Seventh Framework Programme

Theme 6

Environment

Project: 603864 – HELIX

Full project title:

High-**E**nd c**L**imate **I**mpacts and e**X**tremes

Deliverable: 5.8

Synthesis Report of WP5

JRC

date of deliverable: 31/10/17

Contents

EXECUTIVE SUMMARY

The main purpose of this report is to synthesise the main findings of the HELIX work package (WP) dealing with the socio-economic impacts of climate change at the global scale. The WP activities have been wide and varied and have dealt with challenging methodological issues. There are three kinds of research activities: the first one dealing with the socio-economic projections (mainly gross domestic product, GDP), the second one with individual climate impact areas and the third one with the integration of impacts. The first activity of the WP (deliverable D5.1) has consisted of the generation of socio-economic projections consistent with the shared socioeconomic pathways (SSPs). The MaGE macroeconomic growth model has been used for that purpose, producing the set of five SSPs with results for all individual countries at the global scale.

The second set of activities has assessed the socio-economic implications of climate change for traditional impact sectors like transport (deliverable D5.4) and energy (deliverable D5.5) and has also explored the possible impacts due to human health (malaria; deliverable D5.3), migration and food security (both covered in deliverable D5.7).

In the third set of activities, the impacts have been integrated into two economic models: the integrated assessment model FUND and the multi-sector economic model GEM-E3. That has been made in two phases. In phase 1, at an early stage of the project, as the HELIX climate runs were not ready yet, the results from the ISI-MIP fast track were integrated into the economic models to test the methodology (deliverable D5.2). In phase 2, at the end of the project, the HELIX climate impact results (from WP4 and WP5, using the HELIX climate runs) have been used (deliverable D5.6).

The methodological architecture of the work package ranges from quantitative models (like the bottom-up, technology-rich POLES energy model) to more qualitative approaches (like the one used in the study of migration and climate change). Adaptation has been considered in the economic models because they consider how markets react to climate shocks by adjusting the market prices. Moreover, uncertainty has been considered in the analysis as part of the results refer to the full range of HELIX climate runs, beyond the ensembles associated with the various warming levels. The findings of the WP are many and are detailed in the respective chapters of this document.

1 INTRODUCTION

The main purpose of Work Package 5 (WP5) of the HELIX project is to make a comprehensive global assessment of economic impacts due to climate change following a multi-sectoral, bottom-up impact perspective. Various methodologies are combined to produce global estimates.

This report summarises the main methodological aspects and conclusion of the activities developed within WP5 and covered in the seven different deliverables. The first deliverable (D5.1) deals with the provision of socio-economic scenarios that are consistent with the Shared Socio-economic Pathways (SSPs). Deliverable number two (D5.2) made a preliminary assessment of impacts using climate information from a previous study, ISI-MIP fast-track, and looking only into the 4°C climate future. This was an opportunity to test the methodology before considering the HELIX climate runs.

Deliverables number three to six (D5.3 to D5.6) cover five key impact areas: human health (D5.3), transport (D5.4), energy (D5.5) and migration and security issues (D5.6). They have a variable degree of focus. While the health report only focuses on malaria, the transport sector covers sea ports in Europe, and the energy study covers both Africa (with the TIAM-UCL model) and the whole globe (with the POLES model).

Finally, deliverable number seven (D5.7) makes a comprehensive economic assessment. The FUND model makes an analysis of economic impacts. The GEM-E3 model uses HELIX biophysical impact models from four impact areas with a global coverage (agriculture, river floods and coasts from WP4 and energy from WP5), all of them using the HELIX-specific climate runs. In particular, the GEM-E3 analysis takes into account a set of specific warming levels (WLs), as in other work packages of the project. The WLs considered are 1.5°C, 2°C, 4°C and, for the few sectors for which those warming levels are simulated, 6°C.

The report is organised in seven additional sections, each one synthesising one of the WP5 deliverables.

2 SOCIO-ECONOMIC SCENARIOS

The Climate Change community has proposed in the last few years a new interdisciplinary framework to elaborate scenarios for the analysis and assessment of climate change mitigation and adaptation options. This framework works in two dimensions: one is the Representative Concentration Pathways (RCPs) with scenarios about climate forcing, the other is the so called Shared Socio-economic Pathways (SSPs), which analyses the socio economic aspects related to climate change. In particular, the SSPs consist of five storylines or narratives (SSP1 to SSP5) about a set of variables including population, technical progress and economic growth (i.e. GDP) among others.

Socio-economic scenarios of economic growth (economic activity or GDP) and demographic development (population) are needed to simulate biophysical impact models. The main purpose of this section is to explain the generation of a set of socio-economic scenarios, based on the SSPs, for the HELIX project.

The five SSPs are generated with a macro-econometric growth model, the MaGE model (Fouré et al 2012), which has been developed at the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). The model has a solid empirical basis because most of its parameters are statistically estimated using a panel data with world country-level information and long-time series.

MaGE is a macroeconometric model of the world economy suitable for long term socio economic projections of the current century. It is based on a three-factor production function, i.e. labour, capital and energy, plus two forms of technological progress, one for the aggregate bundle of labour and capital and the other specific for energy, i.e. energy productivity. The OECD has used the ENV-growth model (very similar to MaGE) to produce their SSPs.

Figure 1 gives an overview of the trend of world GDP per capita and a measure of between country income distributions at global level (measured with the Gini coefficient, a measure of between countries income inequality).

Figure 1. World GDP projections and Gini coefficients

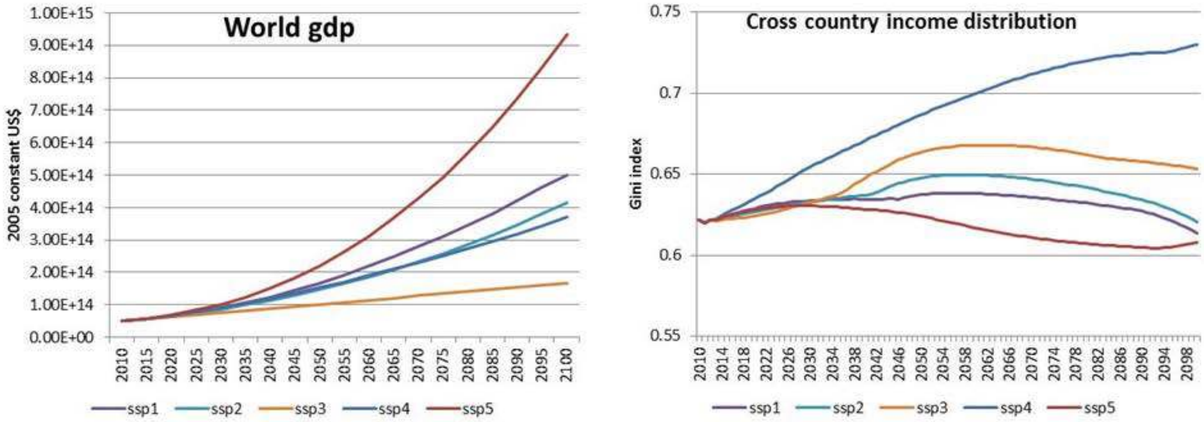


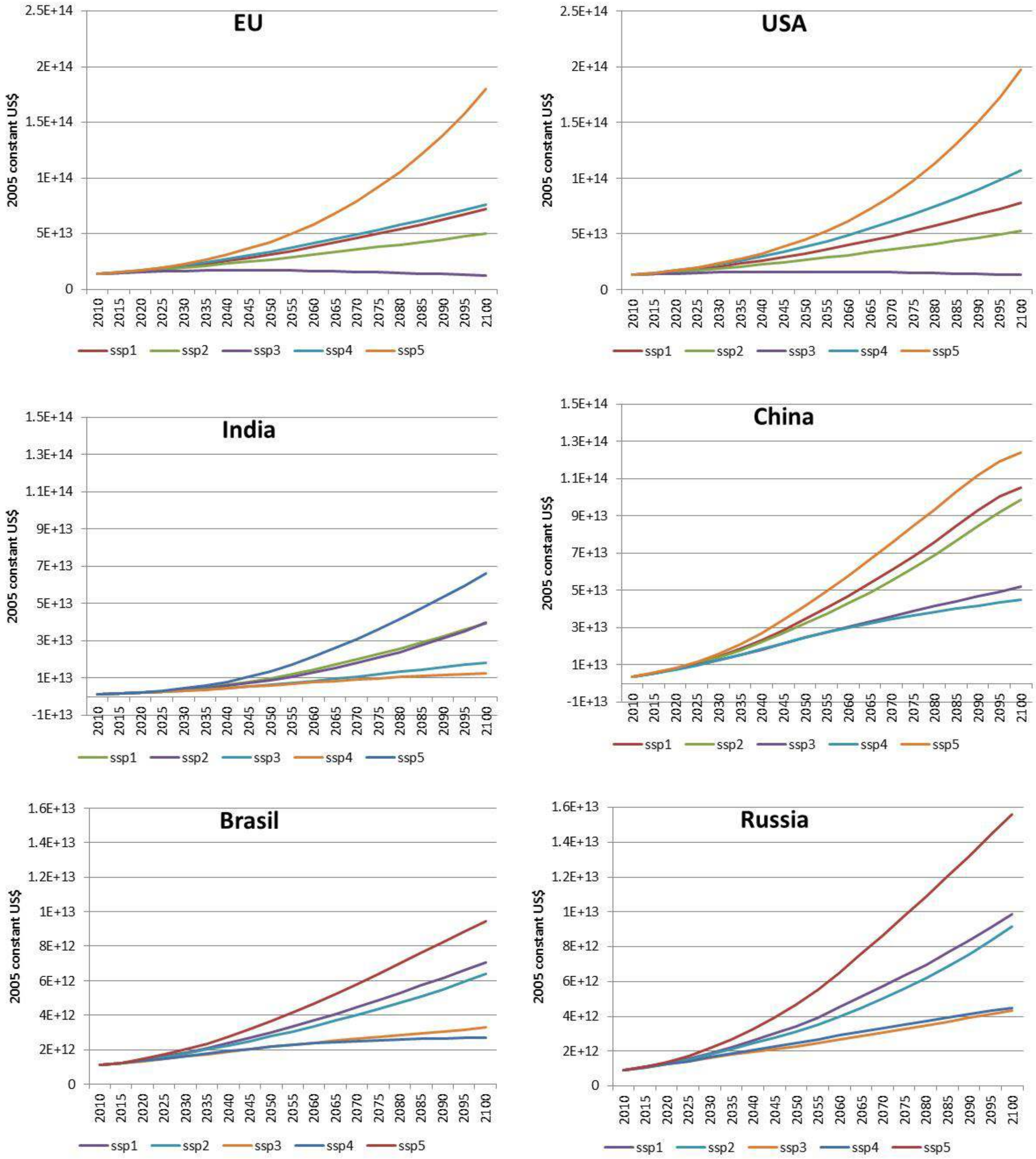
Figure 2 shows the GDP projections (in billions of US 2005 dollars at market exchange rates) for the five SSP scenarios plus the reference for six important economic regions: China, Brazil, EU, USA, Russia and India. The first three graphs show the projections for China, the EU and USA. For China the GDP projected for 2100 ranges from the 45 trillions of US $ of the SSP4 up to the 124 trillions of SSP5, in this last case a 30 fold increase compared to the GDP in 2010. For the USA the range of projected GDP is much larger; projections range from the 13 trillions of SSP3 to the 197 trillions of SSP5. Compared to the 30-fold increase in China, US GDP in 2100 is 13 fold the GDP in 2010. A similar large difference is found for the GDP projections of EU which cover a range between 13 and 179 trillions of US$ with an overall increase that spans from around 1 to 11 fold increases.

