PROJECT FINAL REPORT

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This section must be of suitable quality to enable direct publication by the Commission and should preferably not exceed 40 pages. This report should address a wide audience, including the general public.

The publishable summary has to include 5 distinct parts described below:
• An executive summary (not exceeding 1 page).
• A summary description of project context and objectives (not exceeding 4 pages).
•A description of the main S&T results/foregrounds (not exceeding 25 pages),
•The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results (not exceeding 10 pages).
• The address of the project public website, if applicable as well as relevant contact details. Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc...), as well as the list of all benefici aries with the corresponding contact names can be submitted without any restriction.

Content

4.1 Final publishable summary report

Executive Summary

The policy discussion of whether we can limit global warming to not more than +2°C will be of central importance at the upcoming COP21 negotiations in Paris in December, 2015. In this context, the following scientific questions are of major importance:

- what might be the potential impacts of a +2°C global warming compared to the preindustrial period for various regions of the globe, and economic sectors?
- what are the differences between a +2°C and a +3°C global warming?
- what might be prevented if global warming is limited to +2°C rather than +3°C?

A key objective of the IMPACT2C project was therefore to examine the impacts of +2°C global warming on Europe and the key vulnerable global regions in Africa (Nile and Niger river basins), Bangladesh and the Maldives. This four-year multi-disciplinary research project (www.impact2.eu) started in October 2011 and was funded by the European Commission's Seventh Framework Programme under the grant agreement no. 282746. Researchers from 29 different institutions and 17 countries worked together within this project; the project was coordinated by the Climate Service Center in Hamburg, Germany.

A comprehensive assessment of the impacts and costs of a temperature increase of +2 °C (or +1.5°C) on different sectors such as water, energy, agriculture, infrastructure and health has been undertaken. Project partners introduced a number of innovation approaches. A sampling method to provide information across the matrix, taking into account the combination of emission scenarios, climate and impact models, and socio-economic pathways allowed the consideration of uncertainty in any subsequent analysis.

The key messages of the IMPACT2C project can be summarized as follows:

- A global warming by 2°C substantially affects a wide range of sectors and regions throughout Europe. Some regions or sectors will benefit from a future warming, but some will experience disadvantages.
- To assess the impacts of climate change on specific sectors, cross-sectoral relationships have to be included into the analysis.
- In most regions of Europe, the projected regional warming is more pronounced than the global mean warming. Projections for annual mean precipitation show wetter conditions in northern Europe and drier conditions in southern Europe.
- Under a 2°C global warming, a European-wide increase in the frequency of extreme events is expected. Heatwaves are projected to double while extreme precipitation events tend to become more intense.
- A limitation to 2°C global warming will not stop sea-level rise due to the delayed reaction of the oceans. Therefore costs due to coastal flooding will incur even with adaptation measures.
- Bangladesh and the low-lying islands like Maldives are expected to feel the consequences of climate change, due to the continuous rise of sea-levels enhancing the risk for storm surges and flooding.
- For West and East Africa, the warming is above the global temperature increase. West Africa could experience a modest increase in rainfall, whereas for East Africa no clear trend is projected.

In summary, the IMPACT2C project provided easily accessible climate-related information to policymakers, the media and other interested parties. The project results were put together in a series of the Policy Brief Notes. The IMPACT2C web atlas (www.atlas.impact2c.eu) was produced to provide input for the development of recommendations on possible adaptations strategies.

Summary description of project context and objectives

IMPACT2C identified and quantified the impacts and most appropriate response strategies of +2°C global warming for Europe and three vulnerable regions in other parts of the world: Bangladesh, Africa (Nile and Niger basins) and the Maldives.

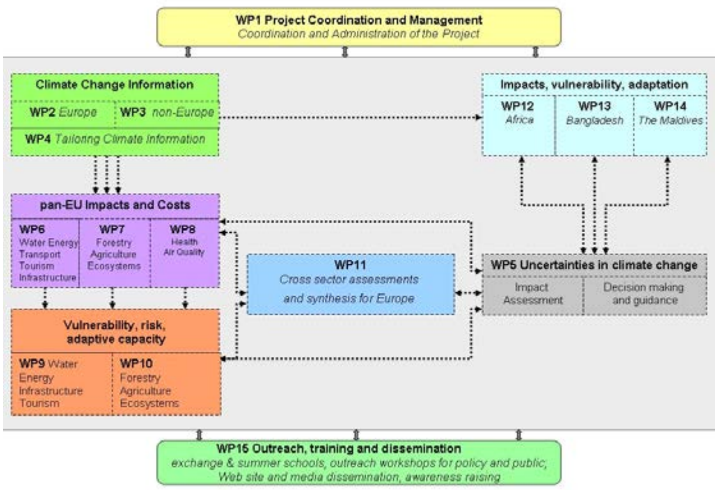
The overall objectives of IMPACT2C were:

- determination of the climate in Europe and most vulnerable regions for +2 °C (when appropriate +1.5°C) global warming compared to pre-industrial level;
- consideration of impacts from a cross-sectoral perspective, e.g. for particularly vulnerable areas that are subject to multiple impacts where cumulative effects may arise (e.g. in the Mediterranean region) and in relation to cross-cutting themes (e.g. cities and the built environment).

The project:

- provided detailed information based on an ensemble of climate change scenarios. It was tailored to the needs of various sectors, for the time slice in which the global temperature is simulated to be +2°C above pre industrial levels;
- provided a detailed assessment of risks, vulnerabilities, impacts and associated costs for a broad range of sectors against the background of socio-economic scenarios consistent with the development paths aimed at global warming being limited to 2°C;
- developed a balanced mix of response strategies (technological, governance, capacity building) accounting for the regional differences in adaptive capacities, which are distinguished between those that can be accommodated autonomously and those that require additional policy interventions.

To meet these project aims, IMPACT2C was divided into 15 work packages (WPs). Out of these, 13 were research WPs, one served to manage the project, and the remaining WPs deals with the objectives of outreach, training and dissemination.



IMPACT2C was coordinated by the Climate Service Center, Helmholtz-Zentrum Geesthacht.

The team (Table PES1) was made up of 17 nationalities and integrates the expertise of climate scientists and sectoral impact specialists from both the natural and social sciences, together with local specialists from the regions addressed.

Figure 1 *Workpackages and their interactions.*

Table 1. List of Beneficiaries

No	*Participant organisation name/Corresponding contact*	*Country*
1	Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH, Climate Service Center/**HZG – Coordinator/ Daniela Jacob**	Germany
2	Potsdam Institut fuer Klimafolgenforschung/ **PIK / Fred Hattermann**	Germany
3	UniResearch, Bjerknes Centre for Climate Research/ **UniRes /Stefan Sobolowski**	Norway
4	Meteorologisk Institutt/**MET.NO/ Jan Erik Haugen**	Norway
5	Sveriges Meteorologiska och Hydrologiska Institut, Rossby Centre /**SMHI/ Erik Kjellström**	Sweden
6	JRC -Joint Research Centre- European Commission/ **JRC/ Alessandro Dosio**	Belgium
7	Agenzia Nazionale per le Nuove Tecnologie,L'energia e lo Sviluppo Economico Sostenibile / **ENEA/ Sandro Calmanti**	Italy
8	Centre National de la Recherche Scientifique Institut Pierre Simon Laplace/ **CNRS-IPSL/ Robert Vautard**	France
9	Centre National de Recherches Meteorologiques METEO-FRANCE/**MeteoF/ Michel Déqué**	France
10	Universität Graz, Wegener Zentrum für Klima und Globalen Wandel/ **UNIGRAZ/ Heimo Truhetz**	Austria
11	Joanneum Research Forschungsgesellschaft MbH / **JR / Franz Prettenthaler**	Austria
12	Internationales Institut fuer Angewandte Systemanalyse **/ IIASA / Michael Obersteiner**	Austria
13	Danmarks Meteorologiske Institut / **DMI / Ole Bøssing Christensen**	Denmark
14	Koninklijk Nederlands Meteorologisch Instituut / **KNMI / Geert Lenderink**	Netherlands
15	Wageningen Universiteit / **WU /Fulco Ludwig**	Netherlands
16	Technical University of Crete / **TUC / Ioannis Tsanis**	Greece
17	Paul Watkiss Associates Ltd/ **PWA / Paul Watkiss**	UK
18	Universite de Lausanne / **UNIL / Hans-Jörg Albrecher**	Switzerland
19	University of Southampton/ **SOTON / Robert J. Nicholls**	UK
20	Stockholm Environment Institute Ltd /**SEI-OXFORD / Ruth Butterfield**	Sweden
21	**MET OFFICE / Jason Lowe**	UK
22	Ministry of Housing and Environment /**MHE / Ali Shareef**	Maldives
23	Bangladesh Center for Advanced Studies / **BCAS / Md. Abu Syed**	Bangladesh
24	International Water Management Institute /**IWMI / Simon Langan**	Sri Lanka
25	Stichting Wetlands International / **WI / Pieter van Eijk**	Netherlands
26	World Health Organization, Regional Office for Europe, Kopenhagen-Rome/**WHO / Bettina Menne**	Switzerland
27	Institute of Water Modelling / I**WM / Asif Zaman**	Bangladesh
28	African Centre of Meteorological Application for Development / **ACMAD / Andre Kamga Foamouhoue**	Niger
29	Global Climate Forum E.V./ **GCF/ Jochen Hinkel**	Germany

The expected impact of the project raised from the statement made in the work programme: "Identification and quantification of impacts of a global temperature increase up to 2°C in Europe and vulnerable regions of the world".

Innovative aspects of IMPACT2C were as follows:

- the project considered a cross-sectoral perspective to complement the sectoral analysis, (i) by undertaking case studies for particularly vulnerable areas that are subject to multiple impacts (e.g. the Mediterranean region), (ii) by focusing on cross-sectoral interactions (e.g. between the agricultural, water and the energy sectors and competition for land use) and (iii) by undertaking cross-cutting themes which adopt a different orientation (e.g. cities and the built environment);

- the project used harmonized climate and socio-economic assumptions/scenarios to ensure that individual sector assessments are aligned to the 2°C (1.5°C) scenario for both impacts and adaptation, and are compatible between sectors;

In addition to several European case studies, IMPACT2C assessed climate change impacts in a few selected representative areas that are particularly vulnerable to climate change. These include Bangladesh, two regions in Africa (Nile and Niger basins) and the Maldives.

The project included an ambitious awareness-raising programme that disseminates the findings effectively and provide easily accessible climate-related information to policy-makers, the media, and users in general.

IMPACT2C put this information together in the IMPACT2C web atlas (www.atlas.impact2c.eu) and in a series of the Policy Brief Note that highlights the risks, trade-offs, synergies and costs. This information is particularly useful for the European authorities who participate in international negotiations on climate change.

Project web-site: www.impact2c.eu

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Main S&T results/foregrounds

All results of the project are summarized in the project publications, deliverables, policy brief notes and in the IMPACT2C web-atlas (www.atlas.impact2c.eu) .

Climate change scenarios for Europe

(initial results of Workpackage 2)

Key messages

- Robust and significant changes in climate conditions have been identified for Europe when the global mean temperature reaches +2ºC above preindustrial levels.
- Notably, a stronger warming than the global average is projected in northern and eastern Europe in winter and in southern Europe in summer.
- Projected changes in extremes, including increasing numbers of heat waves, decreasing cold spells, decrease in freeze-thaw cycles and more severe precipitation events.
- The results of regional climate simulations at 50, 25, 12.5 and 6.25 km horizontal grid spacing show clear added value with increasing resolution. For example, higher resolutions provide relatively stronger climate change signals in high-altitude mountain areas and better simulation of precipitation extremes.

When will global warming reach +2ºC?

A procedure for identifying when global mean temperatures first reach 2ºC (1.5ºC) above its preindustrial level has been jointly developed between the different Workpackages. The following definitions have been taken into account):

In this study the +2^{o}C period is defined as the time when the 30year average global mean temperature reaches +2^{o}C, compared to the identified 'preindustrial' period of 1881–1910 (Vautard et al,2014). Past preindustrial warming until the base period (0.46 K) is considered as temperature rise in a 30year running mean from 1881–1910 to 1971–2000. Thirty year running means, starting from the base period 1971–2000, are calculated for the general circulation models (GCM). The year of crossing this threshold thereby indicates the central year within this 30-year time period.

This concept is illustrated in Figure 1 that shows the increase in global mean temperature in global circulations models (GCM) used in CMIP3 and CMIP5. As can be seen, different GCMs (and different simulations with the same GCM) reach +2ºC at different times. In RCP2.6 most GCMs do not reach +2ºC at all. For RCP4.5, RCP8.5 and SRES A1B the central estimates all lie in the relatively narrow time frame between 2042 and 2050.

There were two main streams for regional climate model simulations; one based on regional climate model simulations at 25 km resolution from the ENSEMBLES project (van der Linden and Mitchell, 2009) – *fast track*, and one based on the EURO-CORDEX simulations at 12 km resolution (e.g. Jacob et al. 2013) and MED-CORDEX – *slow track.* The ensemble of mandatory simulations is described in the Appendix.

Five regional climate models (RCMs) have been selected for the fast and slow tracks (See Appendix). They were used as a basic subset – as *mandatory simulations*- and represented the entire ensemble's spread and were entirely independent. The following three criteria have been considered particularly important for such selection (detailed in Deliverable 5.1): RCMs should have different driving general circulation models (GCMs); RCMs should be developed by different institutions and RCMs should projected climate change signal differently.

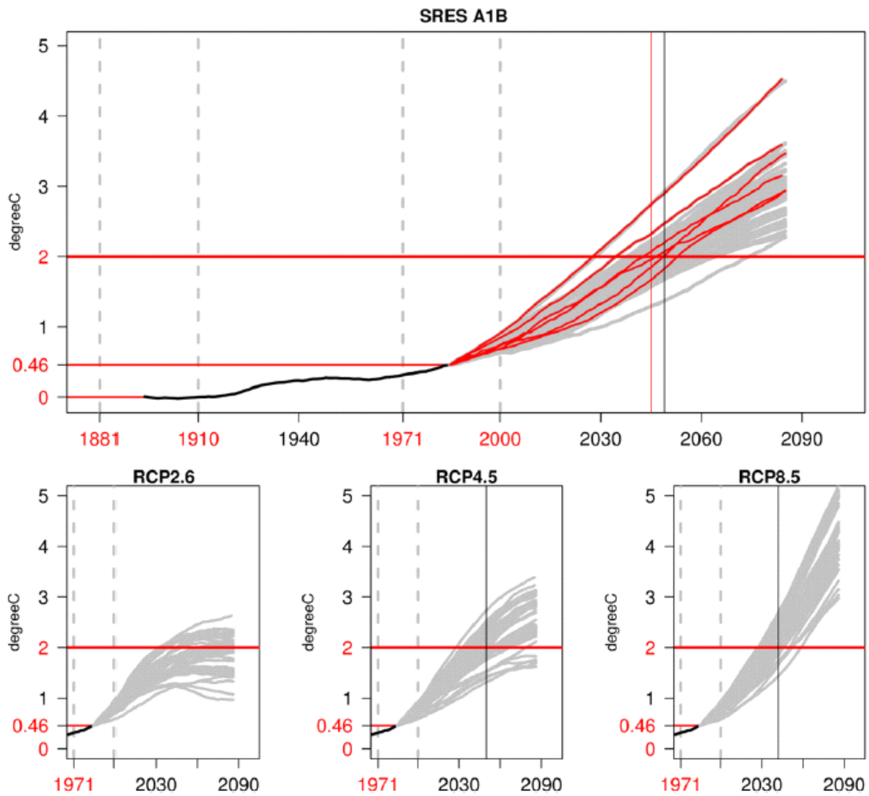

Figure 1. ***Global mean temperature (30-year running mean; grey lines) for the SRES A1B ensemble (top panel) and for the RCP2.6, RCP4.5 and RCP8.5 CMIP5 simulations (bottom panels) exceeding the +2ºC threshold (bold red horizontal line). The average observed temperature compared to preindustrial (1881–1910) is depicted in the upper panel (black line). The CMIP3 and CMIP5 ensemble median years for reaching the 2ºC target for each emission scenario are shown as black vertical lines, whereas the red vertical line represents the median year of the six driving GCMs of this study, which are highlighted in red. Since most RCP2.6 simulations stabilise below +2ºC, no median year that exceeds the +2ºC threshold is shown. From Vautard et al. (2014).***

Robust changes in the European climate

Results from the "fast track" simulations, based on 15 different RCM simulations with boundary conditions from six different GCMs, showed significant and robust changes in the European climate (Vautard et al., 2014). Analysis of the "slow track" EURO-CORDEX (Sobolowski et al., 2015) simulations confirmed these findings.

