vast array of social, political and economic evolutions and challenges affecting today the world societies in five main dimensions:

- *Global public goods*, like knowledge, technologies, climate and the environment. The common aspect of such goods is their trans-boundary nature requiring extended cooperation of the world societies because of free riding incentives: anybody can benefit from the efforts of others to produce or manage them without taking part.
- *Global flows of goods, services and people*. Usually seen as the core of the global change problem, it refers to the unprecedented rise of the trade of goods between nations and the emergence of newly industrialized countries in the most populated areas of the globe, especially Asia today and probably Africa tomorrow.
- *Global risks.* Today perceived mainly through the lenses of the ongoing financial crisis, the vulnerability of the world societies to risk encompasses a large set of problems going from health and ageing risks to climate risks together with political risks, terrorism, technological and environmental risks, food, water and energy access risks and loss of people economic security in a quickly changing world.
- *Global governance.* Facing so much pressing challenges put at stake the international relations system which has emerged from the Second World War. It also challenges the ability of the EU to maintain the pace of political, social and economic progress it has managed to secure for an increasing number of Europeans since fifty years.
- *Global society.* Epitomized in the public opinion through the development of internet and social networks at the world scale, it refers to the search for a social, political and cultural sharing of values to stand an ever more common future. The problem covers a vast set of issues ranging from the role of the medias, the emergence of a world public opinion and domestic political tensions resulting from the limited ability of national governments to cope with ever more internationally driven socioeconomic trends.

The outcome of such trends and challenges may be described as resulting from a mix of interlinking forces and fragmentation forces. Pessimists and optimists divide themselves according on their views concerning the respective importance of these forces. History tells us that previous episodes of this kind have resulted in major crisis. The XIV century crisis in Europe resumed in the end of the Middle Age, the Renaissance and the entry in the so-called 'Modern' Age. The XVII century crisis happened worldwide and had strong impacts over the further divergence between Asia and Europe while

designing the cultural, scientific and economic background for the emergence of the contemporary Western industrialized societies which have dominated the world until today.

It may thus appear questionable that the Global-IQ project, like most projects of its kind, focuses primarily on extending to the current century the main trends that can be observed today, without explicitly considering the possibility of socioeconomic or environmental tipping points, major potential crisis or unexpected breakthroughs, especially in the technological domain. First, the Global-IQ project is quantitative oriented, based upon existing data and future trends modeling. Introducing random tipping points, by definition hardly predictable, would get unrealistic figures in this setting. Second, existing evidence for the past century shows that despite major crisis, the main economic trends of growth have followed almost regular patterns and the same holds for population or for the pattern of carbon emissions for example. Third, the project has devoted much care to explore cutting issues able to modify unexpectedly the projections. It also includes specific investigations on the problem of risk and uncertainty management in the long run future.

The Global-IQ project is original in three respects. Contrasting with most studies of global change, which focus upon specific aspects of such changes, the project intends to provide an integrated view of global changes, mixing studies of specific sectors with large scale approaches. Second, the project seeks to identify the main trends of global changes and project them toward the end of the century. Thirdly, while most long run studies are prospective oriented, the project has a strong quantitative orientation. Benefiting from the highly competent modeling capacities of the partners, the project is able to provide quantitative assessments of global changes trends in various dimensions. Fourth, the project has a strong focus on the climate change issue, surely the most pressing environmental challenge faced by humanity in the present century. Anyway, many insights provided inside the project have a larger potential of application for policy than the climate problem alone. Last, the project has a strong economic orientation, merging the various skills of the partners in economics to assess the main dimensions of global change from an economic point of view.

To address the challenging complexity of the project objectives, Global-IQ has adopted an integrated matrix approach. The project intends to cover six broad areas of global changes:

- Population and economic growth
- Competitiveness and trade
- Energy and energy security
- Feeding a growing population
- Environment
- Climate change

To achieve this aim, it combines top-down approaches (‘global’ looks) with bottom-up approaches (‘sectoral’ looks). It also combines conceptual investigations with empirical research. Thus the full array of economic competencies: theoretical models, econometric studies and assessment models, are mobilized inside the project.

The workpackage architecture of the project reflects these initial choices.

- WP1 is global scale oriented and follows two main objectives:
  - Produce a general conceptual framework to define and analyze global changes,
  - Make a review of the global impacts of global changes
- WP2 is sectoral oriented with the following objectives:

- Literature reviews:
  - Review and meta-analysis of monetary values for non-market values
  - Survey of the existing empirical evidence on competitiveness effects
- Econometric studies
  - Analysis of the effect of environmental variables on environmental concerns, adoption of efficient devices and habitual behavior of households
  - Ancillary Benefit of GHG mitigating policies
  - Ancillary Benefits Estimation in Developing Countries
  - Estimation of nested CES production function for CEE countries
- Conceptual investigations
  - Theory of competitiveness with heterogeneous firms
  - Climate change mitigation with second best policy tools

- WP3 and WP4 are modeling oriented with the objectives:
  - Harmonization of model assumptions to enable comparison of scenarios, development of existing global models in order to capture the so-far neglected socio-economic dimension of global change impacts (including non-environmental global changes), development of methods to assess society-wide major socio-economic impacts of global changes. This includes the development of methods to integrate sectoral and partial analysis into general equilibrium models.
  - Production of reference scenarios assessing socio-economic dynamics along the lines developed in WP1, at the EU, National and macro-regional level, with the models integration developed in WP3, development of alternative scenarios that depart from the reference path and explore alterations of the major driving forces of global changes. Production of aggregate impact functions, under limited adaptation to global changes at the EU, National and macro-regional level.

- WP5 makes the synthesis of the modeling achievements of WP 3 and WP4 to produce a set of scenarios in order to estimate economic and social impacts to global changes, at the EU, National and macro-regional level, when economic agents optimally adapt to global changes. It also produces a cost-benefit analysis of global changes for global warming with emphasis given to the inter-linkages between economic growth, vulnerability and adaptation.

- WP6 develops theoretical and empirical innovations concerning discounting, risk and ambiguity. It implements theoretical innovations concerning discounting and risk valuation inside the models used within the project.

As appears from the above short description of the architecture of the project, modeling and assessment is at the core of Global-IQ. One main issue explored through the models is the adaptation challenge to climate change. The analysis contrasts scenarios of full adaptation (that is without constraints) and limited adaptation scenarios (constrained adaptations). A large array of constraints is considered for different sectors and geographical scales.

MAIN SCIENTIFIC RESULTS

The Global-IQ project has produced three types of contributions: quantitative predictions from integrated assessment models (IAMs), empirical analysis and case studies, conceptual advances. Its results cover three main areas described more in detail in the sequel: global changes assessment through IAMs, specific sectors studies and exploration of key endpoints, management of a risky and uncertain future.

MODELING GLOBAL CHANGES

Modeling and assessment of global changes are at the core of the project activities. Global-IQ benefits from the expertise of lead European research centers in the field.

The Global-IQ modeling suite

The Global-IQ modeling suite is composed of 7 models developed in 5 institutions involved inside the project:

Model acronym	Institution	Model class	Scope
GLOBIOM	IIASA	Partial equilibrium	Food, agriculture, forestry and water
GRACE	ISIS	Spatial	Transportation systems
ICE	WIIW	CGE	Trade, competitiveness, labor
ICES	FEEM	CGE	Global climate change
MagPie	PIK	Partial equilibrium	Agriculture, forestry, environment
REMIND	PIK	Ramsey type growth, global	Energy, growth
WITCH	FEEM	Ramsey type growth, global	Energy, growth

Considering the characteristics of these different models, it has been decided to proceed to a number of developments adapting them to the implementation of the scenarios and to relate the models' results with one another as far as possible. These developments can be grouped into several themes:

- Implementation of linkages between models: GLOBIOM and WITCH on the one hand, as well as MAgPIE and REMIND on the other hand have been soft-linked to better represent the bio-energy supply.
- Improved modeling of the climate impacts on the global economy and in particular on the agricultural sector: damage functions have been implemented in the REMIND model; in GLOBIOM and MAgPIE, climate change impacts on the agricultural sectors have been analyzed through the input of impact coefficients on yields.
- Improved modeling of the energy sectors: in REMIND and WITCH, the representation of the different energy sub-sectors as well as the representation of energy storage, transportation and trade has been significantly refined.
- Modeling of transport infrastructures, transportation costs, and transport pollution: in GLOBIOM, the calculation of transportation costs has been refined on the basis of a downscaled representation of transport infrastructures. The GRACE tool on his side has been used to provide local future scenarios of pollutants emissions due to road transportation.
- Modeling of changes in trade and competitiveness patterns and in labor markets: the ICE model has been used to investigate future changes in trade and competitiveness patterns as well as changes in labor markets characteristics.

Building the scenarios matrix

Ahead of the quantitative assessment work, the project has first identified several critical areas of global changes:

Population	**Population growth, ageing, urbanization, health, lifestyles**
Economy	Affluence, growth, trade, competitiveness, energy and food security
Environment	Climate change, pollution, ecosystem services and biodiversity
Natural resource base	Land use, water use, raw materials and exhaustible fossil resources.

The megatrends of global evolution in these 4 dimensions have been asserted, the objective being to build a reference scenario for future work. We have borrowed elements of the IPCC SSPs framework to generate a consistent set of scenarios, but we did not restrict the analysis to climate change. We build the Global-IQ Reference scenario by reproducing population and economic growth of the SSP2 scenario. The SSP2 is a central-case scenario because current trends are assumed to continue indefinitely in the future. In this report the "Reference" scenario and the "SSP2" scenario are interchangeable. The Global-IQ Reference scenario is characterized by:

- Slowly decreasing fossil fuel dependency
- Reductions of resource and energy intensity
- Uneven development of low-income countries
- Few weak global institutions
- Slow continuation of globalization, with some barriers remaining
- Well regulated information flow
- Medium economic growth, slow convergence
- High intra-regional remaining disparities
- Medium population growth related to medium educational investments
- Delay of achievement in the Millennium Development Goals (MDGs)

We have then transformed the qualitative features of the SSP2 reference scenario into quantitative features able to be accommodated by the modeling suite whose details are appended below:

Population

- Global population increases from 6.8 billion to 9.2 billion in 2050. Europe's population is stable, with Eastern Europe losing about 10% of its population.
- Africa, the Middle East, South Asia and India, a contiguous stretch of the planet that already faces paramount challenges, will be home to about 80% (two more billion people) of the additional population of the globe by 2050.

Economy

- Global economic activity triples in size from 2010 to 2050. The global growth rate per year ranges from 2 to 3%. European countries grow slower than the global average. The USA grows at a slightly higher speed than Europe. The fastest growing region is Sub-Saharan Africa, followed by India.
- Despite slow population growth and slow economic growth, Europe and the USA still command high shares of total global production in 2050.
- Global inequality declines, but substantial income differences remain in 2050.
- Final and primary energy demand increase by 80% from 2010 to 2050. In Europe final energy demand is almost flat from 2010 to 2050.
- Without additional policies, the global and European energy systems continue to be dominated by fossil fuels: in 2050 70-80% of electricity generation and more than 80% of primary energy is from oil, coal and gas.
- Europe has substantial energy deficit. Together with China, Europe is the dominant energy resources importing region until 2050.

- The demand for agricultural products should increase by 50% and 18% at respectively the global and European scales, between 2010 and 2050.
- The increasing demand could be satisfied with relatively stable or even slightly decreasing level of prices, thus projecting relatively comfortable future for consumers, especially in Europe.
- The role of Europe as a major producer in the future is uncertain, with scenarios picturing a share of Europe in future global supply either declining or remaining stable.
- Europe is projected to remain a net importer of agricultural goods, and could even see its agricultural trade deficit increasing.

Environment

- Total GHG emissions from agriculture, forestry and other land use (AFOLU) could reach cumulative levels of 312 to 437 GtCO2eq by 2050, with the methane emissions amounting to more than the half of total AFOLU emissions
- Radiative forcing is equal to 7.4-6.6 W/m2 in 2100. The increase of mean global temperature with respect to the pre-industrial age averages 4°C.
- Climate change is going to cost about 4% of global GDP per year, in 2100.

Natural resources base

- Increase in global cropland is projected to be in the range of 11-15%, with major cropland expansion in Latin America and Africa
- Pressure on water resources is uncertain, and depends on the extent of irrigated agricultural production. Change in global irrigated area ranges from -26% to 26% in 2050 compared to 2010
- There persist substantial differences in the predicted future cost of fossil fuels, due to the uncertainty on the total recoverable amount of fossil resources.

To build deviation scenarios from this central figure, we consider 6 main challenging areas for the global future:

1. Population and economic growth
2. Competitiveness and trade
3. Energy and energy security
4. Feeding a growing population
5. Environment
6. Climate change

To deal with possible cutting issues crossing these different aspects of global change, we next introduce different assumptions over:

- Trade regimes
- Global fossil resources and energy markets
- Climate change mitigation policies
- Environmental policies
- Lifestyles
- Demography and population migration

The next steps are: 1) to select the most suitable models to address these different issues; 2) to select the models for runs of common scenarios; 3) to assess the sensitivity of the results to models assumptions; 4) to build a scenario matrix crossing models, broad areas and potential deviations from the reference scenario. The process resulted into 173 scenarios for global change summarized below. Greater details on the set of scenarios are publicly available at www.giq-europe.eu.