Brazil, Russia and India have lower GDP levels and for Brazil and Russia the model projects also relatively low growth prospects. Brazil has a GDP that goes from 2 to 8 trillions and in 2100 it will be 8 times higher than in 2010 at most. For Russia, both projected GDP and growth prospects are higher, up to 14 trillions, i.e. a 15-fold increase compared to GDP level in 2010. Projections for India are substantially higher with a GDP ranging from 12 to 59 trillions and growth prospects that go from 9 to 48 fold increase.

By looking at the scenarios, SSP5 or "Conventional development" is the one with highest GDP growth prospects. This scenario is in fact characterised by low energy price, countries are still heavily dependent on fossil fuels, but the social costs of GHG emissions are not internalised. Conventional growth paradigms are enforced and these are assumed to imply very high increases in productivity. Contrary to what is projected for SSP5, the results for the other scenarios are rather mixed. For instance, SSP3 (the second SSP consistent with the RCP8.5, in addition to SSP5) is characterised by very low GDP level for both advanced and emerging economies. For USA and EU there is almost no

GDP increase, mainly due to decreasing productivity. Slightly better GDP prospects are evaluated for the BRICs where productivity decreases less.

Figure 2. GDP projections for China, EU and USA, Brazil, India and Russia



3 IMPACTS UNDER 4°C WARMING LEVEL (ISI-MIP FAST TRACK)

Work Package 5 of the HELIX project made a global assessment of economic impacts due to climate change in two phases. The first phase is a preliminary assessment with the existing ISI-MIP fast track impact results and other bio-physical impact results. In particular, it uses existing information on climate impacts regarding crop productivity and coastal impacts to obtain a first preliminary global assessment of economic impacts at 4°C global warming. The ISI-MIP project only considered the RCP8.5, with five climate models, with four of them reaching the 4°C level before 2100 - the end of the simulation period in ISI-MIP.

The economic model used to integrate the biophysical impacts, the computable general equilibrium (CGE) GEM-E3 model, has been extensively used in similar applications in Europe, in the context of the PESETA projects (e.g. Ciscar et al, 2011). A similar CGE model was used in the USA Risky Business project exploring the climate risks in USA (Houser et al. 2015). The multi-sector perspective is a distinctive feature of CGE models. CGE models focus on the overall reallocation of resources in the economy. Thus CGE models consider both the direct effect of a climate shock for instance within the agriculture sector and the indirect effects in the rest of the economy, associated with cross-sectoral transactions, as captured by the underlying input-output tables in the model. The CGE analysis of climate impacts follows a static comparative approach, estimating the counterfactual of future climate change (reaching the 4°C) occurring under the current socioeconomic conditions.

The assessment of agriculture impacts uses the AgMIP project data. It covers the seven ISI-MIP crop models and the five global circulation models (GCMs). It thus captures the variability due to the use of various climate models and biophysical agriculture crop models. The coastal impact assessment focuses on one coastal impact model and one specific sea level rise, compatible with the 4°C climate change scenario. It is based on the results from the ClimateCost project, which used the same coastal model as in ISI-MIP. Regarding the climate scenarios, while the agriculture assessment is based on the RCP8.5, the coastal impacts built on the A1B SRES scenario.

The agriculture results are presented in **Table 1**, regarding the average percentage changes in GDP and welfare resulting from the series of simulations. The effects of 4°C global warming are estimated to be 1.2% loss of global GDP or 2.1% loss in global welfare. If the positive effect of higher atmospheric CO_2 concentrations on biomass growth is taken into account, the GDP loss is reduced to 0.02%, and the welfare loss is by 0.03% only. In term of the monetary values of these changes, the global GDP loss is 634 bn US$ (constant CO_2) and 9 bn US$ (CO_2 fertilisation), while the welfare loss value is 648 bn US$ (no CO_2 fertilisation) and 10 bn US$ with the CO_2 effect.

Table 1: Average percentage change in GDP and welfare (EV) at 4°C warming

	with CO2 fertilisation		without CO2 fertilisation	
	GDP %	EV %	GDP %	EV %
China	0.47	1.40	-2.43	-6.39
Japan	0.50	0.75	-0.07	-0.42
Korea	0.40	0.30	-1.28	-3.21
Indonesia	-1.22	-1.97	-4.87	-9.12
India	-1.63	-2.96	-7.77	-14.83
Australasia	0.25	0.78	-0.39	0.08
South Asia	-0.19	-0.48	-4.80	-9.31
Rest of South-East Asia	-0.42	-0.70	-2.53	-4.94
Canada	0.12	0.52	-0.16	0.29
USA	-0.11	-0.21	-0.53	-0.87
Mexico	-0.63	-0.97	-1.27	-2.25
Brazil	-0.48	-0.93	-2.08	-3.50
Central America and Caribbean	-1.62	-2.62	-3.48	-5.52
Rest of South America	0.45	1.03	-0.97	-1.02
Middle East and North Africa	-0.06	-0.04	-2.02	-4.71
Sub-Saharian Africa	-3.35	-6.17	-9.24	-16.65
South Africa	0.11	0.51	-0.45	0.40
Northern Europe	0.28	0.72	-0.20	0.03
UK & Ireland	0.06	0.12	-0.24	-0.61
Central Europe North	0.25	0.55	-0.35	-0.51
Central Europe South	-0.02	0.02	-0.76	-1.16
Southern Europe	0.10	0.20	-0.67	-1.04
Rest of Europe	0.05	0.13	-0.45	-1.17
Russia	0.24	0.47	-2.01	-4.47
Rest of former USSR	0.06	0.11	-3.05	-5.83
World	-0.02	-0.03	-1.15	-2.12

Considering climate change alone, with no CO_2 fertilization, the area most affected by the 4°C warming is Asia with most regions recording significant reductions in GDP and welfare. India, Indonesia and South Asia lose 7.8%, 4.9% and 4.8% of their GDP, respectively, with the EV change being even more pronounced: 14%, 9% and 9%. Accounting for the CO_2 fertilisation effect alleviates most of the damage, although for India and Indonesia the GDP loss remains above 1%. On the American continent, when considering climate change alone, Central America and Caribbean, Brazil and Mexico are most affected with their respective GDPs dropping by almost 3.5%, 2.1% and 1.3%. The CO_2 fertilisation eases the reduction with only Central America and the Caribbean GDP remaining above 1% at 1.7%.

Table 2 presents economic implication of the coastal impacts in two measures: GDP and EV (welfare), both in percentage change and absolute change (bn US$). The global GDP falls by 0.2% which reflects

113bn US$ reduction. The largest GDP loss is estimated for Central Europe North (0.7%) and Rest of South East Asia (0.36%). Other EU regions' GDP change in range 0.18% to 0.24%, which is close to the global average. In the welfare terms (EV), the global reduction is 0.73% or 223 bn US$. The welfare impacts are largest in Asian regions with the Rest of South East Asia loss of 4.62%. The EU regions' welfare reductions are in range of 0.3% to 0.8% with Central Europe North loss of 1.81%.

Table 2: GDP and welfare effects of the SLR

	GDP %	EV %	GDP bn US$	EV bn US$
China	-0.13	-1.80	-5	-23
Japan	-0.25	-0.67	-11	-15
Korea	-0.17	-1.08	-2	-6
Indonesia	-0.14	-0.76	-1	-2
India	-0.09	-1.39	-1	-9
Australasia	-0.06	-0.16	-1	-1
South Asia	-0.16	-1.79	-1	-6
Rest of South-East Asia	-0.36	-4.62	-4	-28
Canada	-0.12	-0.44	-2	-3
USA	-0.15	-0.34	-21	-31
Mexico	-0.03	-0.08	0	0
Brazil	-0.04	-0.14	-1	-1
Central America and Caribbean	-0.05	-0.12	0	0
Rest of South America	-0.14	-0.68	-1	-4
Middle East and North Africa	-0.13	-0.85	-3	-9
Sub-Saharian Africa	-0.06	-0.55	0	-2
South Africa	-0.05	-0.07	0	0
Northern Europe	-0.24	-0.80	-3	-4
UK & Ireland	-0.20	-0.49	-6	-9
Central Europe North	-0.70	-1.81	-36	-50
Central Europe South	-0.18	-0.44	-6	-9
Southern Europe	-0.14	-0.30	-6	-7
Rest of Europe	-0.16	-0.43	-2	-2
Russia	-0.07	-0.24	-1	-1
Rest of former USSR	-0.07	-0.17	0	0
World	-0.20	-0.73	-113	-223

4 HUMAN HEALTH (MALARIA)

The socio-economic impacts of changing risks to human health, due to climate change, are studied in deliverable D5.3. Climate change is projected to bring about heightened prevalence in many vector and water borne diseases. Many of these diseases are expected to appear in regions where they have been long eradicated or never experienced before. Designing policies to mitigate or adapt to these scenarios requires calibrating the monetized impacts. Multiple economic impact assessment models exist in order to calculate, amongst others, the social cost of carbon (SCC, which represents the long-term monetary damage caused by an additional ton of carbon dioxide emissions in a given year). The monetary impacts of diseases are used as inputs into these impact assessment models. They are estimates of populations' willingness to pay to avoid morbidity and mortality. In their current form, none of the models take into account the added impact of these diseases being experienced for the first time.

To this end the FUND impact assessment model (e.g. Tol 2008) is re-run with the updated disease valuation (willingness to pay) figures. Since obtaining disease valuation requires dedicated surveys, only one disease was chosen as a case study – malaria.

After years of decline, malaria prevalence may increase in the future due to climate change, especially in areas that have not experienced the disease. Any policy that aims to mitigate or adapt to this scenario needs to take into account the economic benefits of avoided malaria (willingness to pay - WTP to avoid malaria). Much work has been done on WTP, but not much is known about how WTP changes with the probability of becoming ill. To this end a survey (the main survey sample size was 1409, with an average response rate of 81%) was carried out in Mumbai, India, to compare respondents' WTP to avoid malaria across risky and less-risky areas. It is found WTP to be 10% higher in risky areas than in less-risky areas. It is also observed WTP to increase by more than 15% between malaria-naive and experienced respondents. This indicates an unfamiliarity premium for populations unaccustomed to malaria, but at risk of outbreaks. These findings indicate substantially higher returns to climate change mitigation policies than previously thought.

