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A review of climate impact indicators across themes: Description of strengths, weaknesses, technical requirements and mismatches from user expectations

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Abstract

This deliverable documents, reviews and explores climate change and impact indicators potentially relevant for the objectives of the CLIPC project. The potential indicators are documented in the light of reference criteria sampled from previous work and refined via both internal discussions and an expert workshop (of Milestone 29) conducted in cooperation with the European Environment Agency. Methodological descriptions, data requirements and availability, treatment of uncertainty, fitness for purpose of indicator time series and seven other relevant criteria are documented for a total of 87 climate change and impact related indicators.

Strengths and weaknesses of indicators have been discussed at a general level and also outlined both on an indicator-by-indicator basis and in the light of potential uses of indicators. For the latter two the analysis is as yet indicative due to lack of detail on the uses of indicators and lack of full harmonization of the indicator criteria across different indicators. The evaluation of indicators has made it possible to identify a consistent set of criteria and approaches for the incorporation of indicator information in the CLIPC portal as metadata for the indicators. It has also laid the foundations for forthcoming work in WP7 regarding the calculation of existing, and elaborating new, indicators as well as important input for WP8 for work related with aggregation of indicators.

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Executive Summary

Objectives:

This deliverable has four main objectives:

1 - Elaboration of criteria for examining climate impact indicators.
2 - Documentation of an expert workshop involving relevant partners to discuss the criteria.
3 - Creation of a catalog of potential impact indicators to be made available via CLIPC.
4 - Assessment of strengths and weaknesses of climate impact indicators.
5 - Identify mismatches between user needs and the indicators documented.

Results:

In this deliverable, a total of 81 climate change and impact indicators are examined using a consistent set of reference criteria. These include aspects such as the methodological description of indicators, the data requirements and availability for indicator calculation, treatment of uncertainty, fitness for purpose of indicator time series and seven other relevant criteria. An analysis of previous work conducted by initiatives providing collections of climate indicators, and follow-up discussions in an expert meeting workshop, ensures that the criteria selected are in line with the core purposes of WP7.

The indicators were grouped in three tiers, with Tier-1 focusing on the climate system, Tier-2 indicators the impacts of climate change in bio-physical systems and Tier-3 indicators on the socio-economic systems affected by climate change. An analysis of the scientific and technical strengths and weaknesses of indicators was feasible but only at an aggregate level. As a particular strength of indicators gathered it can be pointed out that a large proportion of the input data for the indicators is in the public domain. This is mostly visible for Tier-1 and Tier-2 indicators. For half of the Tier-3 indicators documented some data restrictions have been documented. It should also be noted that the total number of Tier-3 indicators is relatively small in comparison with the other Tiers.

Indicator uncertainty is a key issue. In the indicator documentation, some information on uncertainties was available for approximately 2/3 of the indicators. The detail of description varies but in general information of uncertainty introduced by the indicator method and that related to the input data is documented. This particular aspect is to be further strengthened in the running of WP7 via more engagement on harmonizing the uncertainty descriptions. An apparent weakness of the indicators documented is the lack of regular updating. This is particularly the case when the indicators have been developed and presented as the output of specific research projects and not maintained by organizations responsible for monitoring or statistical data.

An evaluation of strengths and weaknesses on indicators-by-indicator basis has been proposed and conducted for particular cases. Its completion will need to expand beyond the time frame of this deliverable as an overarching activity of WP7 until the production of the CLIPC portal.

In an attempt to explore strengths and weaknesses of indicators further, we used preliminary results of the user consultation of WP2 in an attempt to evaluate indicators for specific purposes (as stated by users). Although the preliminary user consultation made it possible to identify general uses of indicators (e.g., production of risk and vulnerability assessments), details on particular applications of indicator by users are missing. Because only general uses are known, the evaluation of indicators from a user's perspective suffers from our incomplete knowledge on much weight a particular user might attribute to particular strengths and weaknesses. Despite these limitations, the deliverable gathered an extensive set of information on impact and climate change indicators and developed the approach for analyzing strengths and weaknesses of indicators. The documentation sets the standards of information in the metadata to be included for the impact indicators in the CLIPC portal.

The sample of indicators gathered at the time of writing have been observed to match the user needs for using indicators as input for climate research and for the purposes of awareness raising. The uses of supporting the elaboration of adaptation strategies and vulnerability studies can already be supported by the indicators gathered, although in these cases it is still preliminary to make definitive judgments in the light of draw backs previously highlighted. Further interaction with users and subsequent updates of indicator documentation will help to clarify this.