Macro challenge	Subtopics	Full adaptation	Limited adaptation
Reference	---	7	21
Climate change impacts	Agriculture	8	23
	Long-term impacts and cost-benefit analysis	12	6
	Economy-wide impacts	3	12
	Trade	2	2
Climate change mitigation	Representative concentration pathways	12	27
Competitiveness and trade	Trade policy	2	1
Energy	Non-conventional resources	8	6
Environment	Biodiversity	3	3
	Lifestyle changes	1	---
	Local pollutants	1	1
Population and migration	Population growth and distribution	8	4
Total		**67**	**106**

Adapting to global changes

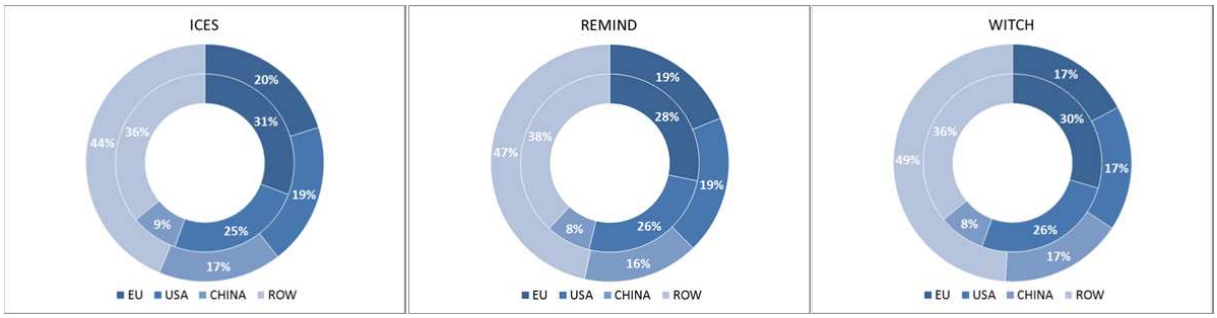
The 173 potential global changes scenarios considered inside the project split into two main categories depending on the extent of the adaptation potential of the global economy to these changes. Adaptation may be done at the private economic agents scale, households or firms. It is also an area for public intervention, which requires planning and most probably internal coordination between public authorities and private agents inside each country together with regional and international cooperation.

The objective of the assessment exercise inside the Global-IQ project is to optimize the adaptation strategies of the private agents, that is, taking into account the costs and benefits of adapting for the private sector, determine the adaptation path they should adopt. Second, we want to extend the exercise up to 2100 in order to take fully into account the effects of global warming which requires considering very long term horizons. It is almost impossible at this time range to explicitly describe the potential public adaptation policies that could emerge at the national or international level. Thus we confine only on private adaptation.

However we contrast two situations. In the limited adaptation scenarios, private agents face adaptive constraints in three domains: technologies (access and transfers), factor substitution (primary energy, land, water, labor and capital), and trade (trade barriers and transportation routes). In the full adaptation scenarios, private agents move inside a fully integrated global economy without factor, technologies or trade barriers. The potential for public adaptation policies may thus be assessed through a comparison between these two benchmark situations. We focus here mainly on the full adaptation results.

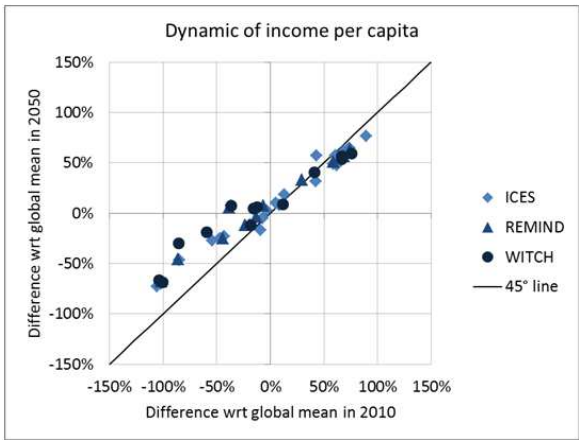
Growth and world inequalities trends

We use the Ramsey growth models ICES, REMIND and WITCH to generate endogenously computed growth trends at the global and regional scales between 2010 and 2050.



Note: inner circle, 2010; outer circle, 2050.

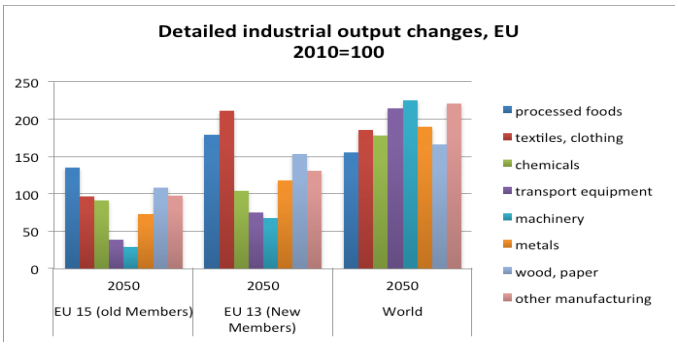
The figure shows the simulated shares of global GDP originated in Europe, the USA and China in 2010 and in 2050. Europe and the USA generate about 55% of world GDP in 2010 and 40% in 2050. China's share of global GDP doubles, from 8 to 16%. The share of all other economies also increases. The world in 2050 is less polarized than in 2010. Half of global GDP is controlled by the USA and Europe in 2010. In 2050 China, Europe and the USA are the three global economic superpowers and almost equally share fifty percent of the global economic activity.



Crossing the models computed growth trends with population trends assumptions from the reference scenario gets the dynamics of countries income inequalities. The simulations show a slow convergence of income. In general, poorer economies grow faster than richer economies, but wide disparities persist within the two groups. For example, income per capita grows at a rate equal to about 4% per year in China and India, but only at about 2.5% in Northern Africa and the Middle East.

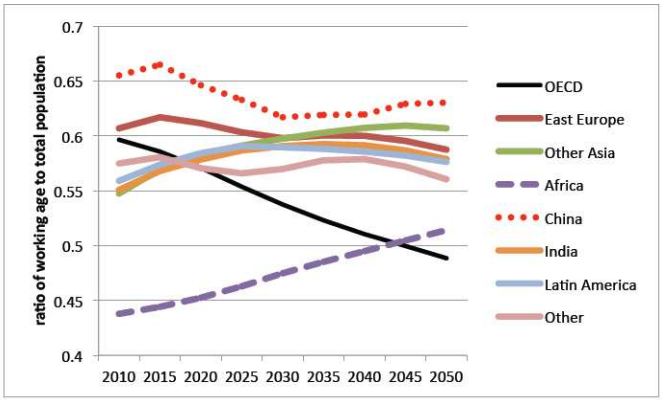
Competitiveness, labor, migration and trade

Different relevant issues uncovering various aspects of global changes have been explored inside the project: dynamics of EU competitiveness, skills dynamics effects and population migration, effects of trade liberalization, opening of new trade routes, food price transmission. The main results of the study are the following.



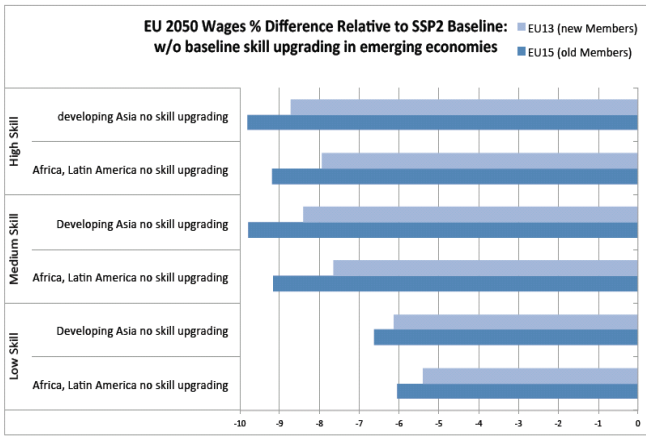
EU competitiveness

The projected figures show strong challenge for the EU industry with various falls of output. Eastern countries face better prospects than western countries. The move towards the services continues in western EU countries.



Labor dynamics

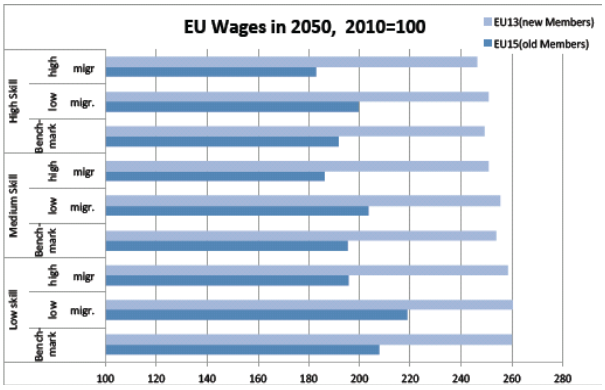
Between 2010 and 2100, 3.9 billion more people will live in Africa. Africa gets a larger share of the world labor force. This has important impacts over population migration potential and the dynamics of the regional wage structure.

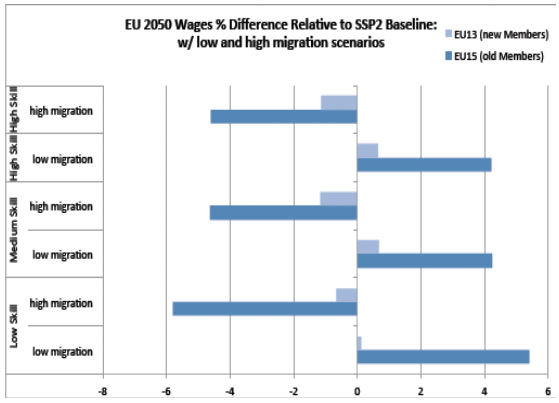


Skills dynamics

Projected estimations from the ICE model show the wage increases in the EU depending on the skills improvements of Asia and Latin America. With trade linkages, education policy (skills upgrading) in emerging markets with a growing labor force are transmitted to the EU. The EU is more competitive (more demand for EU value added) with higher skills levels as a policy response to the emerging markets.

Population migration





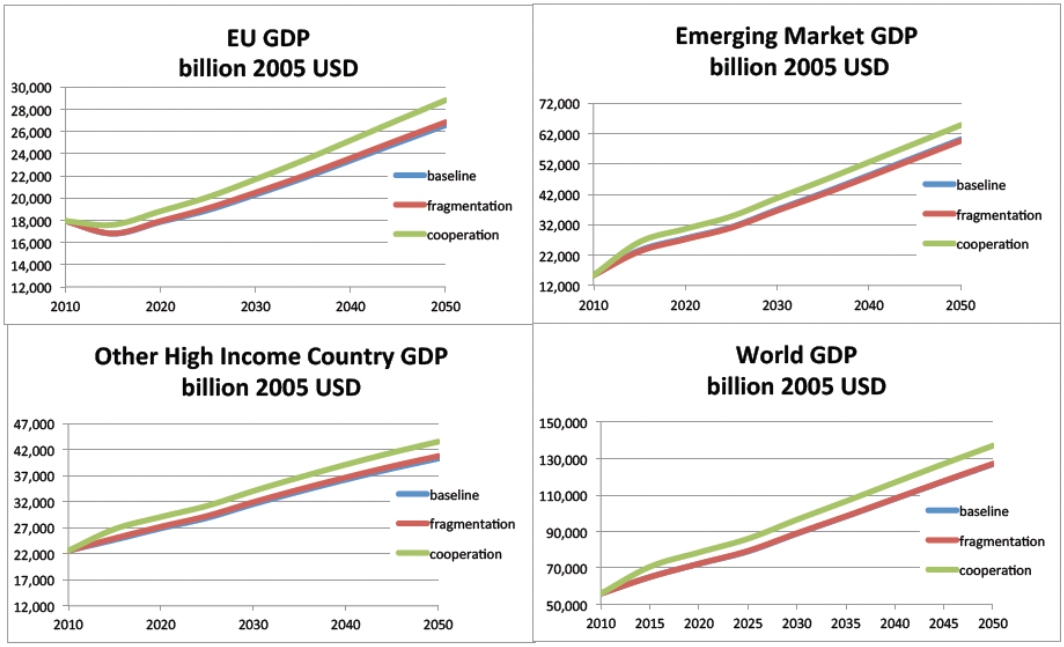
Migration has complex effects over wage dynamics in the EU depending of the skills structure. ICE simulations illustrate that migration has both positive and negative effects under trade linkages. On the one hand, moving workers to high income countries mitigate potential carbon emissions in low income countries while on the other hand it has negative impacts on EU wages.

International trade

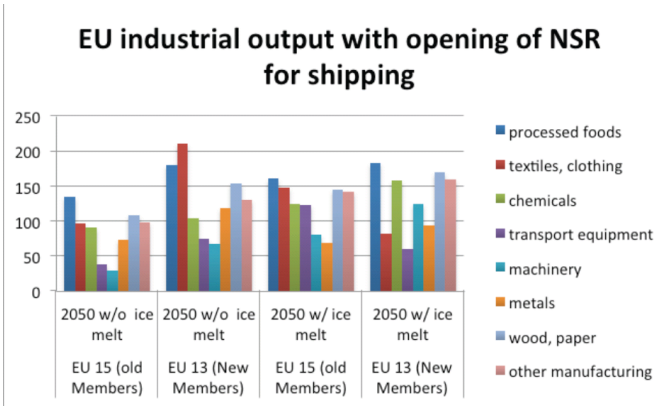
In view of the predicted deindustrialization of the EU 13 members by 2050, we have simulated through the ICE model trade barriers at the EU borders to protect home most impacted industries. Even a partial unwinding of the deindustrialization of the EU is linked to roughly $450 Billion dollars in increased trade by 2050. Indeed, a full unwinding is linked to roughly $1,000 Billion dollars in world

trade. It isclear that the shifts in EU competitiveness are linked to changes in global patterns of production and trade. It is also clear that there are potential gains to a protectionist policy on the EU side, but that this is outweighed roughly 2:1 in losses to trading partners.

Trade between nations evolves more and more outside the WTO system and takes the form of bilateral of regional trade agreements. We refer to this evolution as a fragmentation process and want to compare the consequences of a regionally segmented world with respect to a full cooperative one. We focus here on two scenarios, applied against the Global-IQ reference scenario using the ICE model. The first involves global fragmentation, with the emergence of large blocks covering trans-Atlantic trade, Latin American trade, and trans-Pacific trade. In this case we assume that trade costs fall within the blocks (we assume a fall of 15% for trade cost of goods and 5% for the services) but not against the rest of the world, while remaining tariffs within the blocks are eliminated. In the cooperation scenario, we assume that trade costs (non-tariff barriers or NTBs) fall uniformly globally by the same 15% and 5%, remaining tariffs being also eliminated globally.