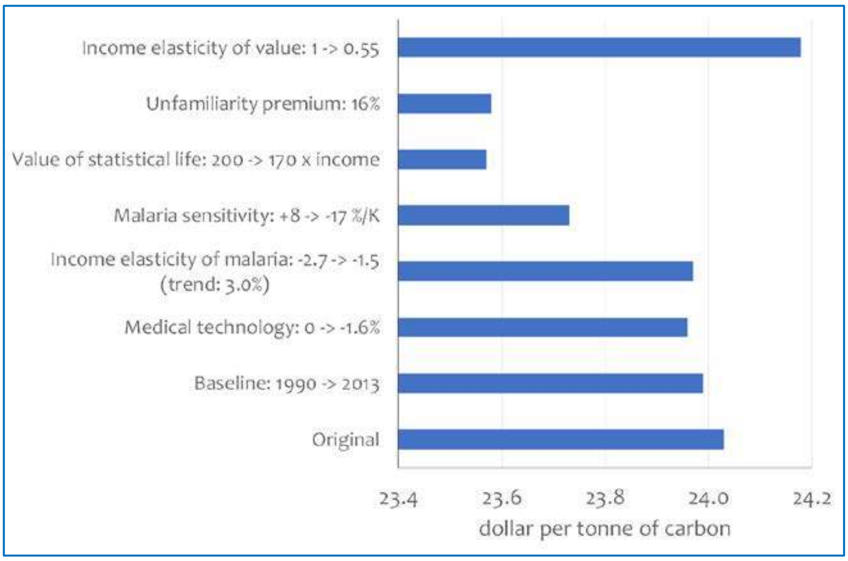
The difference in willingness to pay between malaria naïve and non-naïve groups was used in the re-run of FUND. It should be noted that other parameters in the FUND model were updated as per the literature. Hence, the Deliverable D5.3 is made up of two parts. Part A reports on study from measuring malaria WTP in Mumbai, India. Part B presents results from the re-run of the FUND model.

Part A: Malaria naïve populations have just above 15% higher willingness to pay to avoid the disease than non-naïve populations, indicating an "unfamiliarity premium".

Part B: Including this unfamiliarity premium, amongst other parameter updates, leads to the social cost of carbon barely bulge. The previous model calculated a social cost of carbon of $24.03/tC, while the new model gives an output of $23.52/tC. This is slight dip is largely due to the decrease in malaria prevalence observed worldwide since the previous calibration of the model.

This result (**Error! Reference source not found.**) is the outcome of two opposing effects on the social cost of carbon: the positive impact of the unfamiliarity premium and the negative impact of less-than-previously thought number of malaria cases in recent year. The fact that these effects almost cancel each other out show that the prospect of an increase in malaria prevalence due to climate change is enough, in valuation terms, to offset the gains made towards eradication of the disease.

Figure 3. Decomposition of the change in value of SCC used in the FUND model



Moreover, the existence of a positive unfamiliarity premium for one disease suggests that similar premiums exist for other climate change sensitive diseases. Thus the final social cost of carbon presented in this deliverable is (still) relatively conservative.

5 TRANSPORT

The transport deliverable aims to provide a comprehensive view of the impacts of climate change on transport by covering all transport modes. For the majority of transport modes the investigation of climate change impacts builds on previous studies taking benefit of the significant efforts that have already been made to analyse the topic. Issues covered include vulnerability assessment, cost analysis and review of adaptation strategies. Furthermore, coastal impacts on seaports in Europe are analysed for two climate scenarios using the projections produced by the HELIX team working on coastal impacts. The ports in risk of inundation are identified with the help of the Extreme Sea Level (ESL) data produced by Vousdoukas et al (2016a, 2016b, 2017).

Transport infrastructure is designed and constructed to be resilient to various stresses along its life span but it is vulnerable to extreme weather events. The main finding of relevant studies is that the transport sector is more sensitive to extreme events such as storm surges, flash floods and wind gusts than to incremental changes in the mean climate variable. The frequency and severity of extreme events increase the deterioration pace of transport infrastructure, as well as the probability of disruptions or delays of transport services. As a result of the projected increase of the frequency and severity of extreme events according to several climate scenarios, significant changes might be required in planning, design, construction, operation and maintenance of transport systems.

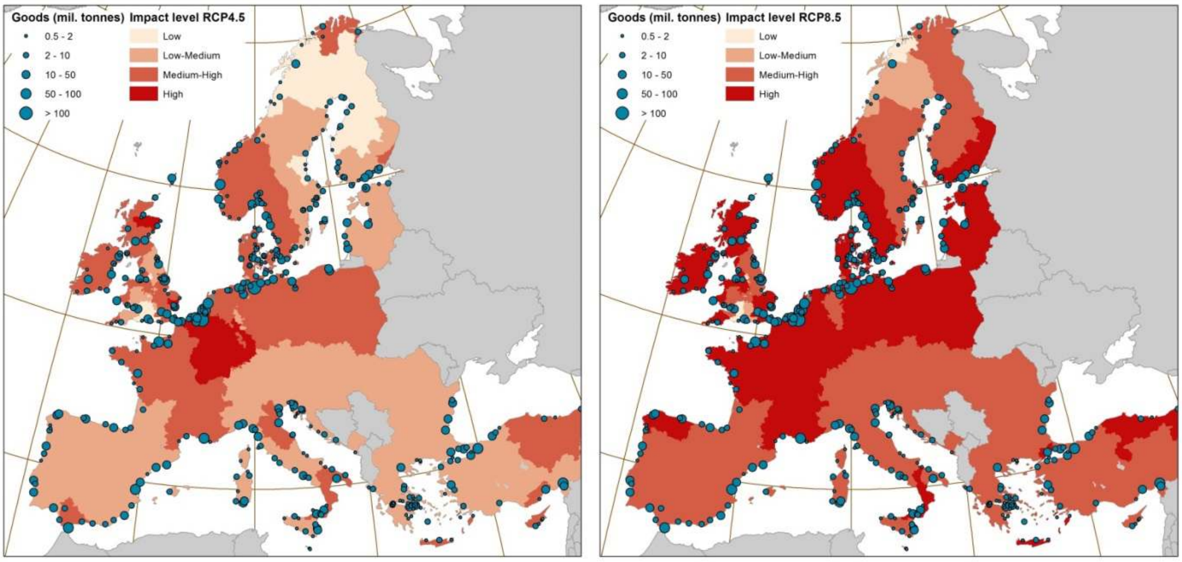
For the analysis of the impacts on seaports in Europe, all European freight ports are covered focusing on those handling more than 0.5 million tonnes annually, while the risk level is associated to present day ESL and the increase of ESL from the present to 2100. Following the evaluation of the risk of ports according to the projected exposure to sea level rise and extreme weather events, the level of impacts can be measured in relevance to the volumes of cargo handled annually in the ports affected by high ESLs. Furthermore, the results are aggregated at country level and it is possible to see which countries are already threatened by particularly high water levels and which countries' exposure is expected to change in the future.

Very important for the analysis is to take benefit of the available data sources; the ESL data offer a good opportunity for analysis at the geographical level and for the RCP scenarios they are available. At first the data on present day ESL in combination with the information on corresponding frequencies provide an indication of the projected disruptions and their spatial distribution. The differences between the scenarios regarding global temperature increase are assessed by comparing the RCP4.5 and RCP8.5 scenarios and they refer to the number of additional ports to be exposed to a high ESL from 2010 to 2100. According to the worse scenario (RCP8.5) it is estimated that the cargo volume to be handled in the additional ports exposed to ESL higher than 4.5 meters from 2010 to 2100 is 25% higher than according to the RCP4.5 scenario.

Following the identification of major ports at relatively high risk, the wider impacts of potential disruption of port operations are evaluated. This is made by looking at the impacts on hinterland in Europe and on foreland worldwide. Such an assessment is particularly challenging with the level of information available and considering the assumptions that need to be made.

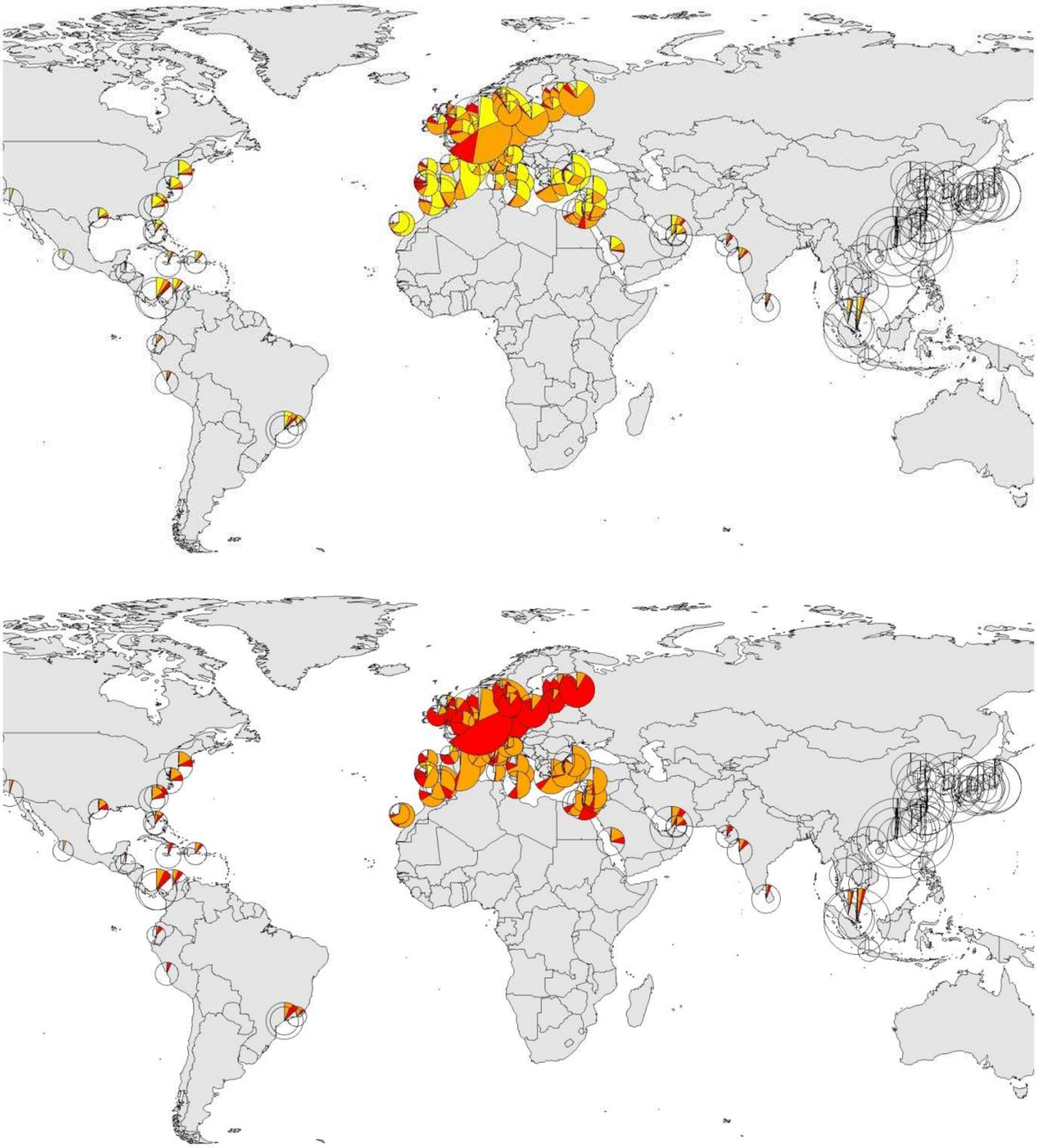
Figure 4 presents the results regarding the impacts on hinterland. The colour variation reflects the impact variation according to the increase of ESL from 2010 to 2100. The regions that appear red are those projected to be most severely affected as they are predominately served by ports projected to be exposed to high ESL increase. The regions to be mostly affected are in Germany, the Netherlands, Belgium, France, Denmark, Sweden, Norway, Poland and the Baltic countries. There are also regions to be severely affected in the UK, Spain, Italy and Turkey.