Changes in the climate at the time of +2ºC warming are very similar in the EURO-CORDEX simulations compared to those identified from the "fast-track" ENSEMBLES simulations. This includes: stronger warming compared to the global average; most pronounced warming in the North and East in winter and in the South in summer; more precipitation in the North and more severe heavy precipitation extremes in most of Europe. Figure 2 shows temperature related changes based on 10 RCM-GCM combinations. Very strong rises in minimum temperatures in winter are seen in northern and eastern Europe. Another prevalent feature is stronger warming, both in minimum and maximum temperatures, in high-altitude areas such as the Alps and the Pyrenees. The high resolution of the EURO-CORDEX RCMs enables the detection of strong changes in temperatures due to feedback processes involving retreating snow cover in high-altitude regions.

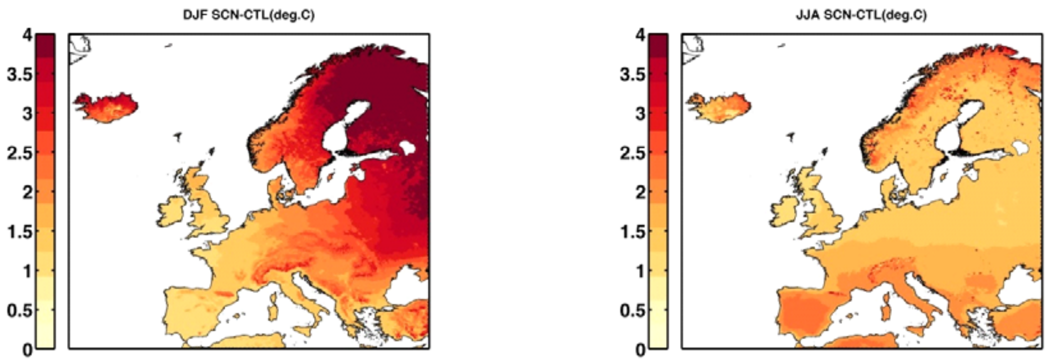

Figure 2 ***Changes between the 1971–2000 and the +2ºC period, in seasonal mean Tmin in winter (left) and Tmax in summer (right). From Sobolowski et al. (2015).***

Increasing the resolution beyond EURO-CORDEX

Even at the EURO-CORDEX 12.5 km grid spacing small scale details of the terrain and small-scale processes are not fully resolved. For this purpose a regional climate model (HARMONIE-Climate) has for the first time been used for a longer climate simulation downscaling the ERA-Interim reanalysis on a Pan-European scale at 6.25 km horizontal grid spacing (Lindstedt et al., 2015). An evaluation against observational data reveals that the model is equally good, or better, when compared to a coarser-scale version of the model (15 km grid spacing). In particular better predictions for the very rare, high-intensity precipitation events are given.

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Tailoring climate information for the local scale and impact modelling

(initial results of WP4)

User requirements

As because the impact groups were very diverse in this project and the choices for meteorological variables and derived indices varied greatly, the user survey was initiated. The survey also looked to initiate discussion on climate input for partners with little experience with climate data at an early stage of the project.

Questions on the user requirements were formulated into seven categories: 1) domain & spatial resolution of data, 2) which meteorological variables are used, 3) use of derived specific (meteorological/hydrological) variables and indicators, 4) use of observational data, 5) use of specific input time series, 6) experience with sensitivities of impact models to climatic input, and 7) technicalities on the provision of data.

Based on the user request a list of specific climate indices, dealing with heat waves, cold spells, extreme precipitation, number of (consecutive) dry/wet days, etc. has been identified, and this list formed the basis of climate input for the IMPACT2C web-atlas.

One of the most prominent requirements from the user survey is the need for bias correction of the meteorological input for the impact models.

Bias correction

Climate simulations usually contain systematic errors when compared to observations, which are derived from inadequate parametrizations of physical processes, coarse resolution, topography, spatial smoothing and structural errors in the models. Many applications (e.g. impact models) require data that is corrected for these model biases, in particular if the impact model is non-linearly dependent on the meteorological input. This is for instance the case if the system is highly dependent on whether or not a certain threshold is exceeded for a specific variable.

Consequently, an empirical-statistical technique, called quantile mapping (QM) (Wilcke et al. 2013, Gobiet et al. 2015) has been used to correct biases in standard meteorological variables (temperature and precipitation) of all mandatory climate simulations. The correction is carried out on the 25 km grid of E-OBS (Haylock et al. 2008) at a daily scale. In addition, bias corrected radiation data has been provided for the hydrological modelling (WFDEI, http://www.eu-watch.org/data_availability, Weedon et al., 2011). The list of processed output variables is shown in the appendix.

Besides production of bias adjusted and re-gridded data and the climate indices provided for the IMPACT2C modelling activities (discussed in the following sections), the work using a number of advanced and/or explorative techniques, e.g. bias correction of winds were carried out.

References:

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Assessment of uncertainties *(initial results of WP5)*

As mentioned before, climate simulations contain systematic errors which influences the results of climate impact research.

Within IMPACT2C the major advancement to overcome this was in developing multi-model-multi-scenario ensembles for climate as well for the impact models which ensures consistency of the climate to impact model linkages.

By doing so, the ensemble of climate simulations together with percentile analysis and a Mann-Whitney rank sum test capture in the best way a wide range of potential future climate change under +2^{o}C degree warming. The selected 20th , 50th , and 80th percentiles are appropriate not only for the main tendency but also exclude the effects of outliers or more extreme projections.

Furthermore, IMPACT2C applied an innovative approach that looks at the climate model responses when each model hits 2^{o}C. It allowed the time element to be remove, e.g. to compare model A at 2^{o}C (2030-2060) with model B at 2^{o}C (2045- 2075).

In addition to the RCP scenarios, a number of SSP projections have been used as a basis for forecasting adaptive capacity into the future (see the Appendix).

However it was difficult to develop general guidelines on model use for the impact study. It was found to be most effective for decisions of usage to be made based on specific aims/questions. The crop impact studies (WP7) showed that uncertainties could be traced not only to different spatial and temporal sources, including input data, but also to model structure, process parameterisation and model validation status.

The major challenges remain for adaptation and quantification of impacts and the associated costs. These results are still highly uncertain. The adaptation options are time dependent, because impacts are a result of a) future climate associated with b) future socio-economic developments (e.g. population), so impacts at 2^{o}C in 2040s are different to 2^{o}C in 2070s, because population and GDP will differ between these time frames. Apart from depending on known science and plausible future greenhouse gas emissions, difficulties in decision making create uncertainty in future impacts and potential adaptation measures.

Nevertheless in IMPACT2C the sources of uncertainties were addressed throughout all paths of the modelling chain using the ensemble approach not only for climate models abut also for SSPs and impact models and analyzing the uncertainties through sensitivity studies.

What does +2^{o}C global warming mean for Europe ?

IMPACT2C enabled the subsequent synthesis that brings together all the results in a harmonised analysis for Europe. The IMPACT2C project ran a large number of impact models. The ensemble of the impact models used in the project is described in the Appendix. Figure 3 shows the linkages of models across different sectors.

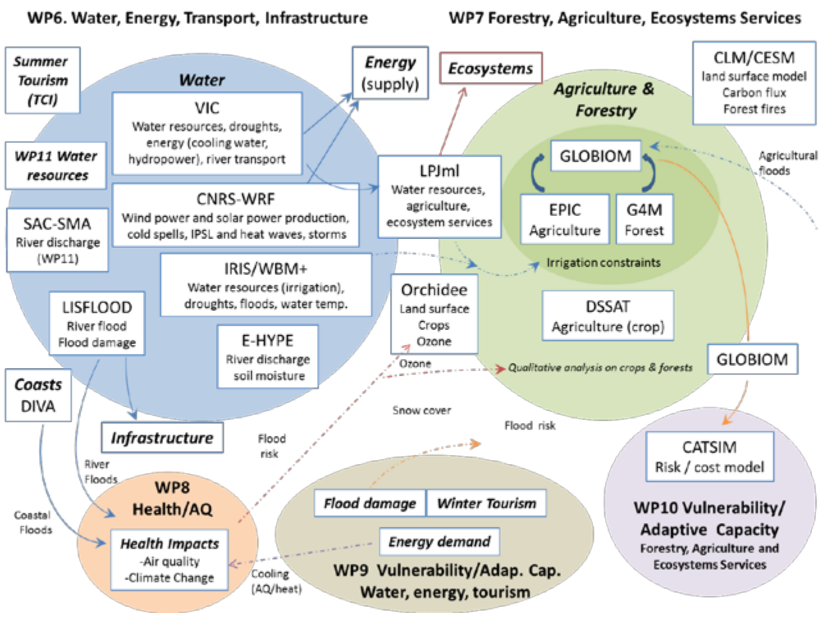


Figure 3. The **linkages of models across different sectors**

Water

(initial results of WP6)

In Europe, freshwater resources are crucial for many sectors and sector activities including agriculture, hydropower generation, cooling water for power plants and domestic and industrial water supply. At the same time, water can have a direct impact on safety and livelihoods through floods that can lead to disastrous human and economic losses. Future climate change is expected to have a strong impact on the water cycle and the hydrological extremes, as shown below:

Key messages

- ***Water Cycle***: Annual mean *runoff* increases roughly North of 45N and it is most pronounced in winter (the same as for precipitation); in general 30 - 50% of the increase in precipitation is counteracted by enhanced *evapotranspiration*; higher altitudes will see a reduction of the snow season on one to two months.
- ***Extreme flood*** magnitude is expected to substantially increase over large parts of central and southern Europe, which can partly be explained by an increase in extreme rainfall. Extreme flood magnitude in northern Europe caused by snow melt is expected to decrease due to reduced snow accumulation.
- No clear pan-European trend in changes in ***extreme streamflow droughts***. Extreme streamflow droughts are projected to intensify in some areas in southern and southeastern Europe and to weaken in some areas in northern and northeastern Europe.
- Water using sectors in especially Southern Europe will be affected by changes in the water cycle due to a combination of reduced summer rainfall and enhanced evaporation. This will negatively affect dryland agriculture, irrigation, cooling water availability and hydropower potential.

Impact on water cycle

Results show important changes in European water resources in a +2^{o}C world, with strongly different patterns emerging across the continent.

The analysis of the changes in run-off and river discharge under +2^{o}C global warming shows an increase in most parts of Europe. However, there is a strong North-South gradient in the projected changes. The largest increases in run-off and discharge are seen in the East and the far North of Europe, while there are decreases in parts of the Mediterranean, especially in the South of Spain, Portugal, Sicily and parts of Greece. There are also seasonal patterns to these changes. The climate models indicate that winter precipitation increases almost everywhere in Europe. This leads to more runoff in most of Europe, especially in Scandinavia where today, low flows occur in winter due to snow storage but where in the future a larger part of the precipitation falls as rain instead of snow.

The changes in summer are more complex. Due to a reduction in precipitation and increase in evaporation runoff and river discharge reduces in Southern Europe. In the Norwegian and Swedish mountains run-off is decreasing due to a reduction in summer snow melt. As a result of the warming climate, there is less snowfall in winter. Especially at lower altitudes the snow season (number of days with more than 30 cm snow pack) will reduce under a warmer climate.

The annual snowmelt peak will come earlier in the year in the future because of higher temperatures. Summer run-off originating from snow melt will reduce in the future. This is caused by a combination of faster melting of the snow due to higher temperatures and because in the future a higher percentage of precipitation will come as rain instead of snow. This will result in reduced summer discharge in river originating in the Alps.

Decreases in precipitation in parts of the Mediterranean region lead to less evapotranspiration (Figure 4). Increases in evapotranspiration reach an annual maximum in spring, when changes in the duration of snow-cover are large and temperatures relatively high, especially in the Alps, Fennoscandia and the former Soviet Union. The largest declines in evapotranspiration occur in Summer on the Iberian Peninsula, South France and Bulgaria, due to declining amounts of soil moisture.

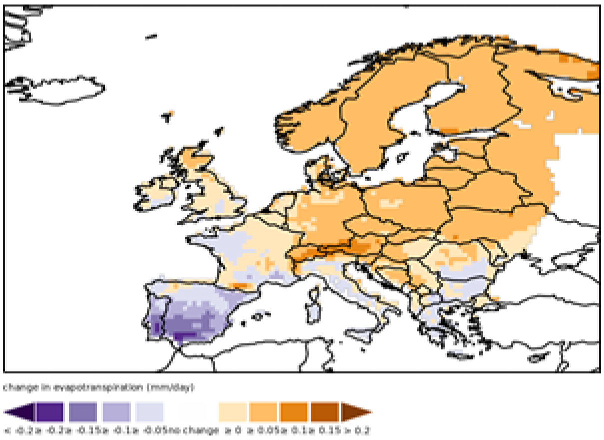


Figure 4. Changes in the water cycle (run off) in Europe under 2°C global warming. Figure shows changes relative to the 1971-2000 in run-off [mm/day] (for RCP4.5 only)

With the projected increase in heavy precipitation events, there is also the potential for higher flood risks. IMPACT2C has investigated this by looking at the change in flood risk using the metric of a QRP10 and QRP100. The results (Figure 5) show that for much of Europe, the one-in-10- and the one in 100 year flood event – as experienced in today's climate - is projected to become more severe (i.e. more frequent).

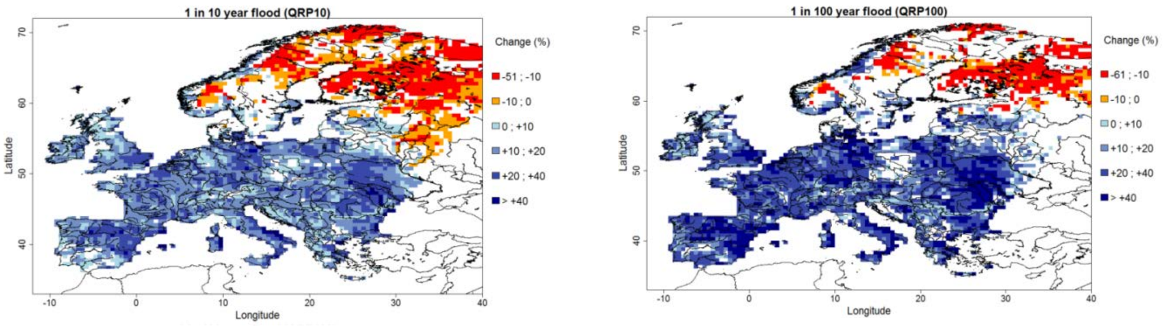


Figure 6 Median of Relative Future Changes in high flows under +2oC global warming for one in ten year events (QRP10, (left panel)and one in hundred year events (QRP100, right panel). The median is computed over 33 members (11 mandatory climate simulations x 3 Hydrological models). Only significant changes are shown here.