The simulations show a very modest positive impact of regional agreement over GDP rise up to 2050 not only for the world at large but also for the countries potentially benefiting from trade fragmentation like the US and the EU. By contrast, trade liberalization in a world which becomes less polarized around core regional growth districts shows substantial growth benefits.

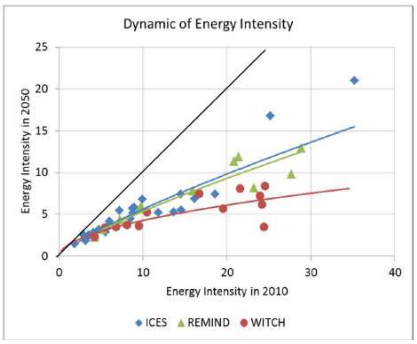


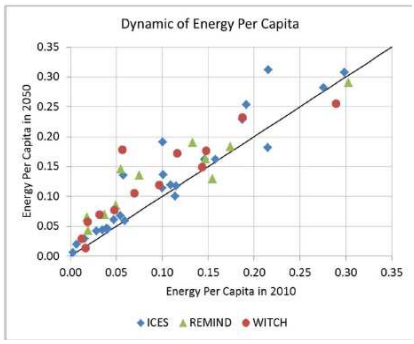
Northern Seas Route

Climate models predict dramatic ice melting in the Arctic Ocean. Simulations show that the opening of a new northern seas trade route (NSR) between Europe and East Asia could have significant positive effects on EU industry output, turning a fall into a positive growth.

Energy

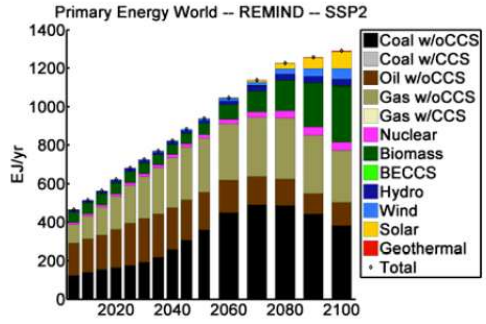
Models runs show a dramatic increase of the world energy demand by more than 80% until 2050. The EU energy consumption remains stable at this same horizon.

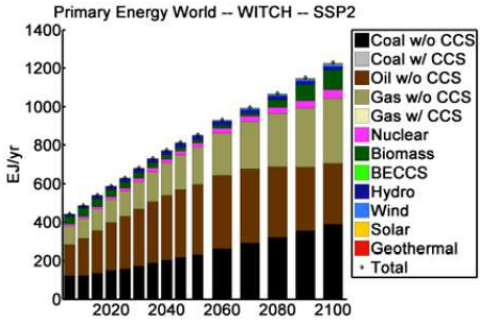




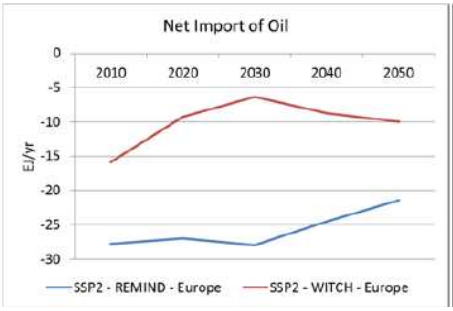
All models predict a significant rise of energy intensity until 2050. However there is no convergence of energy efficiencies between countries.

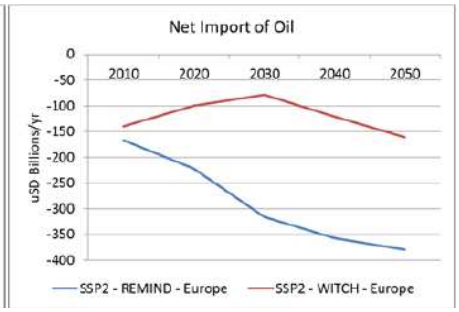
Although the models agree broadly on the aggregate energy consumption trend, their own assumptions show significant divergences with respect to the dynamics of the energy mix up to 2100.





These divergences have of course strong implications for climate change with respect to the share of carbon free renewable energies. All models predict however the dominance of fossil fuels at least up to 2050. The large differences between the models concerning the energy mix dynamics translate into divergent evolutions of EU imports of fossil fuels and price dynamics, as illustrated below for the example of oil.





Model runs with alternative scenarios show the same sensitivity of the trends of relative consumption of coal, oil, gas and also the potential rise of renewable energy. However all models show an increase of energy imports in Europe, amounting to 80% for oil and 90% for gas. China faces the same kind of energy security problems by 2050, becoming the main competitor of the EU on the world primary energy market.

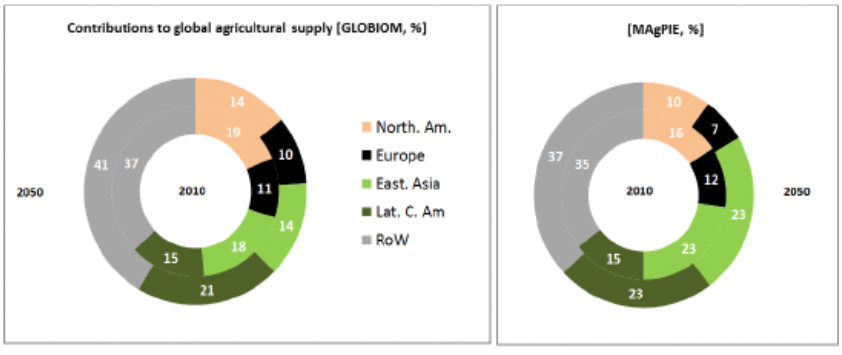
The future of concentrated solar power (CSP) in Europe and in Middle East and North Africa (MENA): a Trans - Mediterranean power grid?

We have examined the effects of introducing Concentrated Solar Power (CSP) transmitted by means of Super-Grids (SG) in five regions of the world: China, Eastern Europe (E-EU), Western Europe (W-EU), the Middle East and North Africa (MENA) and the United States of America (USA). The Integrated Assessment Model WITCH is used to perform a numerical assessment of the economic and technological potential of CSP and its transmission over long distances. The model was upgraded for the project to include CSP and trans-Mediterranean power grids. The analysis of the simulation scenarios shows that:

- An extensive use of CSP will generally become optimal after 2050. Constraints on the use of nuclear and/or of IGCC coal with CCS have an impact on the size of investments in 2050, but a smaller effect on later years, when the cost of CSP declines sharply. CSP generation by MENA is optimal from 2040 onwards and large, under all climate policy scenarios. In the second part of the century it becomes optimal even in the Business as Usual scenario.
- In the first part of the century, it is convenient for Europe to import electricity from the MENA region only when there are constraints to the expansion of nuclear and/or to the use of IGCC coal with CCS. Trade starts around 2040, at about 30c$/KWh. The price of CSP decreases over time to 10-11 c$/KWh.
- In the second part of the century, CSP covers a very large share of the electricity mix in all regions in which the option is available.
- CSP is an important technology option that has a high stabilization cost option value, especially in coal intensive countries. Depending on the scenarios, the option value, measured as the percentage of discounted GDP, ranges between 2.1 and 4.1% of GDP in MENA, between 1.1 and 3.4% in China, between 0.2 and 1.2% in the USA, between 0.1 and 1.3% in E-EU and between 0.1 and 0.4% in W-EU. Most importantly, CSP reduces greatly the option value of nuclear power and IGCC coal with CCS.
- If we compare our results with the literature we find it optimal to invest later than most studies do. We also find that it is optimal to invest less in CSP if we do not constrain nuclear and/or IGCC coal with CCS. The constrained scenarios increase the expansion of CSP and anticipate it.

Agriculture, forest, land and water

Due to an increasing and wealthier population, food consumption is expected to increase by 54% to 98% between 2005 and 2050. The ability of meeting this demand through an increased supply is challenging. This is reflected in the large variances of the potential price impacts between assessment models. Depending on the models used, it is estimated that the prices of main agricultural commodities could either decrease by 17% or increase by 37% in 2050 compared to 2005 under SSP2 assumptions. In the project we impute 60% of supply increase to technical progress and 20% to crop area increase. The projected regional contribution to supply increase in the GLOBIOM and MAgPie are illustrated below.

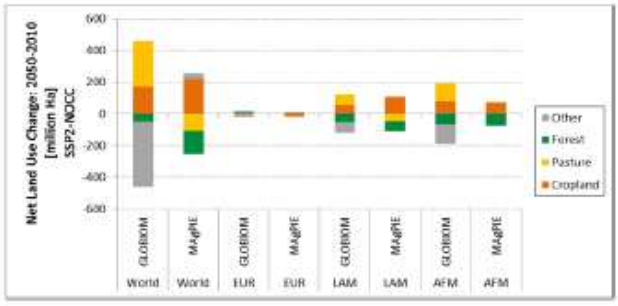


For Europe, the two models largely disagree. For GLOBIOM the European supply largely increases (+52% compared to +79% at global scale)

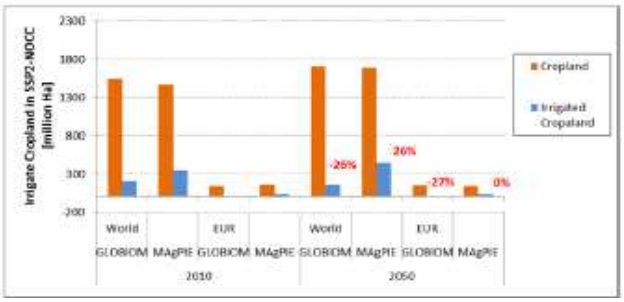
with a worsened European agricultural trade deficit: from -25 billion US$2005 in 2010 to -31 billion US$2005 in 2050. For MAgPIE, the scenarios are more pessimistic for European producers: supply remains similar to 2010 level (-2%). The drop in European agricultural trade deficit in MAgPie is three times more intense than for GLOBIOM (4 billion US$2005 in 2010 compared to -34 billion US$2005 in 2050).

Land use, forest and water pressure

The up to 2050 projected increase of cropland ranges from 11% for GLOBIOM to 15% for MAgPIE, meaning an additional 171 Mha and 220 Mha respectively. These results are in line with the FAO projections and recent agricultural models comparison exercise (AgMIP). GLOBIOM and MAgPIE simulate land use dynamics at a high resolution level, including the conversion of forest and other natural vegetation types (such as unmanaged grasslands, savannahs, schrublands) into agricultural land covers (cropland, pasture) at an increasing conversion cost.



Both models project deforestation equivalent by 2050 to a loss of 1% (GLOBIOM) and 4% (MAgPie). In addition, GLOBIOM simulates an increase of about 80% of managed forest by 2050 at the expense of primary forest. Latin America and Africa-Middle East account for around 80% of total cropland expansion from 2010 to 2050.



Models strongly diverge in their projections regarding irrigation worldwide. MAgPie projects a 26% increase in irrigated cropland area while GLOBIOM reaches the opposite conclusion of a 25% decrease over 2010-2050.

Without considering GHG emission mitigation efforts, both models project considerable additional emissions from 2010 to 2050. Global cumulated emissions from agriculture, forestry and other land uses (AFOLU) between 2010 and 2050 average 312 (GLOBIOM) and 437 Gt (MAgPie) of $GtCO_2eq$. Consistent with overall land use dynamics, cumulated global carbon dioxide (CO_2) emissions due to land-use change amount to 67 (GLOBIOM) and 114 $GtCO_2eq$ (MAgPie). Methane emissions from agricultural production represent more than half of the total AFOLU cumulated emissions (186 $GtCO_2eq$ or 60% for GLOBIOM; 222 $GtCO_2eq$ or 51% for MAgPIE).

Environment, pollution and biodiversity

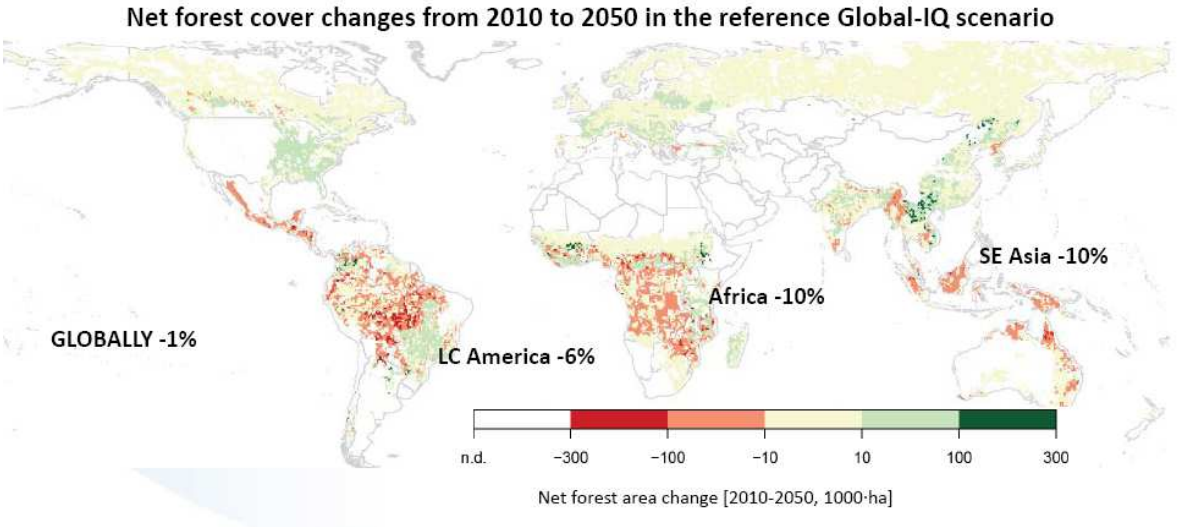
Modal shifts and air pollution

The EU commission Transport White Paper (TWP) defines a list of major initiatives to guide the European transport system towards a substantial decarbonisation. The TWP identifies 3 main pillars of action: 1) Developing and deploying new and sustainable fuels and propulsion systems; 2) Optimizing the performance of multimodal logistic chains; 3) Increasing the efficiency of transport and infrastructure use with information systems and market-based incentives.