Figure 4. Impacts of the ports affected by ESL_{100} increase from 2010 to 2100 on hinterland (NUTS3 regions) according to RCP4.5 (left) and RCP8.5 (right)



From the analysis of the impacts on hinterland, it has been possible to assess the risk of European regions based on the risk level of ports in proximity. From the analysis on the impacts on foreland, it has been possible to identify European and overseas destinations to be mostly affected based on their connections with the ports at risk. Figure 5 shows the impacts on ports worldwide .The size of the pies represent the total number of connections or port calls and the coloured pieces of the pies represent the part of the total connections to ports exposed to different levels of ESL increases. The highest secondary impacts appear to occur in Europe and specifically North Europe which is also the area where the highest ESL increases are projected to take place.

Figure 5. Worldwide links of European ports affected by ESL increase according to RCP4.5 (top) and RCP8.5 (bottom)



6 ENERGY

Energy demand is sensitive to climate change. In particular, both heating and cooling demand can be affected in a warmer climate future. Two bottom-up, engineering energy models (TIAM and POLES) have been run to explore the implications of climate change on energy demand. While the TIAM analysis has focused on cooling demand in Africa, POLES makes a global assessment exploring both the implications for cooling and heating demand.

6.1 THE TIAM-UCL MODEL ANALYSIS: COOLING DEMAND IN AFRICA

Two metrics, Apparent Temperature and Humidex, are used to calculate heat stress in both present and future climates and then derive heat stress from the ensemble of CORDEX-Africa simulations (Nikulin et al, 2012) for a control period and at two specific warming levels, +2°C and +4°C above pre-industrial. The bias correction was performed as part of the HELIX project.

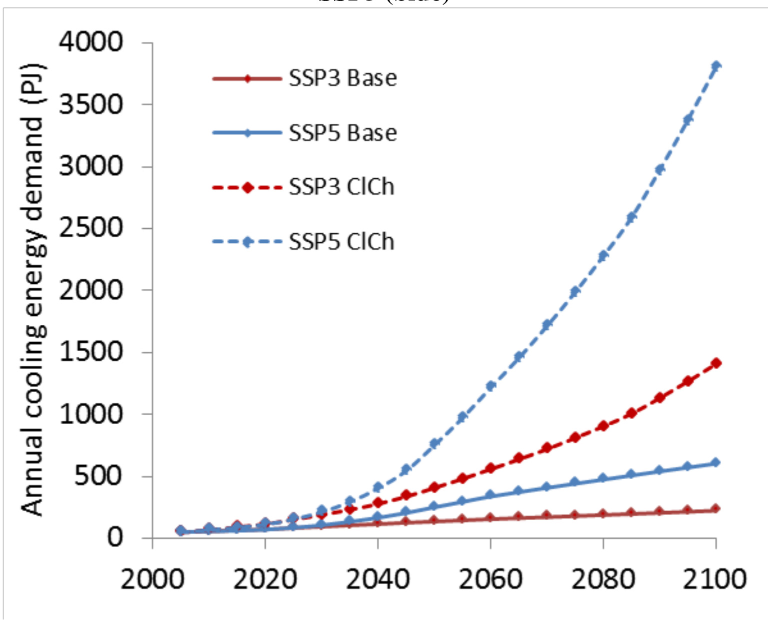
The increase in temperatures and changes to the precipitation distribution under climate change are projected to increase the intensity of heat stress events in Sahel and introduce new heat stress events in Northern and Central Africa. As the intensity of heat stress as well as economic performances increase in Africa it is expected that the use of cooling technology will increase. The energy system therefore will need to be able to supply more energy to power fans or air conditioning units to prevent heat stress. This study presents the costs of mitigating heat stress specifically with a focus on Africa under high-end climate change scenarios. The analysis is based on the TIAM-UCL model (Anandarajah et al. 2011).

TIAM-UCL is a technology-rich global optimisation model, which derives the least-cost future energy system within given technological, economic and policy constraints. It models the flows of energy carriers from primary resources to final service demands via stages of extraction, transformation and transportation. With perfect foresight over the chosen time period, the model selects energy technologies based on their investment and running costs and operational parameters, so as to meet service demands while minimising the total cost of the system. The world is represented as 16 regions, one of which is Africa

The cooling requirement to turn a heat stress event into a non-heat stress event is computed. The TIAM model finds the least cost future energy system that meets the projected increase in demand and derive the increase in energy system costs. Due to the increased cooling energy demand required to mitigate heat stress resulting from the 2°C global average temperature rise, the energy system cost increases by 0.26% to year 2035, which is equivalent to approximately $51.3 billion. Due to the heat stress resulting from the 4°C global average temperature rise, the energy system cost increases by 0.60% to year 2076, which is equivalent to approximately $486.5 billion.

Using the same physical climate change drivers (extracted from the representative concentration pathway RCP8.5) the effect of the increase in energy demand from cooling under SSP3 and SSP5 socioeconomic pathways are also investigated (Figure 6). The total increase in energy costs to prevent heat stress in Africa is found to be $51bn / $46bn by 2035 and $487bn / $1.040bn by 2075 under the SSP3 / SSP5, respectively. However stronger economic development under lower population growth in SSP5 makes the relative costs to Africa's GDP lower than in the SSP3 case. Higher economic development per capita could increases the aptitude to adapt to higher temperature in Africa.

Figure 6. Cooling energy demand for Africa in the base and under climate change for SPP3 (red) and SSP5 (blue)



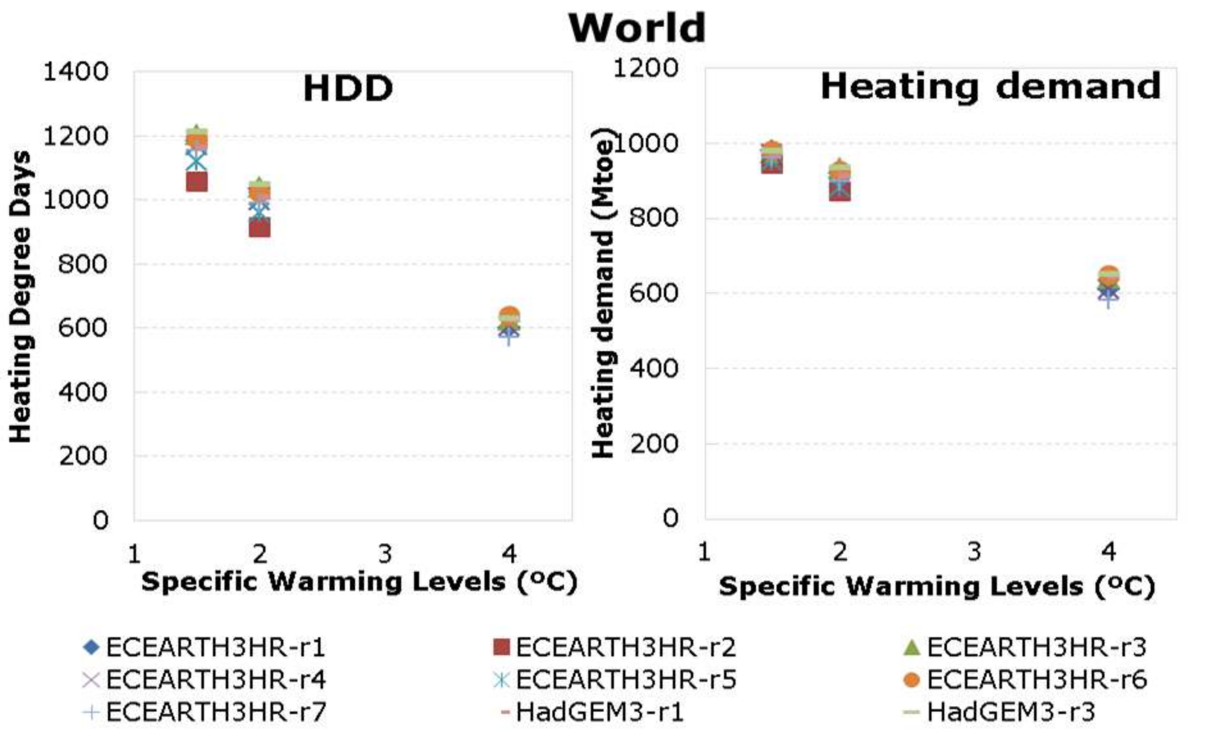
Note: Base (no climate change impact; solid line); Climate change (ClCh: effect on cooling requirement resulting from heat stress avoidance; dotted line)

6.2 THE POLES-JRC MODEL ANALYSIS: GLOBAL ENERGY DEMAND

The POLES energy model (Keramidas et al. 2017) is used to assess the effects on the global energy system in the residential sector for the set of HELIX climate scenarios. The daily average temperatures are transformed into heating and cooling degree-days, which are used to assess heating and cooling needs evolution in time and for given Specific Warming Levels (SWL) of 1.5, 2 and 4 degrees Celsius. The POLES-JRC model also accounts for the impacts of income, energy prices, insulation efforts and improvements in technology efficiency. The time-step is annual, so short-term extreme events are not assessed.

Results show that the increase in global average temperatures leads to a decrease of heating needs of around 50% at world level (Figure 7). On the other hand, demand for residential air cooling increases over time (Figure 8), due partly to the higher summer temperatures and partly to the higher equipment rate (allowed by a higher economic development). Residential cooling needs by the end of the century reach the current level of total final energy needs for residential heating. The resulting sum of global heating and cooling needs increases by around 50% by 2100.

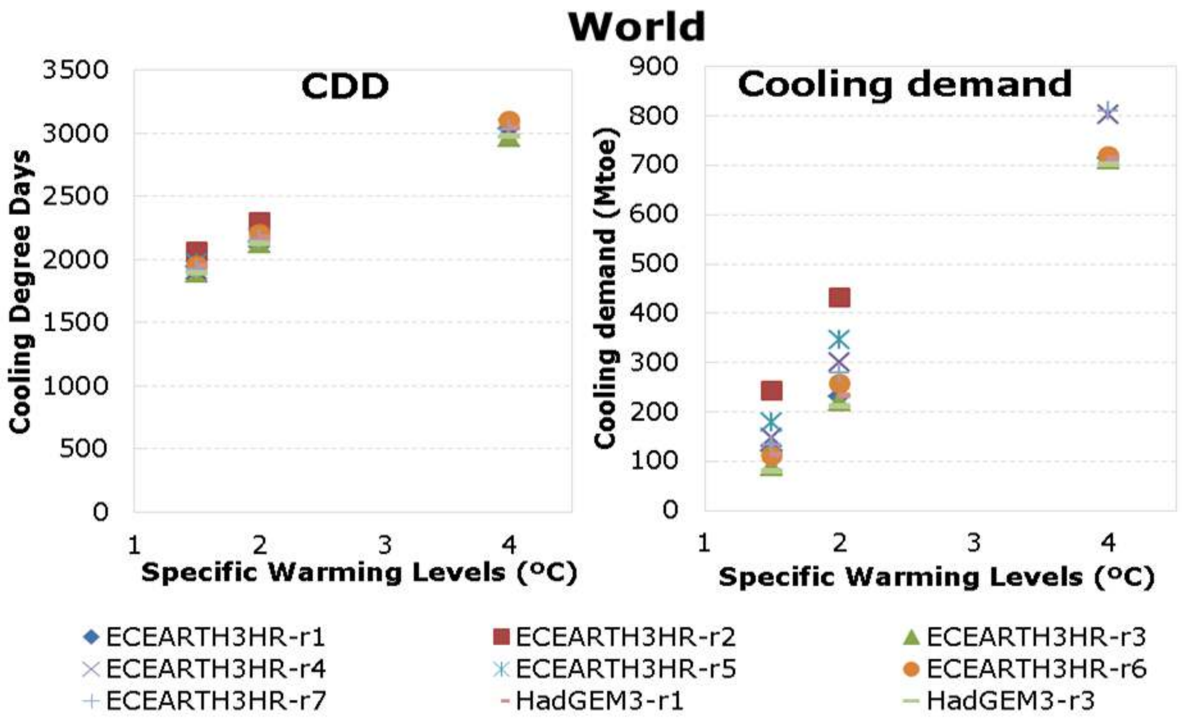
Figure 7. HDD and heating needs at 1.5, 2 and 4°C SWL for the world



A scenario without climate change was also tested, based on today's temperatures. Even then, the Air Conditioning equipment rate of hot countries will increase due to growing income, leading to some increase of electricity consumption to satisfy cooling needs; heating needs decrease due to improved efficiency, but to a lower extent than with a changing climate. The total energy consumed for heating and cooling at world level also increases by around 50% by 2100.