There are potential changes in low flows and hydrological droughts, though again there is a very strong distributional pattern to these changes, above and below a diagonal split across Europe. Low flows will decrease in magnitude and last longer in the Mediterranean, in France and parts of the British Isles. This is linked to a decrease in mean summer precipitation in these regions, further heightened by increasing evapotranspiration. In the rest of Europe there will be increases in low flows will be higher in the future and low flow periods will be shorter.

Value at Risk from floods and reform recommendations for the financial risk transfer mechanism

(initial results of WP9)

Floods rank amongst the widest-reaching and commonly occurring natural hazards in Europe. If the population and the GDP remain the same compared to the period of 1971-2000, the flood damage is projected at 13.4 billion Euros/year, with 602 000 people/year potentially being affected.

Therefore it is of major importance to have a sound understanding of the distribution of insured losses due to flood damages to residential buildings. Within IMPACT2C the suggestions on institutional (and regulatory) reform for the financial risk transfer mechanisms to increase adaptive capacity in the EU-27 have been derived from (i) analyses and results of flood loss modelling and (ii) qualitative data – collected in previous reporting periods – on the national (flood) risk transfer systems. In this context the testing of a completely different reform option, i.e. the establishment of Joint Risk Pooling Initiatives, took place. This new option takes advantage of Europe's magnitude and diversity when it comes to flood risk.

Sea level Rise

(initial results of WP6)

The European Union is at risk of the adverse effects of rising sea-levels, potentially leading to an increase in number of people affected by flood events and increased damage costs unless adaptation is undertaken. The IMPACT2C research answers a question, 'What are the impacts and costs of sea-level rise around Europe in a 2°C world?'

Key messages

- Adaptation needs to consider long-term conditions, as sea-levels will continue to rise even if temperatures stabilize at +2°C;
- Highest potential flood costs projected for low-lying North Sea nations;
- Some costs will occur even under conditions of adaptation

The initial results demonstrate that despite climate mitigation promising to reduce global mean temperatures, this does not translate into an immediate decrease in global mean sea-levels. A reduction in the rate of sea-level rise could take many decades.

The initial results from the climate model HadGEM2-ES show that sea-level rise in a 2°C world could range from 0.11m (in the 2030s under a high emissions RCP8.5 scenario) to 0.46m (in the 2080s under a climate mitigation scenario, RCP2.6), and could raise further into the 22nd century.

Results of adaptation modelling indicate, assuming that present day adaptive measures such as dikes are raised with sea-level rise, the expected number of people at risk from flooding annually in the EU could be between 5,300 and 7,000 people per year, largely in the low-lying countries surrounding the North Sea.

A climate mitigation (2°C) scenario compared with a high emissions (5°C) scenario could reduce the effective number of people flooded annually by 50%.

The methodology used in IMPACT2C assumes that following present day practices, hard adaptation measures such as sea dikes will continue an important method to reduce impacts (Figure 7).

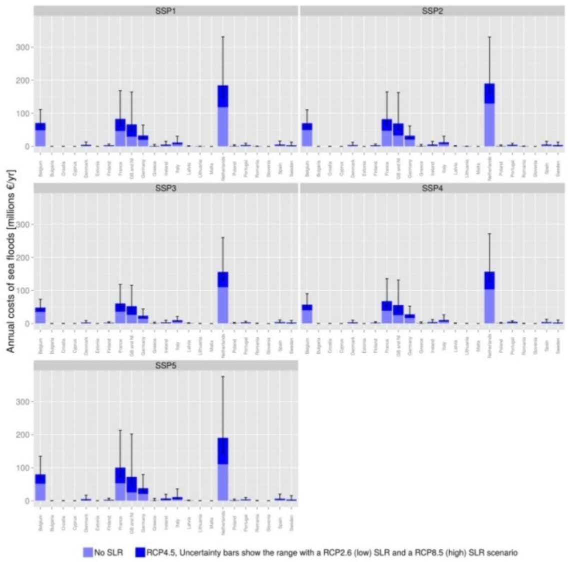


Figure 7. Annual costs of sea floods per EU country for each SSP scenario in the 2080s. The dark blue bar indicates a RCP4.5 mid scenario, with uncertainty bars showing the range of impacts with low (RCP2.6 low) and high (RCP8.5) scenario. A scenario of no sea-level rise is indicated for each country by the lighter blue bar.

The costs of climate change adaptation could also reduce if alternative approaches of sand nourishment, accommodation of key infrastructure to sea-level rise or selective managed realignment were considered.

Energy

(initial results of WP6 & WP9)

Climate change will impact both future energy supply and demand. Regarding the energy supply, direct and indirect climate change effects can be distinguished. The direct effects on energy supply are mostly related to changes in renewable energy potentials. Therefore, the IMPACT2C community analysed changes in solar power potential, wind energy potential and gross hydropower potential under +2°C global warming. Indirect effects of climate change on energy supply are based on changes in environmental conditions which are influencing the energy production potentials. As an example, inland water temperature was analysed to assess the usability of cooling water for thermal power plants.

Future climate change is expected to have a strong impact on the energy sector as shown below:

Key messages

- ***Solar photovoltaic potential**** decreases over most of Europe, except over southern countries where minimal change is projected. The change is projected to be below 5% (to 10%) over most of Europe.
- ***Gross hydropower potential**** is projected to increase in northern and northeastern parts of Europe and to decrease in southern European countries. The changes in gross hydropower potential can be related directly to changes in river discharge;.
- ***Wind energy potential**** is generally projected to decrease over Europe, except over southeastern Europe and the Baltic Sea where an increase is projected. However the direction of change is uncertain over most of Europe The changes are of the order of 5% or below.
- Rising ***water temperatures*** combined with declining river discharge during summer in most parts of Europe are projected to reduce the availability of potential cooling water and thermoelectric power.
- Decrease in **electricity demand** is projected for most European countries. Italy is the only one country for which an increase in the risk of high electricity demand is projected due to increased cooling demand in summer.

*) as generated both in terms of power potential at the grid point scale over entire Europe and in terms of power production as generated by current and planned wind farms or power plants at the national level for different European countries;

**) the gross hydropower potential (GHP) quantity which corresponds to the energy available if all runoff were converted into power at all locations.

Impact on wind energy potential

Wind energy density is stronger over sea than over land (Figure 8). Overall, the general spatial pattern of wind energy density is projected to barely be affected under +2°C global warming. The magnitudes of projected changes are of the order of 5% or below. However, the direction of change is uncertain over most of Europe. Nevertheless, the majority of models project a decrease over the Mediterranean region, the Atlantic Ocean and northern continental Europe. Consistent increases are projected over south-eastern Europe and the Baltic Sea.

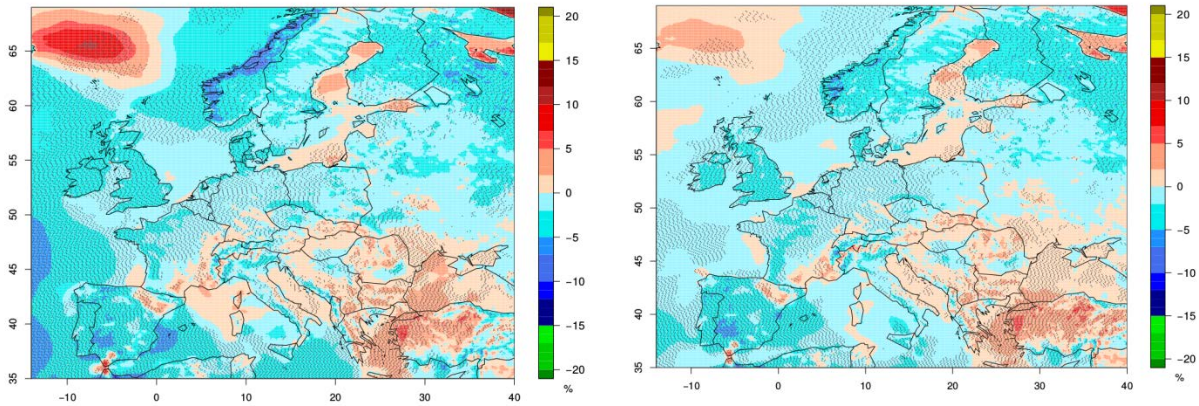


Figure 8 (left) Ensemble mean changes in annual wind energy density at 90m (W.m^{-2}) under +2°C global warming with respect to the recent period (in %), were assessed from the 5 RCP4.5 simulations set (left). The figure on right was assessed using the 9 RCP4.5-RCP8.5 simulations set.

Impact on solar photovoltaic potential

The solar photovoltaic potential (PV) exhibits a positive gradient from northern to southern Europe. According to most models, decreases in mean annual PV potential are highlighted over most of Europe, reaching magnitudes of 5 to 10% decrease in northern countries (Figure 9). There is an exception in southern countries where changes are not statistically significant.

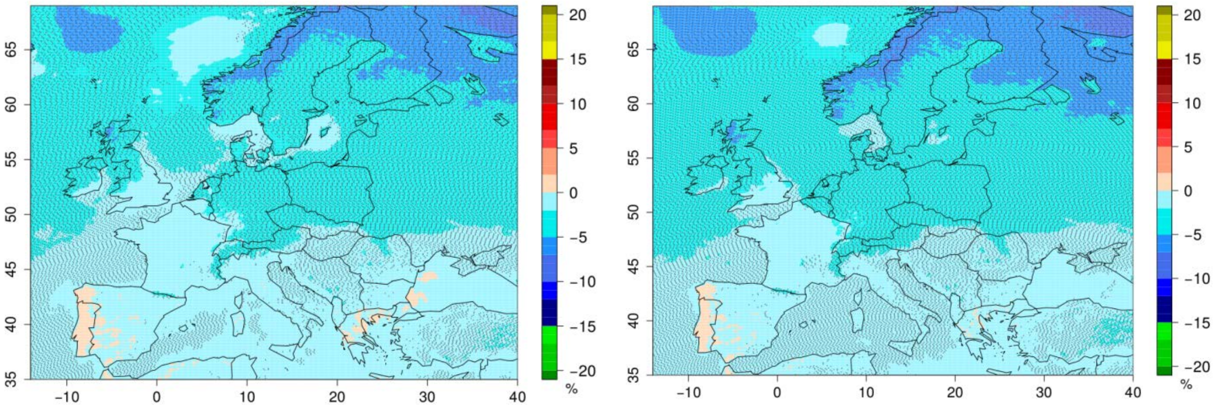


Figure 9 (left) Ensemble mean solar PV potential (kWh.yr-1.m-2) under a 2°C global warming with respect to the recent period (in %), assessed from the 5 RCP4.5 simulations set (left). The figure on right was assessed using the 9 RCP4.5 and RCP8.5 simulations set. Grid points where changes are robust are marked with black dots.

Impact on gross hydropower potential

Climate change was estimated to increase gross hydropower potential by 10 to 20% in the northern and northeastern European countries (Figure 10). Southern European countries, especially the Iberian Peninsula and Greece, are projected to experience a 5 to 10%.decrease in gross hydropower potential.

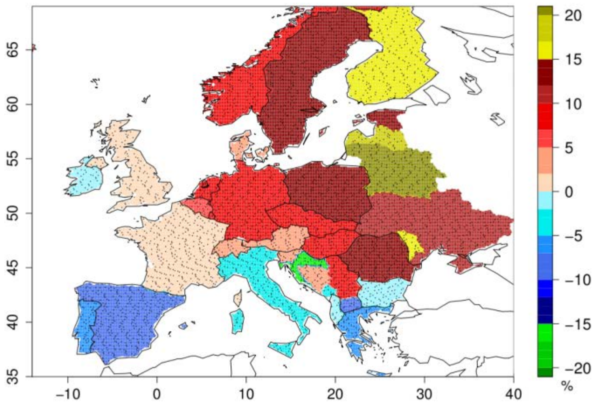


Figure 11. Ensemble mean national gross hydropower potential (MW) under +2°C global warming with respect to the recent period (in %), assessed from the 5 RCP4.5 simulations.

Impact on thermoelectric power capacity

Water temperature is an important indicator for cooling water potential and thermoelectric power generation. The initial results indicate a high agreement in change (almost 100%) for most parts of Europe showing robust increases in projected water temperature. Furthermore Increasing water temperatures combined with reduced streamflow may increase restrictions on cooling water use and if current environmental objectives were maintained this would reduce the potential for thermoelectric power production between 10 to 20 % in many European countries.

Impact on electricity demand

(initial results of WP9)

Figure 12 presents the modelling results exemplarily for Italy and France, which show quite different temperature-load-relationships. While France presents an example for a future country dominated by heating , Italy is exemplary for a country with distinct cooling effects.

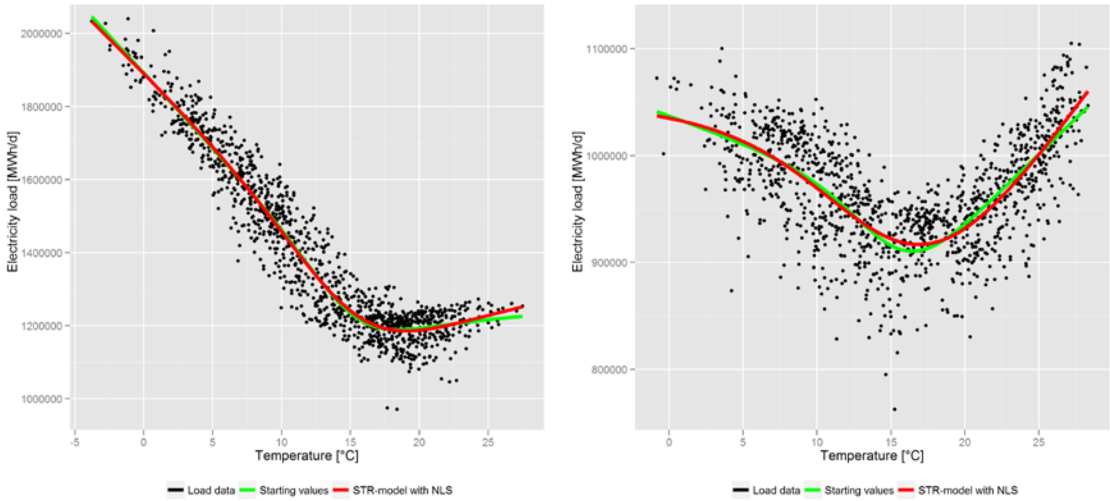


Figure 12: Temperature impacts on electricity load in France (left) and Italy (right) on working days.

Overall, +2 °C global warming reduces the total electricity consumption in all considered European countries, except for Italy (Figure 13) . In relative terms, Weather Value at Risk (VaR, 95 % - *Weather-VaR (α) denotes 'the Value at Risk resulting from adverse weather conditions, and represents – for a given level of confidence [α] over a given period of time – the maximum expected loss'*) of electricity demand increases in Italy , while in all other countries a decrease in VaR is seen. In absolute terms, the highest decrease in electricity demand is measured by far in France because of the French energy policy. All in all, in most countries, the heating effect dominates, which in combination with warmer temperatures results in a decrease of electricity demand. The sole exception of this rule is Italy, where due to the increase in cooling demand an increase of electricity demand is anticipated by the climate scenarios.