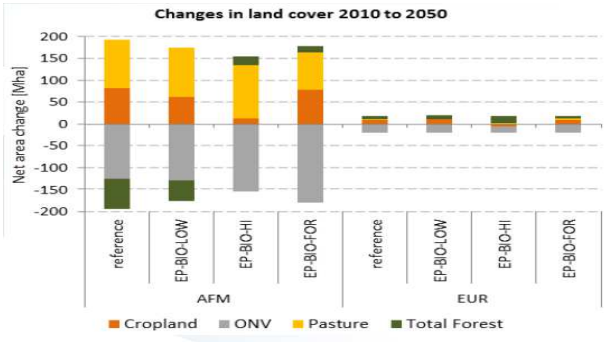
To assess the potential impacts of the TWP, we examine a variant of the GLOBAL-IQ reference scenario with a 15% increase of public transport and full adoption of the most carbon efficient technologies in transportation. The model runs show that CO2 emissions decrease by 34% instead of a 15% increase in the reference scenario; SO2 emissions decrease by about 38% in 2050, instead of a slight increase by 0.2% in the reference scenario; PM10 emissions decrease in 2050 by about 70% (-9.3% in the reference scenario); Nitrogen oxides emissions decrease by about 66%, (- 19.4% in the reference scenario); last NMVOC shows a 72% decrease (- 18% in the reference scenario).

In monetary terms the social benefit would amount to € 28 billion by 2050, with air pollution costs reduction accounting for 51% of the total (€ 14.3 billion), followed by climate change costs (€ 4.8 billion), accident costs (€ 4.3 billion), congestion (€ 2.9 billion), and noise (€ 1.5 billion).

Biodiversity



Model runs have shown highly heterogeneous deforestation impacts of farm land use increase in response to a higher world food demand. Land conversion is a threat for biodiversity conservation. We have considered three different scenarios, aiming at representing different policies targeting biodiversity protection, and then compute their implicit costs and spatial impacts. The first scenario corresponds to the "Zero Net Deforestation and Forest Degradation" (ZNDD) scenario presented in the 2011 WWF report. In GLOBIOM, we ban at high spatial resolution net conversions from managed forest to cropland and primary forests to both cropland and grassland for the whole world. Although not particularly targeting biodiversity as such, this scenario indirectly protects areas potentially host to rich biodiversity, and concerns 42.3% of the global forest cover. Two additional scenarios targeting more specifically biodiversity have been also considered: 1) forbidden land-cover conversions at high resolution for pixels defined as biodiversity priority areas; 2) In addition, forbidden conversions from grassland to cropland and from other natural vegetation to cropland.

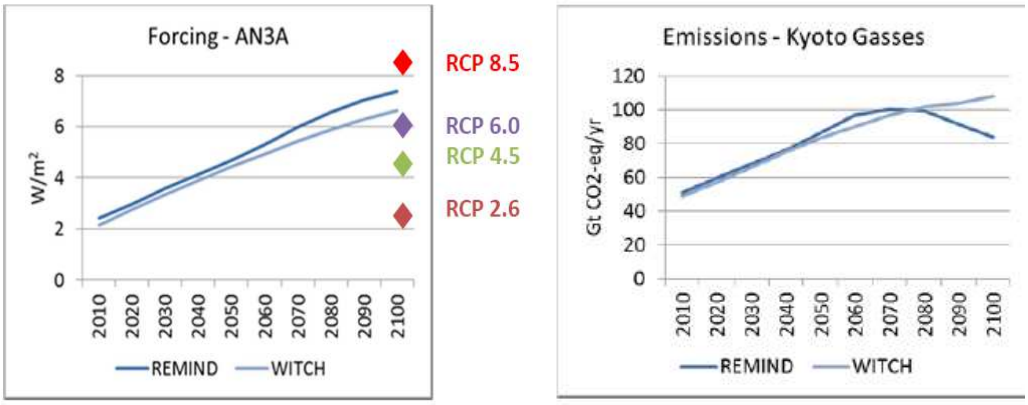


The GLOBIOM simulations show modest effects for the EU, more significant worldwide. Forest area increases up to 5% (1% in SSP2). Land conversion is moved toward lower biodiversity richness areas but also less productive lands (-18% for other natural vegetation against -14% in SSP2). This has

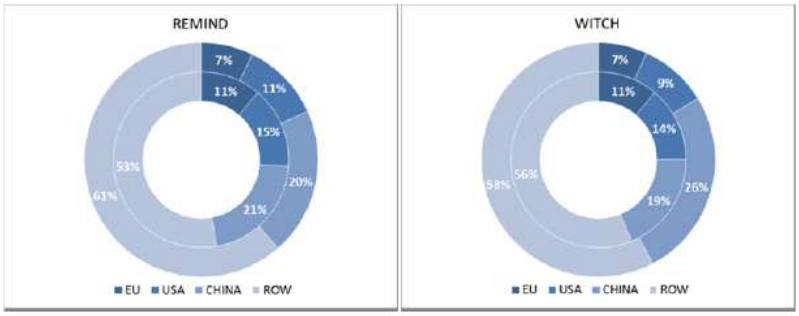
strong food consumption impacts (+8% intake/cap in Africa instead of + 18% in SSP2) and price impacts (+ 36% rather than -2% in SSP2).

Climate change

The models predict a permanent rise of carbon emissions in the SSP2 reference scenario. They differ in predicted trends after 2080. With respect to Reference Concentration Pathways (RCP), the impact of this predicted trend over cumulated pollution targets a high forcing scenario between RCP 6.0 and RCP 8.5. This corresponds to a temperature rise around + 4° by the end of the century.



China and India are the main contributors to the emissions increase (around 20% each of the total emissions increase).



The share of emissions between countries follows more or less the growth trends of economic regions. A less polarized world will result in a more dispersion of emissions levels around the world.

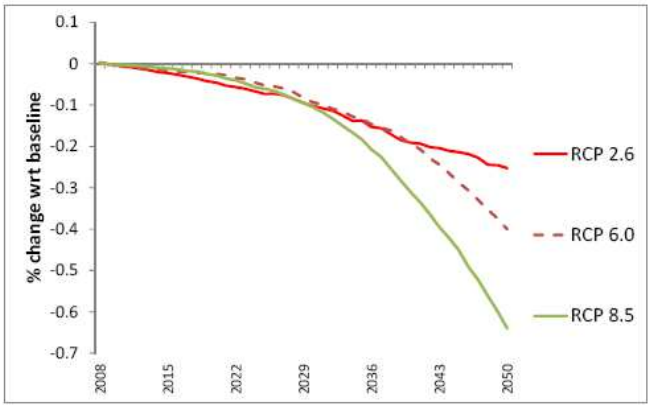
Climate change impacts

We first consider the impacts of climate change in the reference scenario. The high 8.5 RCP scenario seems excessive and we concentrate on the RCPs 2.6, 4.5 and 6.0. Our objective in doing so is to perform a cost-benefit analysis of the RCPs as carbon stabilization policy objectives. This requires computing the climate impacts in the 3 scenarios and next to compare them to the mitigations costs they suppose.

Using the GLOBIOM and MAgPie models we have estimated the climate change impacts on agricultural yields. Such impacts are highly sensitive to the biophysical assumptions about the effects of climate regimes on crops. The models using different biophysical representations, it comes at no surprise that they produce contrasted results. GLOBIOM simulations based on the EPIC crop model predict overall yields decreases between – 3% and -11% in 2050 with respect to 2010 while MAgPie based upon the LPJml crop model predicts a + 6% increase. Both models predict however highly heterogeneous regional impacts. In addition agricultural impacts are highly sensitive to the adaptation strategies of the farmers: technological adoptions, crop choices, land use decisions,

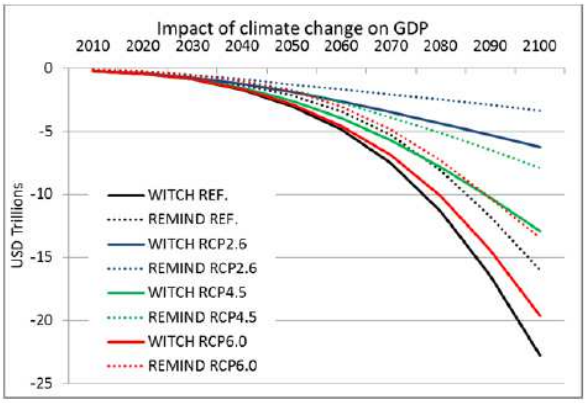
irrigation practices. Last, the heterogeneous spatial impacts of climate change should induce crop relocation while international trade should balance more or less the climate impacts on food prices and markets. When accommodating for the farming sector reactions, both models conclude to limited impacts of climate over food consumption until 2050 under full adaptation. Runs with constrained adaptation possibilities show more pessimistic figures with increased regional discrepancies.

To produce global figures of climate impacts, we have mobilized inside the ICES model relevant figures produced from various projects and studies. In addition to agricultural impacts already described, we have considered: 1) Sea level rise through the DIVA model and the Climate Cost project; 2) Fisheries through the SESAME project; 3) Tourism through Climate Cost; 4) Energy demand through the POLES and Climate Cost projects; 5) Forestry through Climate Cost; 6) Ecosystem services through a reduced form; 7) Health through a reduced form.



As expected, RCP 2.6, a stabilization scenario, produces the lower costs, while RCP 6.0 is in the middle of the range. In 2050 total costs remain small, even though the climate scenarios considered are those consistent with the higher CO2 concentrations. Temperature increase indeed is slightly beyond the 2.5°C increase. Impacts are still manageable remaining at -0.6% of GDP in the highest concentration RCP 8.5. The worldwide impact hides strong regional differences however. India and South Asia, followed by Sub-Saharan Africa are expected to lose respectively 4.2%, 4% and 2.2% of their GDP in 2050 even in a moderate warming world.

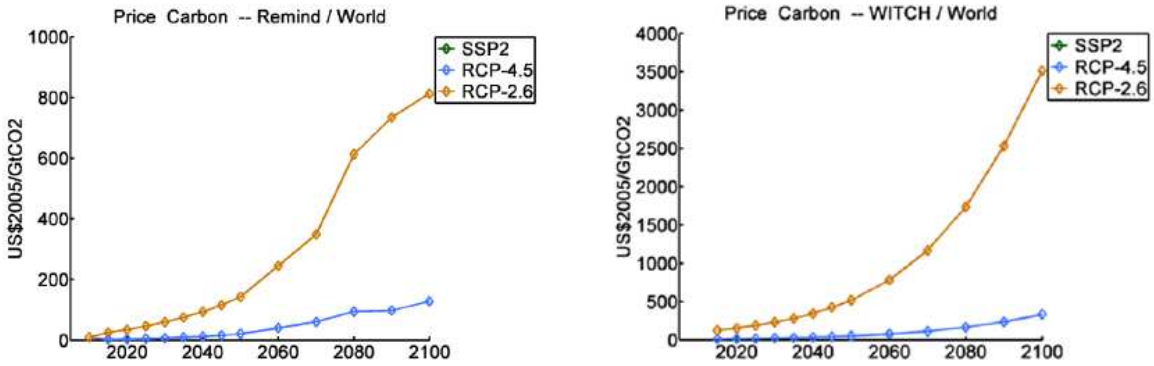
We use the climate change impact functions estimated using ICES, the temperature and the GDP pathways of WITCH and REMIND to estimate the economic cost of climate change. It is important to note that we do not run WITCH and REMIND directly with the damage functions provided by ICES. We simply calculate damages after GDP and the global mean temperature have been determined by the models. This method does not guarantee full consistency but still provides very useful and sufficiently accurate insights up to 2100.



Negative impacts of climate change amounts to 4% of the world GDP by 2100 (around – 20 trillions US$).

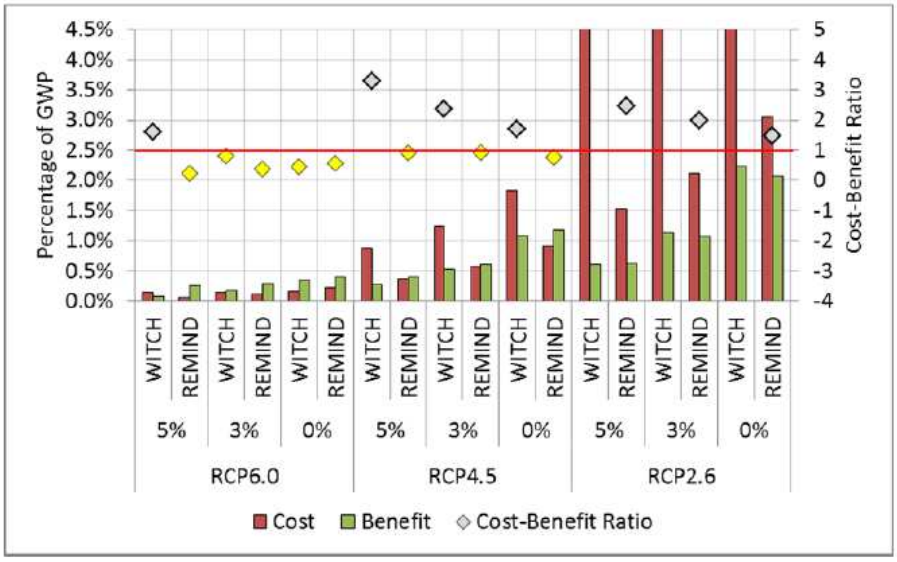
In order to complete the cost-benefit exercise we have also computed the mitigation costs implied by the climate targets RCP 2.6, 4.5 and 6.0. For this aim, we have run the models imposing the corresponding concentration targets as constraints. Corresponding shadow prices of the constraints then provide the mitigation costs estimates used in the cost-benefit analysis. As an example, the below graphs illustrate the projected dynamics of the opportunity cost of carbon up to 2100 in the different

climate stabilization policies. Logically, the stringent RCP 2.6 scenario results in much higher implicit carbon prices.



Two main areas of mitigation costs have been extensively studied: 1) The energy sector: demand impacts, energy mix impacts, energy prices and fossil fuel trends impacts; 2) The agricultural sector: demand impacts, land use and crop location impacts, market and prices impacts.