CDD, cooling needs and GDP per capita at 1.5, 2 and 4°C SWL for the world

Figure 8. HDD and heating needs at 1.5, 2 and 4°C SWL for the world



The global climate change impacts are the sum of diverse regional situations:

- The relatively colder Europe sees a decrease of the sum of heating and cooling needs (-42% by the end of the century).
- China sees a 20% increase of the sum of heating and cooling. By then, the (increasing) cooling needs will have reached the (decreasing) heating needs.
- India increases its cooling consumption dramatically, far more than its current and expected level of heating demand.

Finally, it is worth noting a dramatic increase of cooling needs is expected in Asia and other hot and developing regions like sub-Saharan Africa, the two regions that will concentrate most of world's population. Therefore there is a strong case for improving the energy efficiency of new devices, developing the local power infrastructure necessary to cope with such a rise and anticipating and trying to mitigate possible peaking needs in particular.

7 MIGRATION AND SECURITY ISSUES

This section presents findings from two studies under the D5.7 'Global assessment of impacts on migration and security issues' of the HELIX project. The first study considers the impacts of climate change on migration, and the second considers the impacts of climate change on food insecurity at the national level across the globe.

7.1 MIGRATION

Current figures indicate that roughly one person out of seven – that is 940 million people – was not born in the place where s/he currently lives. In this number, only one quarter – 230 million people – are international migrants.

In spite of the progress in computing power and modelling capacity, a robust quantitative modelling of how migration is affected by climate change cannot be done, even less at the global scale. Migration modelling remains very difficult, and is still at a very experimental stage (Bie and Van den Broeck 2011). Though modelling exercises have proved promising (Henry et al. 2003, Massey et al. 2007), they remain very scarce in the literature. Different types of models have been applied to study environmental migration, and mostly gravity models or agent-based models (Kniveton et al. 2008) – no global model of migration, however, has been developed so far.

Any modelling of human behaviour remains difficult, and this is especially the case for migration, a human behaviour determined by a wide array of factors, some of them could appear irrational if considered from a perspective of a distant location. This means that it is impossible to feed climate data into a migration model, and that the use of climate information to forecast future migration will remain highly contingent of the context in which migration will happen. Those are the reasons why HELIX follows an empirical, case-study-based approach.

The HELIX method relies on a careful analysis of diverse and representative case-studies, in different contexts and for different types of climate impacts. The case-studies were chosen for their representativeness of different contexts and types of climate impacts, in West Africa (Benin, Burkina Faso, Senegal), East Africa (Ethiopia, Tanzania) and South Asia (Bangladesh). In this deliverable are presented the case-studies on Burkina Faso, Senegal and Bangladesh. The case-studies on Benin, Ethiopia and Tanzania are presented in deliverable D8.5 on Africa. It should be noted, however, that the key findings presented are drawn from all case-studies conducted for the HELIX project, not just those presented in this deliverable.

In each case-study, the key objective was to find out how people had reacted to previous environmental changes and shocks, and try to identify the key variables that would affect how they might react to other changes or shocks in the future. Such extrapolation is of course extremely difficult by nature, especially when the expected environmental changes are unprecedented, with a possibility of reaching some tipping points. For this reason, this extrapolation does not allow for any quantitative assessment or estimate, but highlights some key patterns of reaction to environmental changes that might help us better anticipate migration and displacement driven extreme climate scenarios.

There are four key findings in the migration analysis of the HELIX case studies, which are detailed in what follows. First of all, there is no correlation between the magnitude of climate and social impacts. Even though such a correlation might appear logical on a first account, it is not supported by the evidence gathered in the case-studies. Rather, on the contrary: a succession of small climate impacts can result in major social transformations, while major climate impacts can have small impacts on migration. The migratory system of Bangladesh, for example, where migration is often routinely conducted as part of adaptation to floods, is often better able to absorb climate shocks, compared to others migratory systems without the same capacity. Yet is often a succession of small climate shocks that will drive migration movement, rather than major disasters. Migration requires indeed the mobilisation of very significant resources – most financial ones. This explains why some major climate shocks can result in small migration movements, as the populations are deprived from essential resources that would enable them to relocate in a safer place.

The second finding is that aggravated climate change will not necessarily result in an increase of migration. Extreme climate change will increase migration amongst certain populations, but also diminish it amongst others. More people are expected to move as a direct or indirect result of the impacts of climate change, particularly from the Global South, with an attached assumption that these movements will be directed towards countries and regions in the Global North. This 'climate refugee' narrative gains traction when bolstered by such frequently cited numbers as 200 million people displaced by climate change by 2050 (Myers 2002). These narratives are lent further credence by the fact that scholars and researchers frequently introduce the topic with such statements as, 'climate change will (or is expected to) increase current migration flows'. Typically, these statements come without proper citation, assumed to be so obvious as not to warrant strict empirical or scientific backing.

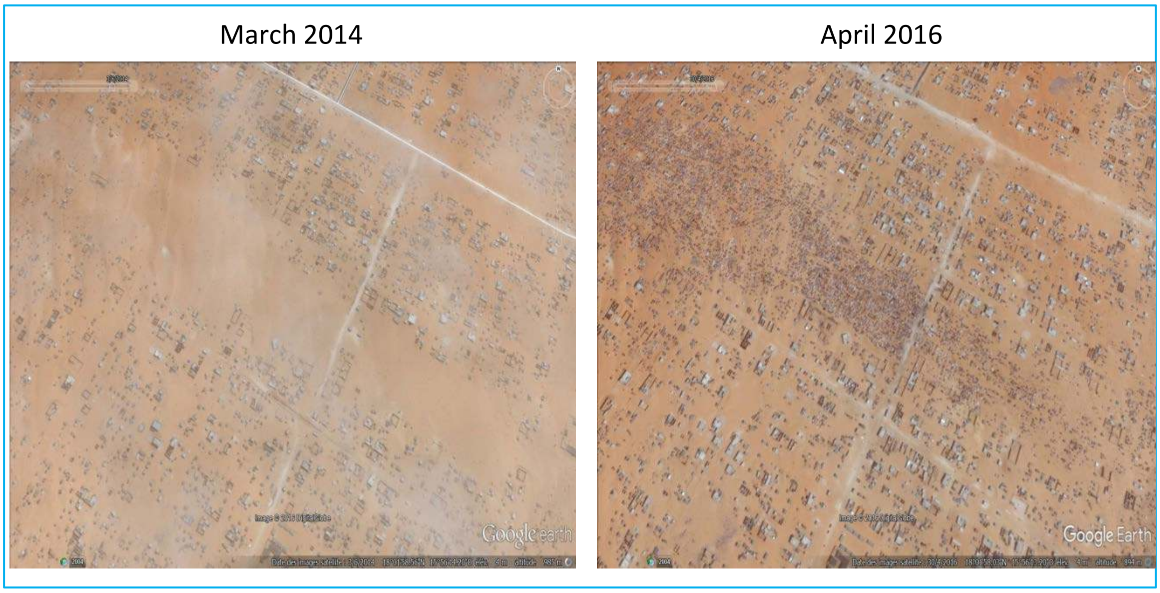
In the case studies performed within the HELIX project, even in cases of extreme climatic events some people continue to live in areas severely affected by climate change. In slow-onset events, such as the coastal erosion experienced in the Senegalese case study, it is noted that the proportion of those who leave is much smaller than the proportion that stays. Multi-causal factors contribute to this immobility, including place attachment, lack of financial resources with which to move, demographic factors such as age, life phase, etc. Importantly, human migration can also diminish in certain contexts with the increase in impacts of climate change. For example, adverse effects on natural resource-dependent livelihoods and systemic resilience more broadly can result in fewer resources with which an individual or a household may utilize for migration.

The third finding states that the scale of migration resulting from climate change cannot only be understood in terms of alteration of volume; it is rather a complex and non-linear phenomenon. Climate change also has important impacts on the character of migration dynamics, such as temporal and geographic scales. Even in locations where migration is a common occurrence, such as Bangladesh and Senegal, the geographic distance of migration trajectories, length of migration (temporary/permanent/circular), and geopolitical dynamics (international/internal) of historical migration patterns can be dramatically altered by climate change. In Senegal, where fishermen have long migrated seasonally to 'follow the fish', a decrease in biodiversity and depletion of local fish stocks pushed fishermen to stay much longer periods of time abroad, in Mauritania rather than historical dispersion across West Africa, and their international movements were now coupled with internal relocation because of coastal erosion. Notably, none of the case studies' primary migration destinations were in the Global North. A major finding of HELIX is thus that one must consider not only quantitative increases (or decreases) in migration because of climate change, but also how the other ways in which climate change alters the very character of migration. Furthermore, extreme climate change can result in an increase of migrant populations, but also in an increase of immobile populations. Therefore, rather than inducing a linear migration process where more and more people would migrate as temperatures increase, climate change could divide a community into two groups, between those who have enough resources to relocate and those who do not.

Finally, much will come down to the issue of inhabitability. Extreme climate change is expected to render some place uninhabitable, because of excessive temperatures, sea-level rise, and uncultivable land. The notion of inhabitability, however, is not an objective notion, and is contingent upon one's perspective. The case of small island states is particularly exemplary in this regard, and shows the importance of personal characteristics when discussing inhabitability. As the sea-level rises, some portions of the territory will become uninhabitable. Most likely there will be no collective decision to deem the land uninhabitable, and people will leave one after another, when they consider the land uninhabitable – meaning that this assessment will depend greatly on individual characteristics and preferences.

As the case-studies show, this notion on inhabitability is greatly dependent upon people's perceptions of environmental changes and their causes. These perceptions are sometimes not aligned with the observed environmental changes, yet they – not the actual observations – will determine whether the threshold of uninhabitability has been reached or not. This highlights the need to provide actual climate information to those affected by climate changes, so that their decision on inhabitability can be informed by actual data and not just their own perceptions. Moreover, the perceived irreversibility of these environmental changes will also influence people's decisions to move and the subsequent mobility patterns.