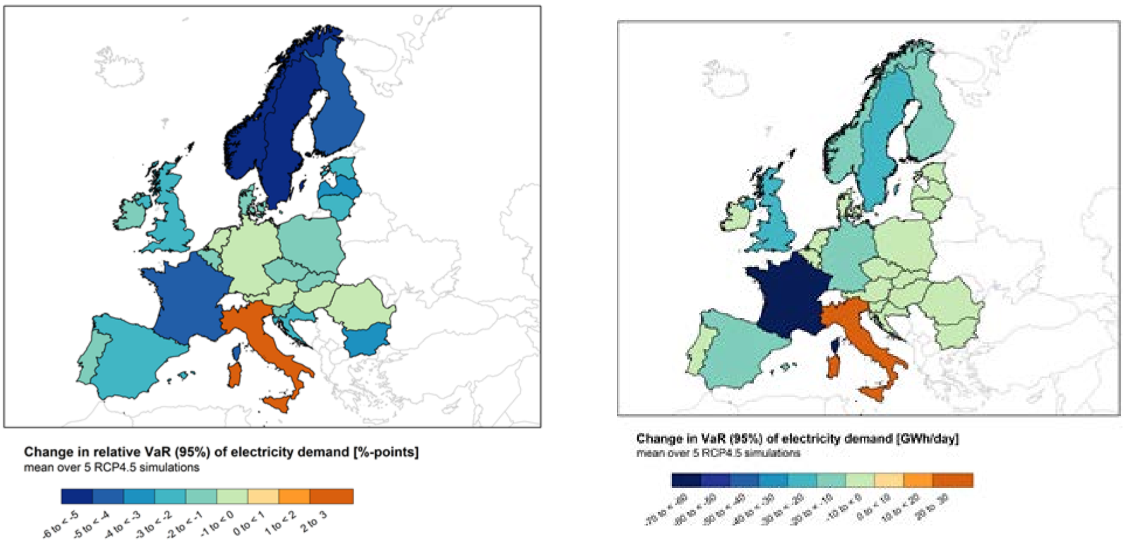


Figure 13: Change in VaR (95%) of electricity demand on working days between 2036-2065 and 1971-2000 (mean over 5 RCP4.5 simulations), in relative terms (%-points, left plot) and absolute terms (GWh/day, right plot).

Agriculture, forestry and ecosystems

Climate change affects the conditions for the growth of plants and thereby nearly all sectors of agriculture. IMPACT2C investigated the direct influences of a changing climate (e.g., temperatures and precipitation) on irrigated and rainfed crop yields and forest production, as well as cropland soil organic carbon

Crop yields

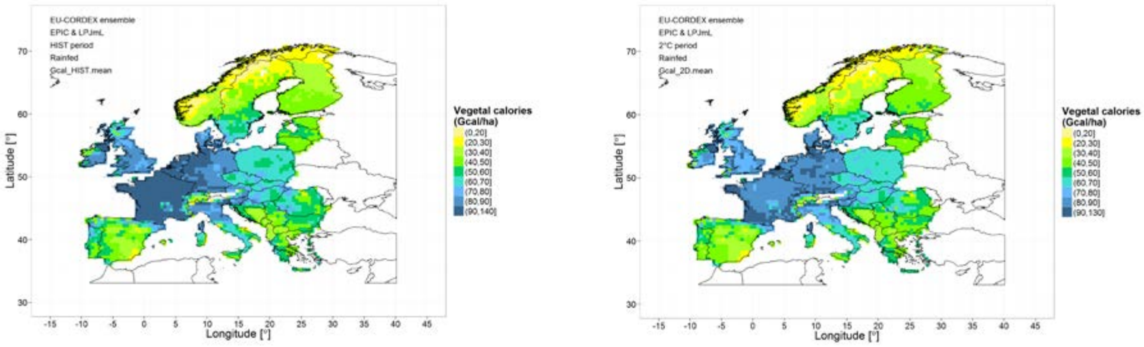
(initial results of WP7)

Key messages

- +2°C global warming is equivalent to the overall loss in ***crop caloric yield*** by approximately 1.6 and 3.5% for rainfed and irrigated systems, respectively. Impacts vary by crops (and also by model), e.g. summer crops respond differently from winter cereals. Robustly negative impacts are expected in western and wouthern Europe.
- ***Summer crop yields*** would increase by more than 20% in many regions of central, western and northern Europe. Winter crop yields would decrease by approximately 20% in western Europe and the Balkans. All crops would provide lower (and more vulnerable) yields in southern Europe (high uncertainty). Negative effects in southern Europe can be lessened by irrigation and/or adaptations in cultivars.
- Potentially positive impacts of global warming are reduced by increased frequency of extreme droughts. Hotspots exists in Spain, Greece, Bulgaria, Romania, Macedonia and parts of Italy: non-irrigated maize, soya and rape yield would decrease by 40 to 60% in dry years. Wheat and barley would experience a loss of about 20%. Also in parts of Hungary, Slovakia, Austria, Czech Republic, Poland and Germany where an average vulnerability is above 20% (especially for maize, soya, rape, spring barley and sunflower). Irrigation would lessen yield losses due to drought.

Impact on rainfed and irrigated crops

It is shown in Figure 14 that the calorie yield (in Mil. kcal/ha) as a combination of the main crops (wheat, maize, rye, barley, rice, sunflower, soya, and rape) for the reference and the +2 °C global warming periods, and the mean impact. Simulated rainfed yields are converted to calories and summed up to the total calorie yield. The calorie maps accumulate biophysical impacts that may significantly vary by crops and regions. Importantly, winter crops are negatively affected in many regions of western Europe due to accelerated phenological development and in South Europe due to drought. Meanwhile summer crops benefit from warming in most of Europe except for the Mediterranean.



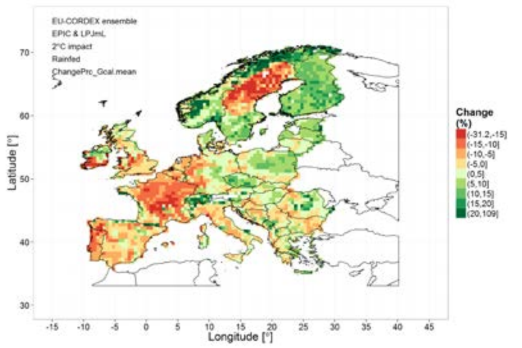
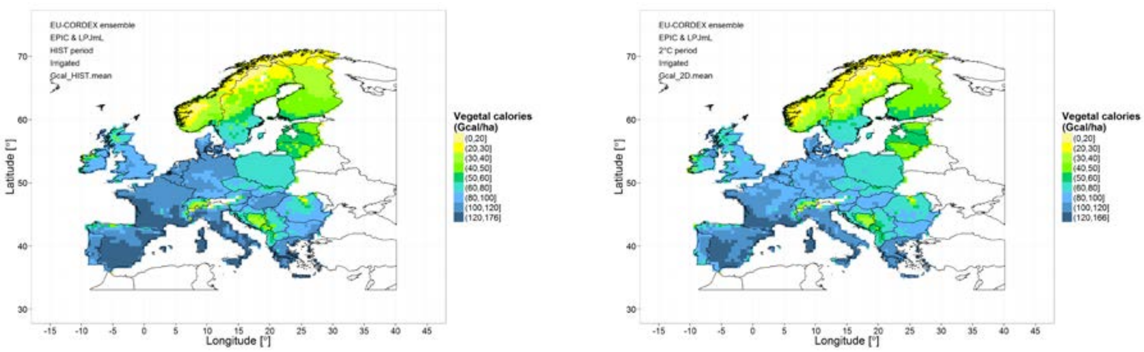


Figure 14 Crop calorie yield maps (rainfed, in 10^6 kcal ha^{-1})for the reference period 1971-2000 and the period corresponding to a +2°C global warmings and mean impact (in %)

The calorie yield (in Mil. kcal/ha), as a combination of the main crops (wheat, maize, rye, barley, rice, sunflower, soya, and rape) for the period of 1971-2000 and the +2°C global warming periods, and the mean impact have been investigated Figure 15. Simulated yields are converted to calories and summed up as an accumulative total calorie yield. Water stress limitation was excluded in these simulations. The calorie maps accumulate biophysical impacts that may significantly vary by crops and regions (winter crops are negatively affected in western and southern Europe while summer crops are positively affected in temperate oceanic and continental Europe. With present day crop management, a +2°C global warming is equivalent to an overall loss in crop calorie yield by 3.5%.



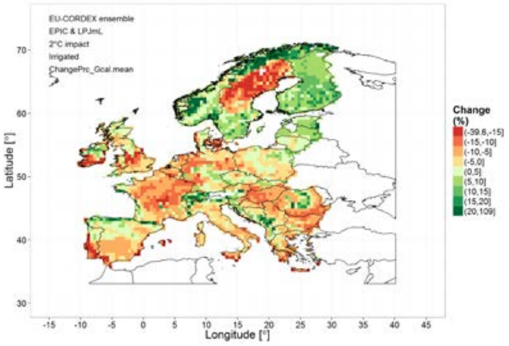


Figure 15 Crop calorie yield maps (irrigated, in 10^6 kcal ha^{-1})for the reference period 1971-2000 and the period corresponding to a +2°C global warming and the mean impact (in %).

Impact on selected services of agro-ecosystems

Key messages

- Reduction in soil organic carbon (SOC) for most of Europe, particularly for northern and eastern regions and the Balkans, with a decline by more than 15% compared to the historical baseline. Conservative cropland management (reduced tillage, no-till and crop residue management) may counteract these negative impacts.
- Under fixed fertilization rates (~2000), plant available nitrogen would decrease significantly by more than 20% for most of Europe meaning worsening crop nutrition from soil pools. Improved Phosphorus availability was simulated for many Mediterranean regions (Spain, Italy or Greece). Insufficient Phosphorus *s*upply may lead to continuously depleting Phosphorus in many countries of eastern Europe and the Balkans. Nutrient status can be efficiently controlled by crop management.
- Runoff changes demonstrate spatially variable patterns. Decrease in growing season ETP in many regions of southern Europe by ~5-10%. Slight increase (2-7%) is simulated for central and northern European countries.
- Net Primary Production generally shows an increasing between 10 and 20% in Pan-European domain for the +2 C global warming.

The simulations indicated the reduction in SOC for most of Europe, particularly for northern and eastern regions and the Balkan countries with a decline by more than 15% compared to the reference period. Higher crop residue inputs from intensive agricultural production may lessen overall decreasing trends in organic carbon in western Europe. Increased temperature in cold northern climates will likely increase SOC mineralization and thus reduce SOC stock on arable land significantly.

Along with SOC also plant ***available Nitrogen*** would decrease significantly: by more than 20% for most of Europe. This is indicated especially for eastern and northern Europe. The overall change of Nitrogen can partly be explained by decreased SOC and increased leaching under heavier precipitation or irrigation. Relatively high present-day **Phosphorus** inputs together with decreased crop production could lead to improved Phosphorus pool in many Mediterranean regions, such as in Spain, Italy or Greece (more than 20% increase in many regions).

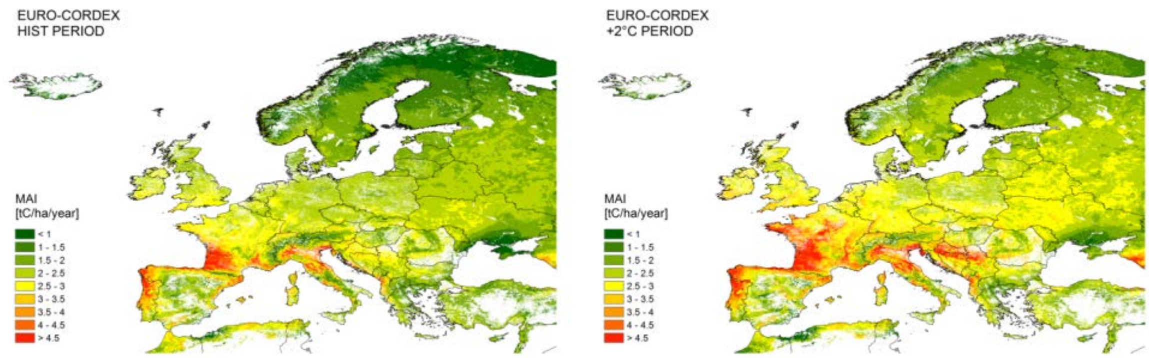
Impact on forests

Key message

- 2°C global warming will positively impact the tree increment potential in many regions.
- Decreased potential increments in arid regions can lead to losing forest suitability.

- Adaptations in tree species through forest management are needed, which increases forest management costs.

Current increments in Europe are in the range from 0 to 5 t C ha^{-1} $year^{-1}$. A +2°C global warming will have impact on the species composition in forests. The estimates in Figure 16 are based on the increment of the most productive species group. The species groups will shift as a result of climate change. Tropical species will appear in subtropical region, subtropical in temperate regions and temperate in regions of boreal species. On the other hand, some regions might lose their suitability. The decision to change from one species to another can only be done after one rotation time, which is typical in the range of 100 years. Such a change has to be done actively by planting young trees, which is typically more expensive than using natural regeneration of the currently present species. This will increase the forest management effort.



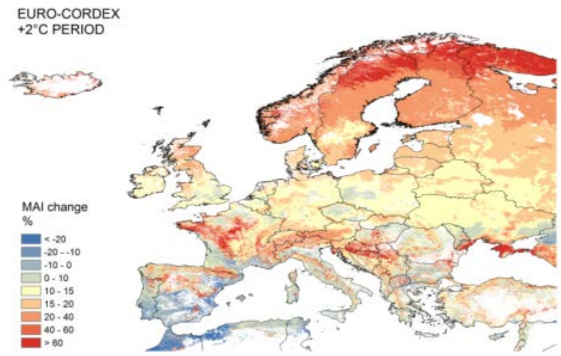


Figure 16 EURO-CORDEX mean potential tree increments (in tC ha-1 year-1) simulated for the reference historical period 1971-2000 and the period of a +2°C global warming, and mean impact (in %) simulated by G4M.

European agricultural production

Key messages

- In a +2°C world, agricultural production is expected to increase on average by 30% in Europe compared to the year 2000.
- At national scale, climate change and adaptation are very strong determinants of future production levels, and induce large production reallocations.
- At a European level, production remains primarily driven by the growing demand for food and by crop yields increases from R&D, and is only slightly effected by an overall negative climate change impacts on crop yields.

On average, a +2°C global warming would decrease the yield of crops of about -3.7% at the European scale. If we assume no adaptation takes place, this translates directly into production losses: the production index would increase only by 31% relative to year 2000 (instead of +36% under a constant climate). Average impact on yields is projected to be negative in most countries but slightly worse in Baltic and south-eastern countries of Europe, and slightly better in a few countries (Finland, UK, Belgium, the Netherlands, and Slovenia).

Yield losses can be counteracted at the farm level by changing management practices but also switching between more suitable crops accordingly. Imports can buffer production losses while consumers can also adjust.

In addition, these are also affected by changes in competitiveness across countries inside and outside Europe (in this project, no climate change impact is considered outside Europe).

However, as seen in Figure 17, the impact on the production index differs far more greatly across European countries if accounting for adaptation. Negative impacts are stronger in most countries, while impacts are postive in countries such as the UK, France and the Netherlands.