The following graph summarizes the conclusions from the cost-benefit analysis putting together impact costs and mitigation costs for the three stabilization policies considered in the Global-IQ project for the WITCH and REMIND models with three discount rates: 0%, 3% and 5%.



The study concludes that the climate policy objective to keep the global mean temperature increase below 2°C does not pass the cost-benefit test. REMIND finds that the RCP 4.5 would pass the cost-benefit test while WITCH suggests that only the RCP 6.0 target, with 3% or no discounting, delivers benefits greater than costs.

ANALYSYS OF SECTORAL ISSUES AN KEY ENDPOINTS

The sector wide studies of the project fall into three main categories:

- Literature reviews and meta-analysis
- Empirical studies and case studies
- Conceptual investigations

The relevant material covers a broad set of issues: health, international trade, environmental valuation, energy demand by households, distributive and policy effects,

Before entering into the detail of the studies and their main results, the work must be replaced inside the overall architecture of the project. The studies fall into two main categories. Some were intended to be able to feed with relevant figures the modeling work inside the project, other explore cutting issues relevant to the analysis of global changes and possible policy options.

Literature reviews and meta-analysis

Literature surveys and meta-analysis of non market valuation of environmental goods in relation to climate change.

The literature has adopted two main ways to assess the impact of climate change over households, a core issue in identifying a 'damage function' for climate change at the households' level. The first one is top-down, asking directly to respondents their willingness to pay (WTP) for avoiding climate change. Such studies concluded for example that Swedes, Americans, and Chinese are willing to pay 1.6%, 1.1%, and 0.9%, respectively, of their income to prevent a warming of more than 2°. This method is susceptible to bias thus many analysts rely on bottom up approaches attempting to derive welfare impacts of climate change as endpoints of more general environmental value losses of ecosystem services. We have synthesized this literature by focusing mainly on existing meta-analysis for ecosystem services valuation. Existing material covers so far mainly forest ecosystem values and wetlands, but other types of ecosystems such as freshwater and marine ecosystems or agricultural land have been investigated. They exhibit an extremely high range of variations: the analysis of Brander (2005) for wetlands worldwide conclude to a mean value of 2800$/ha/y while the older study of Brouwer (1997) came up with an estimate of 62 $/y/cap for the same type of ecosystems. Such discrepancies have methodological motives but reflect also the high intrinsic differences between the ecosystems services to be valued. This is a problem for assessment modelling of climate change since it should rely on highly dispersed distributions of values.

We have performed a meta-analysis of outdoor recreation values for forests in Europe. Relevant studies have been searched through databases like EVRI, peer reviewed literature and EU funded projects (INTARESE, ClimateCost, NEEDS, PASHMINA). The results from the analysis are next used in a benefit transfer exercise to provide country based forest values. The average predicted recreation benefit per capita per year associated with 1 square kilometre of forest is 92 EUR 2012 (925 EUR 2012 per 1 hectare of forest), with 95% probability the average value lies between 58 and 147 EUR 2012. The same has been done for the value of a forest trip, a widely used measure in valuation studies. The predicted benefit per trip for Europe is 10.4 EUR 2012, and with 95% probability it lies between 8.2 and 13.2 EUR 2012. The geographical distribution of the benefits shows that northern European and Baltic countries value far more forest conservation than central European countries.

Valuation of climate change impacts on human health

The review summarizes the existing evidence in Europe from the literature and funded EU projects (ClimateCost, PESETA I & 2, ENSAMBLES, MICRODIS) concerning the potential health impacts of climate change. Climate health impacts come from direct and indirect pathways. Direct pathways include weather extremes (winter cold and heat waves), extreme events (floods, storms), induced air pollutants and allergens increases. Indirect effects are linked to impacts over water and food quality and vector-borne diseases. More indirect impacts resulting from food or water shortages, loss of livelihood or forced population migration are far less monetized today. The review shows large methodological discrepancies in monetary estimates. Mortality costs in PESETA range from 8 years of lost income to 0.5 years of loss for one premature death. Morbidity costs show the same extreme variance from 2990 € to 8074 €. This may be compared to the ExternE methodology which estimates losses in GDP per capita terms concluding to an estimate of 135 €/day. Health valuation approach in integrated assessment models is another example of this lack of consensus. Computations from the FUND model assume a loss of 200 times GDP per capita while DICE studies use an estimate of 2 years of GDP per capita.

Ancillary benefits of climate change mitigation

Ancillary benefits (or co-benefits in the OECD terms) of climate change mitigation are the indirect benefits in terms or air pollution induced by policies intended to mitigate carbon emissions and which at the same time improve air quality in terms of conventional pollutants (sulfur dioxide, NOx, particles). They have recently attracted the research in the context of the climate debate. Mitigation of carbon emissions policies contribute indirectly to the reduction of environmental problems, especially in emerging and developing countries and thus creates an incentive for these countries to participate into an international climate agreement, reducing free riding problems.

To assess the magnitude of these benefits in developing countries, the literature has relied on computable general equilibrium models (CGE) in a top-down way and econometric studies from on-the-field approaches in a bottom-up way. Today, estimates from econometric studies are used as inputs in large scale CGE models for cost-benefit assessment of climate policies. Benefits considered fall in two main categories: health benefits in terms of reduced mortality and morbidity and productivity benefits, environmental policies favouring the substitution from low productivity techniques and equipments (also dirty) to high productivity equipments (cleaner). By now yet undone for developing countries, the analysis has been extended to land productivity effects using atmospheric dispersion models and geophysical modelling. Concentrations are then translated in exposure through response-dose models. Last, econometric protocols (e.g. contingent valuation surveys) or more or less direct measures of health care costs (medical expenditures) produce welfare estimates of health impacts. One difficulty of this method is to derive a good assessment of the initial health status of the population and broad environmental conditions of the country, ancillary benefits being computed in view of the difference between an improved situation thanks to carbon mitigation policies with respect to some baseline situation.

Literature survey on competitiveness effects of unilateral GHG mitigation policies

Because of the principle of 'common but differentiated responsibilities' stated in the UNFCC, climate change mitigation raises the issue of an increasing asymmetry inside the global economy. The problem is not new however. The same may be said of numerous remaining trade barriers between countries or domestic regulation constraints (e.g. labor market, fiscal regimes). The competitiveness

literature has explored already the issue of 'pollution heavens' (PH), the firms having an incentive to relocate their most polluting activities from countries with stringent environmental regulations to countries with lax ones. Recently a burgeoning economic literature has emerged on the theme of the detrimental competitiveness effects for domestic firms of unilateral commitments in GHG emissions rates cuts by developed countries, especially the EU countries. Summarizing the main findings of these studies is the objective of the review.

Even if they benefit from past efforts in studying the global impacts of differentiated environmental regulations (the PH hypothesis), the analysts face serious conceptual and empirical challenges. The potential relocation of high carbon emitting activities to developing countries raises the issue of 'carbon leakages', developed countries 'importing' in some sense carbon from abroad. Carbon mitigation should have strong impacts on fossil fuel markets and more generally on domestic energy markets, thus competitiveness losses are not limited to highly carbon intensive industries but may extend to the whole economies. The potential policy measures to compensate domestic industries from competitiveness losses have strong political economy implications through lobbying activities of the most impacted industrial sectors. 'Dirty' plants are often less productive, protecting them thus slows down productivity and thus competitiveness gains. Growth implications of carbon policies also matter and last there is a strong issue of scale choice for the analysis: either favor a macro approach stressing the main impacts on trade and growth or turn to a micro oriented approach emphasizing the potentially significant heterogeneity among firms inside one country or at the international level.

The review stresses the significant competitiveness losses exhibited in the literature while ex post studies (that is after policy implementation) conclude to more modest figures. The literature has devoted recently a lot of attention to this issue, contrasting border taxes with target measures for impacted industries. If the available studies conclude to a better effect on competitiveness of target measures over border tax measures, the debate remains open, one reason being the lack of account for firm heterogeneity in these studies.

Empirical studies and case studies

The motivation for dedicated empirical and case studies inside the Global-IQ project is twofold. First, some studies were intended to produce estimates or methods able to feed the work done in the modeling part of the project. Second, other studies address shortcomings identified through the literature reviews and extend the present state-of-the-art in various directions. We now summarize the topics analyzed inside the project and present their main findings.

Valuation of mortality risk attributable to climate change

The health impact attributable to climate change has been identified as one of the priority areas for impact assessment. The main goal of the study is to estimate the monetary value of one key health effect, which is premature mortality. Specifically, our goal is to derive the *value of a statistical life* (VSL) from people's willingness to pay for avoiding the risk of dying in one post-transition country in Europe, i.e., the Czech Republic. We carried out a series of conjoint choice experiments in order to value mortality risk reductions. The VSL is about EUR 2.4 million, and our estimate is comparable with the value of preventing a fatality as used in integrated assessment models.

Ancillary effects of GHG mitigating policies (the external costs of energy generation)

GHG mitigating policies can have positive "ancillary effects" on public health, crop yield, ecosystems and building materials, and such effects, if they can be measured in monetary terms, can be

subtracted from the costs incurred on mitigation policies in order to assess properly the social effects of such policies. The relevant review has shown the high variance of results with values ranging from 2 to 585 EUR per ton of carbon reduced.

We have developed a modelling framework to be linked with the macro models, WITCH and ICES, able to provide assessments of ancillary benefits. The soft-linkage procedure is based on estimated damage factors per energy output and per pollutant allowed. For an estimation of the damage cost per kWh of produced electricity and per pollutant, we use country-specific external cost estimates per energy technology and per ton of non-GHG emissions (SO2, NOx, PM, NMVOC, heavy metals) generated within the ExternE (Externalities of Energy) projects. Using the estimated damage factors from ExternE, the ancillary benefits of air pollution reduction, expressed as avoided external costs from emission reduction, are calculated for several integrated global scenarios developed in the Global-IQ project. Based on the computations from WITCH and ICES for "Climate change impacts" and "Climate Change mitigation" with or without adaptation, the results indicate that ancillary benefits, computed only for the European regions, are significant, particularly in the full adaptation scenarios.

Ancillary effects of GHG mitigating policies in Europe: a case study in the transportation sector

Ancillary benefits (co-benefits) of GHG abatement strategies in road transportation sector primarily involve impacts on air pollution. Technological improvements in vehicle emission standards, for example, imply, as a by-product, reductions in pollutant emissions of nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO2), particulate matter (PM) and other pollutants.

The case study provides an assessment of the ancillary benefits in terms of air pollution reduction external costs, estimated for transport activity along one big European transport road freight corridor: the Brindisi (IT)-Koln (DE) South-North European axis. Results show high potential if technological improvement in CO2 emission standards are applied for a typical truck, i.e. from EURO 2 to EURO 4. Considering just one corridor segment, the Bologna-Milano A1 motorway, along 192 km, for which data on traffic volume are available, potential benefits account by an annual € 6.5 million (air pollution) and € 1.4 million (climate change). The impact assessment scenario also provides indications of potential ancillary co-benefits arising from accompanying measures in transportation, such as banning heavy traffic in congested areas or sub urban areas, through the analysis of how unitary costs per vehicle kilometre of congestion, noises and accidents vary during night-day period, traffic conditions and geographical context (sub-urban and rural areas). Along the corridor, transport external unitary costs in sub-urban areas are +17% to +60% higher than compared to the same costs in non urban areas. The reasons stem from a) the traffic conditions in motorways segments located in sub-urban areas, in general more dense and prone to high consumption and emissions per vehicle kilometre; b) the different concentrations of population density in sub-urban areas, generally higher than population living along motorways segments crossing rural areas, rising the costs for noise emissions, accident risks and congestion.

Linking traffic noise, noise annoyance and life satisfaction: a case study

The primary purpose of this study was to explore the link between rail and road traffic noise and overall life satisfaction. We propose a model that links objective noise levels, noise sensitivity, noise annoyance, residential satisfaction and life satisfaction. Since it is not clear whether a bottom-up or top-down relationship between residential satisfaction and life satisfaction holds, we specify models

that incorporate both of these theoretical propositions. Empirical models are tested using structural equation modelling and data from a survey among residents of areas with high levels of road traffic noise and rail traffic noise. We find that traffic noise has a negative effect on residential satisfaction, but no significant direct or indirect effects on overall life satisfaction. These results are very similar for the road and railway traffic contexts and hold regardless of whether the model assumes the top-down or bottom-up direction of the causation between life satisfaction and residential satisfaction.

Ancillary benefits estimation in developing countries: a case study

This research quantifies the value of health costs of air pollution in Beijing, China, in order to assess the potential ancillary benefits that an emerging country could experience if it coupled GHG emissions abatement with reduction of local air pollution. The study was undertaken in combination with Peking University and consists of two separate surveys that elicit in different ways the damages of air pollution to health.

A first survey collected information about the annual medical expenditures of urban dwellers and the number of days of work lost due to airborne diseases, in order to estimate the total costs of illness (COI) borne by a typical individual due to air pollution. The results of this survey, among other things, provide a lowest bound for the health costs due to air pollution for the urban population of Beijing; they do not include the pain and distress caused by the illness, nor the actual costs borne by the public health system to cure the illness. We find that the average COI in our sample is more than 3000 yuan per year, corresponding to almost one month of the average wage (a bit more than 500 US $ per year). This is quite large, considering that it represents just a minimum benchmark for the damages caused by pollution to health. In itself, it already indicates that Beijing could benefit quite significantly from reducing air pollution in terms of health costs: if it could completely eliminate pollution, the savings in terms of COI would range in an order of magnitude of 21 million yuan per year only from hospitalized cases.

We also conducted a second survey, estimating the willingness to pay (WTP) for cleaner air, using different instruments for payment. The study estimates the value of a statistical life (VSL) related to air pollution in Beijing to be at least 16.8 million yuan, while the WTP for avoiding one case of respiratory or cardiovascular illness amounts around 7.7 million yuan, and the WTP for avoiding one case of cold symptom to 50 yuan. These results are relatively high compared to previous studies, especially because people were offered also alternative means of paying for cleaner air, e.g. a tax reallocation away from other public goods.