Figure 9. Growth of refugee camp in Tibesti (Western Chad) over 24 months period



7.2 Security Issues

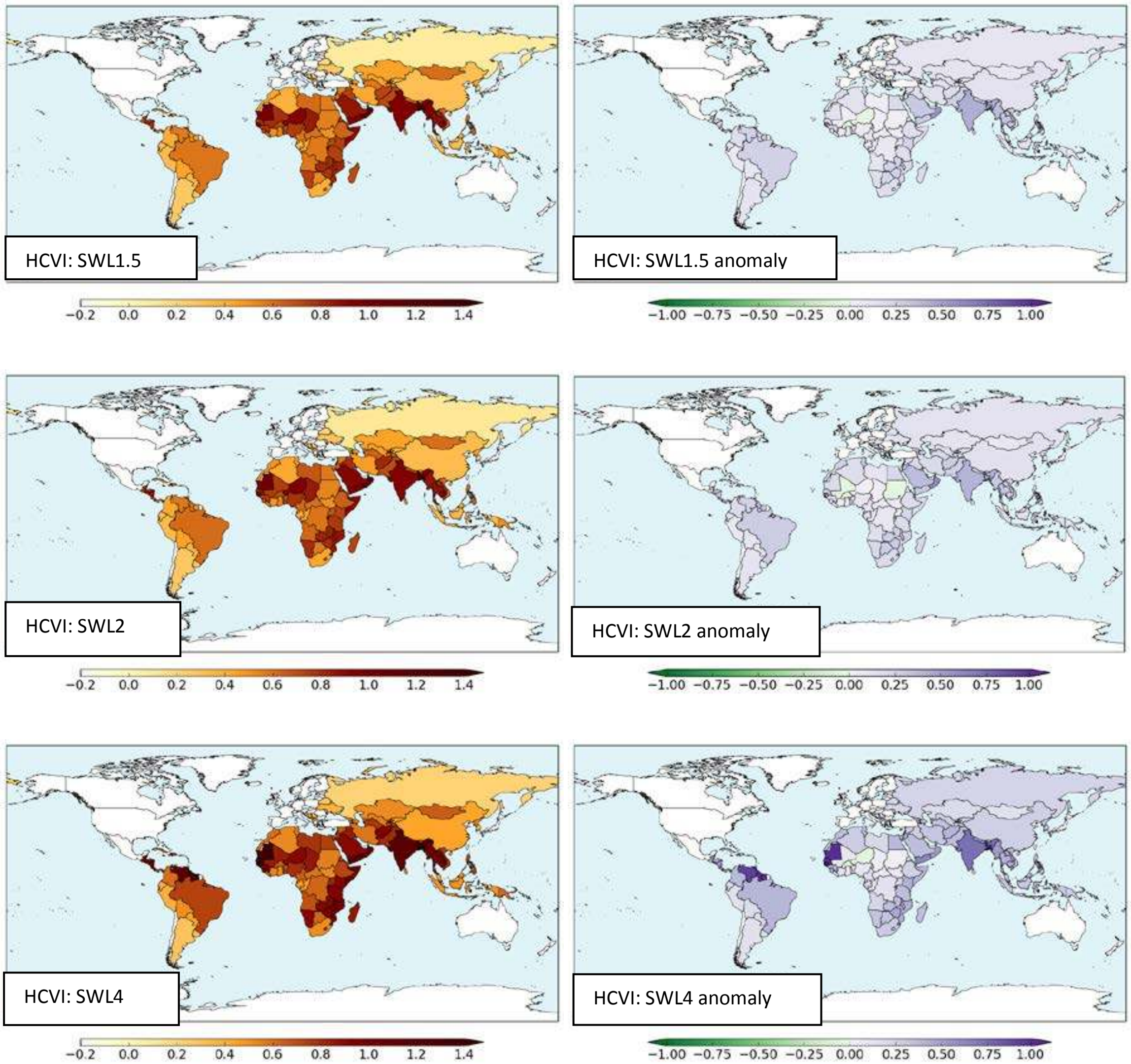
Climate change is a potential risk to all aspects of food security (Porter et al., 2014). In addition, understanding how, when and where climate change will impact those that are most vulnerable to food insecurity is challenging. To gain insight to this challenge, the Hunger and Climate Vulnerability Index (HCVI; Krishnamurthy et al, 2014; Richardson et al., 2017) has been designed to assess the relative national-level vulnerability to food insecurity across developing and least developed countries, as a result of current and future climate-related hazards. Recent analysis with the HCVI concluded that both mitigation and adaptation are required to avoid the worst impacts of climate change and to make gains in tackling food insecurity (Richardson et al., 2017).

The study presented here has investigated the impact of using a different climate model ensemble at a higher resolution than previous HCVI results. This new version of the HCVI was calculated using output from the high resolution ensemble of HadGEM3 simulations (from Work Package 3 of the HELIX project). The geographic pattern of results (Figure 10) is broadly similar to that in Richardson et al. (2017); the highest vulnerability scores in the baseline are found in sub-Saharan Africa and South Asia, and the most vulnerable regions projected to see the largest increases in the future. The absolute values of the HCVI are increased in some regions and reduced in others as a result of using a different ensemble of climate models at a higher resolution. For instance, at 4°C warmer than pre-industrial levels, vulnerability has increased markedly relative to the baseline conditions, particularly across equatorial regions of Central and South America, Africa and South Asia. However, the application of scenarios of adaptation investment supports the requirement for both mitigation and adaptation, although this study highlights the dependence of the results on the models used and the limitations of the empirical approach to adaptation scenarios.

The results from this study suggest also, in the absence of adaptation, that around 5.73 billion people could become more vulnerable to food insecurity in a 2°C warmer world compared to the present-day and 5.76 billion in a 4°C warmer world. In a 2°C warmer world, an estimated 189 million people could become more vulnerable to food insecurity than is currently experienced anywhere under the current climate. In a 4°C warmer world, this figure increases ten-fold to an estimated 1.8 billion people potentially reaching unprecedented levels of vulnerability to food insecurity.

The HCVI methodology was also adapted to account for food imports, which enables the inclusion of developed countries in the calculation. This trade-weighted index weights the HCVI values by the appropriate proportions of locally produced cereals and imports from the global market, taking into account relative wealth and the climate vulnerability of national GDP (via the fractions of agricultural and non-agricultural GDP). Applying the trade-weighting generally results in a small reduction in the vulnerability values, particularly in countries which have a high fraction of imported cereals (i.e. within the Middle East and North Africa region). This first iteration of an HCVI that accounts for food imports only considers the vulnerability of a country's ability to import food. It does not currently consider the impact of climate and climate change on the production of cereals globally, the availability of cereals on the global market, nor the impact this has on global commodity prices or how these transmit to domestic prices paid; this is the subject of future developments of the HCVI.

Figure 10. Maps of the HadGEM3 ensemble mean HCVI (left panel) and the anomaly (right panel) for SWL1.5, SWL2 SWL4 from the baseline HCVI



8 GLOBAL ECONOMIC ASSESSMENT (FUND AND GEM-E3 MODELS)

The global economic assessment has been made with two models: FUND (an integrated assessment model) and GEM-E3, an economic computable general equilibrium model, able to integrate impacts from different biophysical impact models.

8.1 FUND MODEL ASSESSMENT

This deliverable presents new estimates of the total economic impact of climate change using the latest version of FUND and the latest emission scenarios. The version of FUND has five changes: The baseline and scenarios are updated, the sensitivity of malaria is changed, and the value of a statistical life and its income elasticity are altered. These changes have little effect on the outcomes, apart from the scenarios.

The climate impact module of FUND includes agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, energy consumption, water resources, unmanaged ecosystems, diarrhoea, and tropical and extra tropical storms.

Figure 11 shows the global mean temperature as projected. The order of the scenarios is unchanged, but the range narrows further. The world is 2.8°C to 3.7°C warmer than preindustrial by 2100.

Figure 11. The global annual mean surface air temperature as projected

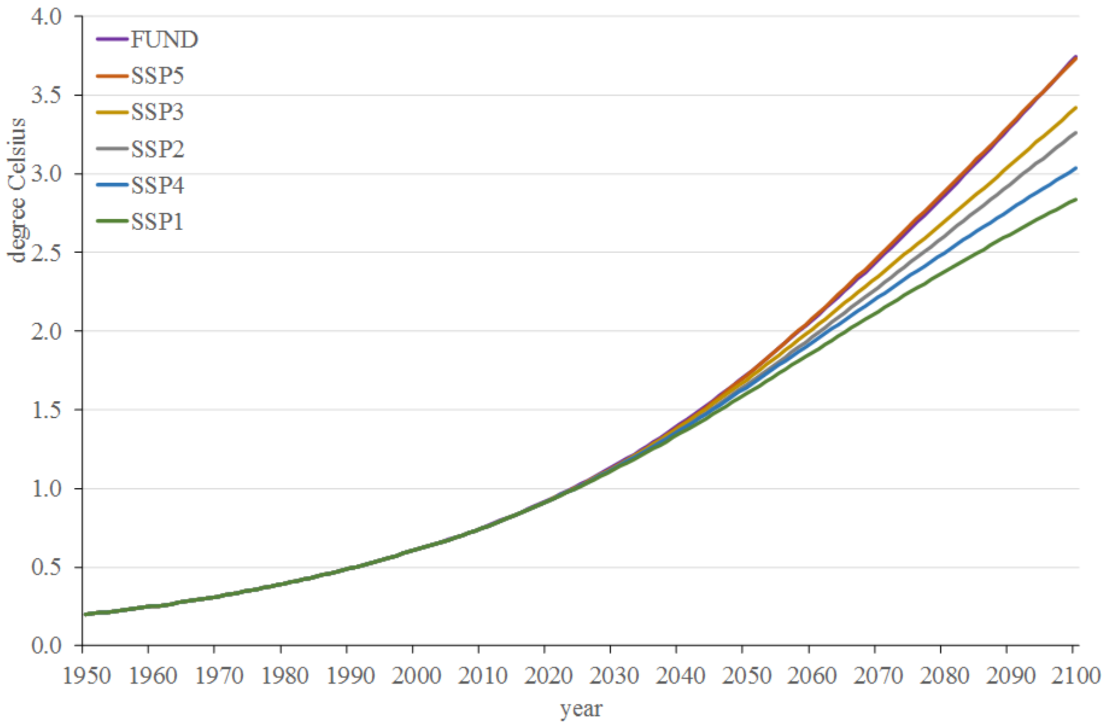
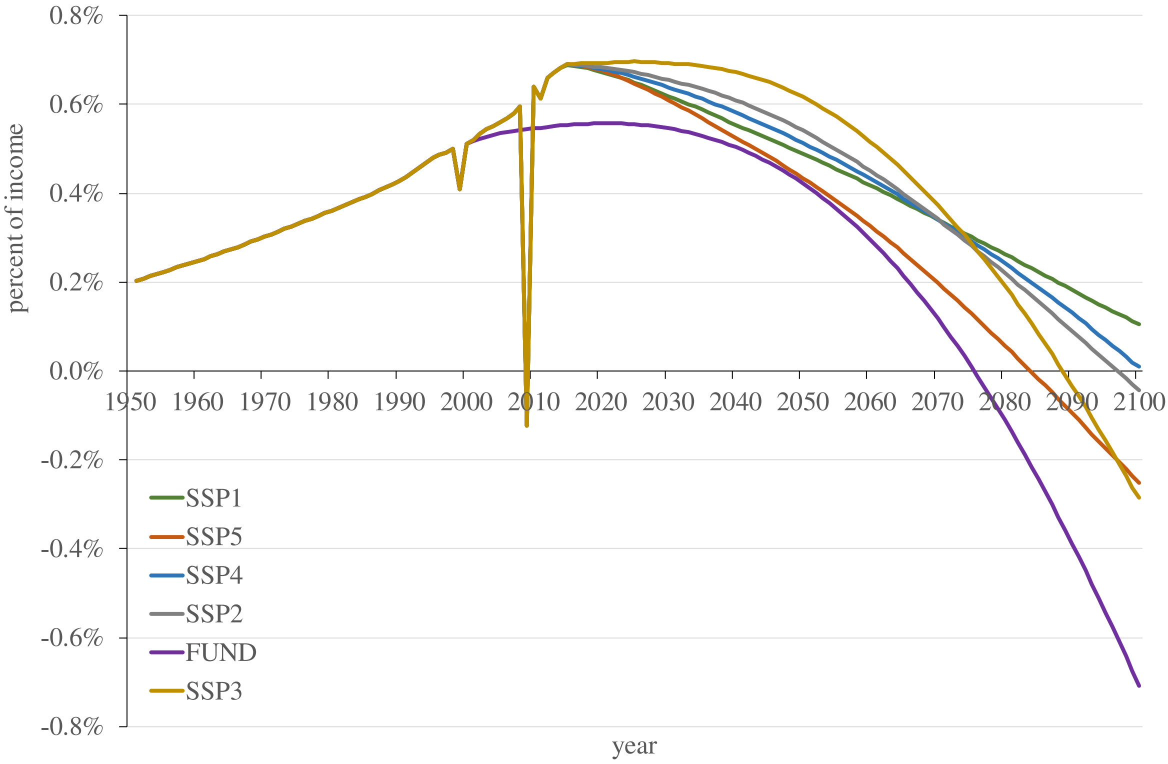