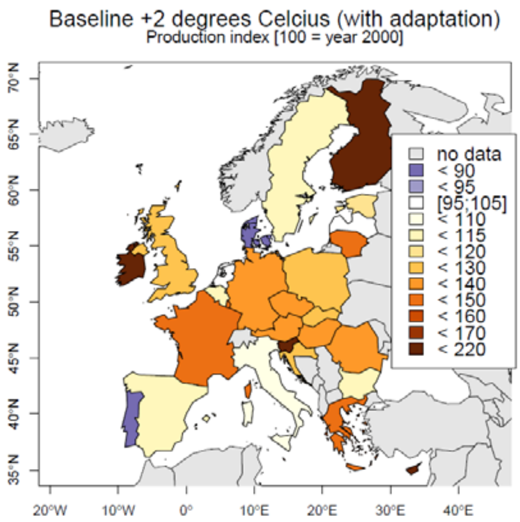


Figure 17 Value of the index of calories produced from cropland (base 100 in year 2000) in a +2 oC world, accounting for all drivers including socio-economic developments, climate change, and adaptation.

The production index increases in mid- and western Europe UK, and Ireland, and decrease in Scandinavian countries (except Finland), Eastern and Southern Europe countries. Climate change is thus as important as other drivers for the evolution of production at national level, if adaptation is included.

Adaptive capacity and vulnerability for agriculture, forestry and ecosystems

(initial result of WP10)

Key messages

- Eastern and southern EU are less able to cope with and adapt to future changes;
- Most regions North of the Mediterranean will face low or very low vulnerability to fires;
- Vulnerability of the ecosystem services sector to negative changes in net primary productivity (NPP) is predicted to be low or very low for the vast majority of the EU. Some northern latitudes will face moderate to high vulnerability due to large decreasing changes in Net Biome Production (NBP) under a +2°C global warming;
- The agricultural sector in relation to future barley yield faces low to moderate vulnerability due to changing drought conditions;
- Some regions of eastern Europe may face high vulnerability to a reduction in maize yields;
- Some regions of Central Europe may face high vulnerability to a reduction in wheat yields

The Outline of the approach taken in IMPACT2C is shown in Figure 18. It combines adaptive capacity with biophysical impacts to arrive at vulnerability estimates. Data were obtained from the EU's Eurostat, the Farm Accountancy Data Network's database, and the World Bank.

Initial results show, that adaptive capacity for agriculture is importantly linked to crop production (irrigated/rainfed) and the revenues of farmers as well as prices on the regional and global levels. Areas high in agricultural adaptive capacity are more likely to cope with future changes and not be as negatively affected by droughts compared to those less prepared.

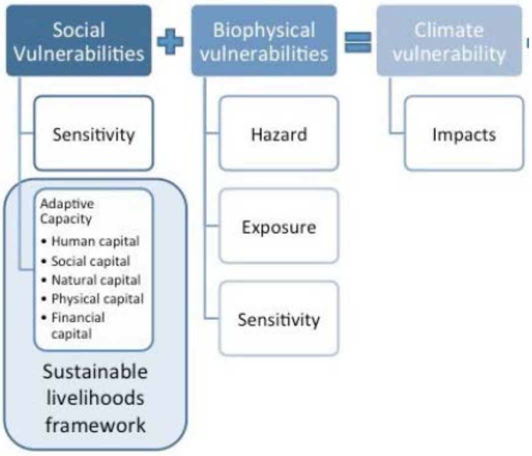


Figure 18 Outline of the IMPACT2C approach.

While countries in the central European region are found to have higher overall adaptive capacity in the agricultural sector than those on the periphery to the south and east (see Figure to the left), southern and eastern countries suffer from a lack of physical and human (and to a lesser extent, natural) capacity compared to the core countries. However there is some bolstering of values from financial capital, where southern drought-prone countries have high adaptive capacity due to the existence of strong drought insurance mechanisms.

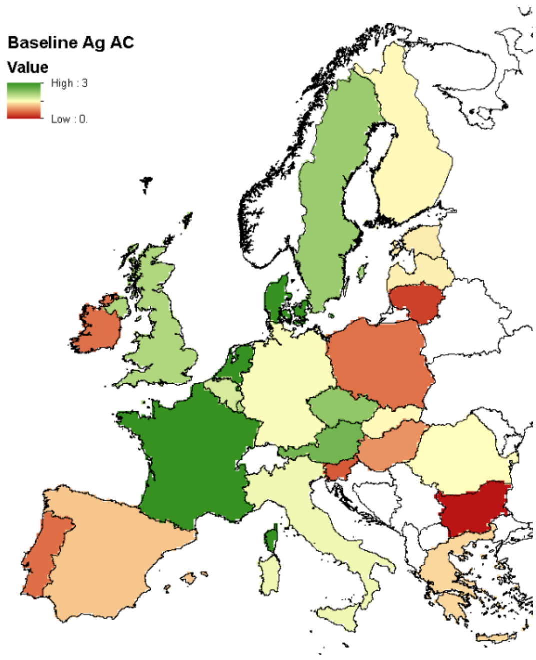


Figure 19 Baseline adaptive capacity for the agricultural sector

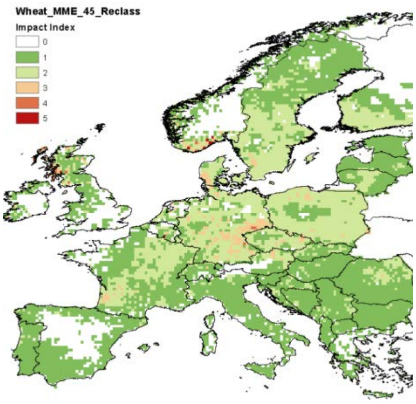
As with agricultural adaptive capacity, the four capital approach has been used to estimate the adaptive capacity index for the forestry and ecosystem service sectors.

For the analysis, vulnerability to increasing drought hazards have been assessed for eight agricultural crops: spring barley, grain maize, winter rapeseed, rice, winter rye, soybeans, sunflowers, and winter wheat. Furthermore, both the yield distribution and monetary loss of barley under climate change have been estimated in Spain on the national scale.

The initial results shown that with the exception of maize yields, the most vulnerable regions according to the approach mentioned above occur mainly in central and eastern Europe (due mainly to a greater decrease in yields than other regions under scenarios run in this project), with Mediterranean countries classified as having low vulnerability to a large degree. Vulnerability of wheat and barley yields are the most pronounced in this regard, although rapeseed is moderately vulnerable in Germany near the North Sea. Maize vulnerability does not follow this trend, and is highest in Hungary and northern Bulgaria, with some small areas of France and Italy also being moderately vulnerable.

The IMPACT2C results indicate that the forestry sector may have difficulty coping with the increasing impacts of fires in southern Europe, especially in Romania to the East, and highlights areas which could be subject to more in-depth assessment. Results for NPP shows that only small areas of Portugal, Spain and northern Scotland look likely to face any difficulty in adapting to future changes.

(for RCP4.5). Vulnerability affecting NBP differs slightly, with most of the EU having low vulnerability expect for the far northern regions of Sweden and Finland.



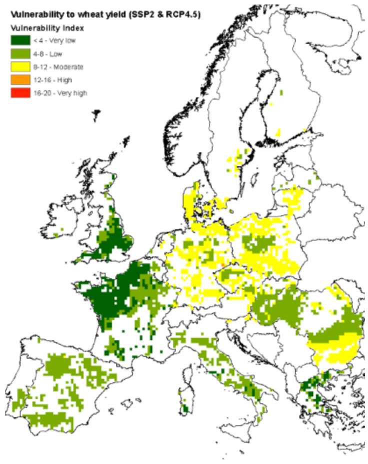


Figure 20 Assessing vulnerability to drought affecting wheat yields under +2°C degrees of global change. The map on the left shows the calculated impact indicator depicting the severity of decreasing yields, from 0 to 5, with 0 being any increase in yield. The map on the right combines impacts with an inverse AC index, and excludes areas which do not have < 5% harvested crop area. Scenario: RCP4.5 / SSP2

Air pollution and health

(initial results of WP8)

Residents of the European Union are at risk from both direct and indirect impacts of climate change. These include air pollution impacts, heat and cold related effects, impacts of extreme events, vector and rodent borne infectious diseases, food and water related diseases, allergic diseases and ultra-violet exposure. Within IMPACT2C the impact of +2°C global warming scenario on ozone, particulate matter air pollution and heat mortality have been analysed.

Key messages

- Changes due to a +2 C global warming are small compared to changes expected from air pollutant emission reduction in 2050.
- Air pollutant emission reductions will continue to largely improve air quality and reduce health issues until 2050.
- For the ***ozone,*** models predict an average increase across southern and central Europe which does not exceed 1 ppb. An average decrease of equivalent amplitude is predicted over Scandinavia. All models predict an increase in ozone in most of Europe in summer, but in winter the uncertainty on the sign of change is high.
- For ***particulate matter (PM2.5)***, changes due to +2°C global warming are uncertain, as models do not agree on sign. In addition, a conclusion on sign of change is made more difficult as models do not simulate the same PM components composition. However, an agreement is found on an increase of desert dust concentration increase over the Iberian Peninsula and southern France in a 2°C warmer climate.
- The health impacts of changes in air pollution under +2°C global warming follow the patterns reported above, and lead to small changes in health impacts related to the reference period. For PM2.5, there is a wide range reported by the models, which varies even in sign. For the ozone, there is a more robust increase in health impacts, but the level of additional health impacts is low.
- Citizens from Mediterranean (Cyprus, Greece and Spain) and central-eastern European countries (Bulgaria, Hungary and Romania) will be most affected by heat.

Figure 21 shows that the differences between in the future and control simulations vary greatly depending on season. In winter, ozone concentrations are higher over Europe in the future scenario; however, in the summer, ozone concentrations are significantly lower in the future scenario over all of Europe for all models. The decrease of ozone during the summer is linked to the reduction in anthropogenic emissions observed from 2005 to 2050, while during winter continental changes are most likely driven by changes in the VOC to NOx ratio, coupled with the increase in temperature.

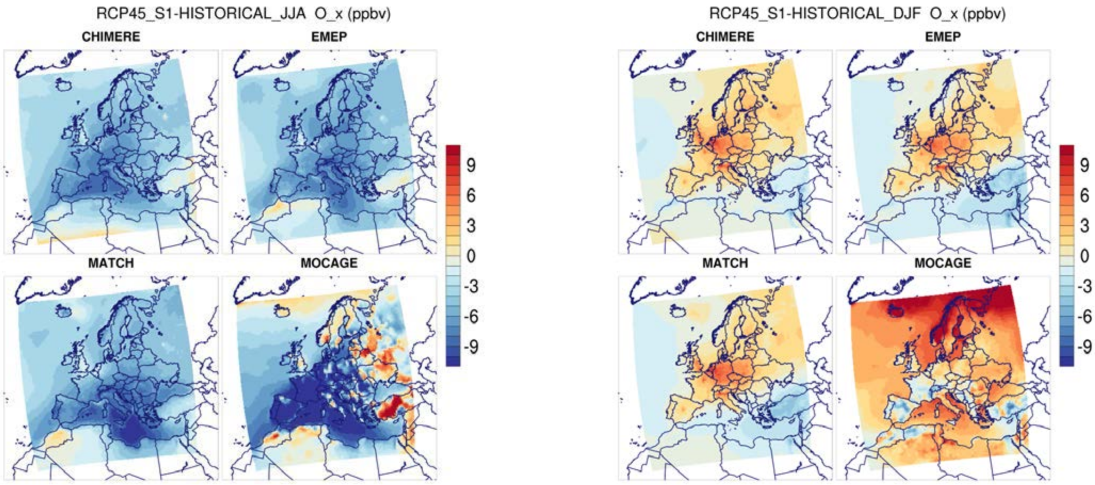


Figure 21 Differences in average O3 concentrations (in ppb(v)) between S1 and 1971-2000 simulated by CHIMERE, EMEP, MATCH and MOCAGE for summer (left) and winter (right).

The levels of PM2.5 are only slightly affected by regional climate change: the ensemble averages range from -0.5 µg.m-3 to 1.1 µg.m-3 over Europe. An increase of PM2.5 levels can be robustly predicted over Spain where all three models agree on the sign of the changes. According to the analysis of separate components, this increase is mainly due to changes in dust emission.

Additionally the impact of climate change on city-scale air pollution has been examined with the focus on two cities: Stockholm and Paris. The CHIMERE model chain simulated air pollution for Paris and the MATCH model chain simulated air pollution for Stockholm. The change in concentrations of SOMO35, NOx, PM10 and PM2.5 has been evaluated. More information can be found in the Deliverable 8.1.

The health impacts for PM2.5 and ozone also follow from and mirror the results presented above. The health impacts for particular matter is shown In Figure 22.

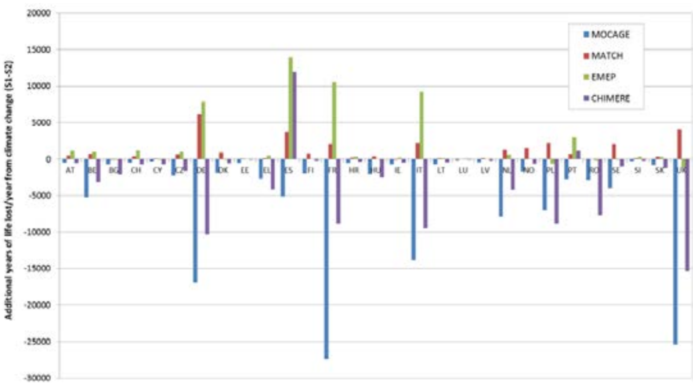


Figure 22 Change in life years lost/year in 2050 from the additional impact of climate change (S1-S2) on PM2.5 concentrations

Climate change affects human health and well-being. In the near future it will lead to an amplification of current health problems, as well as new risks and pressures for the environment and the social and economic determinants of health.

The quantitate review done within IMPACT2C show that climate-change induced rising temperature under + 2°C global warming might lead to between 13000 and 26000 additional deaths per year in EU28. Climate change-induced ecosystem changes will affect vector-borne diseases, e.g. the geographic range of Ixodes ricinus ticks will increase during the 21st century. Climate change is likely to trigger further changes in pollen concentration, volume and distribution, with an associated increase in the prevalence and severity of allergic diseases in many parts of Europe.

Tourism *(initial results of WP9)*

Tourism is a billion euros industry for Europe especially for the southern countries for which summer tourism is an important contribution to their GDP. Tourism, as a human based system is highly dependent on the climatic conditions. Changes in climatic conditions will pose stress in the climate favorability of all European destinations for tourism and recreational activities.

Key messages

- ***Winter tourism:*** Overall, under a +2°C global warming up to 10 million overnight stays are at risk (+7.3 million nights) Austria and Italy are most affected.
- ***Summer tourism:*** In the period of ***June to August,*** favourable climate conditions are projected in central and northern Europe. Some Mediterranean areas are projected to experience warming above the comfort zone. Portugal, Spain, Italy, Greece and Cyprus will be most affected. In the period of ***May to October*** favourable climate conditions are projected to improve over most of the European regions.

The highest weather-induced risk of losses in **winter overnight stays** – in the current period as well as in the +2°C periods – is given in Austria, followed by Italy (see Figure 23). These countries account for the largest fraction of skiing related winter overnight stays in the NUTS-3 regions under consideration, currently as well as in future periods. Among the four 'big players' of European skiing tourism – Austria, France, Italy and Switzerland –, France and Switzerland show the lowest increase in risk of losses in winter overnight stays.