Population dynamics and large scale health effects of global change

The epidemiological transition and the hypothesis of the compression of morbidity and mortality have provided the theoretical background for the expectation of a convergence in mortality patterns. We formally tested and rejected the convergence hypothesis for a sample of industrialized countries during the period 1960 to 2008. After a first phase of convergence during the 1960 decade, a sustained process of divergence emerged with a pronounced increase at the end of the 1980's, explained by the trends of the former Soviet Union countries (Eastern countries). While Eastern countries abruptly diverge after the dissolution of the Soviet Union, differences between Western countries remained broadly the same during the whole period. Western countries transitioned from a strong correlation between life expectancy and variance in 1960 to no association between both moments in 2008 while Eastern countries experienced the opposite evolution.

Land use competition

The impact of climate change on land use depends on how land owners respond to changes of their economic environment. In that respect, the estimation of land use elasticities is a crucial input in the assessment of climate change damages, and the accurate assessment of climate damages calls for spatially explicit models of land use which account for dynamic decision making. Spatially explicit models are important because the environmental harms resulting from agricultural land expansion depend on where the expansion happens. For example, expansion of agriculture into forest land generally results in considerably higher non internalized ecological costs than expansion into grassland. Accounting for time dynamics is also important because farmers respond differently to different sorts of price changes. Year-to-year price variation is somewhat temporary. However, climate change can lead to price changes that may be sustained indefinitely. Quite sensibly, landowners may be willing to pay considerable fixed costs of bringing new land into agricultural production when favourable prices are expected to last for a long time, but less willing when high prices are only expected to last temporarily. Thus, the sort of price variation we observe in the data (short-term variation) may be very different than the price changes in the counterfactuals we are interested in (persistent changes).

We develop a new framework for analyzing land use change with dynamically optimizing landowners. The main methodological contribution of the study is to show how a dynamic land use model can be estimated using a linear regression equation without modelling explicitly how market-level state variables evolve. Using rich data on land use data in the United States, we estimate a relatively large long-run cropland-price elasticity of 0.3. This elasticity is roughly ten times larger than static elasticities estimated using the same data.

To give the results some context, we revisit Roberts and Schlenker's (2013) assessment of the effects of the US biofuels mandate. Comparing the long-run elasticity estimates using dynamic model to static elasticities based on the same data, we find that taking dynamics into account leads to a 160% larger land use effect and a 78% smaller price increase in the long run. An important direction for future work is to quantify how land use elasticities differ around the world. As agricultural activities expand, they will tend to expand more in areas with higher land use elasticities. Thus, the methodology could be used in future assessments of climate change damages to paint a more accurate picture of land use change impacts.

Estimation of nested CES production function for CEE countries

Assessment done through conventional computable general equilibrium models (CGE) relies heavily on various types of elasticity measures. This raises two issues: first the typical non linear forms assumed in CGE models are highly sensitive to errors of measurement of elasticities. Second despite considerable efforts, the modellers cannot for the moment rely on robust estimates for these key parameters.

The objective of the study is to produce estimates of the elasticity of substitution between production factors for industrial sectors in Central and Eastern Europe (CEE) together with Western Europe. We provide estimates of elasticity of substitution between Capital, Labour and Energy for 9 different sectors separate 10 CEE countries and 17 other European member States under 3 different nesting structures of the CES function. We also compute aggregate elasticities estimates for the 27 EU Member States and the European Union as a whole. Although we stress the importance to get empirical evidence for the selection of nesting structure in the definition of the production function,

we have not found any empirically supported preference for using (KL)E, (KE)L or (EL)K nesting structure, all of them fitting the data in a very similar way. We derive these results on an individual sectors base and individual country base both for CEE countries and Western Europe countries together with the EU as a whole.

In view of the climate and energy debate, contrasting CEE countries with respect to non CEE EU members is important because the evidence shows that, despite comparable capital/output and labor/output ratios, the energy/output ratio in CEE countries is twice the level of non CEE EU States. These differences are reflected in elasticities estimates. While roughly equivalent at the whole country scale, sector elasticities of CEE countries appear significantly lower than those of non CEE EU members, illustrating the productivity constraints in energy use faced by the CEE Member States.

Energy taxation and redistribution

It is commonplace observation that energy markets are far from being perfectly competitive. Supply is characterized by strong oligopolistic positions, fixed costs and non convexities resulting in firm concentration. They are also one of the favourite playgrounds of governments for public intervention. Governments pursue more or less contradictory objectives in designing public regulation schemes for energy provision: raise fiscal revenues, secure constant energy delivery conditions, guarantee supply technical efficiency, optimize the energy mix with respect to environmental constraints, secure the access to energy to poor households and protect the competitiveness of domestic firms by avoiding too high energy prices. Second, any energy regulation policy is submitted to various informational, technical (electricity is not storable for example) and institutional constraints. Thus policy design must be framed inside a more or less second best context.

The study addresses this issue for the Czech Republic extending a framework initially developed for the French case. The conceptual model is the following. The domestic economy produces a composite good and secondary energy services from primary energy, capital and labor. Households have different tastes for energy and different productivities and consume the composite good and secondary energy services. The objective of the government is to design a socially optimal regulation scheme composed of an income tax and energy taxes at the households level and the firms levels. Energy consumption is polluting, thus the tax system must internalize the environmental externality. Two cases are distinguished. In the first one, the government is unable to measure individual energy consumption rates and must rely on linear commodity prices. In the second one consumer discrimination is possible and the government can target tax included energy prices to specific firms and households, that is apply non linear commodity prices. In the first case, the energy tax is Pigouvian in the sense that its implement the environmental social cost while the consumption tax is not Pigouvian because of the second best distortion. The model is solved by numerical simulation on econometric estimates of consumption and production characteristics.

The study has shown that the optimal tax on energy inputs is Pigouvian and equal to its marginal social damage. The optimal tax on the consumption of energy, on the other hand, is lower than its marginal social damage. In fact, energy consumption should be subsidised, the case in which the environmental cost of energy consumption is sufficiently high being an exception. The reason for this is the fact that the poor spend proportionally more of their income on energy consumption than the rich. In the case of a non-linear tax on energy, the households segmentation by ISCO codes (on professions) is comparable to the segmentation of the previous studies and the corresponding results are very similar (qualitatively speaking) to the one obtained for US and France. This is not the

case, however, when the households' segmentation is based on total gross earnings. Indeed we show that in this case the subsidy must decrease with income.

Water and energy conservation in the EU: role of climate conditions and concern with global climate change

This study aims at revealing the factors of energy and water conservation in six European countries (Czech Republic, France, Italy, The Netherlands, Norway, and Sweden), with specific focus on the role of the climatic conditions and the concern with global climate change (GCC).

The purpose of this study was to give answers to three inter-related research questions that are pertinent for our understanding of conservation behavior and how it is related to perceived effects of global climate change. To investigate the research questions, we have exploited data from a household survey on conservation behavior conducted in six European countries and macro-level data on climate conditions (namely heating degree days) and economic production in 83 European regions.

Our first research question was whether the multitude of energy- and water-conservation action that consist both of curtailments (change in the consumption) and efficiency (change in the quality of energy and water consuming durable) can be reduced to one underlying latent variable. In other words, it was whether we can find, behind the richness of conservation behavior, the same tendency to resource conservation.

Our answer to the first question is positive. In fact, we found that all conservation behaviors are driven by the same latent propensity to resource conservation. In addition, we have found that conservation behaviors differ in their difficulties. While water and energy curtailments (quotidian actions aimed to reduce the consumption of water and energy) are relatively easier, water and energy efficiency measures (introduction of water and energy-consuming durables) are more difficult.

The second research question was whether climatic conditions and changes in climatic conditions due to GCC have any effect on people's conservation behavior. After all, one would assume that direct experience with GCC (already observable for people living in Europe in the decreasing number of heating degree days) will motivate people to conserve resources that are either threaten by GCC (water) or which consumption contributes to GCC (energy produced from fossil fuels).

Findings of this study suggest that although tendency of people to conserve energy and water is higher in countries with colder climate, there is no relationship between speed of the climate change as manifested in changing heating degrees and conservation behavior. In other words, witnessing relatively fast decline in number of cold days does not lead people to conserve resources.

Finally, the third question of our study was whether concern with global climate change mediates some of the effects of GCC on conservation behavior. Again, the assumption would be that as people witness changing climatic conditions due to GCC, they would become more concerned with GCC and consequently start to conserve resources. Also this question was answered negatively by our study. Although we observe that concern with GCC has an effect conservation of resources, we also see the

speed of climate change, as reflected in speed with which declines the number of cold days, does not have any effect on people's concern with climate change.

To reiterate the most important findings of this study: water and energy conservation behaviors are driven, for the most part, by the same conservation tendency. This tendency is positively related to concern with global climate change. However, this concern does not follow simply from exposure to effects of GCC.

Estimating the willingness to pay for micro-generation technologies: a case study

Micro-generation technologies are considered innovative technologies that may considerably contribute to boosting renewable energy consumption in the residential sector. Although these technologies still face too high capital costs that hinder greater diffusion in the targeted market, they are supposed to play an important role in the future structure of the energy system. Micro-generation technologies are considered among the fundamental instruments to reach current renewable energy targets in order to combat climate change, decrease dependency on fossil fuels and increase energy independency in many countries. It can also have considerable effects on behavioural patterns of the population and trigger positive shifts in energy consumption. In our case study, we thus examined the motivations and barriers of adopting micro-generation technologies and estimated the willingness to pay for individual micro-generation technologies.

Beside costs, other factors may influence the preferences of house owners towards installation of such technology. Our literature review shows that the major barrier identified in previous studies are high capital costs. Although all the studies recognise it as the most important barrier to wider spread of micro-generation technologies in the residential sector, the effect of financial support mechanisms often seems to be rather low or short term. This shows that there are other barriers than strictly costs related that have a significant influence and other supportive mechanisms such as targeted information campaigns or assistance programmes to simplify the process of choosing the proper technology and its subsequent installations should be implemented if the anticipated effect of micro-generation on energy markets is to be met.

Further determinants influencing the decision of a household to adopt a micro-generation technology identified in the literature can be grouped into following categories: i) cost related determinants, ii) non-monetary determinants – environmental concern and self-sufficiency, iii) subjective norms related determinants, iv) determinants related to lack of information and v) compatibility related determinants. Important determinants are related also to the characteristics of the property and especially to the population characteristics. Also the determinants related to institutional framework are mentioned in the literature, however only briefly. The literature also shows that another important aspect hindering the process of adoption is the fact that the typical barriers related to micro-generation technology adoption (capital costs, complexity of the system or administration related with the installation) appear mainly at the beginning of the adoption process, while the benefits (energy savings, environmental benefits or independency on energy suppliers) manifest only in the long term. The literature based evidence is consistent in that households generally incline to micro-generation technologies perceived to be less risky, more compatible with their property, with better established information, more modestly priced and with faster payback. The main barriers that need to be overcome in order to support the spread of these technologies beyond the current consumers segment are thus besides cost reductions also independent

information provision, better advice and support, less disruptive installations and design improvements to make the technologies more user-friendly.

Our case study to estimate the willingness to pay was conducted among Czech households. The willingness to pay was estimated for eight micro-generation technologies using the double bounded dichotomous choice format. Four of the valued technologies were considered as complementary technologies to the existing heating and electricity supply of the household – namely the photovoltaic system, solar thermal system, micro-wind turbines and hybrid solar thermal-photovoltaic systems. Other four technologies were considered as alternatives to the current heating system of the household, namely heat pump and three cogenerating technologies - micro CHP on natural gas, micro CHP on biomass and fuel cell. The estimated mean WTP is about for wind turbine or solar thermal system is about 70,000 CZK (≈€2,600), while mean WTP for PV or hybrid solar systems are both about 80,000 CZK (≈€3,000). Czech households are willing to pay more for micro-generation technologies that would replace their current heating system; mean WTP for purchasing natural gas CHP and boiler on biomass are about 90,000 CZK (≈€3,300), while mean WTP for fuel cells is 105,000 CZK (≈€3,600) and the highest WTP is derived for heat pumps that is 115,000 CZK (≈€4,200).

Conceptual studies

Theory of competitiveness with heterogeneous firms

The literature emphasizes two main channels linking international trade and the environment. The first one is the 'environmental Kuznet's curve' effect. Following this theory, pollution increases over time in the first stages of development before decreasing when the economy becomes mature, thus a positive correlation between income and environmental quality. As an enhancing income dynamics process, free trade should hence have a positive effect over environmental quality. On the other hand the 'pollution heaven' effect moves most polluting activities toward low income countries. This creates carbon leakages in the form of implicit carbon exports from low income countries toward high income countries. Free trade facilitates such transfers and thus may have negative impacts on environmental quality.

One shortcoming of the current analysis of these issues is the assumption that firms are homogenous. Heterogeneity inside industries is a core point of contemporary trade theories, the so-called new-new trade theories. Integrating the environment inside the new-new trade approach is a conceptual challenge and the study contributes to it. Evidence suggests that more productive firms are also less polluting. The modern trade theory states that free trade increases competition, eliminating low productivity firms while increasing the market shares of the most efficient ones. Thus trade boosts the aggregate productivity of industries, inducing potentially environmental benefits.

We start with the case of two nations symmetric in all respect with the exception of their carbon emission rates. Firms are heterogeneous in their labor productivity and the two countries experience the same degree of firm heterogeneity before trade opening. More efficient firms (in labor terms) are also less polluting but we assume that they pollute more in one country than in the other. This setting leads to ambiguous conclusions regarding the effect of trade opening over total carbon emissions. If the production 'cleaning' intensity effect resulting from the rise of the most productive firms at the expense of the less productive ones dominates the output rates increase induced by trade opening, free trade has a positive effect on total emissions while the reverse may hold if the

output scale effect dominates the cleaning intensity effect. In this last case carbon leakage occurs with detrimental environmental consequences.

If the countries differ in size and the largest one is also the dirtiest, the detrimental effect of open trade is magnified. This may lead the smaller country to take unilateral protection measures to avoid carbon leakage and protect the environment. But if the largest and also dirtiest country benefits from a technology shock, the conclusion may be reversed, an argument in favour of trade opening with technological transfers.