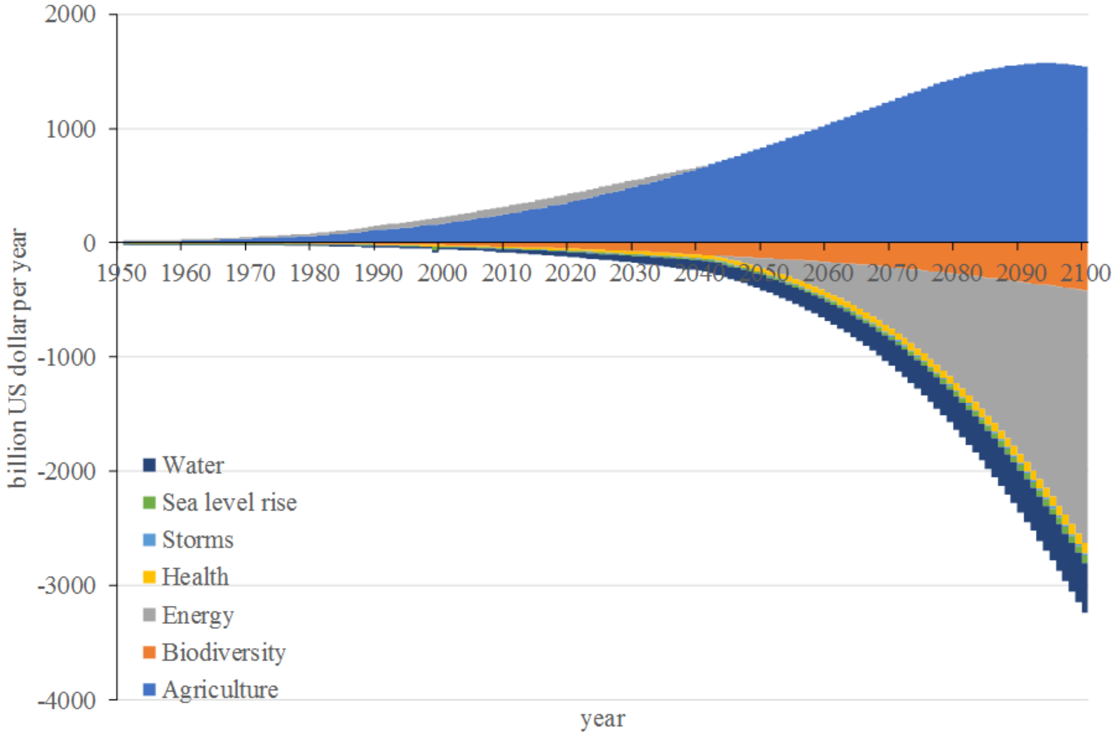
Figure 12 shows the impact of climate change on human welfare as the equivalent income loss. SSP1 is the most optimistic scenario, with positive impacts throughout but falling to 0.1% of GDP by 2100. FUND is the most pessimistic scenario, with impacts reaching -0.7% of GDP by 2100 while continuing to worsen.

Figure 12. The global average impact of climate change on human welfare



The positive impacts notwithstanding, Figure 7 shows that the incremental impacts are negative already (in four of the six scenarios) are will be in the near future (in the other two scenarios). The positive impacts are due to two things: agriculture and energy (Figure 14). Carbon dioxide fertilization is positive throughout, and much of the world's most valuable agriculture takes place below its temperature optimum. Warming increases the demand for cooling in summer, but decreases the demand for heating in winter; the latter effect is larger at first.

Figure 13. The absolute impact of climate change on human welfare, by sector



In line with previous estimates using this model (e.g. Anthoff and Tol 2014, Tol 2013), the impact of climate change is found to be modest in size. More pronounced climate change is worse, but richer societies suffer less. The impact of climate change is concentrated in poorer countries; and dominated by the impacts on agriculture and energy demand. Climate change may be beneficial to human welfare, but additional climate change is detrimental.

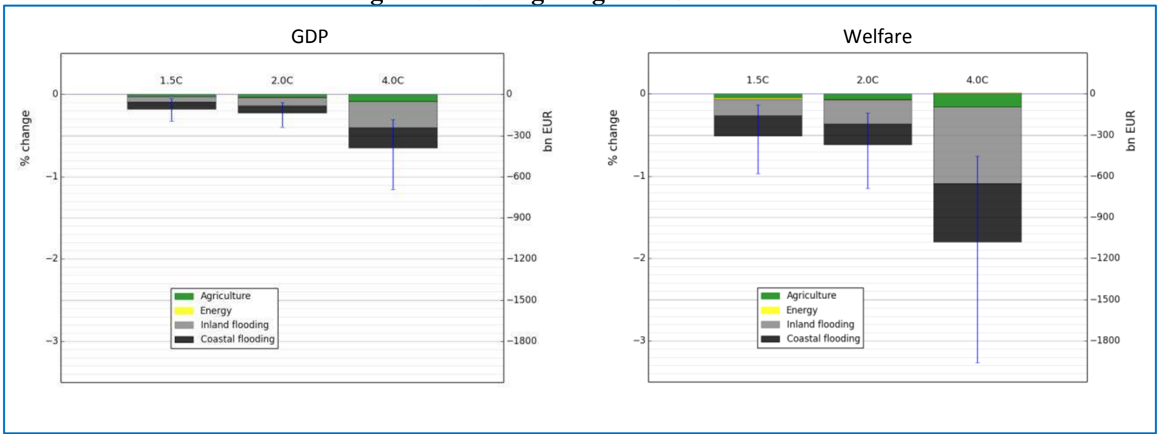
8.2 GEM-E3 MODEL ASSESSMENT

This subsection presents a more comprehensive global assessment than that of the ISI-MIP climate runs (Section 3). This assessment is based on the new HELIX climate scenarios (from WP3), which reach beyond the 4°C warming level, exploring additional warming levels. Furthermore, it also uses the results from the HELIX biophysical impact models (from both WP4 and WP5). Out of the set of impact areas considered in HELIX, four impact categories can be simulated with the economic model: river floods, coastal areas, agriculture and energy. The other sectors (e.g. water, ecosystems, migration and food security) cannot be modelled in economic terms because of the absence of a monetary metrics to value biophysical impacts and establish the consequent linkage with the economic model. Some impacts with an economic dimension were not considered because of their limited geographical scope (e.g. malaria case study).

This section presents an overview of the economic implications of the considered impacts (Inland flooding, coastal damage, energy demand, and agricultural crops), using the GEME3-CAGE model, in a similar way to the analysis made with the PESETA project on climate impacts in Europe (Ciscar et al. 2011). It is assumed that future climate would happen on today's economy (comparative static framework), therefore climate impacts are to be interpreted as one-off shocks.

Figure 14 shows changes in global GDP and welfare (Equivalent Variation, EV) for the three warming levels considered. The global GDP reduction is relatively similar for the 1.5°C and 2°C warming (0.18% and 0.22% loss), but significantly larger at 4.0°C warming: 0.65% loss. In money-metric the losses account to 114, 137 and 396 bn€, respectively. The welfare losses are larger by factor of 2 to 3. The reason of larger welfare losses results from the fact that some damages (e.g. damage to residential buildings or changes in energy demand) affect level of households' obliged consumption, hence welfare, while GDP levels are only indirectly affected.

Figure 14. Change in global GDP and welfare



Up to 90% of the economic losses account to inland flooding and coastal damage, agricultural damage makes up about 10% of the total damage, while the impact of changes in energy demand is barely noticeable at the aggregate, global level which, however, only masks the regional heterogeneity of results as can be seen from regional results.

Regional results confirm that there is a high geographical variability, hidden by the global perspective. In relative terms (Figure 15), the largest GDP reductions are estimated for Asian and Oceanian regions (up to over 3% reduction in China at SWL4.0), South America (about 1% at SWL4.0) and Russia and FSU regions (more than 2% at 4.0°C). Some regions (mainly Europe and the USA) benefit from reduction in net demand for energy (increase in demand for cooling is smaller than reduction in demand from heating) which, at the global level, compensates the increase for residential energy demand in other regions resulting in minor net global effect.

Welfare changes (also in percentage terms) are presented in Figure 16. When compared to the GDP losses welfare impacts are larger. Also, contributions of different impacts to the total are different. For example, changes in residential energy demand lead to change in households' disposable income (and welfare) rather than to changes in overall regional production activity (GDP). Also, river floods are more likely to affect residential households and alter households' budgets (increase in budget's share spent on damage repair leading to welfare reduction) rather than changes in GDP. Most of the global economic damage (up to 90%) is due to inland flooding and coastal damages. Agricultural damage makes up about 10% of the total damage, while the impact of changes in energy demand is barely noticeable at the aggregate, global level which, however, only masks the regional heterogeneity of results as can be seen from regional results.