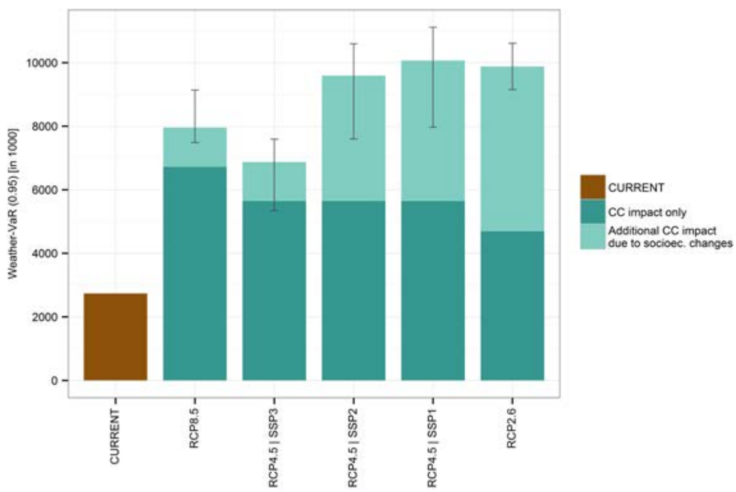


Figure 23 Weather-Value at Risk (0.95)* of winter overnight stays in the +2 °C periods in comparison to the reference period, in absolute (left) and relative terms (right) and aggregated at country level

* *the Value at Risk resulting from adverse weather conditions, and represents – for a given level of confidence [α] over a given period of time – the maximum expected loss'*

Comparing the results of the different RCP simulations, it must be bared in mind that these simulations refer to different time periods in which +2°C may be reached, and the underlying socio-economic development and baseline projections of overnight stays differ at different points in time. As a consequence, in most of the countries the highest risk of losses in overnight stays in absolute terms is achieved in the RCP2.6 scenarios. Although these scenarios do not even hit +2°C within the 21st century, the baseline projections of overnight stays based on GDP and population scenarios (SSP) are highest in RCP2.6 which refers to the end of the century.

Figure 24 shows the resulting Weather-VaR values at country level for the period of May to October. It represents the typical summer tourism season for Europe An overall increase of tourism demand risk is projected for the Mediterranean countries due to changes in the individual climate variables within Tourism Climatic Index** (like maximum temperature that mostly affect thermal comfort), whilst a general decrease is estimated for northern European countries. In most cases, the RCP8.5 scenario shows greater Weather-VaR values in the +2^{o}C period compared to the other concentration pathways.

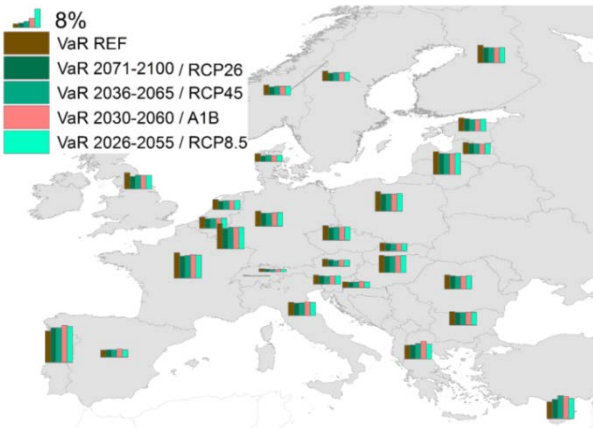


Figure 24 Value at Risk (95%) of summer (May to October) overnight stays – aggregated at country level.

This is attributed mainly to the increased year to year variability in the TCI compared to the RCP8.5 and A1B scenarios.

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Prettenthaler, F., Köberl, J., Bird, D.N., (2015), "Weather Value at Risk": A uniform approach to describe and compare sectoral income risks from climate change. *Science of the Total Environment*, doi:10.1016/j.scitotenv.2015.04.035

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Cross-sectoral analysis of +2^{o}C global warming on the pan-European level

(initial results of WP11)

The analysis of climate change impacts using sector analysis is extremely useful, but does not capture cross-linkages and cumulative effects, and may not provide information in a form that is useful for all users. Therefore these additional aspects have been examined within IMPACT2C.

Key messages

- ***Hot-spot mapping***: the Mediterranean region is projected to experience dis-proportionately high impacts even for 2°C of global warming, due to the combination of negative impacts on agriculture, water resources, cooling energy demand and energy supply.
- Europe will face significant changes in the **water** use sector at two degree warming due to cross-sectoral linkages, with potentially large impacts on the agricultural and energy sector. Increasing water scarcity in southern Europe will affect future land use. While there will be a push to expand irrigated areas due to decreasing yields, water availability especially in summer is likely to limit this expansion.
- ***Households in the UK and Italy***: there will be strong differences in impacts across Europe, e.g. the analysis found relatively modest impacts from climate change on the costs of living in the UK for 2°C of warming, but dramatically higher impacts in Italy (two to three times higher).

- ***Port cities:*** the case study found that coastal cities will face significant challenges in managing the growth in exposure that will come about from both population and climate change.

The information from climate modelling and impact assessment studies is complex, therefore the results of the project have been synthesized and guidance has been produced on the lessons from the IMPACT2C study. It was shown that there will be strong differences in impacts across Europe. An integration and hot-spot mapping exercise using the IMPACT2C sector results indicates a strong distributional pattern across Europe, with hot-spots clearly emerging in the south.

As can be seen in Figure 25, the major losers from a plus two degree world, using the metrics analyzed in this study, are located in southern Europe, with Spain, France, Bulgaria, Romania, and Greece and the major ‘winners’ in far northern Europe, with some areas of Norway and Sweden.

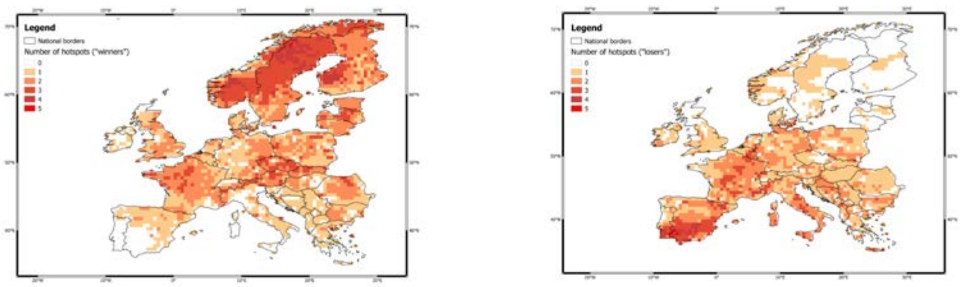


Figure 25 Robust multi-sectoral hotspots ‘winner’ (left panel) and 'losers' (right panel)

The cross-sectoral analysis has been undertaken ***on water***, due to its cross-sectoral dimensions, at European level and with a case study.

Several case studies have been considered. The case study, focusing on Crete, showed that these cross-sectoral water issues will be a particular issue for Mediterranean island states. The results of the study of households in the UK and Italy highlighted that the distributional impacts of climate change should be considered in national, regional and local assessments, and these issues should be considered when designing adaptation policy. The case study focused on ***port cities*** found that coastal cities will face significant challenges in managing the growth in exposure that will come about from both population and climate change. The final case study focused on how the interaction between land use change and climate change will affect future water use for food and energy and the expansion of irrigated areas. This found increasing water scarcity in southern Europe will affect future land use. While there will be a push to expand irrigated areas due to decreasing yields, water availability especially in summer is likely to limit this expansion.

What does +3^{o}C global warming mean for Europe ?

Key message

- While the spatial patterns for the climate change signal over **Europe** remain unchanged, temperature increase and precipitation intensity become more pronounced compare to +2^{o}C global warming.

IMPACT2C shows that the +2^{o}C target could be exceeded in the next 30 years. In this context the scientific questions - what might be prevented if global warming is limited to +2^{o}C rather than +3^{o}C? - is of major importance. Consequently the IMPACT2C community initiated research to explore the impact of +3°C global warming. All available simulations (no additional runs were planned) and the methods developed for the analysis of +2^{o}C impact have been taken into account.

While the spatial patterns for the climate change signal over **Europe** remain unchanged, temperature increase and precipitation intensity have become more pronounced compare to +2°C global warming (Figure 26).

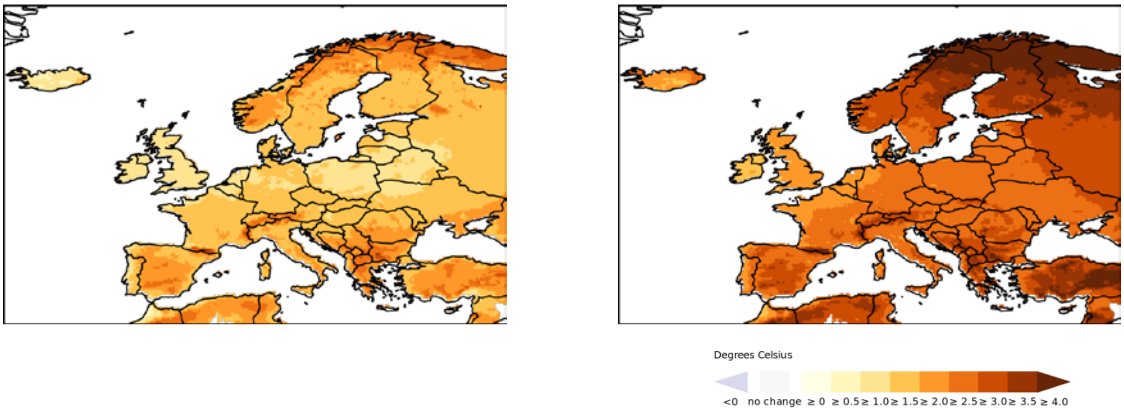


Figure 26 Climate change signal over Europe for the +2°C (left panel) and +3°C (right panel) for mean air surface temperature (left) and precipitation

A comprehensive analysis of the impact of +3°C global warming has been carried out for the following sectors on the pan-European level:

- *Energy:* hydropower potential; solar photovoltaic; thermoelectric sector; electricity demand
- *Water*
- Impact on sea-level rise;
- Air pollution;
- Winter tourism demand

On average, the projected pattern of climate change at +2°C and +3°C global warming remains the same. However, the changes in climate signal could double as shown in Figure 27 for annual gross hydropower potential.

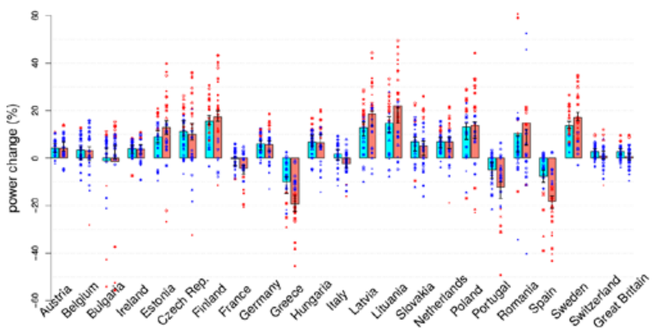


Figure 27 Changes in national mean annual gross hydropower potential under a 2oC (cyan) and 3oC (salmon) global warming. Model individual changes are represented by differing symbols: symbols are red when changes are significant at 95%.

More results of the analysis can be found in the IMPACT2C web-atlas.

What does +2°C global warming mean for the non-European vulnerable regions ?

The ensemble of climate simulations used for this analysis is described in the Appendix.

Nile and Niger River Basins

Africa is one of the most vulnerable continents due to its high exposure and low adaptive capacity. The continent already suffers major challenges from climate variability and extreme events. The IMPACT2C project set out to investigate these potential issues, focusing on two major river basins in Africa, for the Niger Basin (West Africa) and Upper Blue Nile (East Africa).

Key messages

- Over ***western Africa,*** the rain season is shorter and more intense, resulting in a small increase in total precipitation. Under a +2°C global warming, the projected local warming is about the same as the global one.The range of uncertainty in projected warming is about ±1°C.
- Over ***eastern Africa*** the increase in rain intensity compensates the reduction in the length of the rain season. Projected warming is rather uniform over the region and there is a high agreement between different simulations
- ***Fluctuating conditions rather than persistent trends****:* the Impact2C simulations show that global warming may imply large fluctuations of the impact of floods and droughts in rural areas in both river basins. The kind of adaptation strategies to be envisioned will have to cope with fluctuating condition**s** rather than with persistent trends in a well-defined direction (wetter or drier)**.**
- ***Extreme events*** In both basins variability in temperature and rainfall will very likely result in an recurring extreme events like floods, droughts and heat waves. Without having put the tag climate change adaptation to it people already have started adjusting and adapting to such events in order to reduce the risks coming from it.
- ***Vulnerability of people*** The vulnerability of people in both basins is relatively high. A number of reasons of this high level of grass-root level vulnerability are the strong dependence on a natural resource base for their livelihoods and the relatively low access to assets like financing, technologies and information and social networks.

Climate change

The initial results for western Africa (Figure 28) demonstrates that warming above +2°C is more pronounced in the continental part of the domain. The North Sahara desert warms up more than the regions close to the ocean. For precipitation, a modest increase of less than 10% in precipitation is projected for most of the region. As the expected increase in precipitation is not very large, a general risk of an increased water shortage persists, because increased temperatures might also lead to enhanced evapotranspiration.

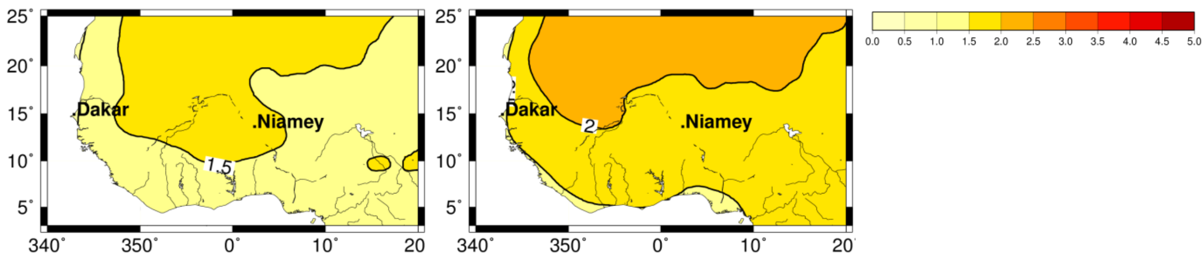
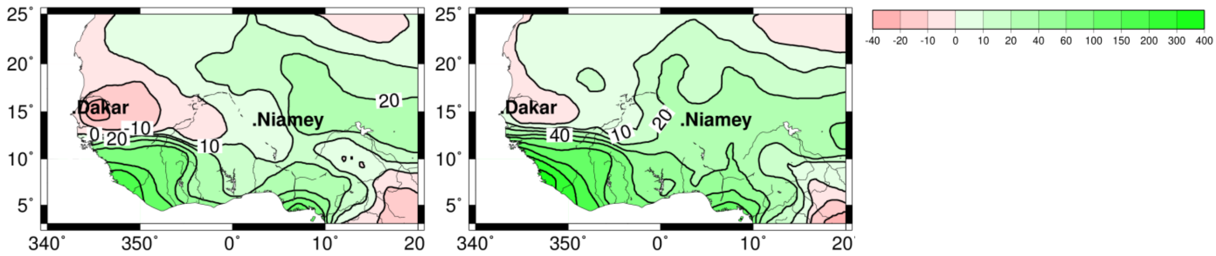


Figure 28 Climate change patterns over Western Africa for temperature [oC]



and precipitation [mm/year] (right) for 1.5oC (right) +2oC (left) global warming relative to 1971-2000

For eastern Africa, the projected regional warming is spatially rather uniform. For precipitation, a slight decrease (around 20 mm/year on average) is projected over Ethiopia, however, there is only a modest consensus of the analysed models on the negative signal. Across Somalia and also around western Sudan, precipitation is projected to increase.