Climate policy in a second best world

Most analyses of global changes are cast with reference to a more or less first best world. This is for example the case for climate change studies in the line of the Stern Review (2006). In these studies, climate change is modelled as a sort of global externality. The analysis then contrasts 'business as usual' situations, where economic agents optimize their behaviour without taking into account their impacts upon global warming and 'corrected' situations, where the economy under policy constraints correctly internalizes the consequences of GHG emissions over future earth climate conditions. We follow an alternative route by assuming that policy makers can only implement more modest objectives because of international negotiation constraints or limited temporal commitment abilities. We focus on the most popular policy objective of stabilizing the global carbon concentration to some security level allowing for a stabilization of the average temperature rise at the end of the century. We explore the implications of such a policy target in different contexts.

First we study the consequences of an atmospheric carbon constraint over the optimal growth trend of the global economy. Such constraints have already been explored in the integrated assessment models literature (IAM) but the results from the models are hard to interpret. We propose an analytical approach able to shed light on the models predictions. We show in particular that even in the simplest growth framework, the economy dynamics can exhibit complex adjustment patterns, involving temporary adjustments of the capital stocks of the economy before it is possible to cope with climate change and return to some positive growth trajectory.

Secondly, we have studied the consequences of demand heterogeneity over the optimal mitigation policy under a carbon constraint. The ability to mitigate emissions varies significantly between sectors, e. g. the transportation sector and the energy production sector. In a first best context, this difference does not change the general Pigouvian principle of charging emissions from any source at their environmental marginal cost. In a dynamic second best context, the optimal policy is quite different.

We show that heterogeneous sectors should face different carbon price schedules, either in the form of taxes or through permit prices in a cap-and-trade system. More precisely, non-point emission sources, like emissions coming from the transportation sector, should be charged at a higher rate than point source emissions. Second, the dynamics of the respective carbon charges should evolve differently over time, even if the willingness to pay of sectors for access to fossil fuels (in short their energy demand functions) are the same.

Thirdly, we have explored the consequences of passive learning-by-doing or active R&D under a carbon constraint. It is currently expected that learning-by-doing should play an eminent role to improve the efficiency of non-carbon based energy generation techniques. This issue has also been

explored by IAM leading to complex findings. The usual economic rationale suggests that learning opportunities should lead to early action, in order to benefit from the potential rents from learning. On the contrary, research activities can delay the development of energy alternatives by pre-empting infant technologies before discovering better industrial avenues.

As before, plugging a policy carbon constraint inside this overall picture leads to rather different conclusions. We show that learning opportunities interact with the exhaustibility of fossil fuels in complex ways. The general outcome is non monotonous carbon price trajectories and also non monotonous trajectories for a subsidy rate aimed at financing the learning effort.

Together with learning, scale effects play an important role in the development of carbon mitigation techniques. We show in particular that learning is not a sufficient motive to trigger early development of abatement techniques while the existence of decreasing returns to scale over abatement induces an early start of an active mitigation policy.

Existing models explore the consequences of learning and R&D in isolation. We also provide an integrated analysis where both may be used in combination to trigger technical advances in non-carbon based energy generation or in carbon abatement technologies. We show how this combination can result in complex patterns where the economy should try to achieve technical progress through only learning or only R&D. We also study the consequences of such mixed policies upon the optimal scheduling of the carbon price and subsidies to technical development. In particular we show the counterintuitive result that during any time phase where the subsidies to the green energy alternatives should be increasing over time, the carbon taxes should be decreased in parallel. This is typically a second-best consequence of a policy targeting an atmospheric carbon concentration stabilization in the long run.

Fourthly, we have explored the issue of portfolio mandates under carbon constraint. It is customary to oppose the US approach of imposing some minimum level of energy production from renewable to the EU approach which imposes some proportion of renewable energy inside the energy mix. The observed evidence is more mixed. Several US states have adopted proportional rules while minimum standard objectives are also observed in Europe. Most analyses of the performances of such policy tools have been cast in a timeless framework and we want to explore the implications of such schemes in a dynamic context. From a second best perspective, these policies combine an overall objective (carbon pollution mitigation) with some renewable energy production objective together with a linkage between them through the energy mix targeting.

We show that the two approaches require combining in different ways a carbon pricing scheme with a renewable subsidies scheme. But the exhaustibility of fossil fuels induces radical differences between the two policies. Maintaining a fixed proportion of renewable energy with respect to an increasingly scarce primary energy source base may lead to the strange outcome that the use of renewable energy could decline in parallel with the use of fossil fuels. Hence proportional mandates are more appropriate initially, to accelerate the development of the renewable energy sector, but it is clear that the proportions will have to be adjusted to the evolution of fossil fuel supply conditions in the future. The analysis also shows that different kinds of the so-called ‘green paradox’ may arise, and that this phenomenon can affect both the proportional schemes and the minimum standard scheme.

RISK AND UNCERTAINTY

Risk and uncertainty are important ingredients in any study of global changes for three reasons. First, risk and uncertainty affect the behaviour of firms, investors and households. Risk behaviour and risk management institutions, either at the private or at the public level, thus impact the speed and scale of global changes while the uncertain and risky components of global changes themselves impact in return the behaviour of global societies. Second, risk dynamics is of prime importance for main economic sectors like insurance and financial markets. These sectors have to play a key role not only in promoting economic growth but also in protecting households and firms against risky global changes like global warming. Third, governments have to design policies able to deal with global changes, either to promote them, in the case of global growth, or to prevent them, in the case of climate change, a hard political exercise that must succeed despite an uncertain and risky decision environment.

One additional dimension renders this exercise particularly difficult: global changes occur more or less slowly, implying to enlarge the decision horizons to the long run, and sometimes to the very long run future. For such long time horizons, not only the interests of the present generations and the present state of the socioeconomic conditions of the world societies must be taken into consideration but also the interests of not yet born generations together with the potential socioeconomic and environmental status of the future societies in which they will live.

The management of long run risks inside a dynamic economic and environmental context is an intense area of research in economics today. It has revived old debates like the problem of discounting properly a long run uncertain future. The Global-IQ project benefits from the contribution of some of the best scholars in the field. The investigations they lead inside the project are both theoretical and empirical and took the form of several essays we summarize now.

Discounting and relative consumption

A lot of evidence suggests that people value their consumption while comparing it to the one of others, a phenomenon known as ‘positional externalities’. The study investigates the consequences of positional externalities in an intertemporal context. We show that in a growing economy, if the positionality effect increases with consumption, then the social rate of discount should be higher than the private one. In addition the optimal discount rate resulting from the Ramsey formula is higher than the social discount rate. Last we show that positional externalities entail significant modifications of the long run discount rates promoted in climate studies since the Stern review. This last result shows that we should be cautious in climate impacts assessment studies and environmental cost-benefit analysis.

State-variable public goods and social comparisons

How much should we spend to fight climate change? Naturally, the answer depends on many factors such as discounting issues, how the funds for the needed investments are raised and on related second-best problems of the economy, including how such investments interact with the use of other policy instruments, and on the nature of preferences. We examine this issue in the context of dynamic positional externalities: people derive their welfare from their present consumption rate while comparing it to the present consumption of their neighbors, their own past consumption and the past consumption of the others. In other words, people compare consumption trajectories over time. We first show that the optimal rule of provision of a public good like a good climate status in

the complex case of intertemporal consumption comparisons is almost the same as in the case of comparisons of only present consumptions. Next we show that in a public good preferences elicitation scheme under an independent individual revelation process, positional externalities promote an increased public good provision. But in referendum schemes where people are asked for their marginal willingness to pay conditional on that all people will have to pay for increased public provision, the reverse holds.

Should a declining discount rate be used in project analysis?

Should governments, in discounting the future benefits and costs of public projects, use a discount rate that declines over time? The argument for a declining discount rate is a simple one: if the discount rates that will be applied in the future are persistent, and if the analyst can assign probabilities to these discount rates, this will result in a declining schedule of certainty-equivalent discount rates.

Discount rates might decline over time for a variety of reasons including perception related factors such as present-bias or hyperbolic discounting, or due to declining growth rates. The study shows that even in the absence of such factors, the conventional approach, with constant expected growth rates, will still give falling discount rates due to the uncertainty in annual growth rates. Thus if we expect 4% growth but the actual growth could be either 1 or 7%, then the certainty equivalent of say a 50% likelihood of 7% and a 50% likelihood of 1% is not equivalent to 4%. Furthermore this difference between a 50-50 chance of 1% and 7% and a certainty of 4% grows over time. In the very long run this certainty equivalent tends to 1% and this is the mechanism through which certainty equivalent discount rates fall over time.

Discounting and catastrophic risk management

The aim of the research is to analyze the implications of extreme events on the choice of discounting strategies for long-term decisions. It argues the advantages of using undiscounted random stopping time criteria which are equivalent to traditional discounted evaluations on average but allow to address explicitly the spatio-temporal variability of catastrophic events. A challenge is that an extreme event, say a once in-300-year flood, may have never occurred before in a given region. Therefore, purely adaptive policies relying on historical observations provide no awareness of the "unknown" risk, although a 300-year flood may occur next year. For example, floods in Austria, Germany and the Czech Republic in 2002 were classified as 1000-, 500-, 250-, and 100-year events.

First of all, the study shows that the net present value (NPV) under constant and declining discount rates equals the average undiscounted random sum of expected cash flows with a random stopping time defined by the given discounting. Therefore, discount rates can be associated with the occurrences of irreversible "stopping time" events determining a finite "internal" discount-related horizon of the NPV criterion. The expected duration of the stopping time and its standard deviation under modest market interest rates of 3.5% is approximately 30 years, which may have no correspondence with expected, say, 300-year extreme events. Secondly, it is shown that any stopping time induces a discounting process. In particular, a set of mutually exclusive stopping time events even with geometric probability distributions, e.g., 1000-, 500-, 250-, and 100- year floods, induces discounting with time-declining discount rates.

The research shows that the concept of stopping time and equivalent undiscounted random criteria allows inducing social discounting that can accommodate the arrivals of catastrophic events better than interest rates related to the lifetime of market products. Since risk management decisions affect

the occurrence of disasters in time and space, the induced discounting may depend on spatio-temporal distributions of extreme events and feasible sets of related decisions.

The social value of mortality risk reduction: the VSL versus the social welfare function approach

Consumption, risk and prioritarianism

Worldwide mortality costs are expected to account for more than half of the aggregate monetary-equivalent global warming damages estimates because of malnutrition, heat waves and vector-borne diseases. Therefore the issue of how to evaluate mortality impacts is an important one in the climate change literature. Moreover, this issue raises significant equity concerns. One of the most debated topics of the socio-economic chapter of the IPCC Report was the use of a smaller value of life in poor countries than in rich countries. The study deals with the issue of mortality, and this issue is approached through the lenses of a social welfare function (SWF), namely from an equity perspective. It asks: to what extent are the properties of the value of a statistical life (VSL) characteristic of various welfarist criteria? If one views as inequitable some of the implications of using VSL to value risk policies, does there exists a SWF that exhibits a more attractive set of implications? In short, what happens if we shift from orthodox cost benefit analysis to some alternative SWF as the societal tool for evaluating risk reductions?

We examine how different welfarist criteria evaluate the social value of mortality risk reduction. These criteria include the classical, unweighted cost-benefit analysis - i.e., the “value per statistical life” (VSL) approach - and less standard SWFs. The SWFs we consider are either utilitarian or prioritarian, applied to policy choice under risk in either an “ex post” or “ex ante” way. We examine the conditions on individual utility and on the SWF under which these frameworks display sensitivity to wealth and to baseline risk (dead anyway risk). Moreover, we discuss whether these frameworks satisfy related properties that have received some attention in the literature, namely equal value of risk reduction, preference for risk equity, and catastrophe aversion. We show that the particular manner in which VSL ranks risk-reduction measures is not necessarily shared by other welfarist criteria.

Last, the research extends the above comparative approach to the choice of a consumption profile under risk. We show that ex ante prioritarianism implies lower initial consumption than utilitarianism while the contrary holds for ex post prioritarianism.

Optimal insurance design of ambiguous risk

Insurance markets play an important role to mutualize individual climate risks, and to mitigate their social cost. In the absence of transaction costs, full insurance would be optimal in order to wash out these risks through their pooling on financial markets. However, the monitoring of these risk transfers is usually plagued by high transaction costs. In some insurance lines, these costs can go as high as 30% to 50% of the actuarial value of the policy. When insurance entails such large deadweight losses, it is intuitive that partial insurance is optimal. On the other hand, there is little doubt that most people face some uncertainty about the distribution of their potential future climate losses. The estimation of individual probabilities associated to various health hazards often differ from observed frequencies. We characterize the optimal insurance contract when the distribution of losses is ambiguous and the policyholder is ambiguity-averse.

The ambiguity aversion puts more weight to the priors which yield a smaller conditional expected utility. This form of pessimism may have various effects on the optimal insurance coverage. The

intuition suggests that it should increase the demand for insurance, but we show that this is not true in general. In particular, the demand for insurance will be reduced by ambiguity aversion if the ambiguity is concentrated on small losses. This explains why climate change risks cannot be fully covered by insurance contracts.

International cooperation under climate ambiguity and ambiguity aversion

We have developed an analytical regional integrated assessment model (IAM), each region having an independent representative household. The households face climate trends uncertainty in the form of ambiguity in climate sensitivity. As a result there exists a range of climate models and scenarios that predict somewhat different impacts on climate from carbon emissions. The households do not know exactly which of these models are most correct and must then form beliefs about which model to trust. We then model ambiguity aversion in our dynamic IAM assuming that a decision-maker updates her beliefs to new information about climate impacts by a time consistent rule.

Each household then chooses whether to consume an aggregate consumption good or invest in carbon-intensive or carbon-neutral capital and technology. Financial transfers directed to abatement and research from one to another household in different regions are endogenous policy decisions taken individually by the households. We first illustrate the global market failure by analyzing the case of international noncooperation (sub-game perfect feedback Nash equilibrium) in the strategies mentioned above. The market failures result in globally inefficient carbon-intensities together with transfers between households in terms of abatement and research in carbon-intensive and carbon-neutral sectors.