From the geographical perspective, the largest climate impacts are simulated to happen in the Asia continent, while Russia and the Rest of the FSU are potentially largely affected by climate change. Regarding the sensitivity of the economic impacts to warming levels, there appears to be a non-linear relationship as impacts rise more than proportionally to higher warming levels

Figure 15. Regional changes in GDP (%)

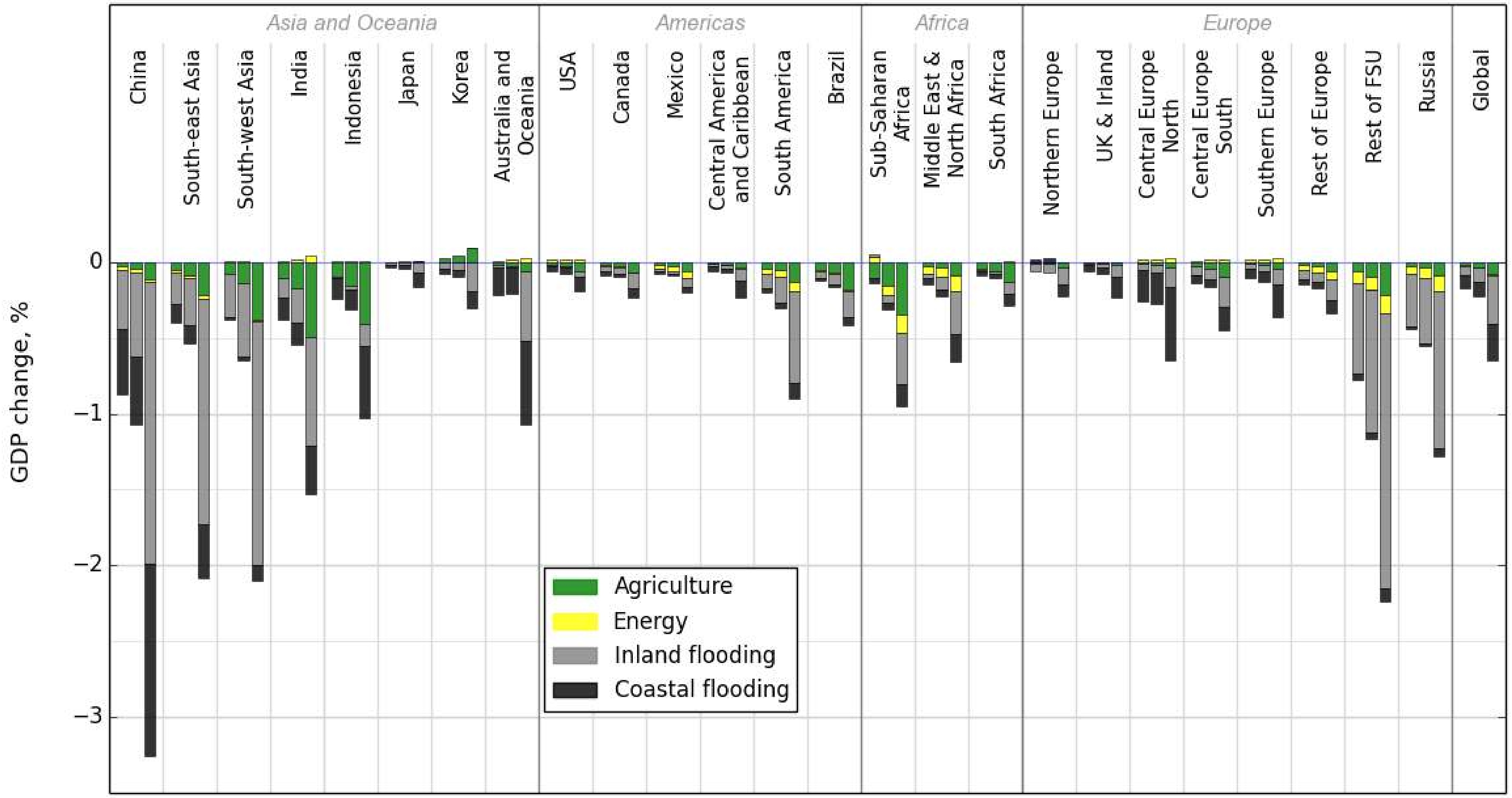
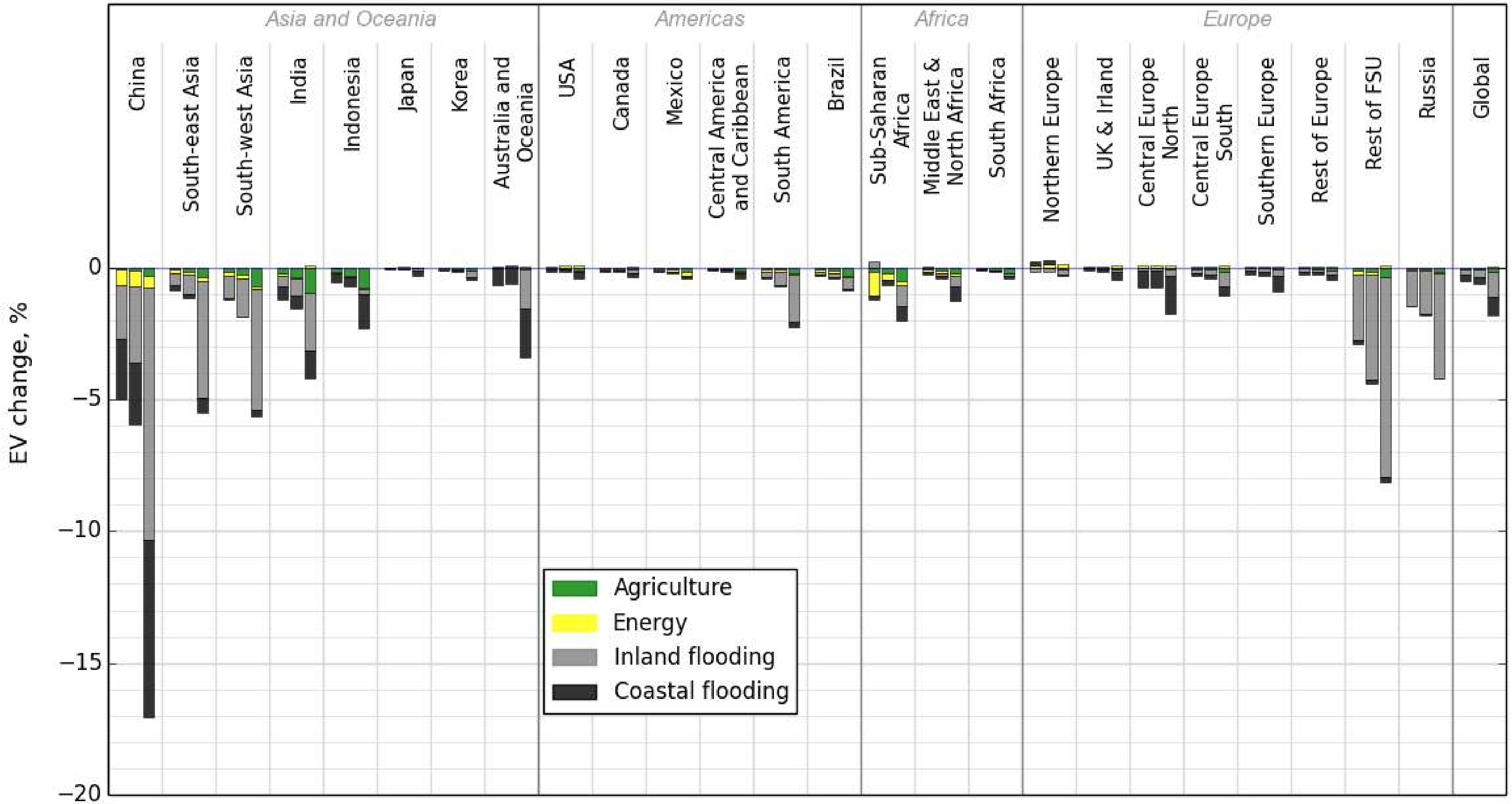


Figure 16. Welfare change (%)



REFERENCES

Anandarajah G, Pye S, Usher W, Kesicki F and C Mcglade (2011), TIAM-UCL Global Model Documentation, Working Paper UKERC/WP/ESY/2011/001, University College London

Anthoff D, RSJ Tol (2014), Climate policy under fat-tailed risk: An application of FUND. Annals of Operations Research:1-15

Bie H, & Van Den Broeck K (2011). Economic drivers of migration and climate change in LDCs. Global Environmental Change. doi:10.1016/j.gloenvcha.2011.09.002

Ciscar JC, Iglesias A, Feyen L, Szabó L, Van Regemorter D, Amelung B, Nicholls R, Watkiss P, Christensen OB, Dankers R, Garrote L, Goodess CM, Hunt A, Moreno A, Richards J, Soria A (2011), Physical and economic consequences of climate change in Europe. Proc. Natl Acad. Sci. USA 108:2678-2683 doi:10.1073/pnas.1011612108.

Fouré J, Bénassy-Quéré A, Fontagné L (2012). The Great Shift: Macroeconomic projections for the world economy at the 2050 horizon. CEPII Working Paper N°2012-03.

Henry, S., Boyle, P., and Lambin, E. F. (2003). Modelling inter-provincial migration in Burkina Faso, West Africa: the role of socio-demographic and environmental factors. Applied Geography, 23, 115-136.

Houser T, Kopp R, Hsiang S, Larsen K, Delgado M, Jina A, Mastrandrea M, Mohan, Muir-Wood SR, Rasmussen DJ, Rising J, Wilson P (2015). Economic Risks of Climate Change: An American Prospectus. Columbia University Press.

Keramidas K, Kitous A, Després J, Schmitz A (2017) POLES-JRC model documentation. EUR 28728 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-71801-4, doi:10.2760/225347, JRC107387

Kniveton D, Schmidt-Verkerk K, Smith C, and Black R (2008). Climate change and migration: improving methodologies to estimate flows, IOM Migration Research series, 33, http://www.iom.cz/files/Climate_Change_and_Migration_MRS_331.pdf.

Krishnamurthy PK, Lewis K and Choularton RJ (2014). A methodological framework for rapidly assessing the impacts of climate risk on national-level food security through a vulnerability index. Global Environmental Change, 25, 121-132.

Massey DS, Axinn W, & Ghimire D (2007). Environmental Change and Out-Migration: Evidence from Nepal. Research Reports. Ann Arbor: University of Michigan, Population Studies Center.

Myers N (2002). Environmental refugees: a growing phenomenon of the 21st century. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 357, 609-613.

Nikulin G, Jones C, Giorgi F, Asrar G, Bchner M, Cerezo-Mota R, Chris-tensen OB, Deque M, Fernandez J, Hansler A, van Meijgaard E, Samuelsson P, Sylla MB, Sushama L (2012) Precipitation climatology in an ensemble of cordex-africa regional climate simulations. J Climate 25(18):6057–6078, DOI 10.1175/JCLI-D-11-00375.1

Porter JR, L Xie, AJ Challinor, K Cochrane, SM Howden, MM Iqbal, DB Lobell, and MI Travasso (2014) Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field CB, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea, and LL White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533.

Richardson K, Lewis K., Krishnamurthy K, Kent C, Wiltshire A, Hanlon H (2017). Food security outcomes under a changing climate: impacts of mitigation and adaptation on vulnerability to food insecurity. In review at Climatic Change.

Tol RSJ (2008). Climate, development and malaria: An application of FUND. Climatic Change 88 (1):21-34.

Tol RSJ (2013), The Economic Impact of Climate Change in the 20th and 21st Centuries. Climatic Change 117 (4):795-808.

Vousdoukas M, Mentaschi L, Voukouvalas E, Verlaan M, Feyen L (2016a). Extreme Sea level - RCP85. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/a565eea4-5422-4c7d-a000-2e10ae872da7

Vousdoukas M, Mentaschi L, Voukouvalas E, Verlaan M, Feyen L (2016b). Extreme Sea level - RCP45. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/e9e42344-119d-479e-9bc7-57400d12a8a2

Vousdoukas M, Mentaschi L, Voukouvalas E, Verlaan M, Feyen L (2017). Extreme sea levels on the rise along Europe's coasts. Earth's Future. DOI:10.1002/2016EF000505 http://onlinelibrary.wiley.com/doi/10.1002/2016EF000505/full

LIST OF FIGURES