Impact assessment

As mentioned above, both Nile and Niger river basins will experience an increase in temperatures. The change in rainfall pattern is more complex and varies according to location within the river basins and with time. This may imply large fluctuations of the flood and drought impacts in rural areas in both regions (Figure 29) and leads to increase the competition, making conflicts related to natural resources more likely, e.g food security.

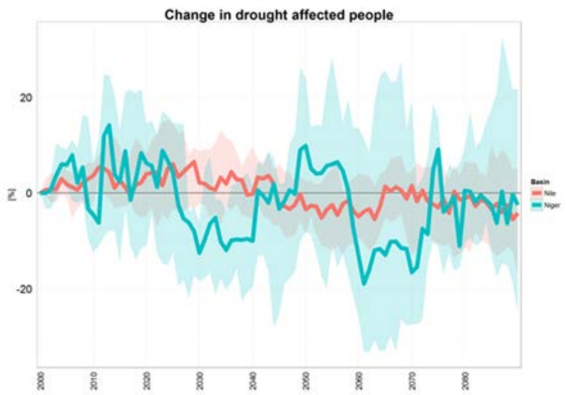


Figure 29. Summary of the projective relative (percentage) changes in drought affected people in the Nile and Niger basins. Thick lines represent the ensemble average among the considered RCM-GCM combinations. The shaded areas represent the middle tercile of the distribution of all models.

Therefore the adaptation strategies have to cope with fluctuating conditions rather than with persistent trends in a well-defined direction (wetter or drier).

It should be mentioned, that the societal vulnerability in both basins is relatively high due to limited vertical and lateral integration in the institutional landscape. Without having attributed the tag climate change adaptation, people already have started adjusting and adapting to climate change in order to reduce risks arising from it.

Nevertheless building adaptive capacity to deal with climate change adaptation should be strengthened on multiple levels from individuals to communities, from county-level to national governmental level and even to international levels.

Bangladesh

Bangladesh is one of the most natural hazard prone countries in the world because of its geographical setting and the associated environmental and socioeconomic reasons. The impacts of climate change in Bangladesh are multifaceted, multi-dimensional and multi-sectoral.

Key messages

- Under +2°C global warming, an increase of precipitation is projected for the whole country and more pronounced in the southeastern part. The model agreement of these changes are high. Projected warming is at the same order as on global scale and is more pronounced in the northern part of the region;

- Land subsidence in Bangladesh is highly variable, dependent on tectonics, compaction and human activity. Even if temperatures stabilize, sea levels will continue to rise;
- Dry season flow may increases in November and December but not sufficient in other months. River salinity will increase by about 2 PPT mainly due to sea level rise. . Average wet season water level is projected to increase up to 60 cm.
- Even if warming is limited to 2°C, Bangladesh is projected to experience multiple and potentially large increases in climate related risks, from the combined effects of sea-level rise, storm surge, river flooding, rainfall variability, and salinity. These will lead to multiple impacts across society and the economy.

For Bangladesh, there is a close match between the magnitude of projected warming for the region under RCP4.5 and the magnitude of the projected global warming of +2°C on average, but with a more pronounced warming towards the northern parts. Precipitation is projected to stronger increase in the south-eastern part of Bangladesh. With respect to coastal flooding, expected impacts are dependent on several factors – including subsidence and sea level rise. However, subsidence is highly variable and sea levels will continue to rise, even if the temperature rise stabilises at +2°C.

Impact assessment

The South West region of Bangladesh is particularly vulnerable to the potential impacts of climate change, including from multiple risks. The IMPACT2C project therefore focused on this region and assessed the potential effects from 2°C of warming on three districts: Kushtia, Bagerhat and Shariatpur.

The results obtained for the Shariatpur district are shown in Figure 30. The simulated average flood levels are projected to increase by 0.2 to 0.5m in the peak monsoon months at 2°C warming. This increased flood level and increased flood duration of about 25 days could have a significant impact on agricultural production.

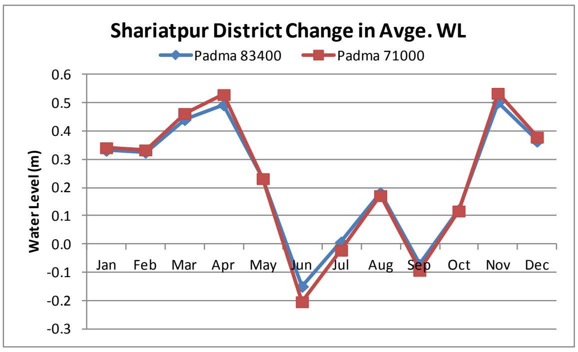
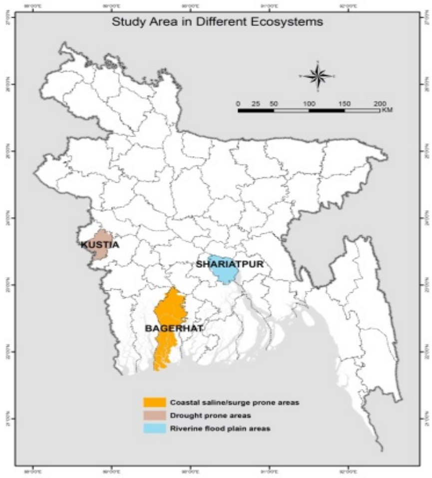


Figure 30 Simulated water levels for +2oC global warming at grid points on Padma River in the Shariatpur District.

With +2°C global warming, Bangladesh will face the combined effects of changes in major river flows, sea-level rise, subsidence and local precipitation and evapotranspiration changes. The following eight adaptation options were proposed for the three selected districts. They were discussed with the stakeholders and experts during the IMPACT2C final workshop and were evaluated based on effectiveness, cost benefit analysis, externality and socio-economic gain:

1. Saline resistant rice variety
2. Rice prawn farming
3. Rising the height of the mud wall of fish and shrimp farms during flood
4. Replantation of crops after hazards/or other management approaches
5. Short rotation rice varieties
6. Using more chemical fertilizers and pesticides
7. Alternative cropping
8. River dredging



Impact of sea-level rise for the non-European regions.

The global effects of +1.5°C and +2°C global warming (with respect to a pre-industrial climate), have been investigated to assess the effects of sea-level rise, with a special focus given to the above mentioned vulnerable areas (western Africa, eastern Africa, Bangladesh and Maldives).

Key messages

- Even if temperatures stabilise, sea levels will continue to rise.
- From the global model projections, among the non-European vulnerable areas mentioned above, eastern Africa seems to potentially experience the largest sea-level rise when the global averaged temperature is projected increase by +1.5°C and +2°C.
- In the models studied, the coastline of **Bangladesh** has a high projected level than the global mean. For Bangladesh, impacts are dependent on relative land level change including subsidence and sea-level rise.
- With sea-level rise, flooding at the **Maldives** from swell events could occur more frequently.

Figure 31 shows projected sea level change (m) averaged over West Africa for the RCP4.5 scenario. The reference period is 1971-2000. Individual climate model from CMPI5 are represented.

The following longitude/latitude box has been used for the averaging: [lon : 0-10E ; lat : 0-10N]. Red and blue dots respectively represent the time slice when 1.5°C and 2°C of averaged global warming are reached.

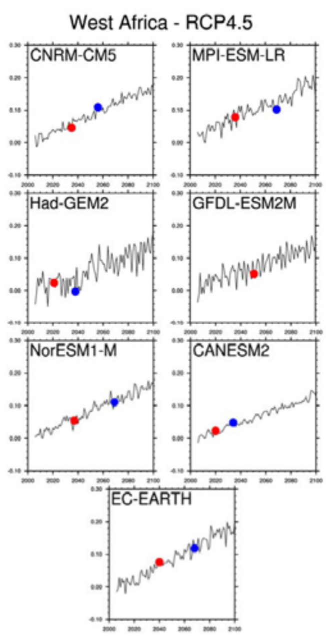


Figure 31 Projected sea level change (m) averaged over West Africa for the RCP4.5 scenario.

The Maldives

The Maldives is a very low-lying small developing state comprising a set of islands in the Indian Ocean. It is widely recognised as one of the most vulnerable countries globally to climate change as a result of sea-level rise as the islands are on average only 1.5 metres above mean sea-level.

Key messages

- Even if global mean surface temperatures stabilises in 2°C world, sea-levels will continue to rise.
- An increase of 2°C with respect to pre-industrial times, could lead to an increase in global mean sea-level rise of between 0.11m (in 2035 under RCP8.5 high scenario) to 0.54m (in 2100 under RCP2.6 low scenario).
- Socio-economic change in the Maldives is as important as changes to natural environmental conditions. Socio-economic change provides the opportunity to increase resilience against extreme events and sea-level rise.
- Long period swell waves have resulted in flood events (most recently in May 2007). They pose an ongoing risk to the low-lying islands.
- Taking Hulhumalé as a case study island where land is artificially raised by 2m above mean-sea level, a sea-level rise of 0.4m-0.6m could result in nuisance flooding during a swell wave flood event assuming no additional adaptation or vertical reef growth. Thus, in a 2°C world, flooding is unlikely to occur.
- As sea-levels continue to rise greater than 1m, flooding under extreme swell wave conditions could lead to occasional flooding to a depth of 0.25m. At this point, adaptation may need to take place.
- This is the first assessment of flood risk in Hulhumalé. Further research could consider uncertainty in model parameters, (e.g. changes to inshore wave conditions, friction values and bathymetry) and more detailed scenarios (e.g. reef response to sea-level rise).

Climate change

The initial results of IMPACT2C demonstrate that in the Maldives area, both length and intensity of the monsoon over ocean are enhanced, contributing to an increase by more than 20% in precipitation at the +2°C warming stage. The expected temperature rise is moderate, but could impact the energy and tourism sector. Indirectly temperature rise produces (at the global scale) a sea-level rise which can be very detrimental to islands with such a low surface elevation.

Impact assessment

To overcome population pressure, the new island Hulhumalé was created by dredging sand and claiming land from the sea. Construction finished in 2002 and it is now home to over 20,000 people. With some knowledge of sea-level rise, engineers raised the island to 2 m above mean sea-level. But with greater scientific knowledge and improved projections since the island was designed, is the island high enough to withstand extreme events?

In IMPACT2C, an initial assessment of overtopping conditions and flood extents suggests that with similar swell wave conditions and sea-level rise associated with +2°C, Hulhumalé would be safe from flooding (Figure 32). However, sea-level rise greater than 1 m (plausible by the end of the 21st century with warming greater than 4°C) could result in more frequent flooding unless adaptation is undertaken.

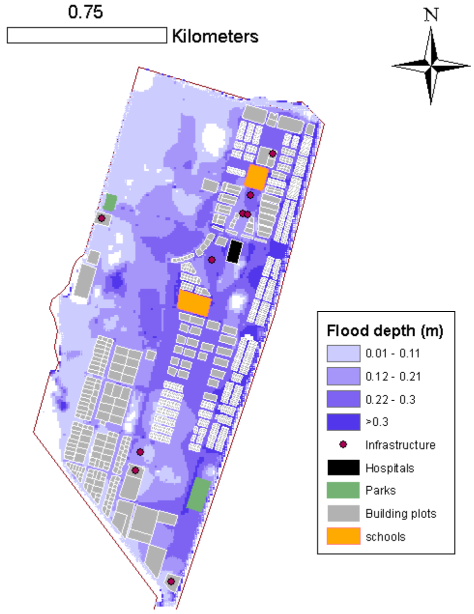


Figure 32 Example of peak water depth distribution on Hulhumalé, from a simulation of the waves from the May 2007 design storm superimposed upon a larger sea-level of 1.4 m AMSL (equivalent to approx. 0.8m of MSLR).

What does +3°C global warming mean for the non-European vulnerable regions ?

The scientific question "What might be prevented if global warming is limited to +2°C rather than +3°C?" is of major importance not only for Europe, but also for the most vulnerable regions of the world. All available simulations (no additional runs were planned) and the methods developed for the analysis of +2°C impact have been taken into account, and the RCP8.5 emission scenario has been considered.

The analysis showed that for all selected region in West and East Africa, Bangladesh and the Maldives the spatial pattern for rain intensity or rain duration is unchanged, but the amplitude of the response is increased, in particular for rainfall intensity with an increase of about 50%.

Under a +3 C global warming, the temperature distribution shows the same pattern over Bangladesh with a magnitude of +1° C higher compared to the +2 C global warming (with good agreement between models). Over the Maldives, a uniform warming of +2/+2.5°C warming is observed (excellent agreement between models). The extreme North (Sahara desert) warms up more than +4°C, whereas the temperature in the regions close to the ocean increase by less than +3°C.

Figure 33 shows the temperature response over East Africa for different global warming scenarios. Although the spatial distribution of the climate change patterns remains the same , temperature increase of more than 3°C is projected over large parts of the domain for +3°C global warming.

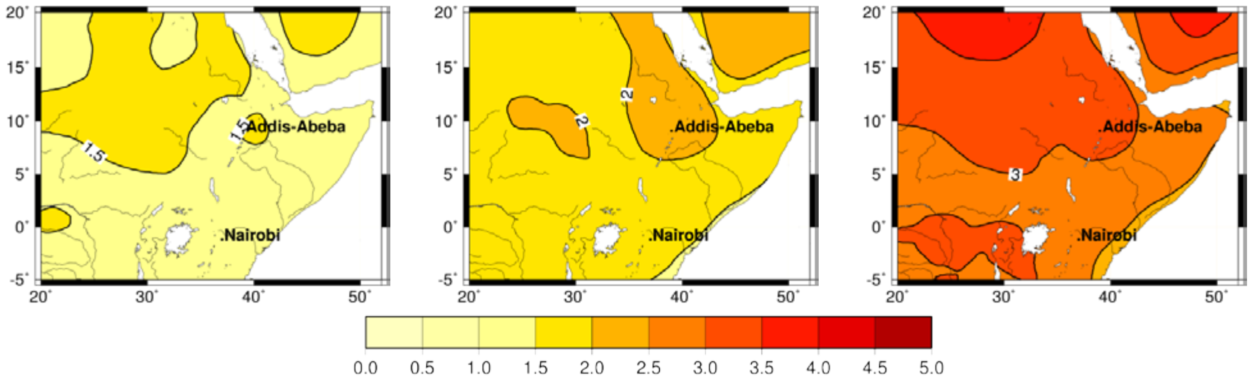


Figure 33 Temperature response over East Africa (°C) ; from left to right for +1.5°C, +2°C and +3°C. Temperature differences with respect to 1971-2000, which is about 0.5°C above the pre-industrial climate.

Potential impact

The policy discussion of whether global warming can be limited to no higher than +2°C is one of central importance at the upcoming COP21 negotiations in Paris in December, 2015.

In this context, the overarching goal of the project was to disseminate research results and to raise awareness with society and policy makers of the impacts of global warming at 2°C and the needs to act.

IMPACT2C identified the following scientific questions, which are of major importance:

- What might be the potential impacts of a +2°C global warming compared to the preindustrial period for various regions of the globe, and economic sectors?
- What are the differences between +2 °C and +3 °C global warming?
- What might be prevented if global warming is limited to +2°C rather than+3°C?