Ambiguity aversion implies that a household values carbon-intensive consumption lower as its shadow carbon cost increases. Applying time consistency we explain how in a cooperative context differences in ambiguity aversion among households either weaken or strengthen the stability of international cooperation.

The relative price of agriculture: the effect of food security on the social cost of carbon

Most integrated assessment models (IAMs) include only an aggregate consumption good, as measured by per capita consumption, in the social welfare function. This simplifying assumption biases the social cost of carbon estimates because climate change is predicted to affect market and non-market goods such as environmental services.

We show that allowing for a change in relative prices between market and non market goods achieves a more restrictive optimal emissions path than the one computed in the Stern Review. In this sense, relative prices can be as important as the discount rate in determining the optimal climate change policy. In addition, the lower the elasticity of substitution between market and non market goods the more likely the conventional IAMs are likely to underestimate the environmental cost of climate change. The research extends these results to three sectors allowing agriculture and thus food delivery to be taken into account.

Spaces for agreement: a theory of time-stochastic dominance

Is there space for agreement on climate change? A non-parametric approach to policy evaluation

The study provides theoretical advances and empirical results on the issue of long term risky investment with special attention to climate change mitigation policies. Because of the large uncertainties concerning future climate and potential impacts, it comes at no surprise that great

controversy surrounds policy proposals to abate emissions, and that this controversy has turned in large measure on positions taken on time and risk preferences.

We want to establish a theory and method able to identify whether there exist `spaces for agreement', that is classes of combinations of discount and utility function, for which one investment dominates another (or `almost' does so), so that all decision-makers whose preferences can be represented by such combinations would agree on the option to be chosen. Our theory unifies the existing theories of Stochastic Dominance and Time Dominance and proposes a general framework for choosing between risky intertemporal prospects, which admits the possibility of pure-time discounting and makes weak assumptions about the risk characteristics of the prospects. Included in our theory is the concept of Almost Time Stochastic Dominance, which provides a way to exclude extreme combinations of time and risk preferences and promises to greatly increase the practical usefulness of the framework.

We then make an empirical application of the theory to climate change, by analyzing a set of trajectories for global greenhouse gas emissions – a set of `policies' – using a stochastic version of the benchmark DICE integrated assessment model. Our results shed new light on the climate-change debate. Although the profile of net benefits from climate mitigation is such that `standard' Time-Stochastic Dominance cannot be established, we use the less restrictive concept of Almost Time-Stochastic Dominance to show that the space for agreement on climate change is indeed large. Since Almost Time-Stochastic Dominance is based on the notion of excluding extreme combinations of time and risk preferences, this result in particular lends itself to the following rather stark interpretation: only those with `extreme' preferences over time and risk would prefer not to cut carbon emissions by a large amount.

Climate policy under uncertain and heterogeneous climate damages

While climate damage uncertainty has been frequently taken into account in IAM's, the heterogeneous nature of damages has received less attention, particularly in combination with uncertainty about climate damages.

The study first uses a simple analytical model to introduce different concepts and then provides more realistic results from the integrated assessment model DICE. We show that taking into account jointly the risky and heterogeneous dimensions of climate damages across the global population can be an argument for substantially stricter climate policy while considering uncertainty and heterogeneity in isolation would not lead to this conclusion. The reason is that a given climate risk borne by fewer people implies greater welfare losses. However, these losses turn out to be significant only if society is both risk and inequality averse and if climate damages are highly heterogeneous. The study discusses also how insurance and self-insurance of climate risk could mitigate this joint effect of uncertainty and heterogeneity and thus admit weaker climate policy.

How to measure the importance of climate risk for determining optimal global abatement policies?

A very common finding in the literature is the small effect of the explicit treatment of climate change uncertainty compared to a cost-benefit analysis based on best-guess (mean) estimates of the uncertainty. We want to highlight the underlying empirical reasons for this finding with an analysis using the integrated assessment model MIND-L, a global stochastic Ramsey-type growth model. As a starting point for the analysis we review previous studies that explored factors enhancing the importance of uncertainty in a cost benefit analysis. Those factors include, inter alia, fat-tailed

climate response risk, exponential climate damages, inclusion of catastrophic risk, and decoupling of the relative risk aversion parameter and the elasticity of intertemporal substitution of consumption.

The study then identifies the reasons for the negligible uncertainty influence in the standard cost-benefit setting in MIND by reconsidering the functional structure of the cause-effect chain from emissions to climate damages. To this end, we project multi-dimensional decision spaces onto a single decision variable for climate policy stringency (cumulative emissions), and derive the marginal cost and benefit curves from a series of constrained welfare maximizations. We identify the saturation effect of temperature increase in response to increasing cumulated emissions, the welfarization of climate damages, as well as the strongly convex mitigation cost curve as reasons for the negligible effect of uncertainty.

Subsequently, we consider two structural changes to increase the risk premium of climate policy. It is shown that the consideration of exponential (as opposed to quadratic) climate damages does indeed increase the risk premium of climate policy to two thirds of the overall welfare benefit, and that the benefits of anticipating uncertainty triples compared to using best guess estimates for climate and damage parameters. Finally, a replacement of the climate module in the model with a linear relationship between cumulative carbon emissions and increase in global temperature results in an increased effect of uncertainty if it is combined with the exponential damages.

Agricultural price volatility under climate change: the impact of multiple objectives on commodity prices

The promotion of biofuels for climate change mitigation and energy security has been criticized to first exert additional pressure on land, thereby potentially cancelling out mitigation gains through increased deforestation and agricultural emissions. Moreover, this additional pressure on land may threaten food security by contributing significantly to recent price spikes. At the same time, without mitigation efforts future changes in climate could increase the volatility of yields and agricultural prices.

To study price volatility effects on food security under biofuels mandates and a changing climate, we implement innovative theoretical developments regarding decision under uncertainty into a stochastic version of the Global Biosphere Management Optimization Model (GLOBIOM), a global, recursive, dynamic, partial equilibrium bottom-up model integrating the agricultural, bio-energy and forestry sectors. We introduce different sources of uncertainty such as weather, occurrence of pests, management changes due to changes in input prices etc., which lead to more volatile yields.

Optimization under uncertainty is done in a two stage approach, maximizing the expected value of welfare for strategic decisions under unknown different scenarios of yield developments, and adaptive decisions depending on the yield scenario realized, such as demand and trade. We assimilate the risk aversion to the preference of the social planner for food security in every state of the nature.

The results show that prioritizing food security by requiring the safety first constraint to hold in all yield scenarios increases food price volatility under the imposition of strict bio-energy mandates. Furthermore, the effect is increasing with the height of the target. However, if bio-energy mandates are only required to hold on average, food price volatility can be kept constant, even if the food security constraint is strict. The same applies to environmental impacts. Ensuring food security requires several million hectares of additional land, mainly sourced from forests and other agricultural land. The introduction of strict bio-energy mandates adds to the sum of deforested area.

Making biofuels mandates applying only on average dampens significantly the effect on deforestation. These findings point toward two important conclusions. First, from a policy perspective, enforcing rigid levels of bio-level targets might come at a severe cost in terms of enhancing food price volatility, which is already under pressure from food security. Second, additional environmental considerations also point to the advantages of more flexible mandates.

Climate change impacts and ambiguity

We use a high-resolution global-scale modeling framework to evaluate the impacts of climate change on the agricultural sector and the expected subsequent changes to agricultural systems. We address the following questions: 1) What transformations are likely to be required from regional agricultural systems? 2) How robust are these transformations across scenarios? 3) To what extent can modeling tools prioritize strategies to avoid maladaptations?

Results show that main cropland areas could decrease significantly in mid to high latitudes of the Northern hemisphere, triggering migration of labor out of the agricultural sector and disappearance of processing activities. Marginal cropland could increase substantially in other regions of Northern, Central and Latin America, Australia, Turkey, Balkan countries as well as in Japan, requiring anticipatory investments in processing chains and physical infrastructure. Lastly, in most of the world, irrigated areas should greatly increase due to climate change, requiring investment into water resource management infrastructures.

We find that most of the above-mentioned transformations are of uncertain magnitude and direction across scenarios. This is due to three main factors: first, spatial patterns of direct biophysical impacts vary among climate models, leading to scenario-specific relocations of production systems while uncertainties with respect to CO2 effects increase everywhere the range of potential cropland increases. Secondly, indirect market effects and socio-economic assumptions further stratify regions according to their response to variable biophysical shocks. For example, price and demand elasticity differentials drive large-scale fall of cropland in Northern America and Europe while boosting output in Latin and Central America. Thirdly, uncertainties concerning changes in precipitation regimes and crop water-use efficiency inflate the potential need for large developments of irrigation.

Last, we illustrate how IAM's can help explore the issue of adaptation investments. For example, investments facilitating large-scale development of marginal cropland are not called for until 2040, and then only in the most extreme scenarios. On the other hand, the output of many regions could be depressed by 2030 without large development of irrigation, but with large risks associated with water infrastructure investments.

General circulation models (GCMs) consistently show that higher concentrations of greenhouse gases (GHG) in the atmosphere will cause global mean temperature to rise, they differ, often quite sharply, on the exact amount of additional warming that corresponds to a given concentrations pathway. Even wider are the differences in the local distribution and intensity of climate change. Uncertainties on climate change amplify the uncertainty that surrounds estimates of the climate sensitivity of physical, ecological and economic systems.

We use the United States (US) agriculture as a case study and we produce the most complete set of climate change impact estimates using all climate models that provided data for the IPCC AR4, three different scenarios on global concentrations (A1B, 20 models; A2, 14 models; B1, 16 models) and three time windows (2010-2039, 2040-2069 and 2070-2099). In total we generate 150 estimates of climate change impacts.

Results show that, for a given year and a given scenario of GHG emissions, estimates of impacts on US agriculture vary widely. The distribution of the impacts changes significantly from one model to another, although agreement increases for scenarios at the end of the century. Unfortunately a clear-cut criterion to rank climate models according to accuracy does not exist and policy makers are left with little guidance on how to assess climate-change impacts.

This creates obvious problems for the expected utility framework, and suggests that novel theory is called for. For this reason, we pursue a different approach that is inspired by economic-theory advances in models of decision making under ambiguity. The proposed parametric framework nests the two extremes of simple averaging and best/worst-case analysis. This increases the amount of information that can be assimilated, facilitates extensional reasoning, and improves credibility of projected averages.

The benefits of international cooperation under climate uncertainty: a dynamic game analysis

Dealing with climate change needs the cooperation among countries to control the greenhouse gas (GHG) emissions together. However, international cooperation on this issue has been considered as a failure. In addition to the free-rider problem, some argue that the uncertainty about global warming can also be one of the reasons.

By making stochastic the deterministic dynamic game for international pollution control proposed by Dockner and Long (1993), we study the welfare gains from international cooperation for CO2 emission control under climate uncertainty through comparing the cooperative and non-cooperative solutions of the underlying stochastic dynamic game.

We attempt to answer two questions: How would uncertainty about global warming affect the net welfare of individual countries in non-cooperative and cooperative equilibrium? How would climate uncertainty change the benefits (welfare gain) from international cooperation on emission control? We show that the expected payoffs for players decrease as climate uncertainty becomes larger, no matter if they cooperate or not. However, the expected welfare gain from international cooperation is enlarged by a higher climate uncertainty.

Strategic carbon taxation and energy pricing: the role of innovation

The study investigate the impacts of a possible innovation in a carbon-free technology over the strategic interactions between the energy seller side and the buyer side within a dynamic game framework in order to study the joint role of innovation and R&D investment and carbon regulation in this strategic interaction context. It has been already stressed in the literature that the supply side reaction to carbon regulation could be an accelerated pace of fossil fuel extraction and thus of carbon emissions, leading to the so-called ‘green paradox’ effect.

In line with the ‘green paradox’ argument, we find that the expectation of possible innovation in a cheap carbon-free technology decreases both the initial carbon tax and the initial producer price, thus implying higher initial resource extraction and carbon emissions. Even though this effect can manifest without strategic interactions, the decrease in initial consumer price, and thus the increase in initial carbon emissions, can be less dramatic in the presence of strategic interactions of carbon taxation and energy pricing between the energy producer side and the consumer side, provided that the environmental damages of cumulative emissions be sufficiently high. This result points out that the ‘green paradox’ effect of possible innovation can be somewhat restrained by the strategic interactions between resource producers and consumers. Moreover, if the consumer side can affect

the arrival time of innovation through R&D, it might exert an R&D effort that is higher than the global efficient level.

Sharing of climate risks across macro regions

The heterogeneity of climate risks between the world regions have led to increasing concerns by policy makers not only to mitigate climate change as such, but also to address the equity issue of compensating the worst hit countries. For instance, the Warsaw international mechanism for loss and damage associated with climate change impact decided at the COP19 in 2013 aims at creating an insurance scheme to provide compensations for developing countries being severely affected by random climate impacts. Therefore, the idea of insurance on a global scale against climate impacts could provide a way of mitigating the economic costs of global warming.

We study how different welfare functions and discount rates affect the optimal climate policy when taking into consideration the regional pattern of risks and their correlation across countries. We then analyze how climate risks could be reduced via an implicit insurance scheme at the global scale across regions and quantify the potential welfare gains from such a scheme. For that purpose, we introduce a disentangled welfare function between risk and time preferences and model global risk sharing via a market of state-dependent Arrow-Debreu securities.

We show that such an insurance scheme allows equalizing relative consumption differences between regions leading to significant potential welfare gains. Our estimates suggest that up to one fifth of total welfare costs from climate impacts could be avoided via such an insurance scheme, which would have a volume of around 250 billion USD from 2015 (about 0.2% of the global GDP). How such an insurance scheme could actually work is not trivial, but risk sharing at the global scale can include relocation of capital and labor (migration), international trade, financial markets, and--potentially most relevant in this context—and explicit risk transfer scheme between nations. While the residual 80% of total damages remain an important welfare loss, our findings suggest that compensating particularly hard hit countries from climate change impacts could reduce the global welfare loss significantly.