IMPACT2C has made contributions and had impacts on various levels through various dissemination channels, e.g newsletters, website, policy briefs, participation and organisation of sessions at major international conferences, workshops for stakeholders, summer school and the IMPACT2C web-atlas.

IMPACT2C was a truly multidisciplinary research project involving climate modelers, mathematics and physicists, to social scientists and economists from different countries and thus created a scientific network all over the world. This networking skill is high of importance because the grand societal challenges can only be solved through working together with many different disciplines and with the engagement of society and political decision makers.

IMPACT2C made a step forward in the understanding of various complex processes and interactions between environmental, economic, social and technological systems by developing of a cross-sectoral perspective to complement the sectoral analysis. It was done by:

(i) Undertaking case studies for particularly vulnerable areas that are subject to multiple impacts (e.g. the Mediterranean region);
(ii) Focusing on cross-sectoral interactions (e.g. between the agricultural, water and the energy sectors and competition for land use) and
(iii) Undertaking cross-cutting themes which adopt a different orientation (e.g. cities and the built environment).

Furthermore, the project used harmonised socio-economic assumptions/scenarios to ensure that individual sector assessments were aligned to the 2°C (1.5°C) scenario for both impacts and adaptation, and were compatible between sectors.

Exploitation

The main exploitable outcomes of IMPACT2C are:

- **IMPACT2C Database** – the IMPACT2C data server was established at the Danish Meteorological and Hydrological Institute. At the server (impact2c.dmi.dk), both bias corrected climate and the data from various impact models can be found for the whole of Europe and three vulnerable regions in Africa, Bangladesh and the Maldives.
- **IMPACT2C atlas** depicts the climate change impacts of a +2^{o}C global warming for the key sectors – energy, water, tourism, health, agriculture, ecosystems and forestry, as well as coastal and low-lying areas – at both the pan-European level, and for some of the most vulnerable regions of the world. By using a multi-model ensemble of both climate and impact projections it is possible to define ranges of impacts and therefore quantify some of the uncertainty around future climate and climate impact projections.

Dissemination activities

The outreach strategy of IMPACT2C was a “living document” and was regularly updated to make it adjustable towards those sectors and regions identified as the most impacted by climate change of 2°C warming.

The outreach strategy was based on major components: the IMPACT2C website (www.impact2c.eu); a summer school for (young) scientists; various events addressing different types and levels of stakeholders; dissemination material, among which an web-atlas showing the main results will be the most prominent; and a close link with the media.

Two summer schools for young scientists from Europe, Africa, the Maldives and Bangladesh have been organised within the project. The first summer school was held in Lüneburg in 2013, and the second was organised together with the ResClim initiative in Bergen, Norway.

Two stakeholder workshops were connected to the first and second IMPACT2C General Assemblies. In addition, two workshops were organised for the local stakeholders in Bangladesh. Close cooperation has been established with various local *stakeholders in the Maldives.*

Within the third IMPACT2C General Assembly at ENEA, an intense podium discussion was organised to inform local journalists about the IMPACT2C project. This session was reported in “In Sole 24 oro” and an ENEA youtoube video (https://www.youtube.com/watch?v=xR1vkwA6c7s).

Two IMPACT2C special sessions were organised within the European Climate Change Adaptation Conferences (ECCA) in 2013 and in 2015 and one within the CFCC15 conference in Paris in 2015.

IMPACT2C drew the key findings together in two issues of the newsletters and in a series of policy briefs that highlighted the risks, synergies and costs. In addition, the IMPACT2C web atlas has been developed, which provided access to a wide range of policy relevant results from the project.

Publications in the peer-reviewed literature and presentations in scientific conferences were the main scientific routes to use and disseminate the knowledge. This has been followed successfully with 31 accepted related papers, and a further 10 submitted.

Appendix

Ensemble of climate mandatory simulations for Europe

Institute-RCM	*Driving-GCM*	*Global warming*		
		+1.5°C	*+2°C*	*+3°C*
Fast-track mandatory simulations from ENSEMBLES (A1B scenario)				
DMI-HIRHAM	BCM	2025-2054	2038–2067	Inf**)
SMHI-RCA	HadCM3Q3	2014-2043	2033–2062	Inf**)
METO-HadRMQ0	HadCM3Q0	2008-2037	2021–2050	2052-2081
CNTM-RM5.1	ARPEGE	2014-2043	2029–2058	2064-2093
MPI-REMO	ECHAM5	2021-2050	2034–2063	2058-2087
Slow-track mandatory simulations from CORDEX (RCP 2.6)				
CSC-REMO2009	MPI-ESM-LR	2035-2064	inf*)	Inf**)
SMHI-RCA4	EC-EARTH	2028-2057	Inf*)	Inf**)
Slow-track mandatory simulations from CORDEX (RCP 4.5)				
CSC-REMO2009	MPI-ESM-LR	2020-2049	2050-2079	Inf**)
IPSL-WRF331F	IPSL-CM5A-MR	2009-2038	2028-2057	Inf**)
KNMI-RACMO22E	EC-EARTH	2018-2047	2042-2071	Inf**)
SMHI-RCA4	EC-EARTH	2019-2048	2042-2071	Inf**)
SMHI-RCA4	HadGEM2-ES	2007-2036	2023-2052	2055-2084
Slow-track mandatory simulations from CORDEX (RCP 8.5)				
CSC-REMO2009	MPI-ESM-LR	2014-2043	2030-2059	2053-2082
KNMI-RACMO22E	EC-EARTH	2012-2041	2028-2057	2052-2081
SMHI-RCA4	EC-EARTH	2012-2041	2027-2056	2052-2081
SMHI-RCA4	HadGEM2-ES	2004-2033	2016-2045	2037-2066

*) ... not reaching +2°C global warming until 2100. Take 2071-2100 as 2C period (decided on Uncertainty WS - Hamburg 2014).;**) ... not reaching +3°C global warming until 2100.

Ensemble of simulations with the impact models (msism – mandatory simulations) for Europe

Sector	*Impact Models and variables*	*WP(s)*	*RCP2.6*	*RCP4.5*	*RCP8.5*
Water	**E-Hype**; **LisFlood**; **LPJm; VIC WBM**	6, 9	2 Msims x 10 hydro model Total 20	5 Msims x 5 hydro model Total:25	4 Msims x 5 hydro model Total:20
Agriculure	**EPIC**:	7,10	Rain fed: 2Msims x EPIC Irrigation: 2Msims x EPIC Total:4	Rain fed: 2Msims x EPIC Irrigation: 2Msims x EPIC Total:4	None
	LPJmL	7	2Msims x EPIC Total:2	5Msims x EPIC Total:5	None
Forestry/Ecosystem services	**CLM4.0-CN**:	7			
	G4M: changes in the output is mainly the potential increment per forest hectare per year and t	7	2Msims x G4M Total:2	5Msims x G4M Total:5	None
	LPJmL:	7	2Msims x LPJmL Total:2	5Msims x LPJmL Total:5	None
Tourism	**TCI**: summer tourism (beach) effects, and value at risk	6, 9	1 EC-Earth SMHI Total:1	5Msims Tota:l 5	4Msims Total:4

Sector	*Impact Models and variables*	*WP(s)*	*RCP2.6*	*RCP4.5*	*RCP8.5*
	Summer tourism value at risk	6, 9	1 EC-Earth SMHI Total:1	5Msims Tota:l 5	4Msims Total:4
	Winter tourism value at risk	6,9	2msims Total:2	5Msims Tota:l 5	4Msims Total:4
Coastal	**DIVA**:	6	2msims Total:2	5Msims Tota:l 5	4Msims Total:4
Energy					
Wind energy	wind power potential & production	6	-	5Msims Tota:l 5	4Msims Total:4
Solar photovoltaic (PV)	PV power potential and production	6	-	5Msims Tota:l 5	4Msims Total:4
Gross hydropower potential	*E-Hype;* LisFlood; LPJm; *VIC WBM*	6	-	5 Msims x 5 hydro model Total:25	4 Msims x 5 hydro model Total:20

Design of experiment for air pollution for Europe

Model chain:

Institute	CTM	Driving GCM	RCM used for downscaling	Chemical boundary conditions
CNRS-IPSL	CHIMERE	IPSL-CM5A-MR	WRF	LMDz-INCA*
Météo-France	MOCAGE	ARPEGE	ARPEGE	MOCAGE
MET. NO	EMEP	NorESM	WRF	LMDz-INCA
SMHI	MATCH	EC-EARTH	RCA4	LMDz-INCA

Emissions used:

Name	Climate	Boundary conditions	Emissions
HINDCAST	1989-2008	2005	ECLIPSE v4a 2005
HISTORICAL	1971-2000	2005	ECLIPSE v4a 2005
S1	+2°C period for RCP4.5	2050	ECLIPSE v4a 2050 CLE
S2	1971-2000	2050	ECLIPSE v4a 2050 CLE
S3	+2°C period for RCP4.5	2050	ECLIPSE v4a 2050 MFR

Socio-economic pathways used in the project

Shared Socioeconomic Pathway (SSP) 2 'middle of the road' scenario (O'Neill et al 2014) was used to estimate the impact of +2°C global warming and associated costs on river flood, sea-level rise, heat mortality. For agriculture and tourism, the analysis was further extended to SSP1 and SSP3, differing from SSP2 in terms of trajectories of population, food preferences, technological progress and trade regimes.

O'Neill B C, Kriegler E, Riahi K, Ebi K L, Hallegatte S, Carter T R, Mathur R and Vuuren D P 2014 A new scenario framework for climate change research: the concept of shared socioeconomic pathways Clim. Change 122 387–400

Ensemble of climate simulations for non-European regions

Institute-RCM	***Driving-GCM***	***Region***	***Emission Scenarios***
CNRM-ARPEGE52	CNRM	Bangladesh, Africa, Maldives	RCP2.6, 4.5, 8.5
SMHI-RCA4	EC-EARTH	Bangladesh ,Africa ,Maldives	RCP2.6, 4.5, 8.5
BCCR-WRF331	NORESM	Bangladesh	RCP2.6, 4.5, 8.5
BCCR-WRF331	NORESM	Maldives	RCP2.6, 4.5, 8.5
DMI-HIRHAM	EC-EARTH	Africa	RCP2.6, 4.5, 8.5
ENEA-REGCM	CNRM	Africa	RCP2.6, 4.5, 8.5
CSC-REMO2009	EC-EARTH	Africa	RCP2.6, 4.5, 8.5
CSC-REMO2009	MPI-ESM-LR	Africa	H RCP2.6, 4.5, 8.5

Ensemble of simulations with the impact models for non-European regions

Africa: *Climate simulations adopted as input for the impact models. "Group" refers to projection group where "M" is MENA-CORDEX, "A" is Africa-CORDEX, "I" is ISI-MIP, "R" is raw RCM, "B" is bias-corrected, "4" is RCP4.5 and "8" is RCP8.5."Models" refers to impact models where "Sm" is SWIM, "H" is Hype and "A" is Africa RiskView"*

Scenario	GCM	RCM	Group	+1.5°C	+2.0°C	Models
RCP4.5	EC-EARTH	RCA4	MR4	2019-2048	2042-2071	Sm,H
RCP4.5	CNRM	RCA4	MR4	2021-2050	2043-2072	Sm,H
RCP4.5	GFDL	RCA4	MR4	2034-2063		Sm,H
RCP4.5	EC-EARTH	RCA4	MB4	2019-2048	2042-2071	Sm,H
RCP4.5	CNRM	RCA4	MB4	2021-2050	2043-2072	Sm,H
RCP4.5	GFDL	RCA4	MB4	2034-2063		Sm,H
RCP4.5	HadGEM2-ES	None	I4	2007-2036	2023-2052	Sm,H
RCP4.5	IPSL-CM5A-LR	None	I4	2010-2039	2026-2055	Sm,H
RCP4.5	MIROC-ESM-CHEM	None	I4	2010-2039	2024-2053	Sm,H
RCP4.5	GFDL-ESM2M	None	I4			Sm,H
RCP4.5	NorESM1-M	None	I4	2022-2051	2053-2082	Sm,H
RCP4.5	EC-EARTH	RCA4	AR4	2019-2048	2042-2071	Sm,H,A
RCP4.5	CNRM	RCA4	AR4	2021-2050	2043-2072	Sm,H,A
RCP4.5	GFDL	RCA4	AR4	2034-2063		Sm,H,A
RCP4.5	CCCma	RCA4	AR4			Sm,A
RCP4.5	MIROC-ESM-CHEM	RCA4	AR4	2010-2039	2024-2053	Sm,A
RCP4.5	MPI-M	RCA4	AR4			Sm,A
RCP4.5	NorESM1-M	RCA4	AR4	2022-2051	2053-2082	Sm,A
RCP8.5	EC-EARTH	RCA4	MR8	2012-2041	2027-2056	Sm,H
RCP8.5	CNRM	RCA4	MR8	2015-2044	2030-2059	Sm,H
RCP8.5	GFDL	RCA4	MR8	2022-2051	2039-2068	Sm,H
RCP8.5	EC-EARTH	RCA4	MB8	2012-2041	2027-2056	Sm,H
RCP8.5	CNRM	RCA4	MB8	2015-2044	2030-2059	Sm,H
RCP8.5	GFDL	RCA4	MB8	2022-2051	2039-2068	Sm,H
RCP8.5	HadGEM2-ES	None	I8	2004-2033	2016-2045	Sm,H
RCP8.5	IPSL-CM5A-LR	None	I8	2006-2035	2020-2049	Sm,H
RCP8.5	MIROC-ESM-CHEM	None	I8	2007-2036	2018-2047	Sm,H
RCP8.5	GFDL-ESM2M	None	I8	2022-2051	2039-2068	Sm,H
RCP8.5	NorESM1-M	None	I8	2017-2046	2032-2061	Sm,H
RCP8.5	EC-EARTH	RCA4	AR8	2012-2041	2027-2056	Sm,H
RCP8.5	CNRM	RCA4	AR8	2015-2044	2030-2059	Sm,H
RCP8.5	GFDL	RCA4	AR8	2022-2051	2039-2068	Sm,H
RCP8.5	CCCma	RCA4	AR8			Sm
RCP8.5	MIROC-ESM-CHEM	RCA4	AR8	2007-2036	2018-2047	Sm
RCP8.5	MPI-M	RCA4	AR8			Sm
RCP8.5	NorESM1-M	RCA4	AR8	2017-2046	2032-2061	Sm

Sea-level rise:
GCMs model used to estimate the impact for
Africa: CNRM-CM5; MPI-ESM-LR; MOHC-HadGEM2; GFDL-ESM2M; NCC-NorESM1-M; CCCma-CANESM2;EC-Earth
Bangladesh: CNRM-CM5 and EC-Earth
Maldives: MOHC-HadGEM2

The Maldives: *Methodology to determine is overtopping could occur with sea-level rise, and if so what infrastructure of the could be affected.*

	1) Determine height of island using data collected from differential Geographical Positioning Survey and link to bathymetric data.
	2) Determine from tide gauge and hindcast data how frequently extreme events have happened in the past, and under what conditions.
	3) Use an overtopping model to determine under what oceanographic conditions inundation could occur using data from 1) and 2) under different scenarios of sea-level rise.
	4) Determine the flood extent and flood depth.
	5) Determine infrastructure affected.

Bangladesh: *The framework to asses the impacts on the hydro-meteorological systems and water resources of Bangladesh*