Finally, in order to pave the way for data integration within WP7, two tentative developments of new impact indicators are envisioned, namely, an indicator of heat-stress of population and moth phenology index. A brief description of the types of data used for the calculation and the schematic steps for indicator calculation are presented.

Perspectives:

The deliverable has set the foundation for much of the work ahead in WP7 but also in WP8. An overall scheme for indicator documentation was put in place and a first large bulk of indicator documented. The next steps are the harmonization of some criteria in order to allow for a full use of the database in discerning indicator strengths and weakness on a more detailed level. This is a long term activity within WP7.

As long term perspectives, the work of WP7 will be focused on the completion and expansion of the review of indicators made in this deliverable. The completion will benefit from longer a longer time frame for filling missing relevant criteria information via more interactions with the partners. In addition, more detailed insights from ongoing user consultation will hopefully allow for a better matching of the indicator list collected to the user needs. The expansion of the indicator list will particularly focus on expanding the Tier2 and 3 indicators.

I. Introduction

Deliverable 7.1 aims to develop a consistent framework for examining climate impact indicators, as well as delivering a state-of-the-art review on selected climate impact indicators that will be further explored in the CLIPC project. A clear outcome of this deliverable is an agreement between partners on a set of criteria to evaluate climate impact indicators. The final results of this deliverable are to be incorporated in the knowledge database developed in WP3.

The concept of an impact indicator is likely to find many meanings, reflecting the different research perspectives that study the evolution of climate and its consequences for the environment and societies. The term has not been unambiguously defined in relation to climate change. The European Environment Agency (EEA 2012) specifies indicators with reference to their purpose. If the purpose is "understanding the causes of impacts of climate change", then the report refers to "climate change indicators". One can assume that "understanding" involves some type of "description" and that "causes of impacts" refer to "changes in the climate system". In broad terms an indicator can be defined to be a measure of the state of a particular system that provides a way to track the evolution of more complex processes, such as different aspects of climate change. An indicator provides information about complex processes while maintaining a certain degree of simplicity.

There is also ambiguity with respect to the use of the term 'index'. The Integrated Climate Data Center (ICDC) defines climate indices as a "calculated value that can be used to describe the state and the changes in the climate system". "Climate indices" are usually measures that have been agreed on and are based on standardized calculation routines, while indicators are also used in a much wider sense. Sometimes an indicator which is constructed by combining two or more distinct metrics can also be called an index. An example is the Palmer Drought Index, which is a measurement of dryness based on recent precipitation and temperature (Wayne Palmer, 1995). A second example would the Forest fire Weather Index (FWI). But there are also climate indices that are determined by making use of a simple climatic variable, for example, the number of frost days, which is calculated by the sum of days in one year with daily minimum temperature below 0ºC. In practice the distinction between indicators and indices appears not to be that important or clear cut. The distinctions reflect conventions and traditions and thus climate researchers commonly refer to indices based on air temperature, precipitation, air pressure and sea surface temperature.[1]

In the field of climate change, the essential climate variables (ECV) are specified as a particular group of indicators. An ECV is "a physical, chemical, or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate" (Bojinski et al., 2014). The calculation procedures for ECV's tend to be fixed as for climate

[1] Climate Indices http://icdc.zmaw.de/climate_indices.html?&L=1 [visited February 20 2015]

indices. It is therefore no surprise that whatever the semantic used to describe a climate change indicator, climate indices or ECV, resulting finding show quite similar attributes. For example the indicator “European temperature” (EEA 2012) provides essentially the same information as the index “Mean of daily temperature” (European Climate Assessment & Dataset project) and the essential climate variable “Air temperature” (Global Climate Observation System).

Indicators or related concepts are not restricted to the presentation of data in the form of graphs and charts. EEA (2012) specifically stresses that indicators should help “understanding the consequences of climate change and determining vulnerability” and therefore the indicators of the EEA include a narrative component. Climate change indicators can be used, and often are, to deal with concepts of vulnerability such as exposure, hazard or intensity (Costa & Kropp, 2013). Similarly, climate change indicators are used as input for discerning the consequences of climate change. An example is the occurrence of storms (denoted by wind velocity) in causing economic damages (Prahl et al., 2014).

In the CLIPC project, an impact indicator is described as an observed or projected measure that indicates a 'relevant' environmental/human/economic impact, and whose causes can be linked to the interaction between changes in climate and society. A meta-classification of impact indicators into three Tiers (see Figure 1) is proposed, from indicators mainly concerning natural systems to those reflecting changes in human systems. An additional distinction can be made based on the timeframe. Generally indicators have been developed based on historical observations-based data to infer trends, but climate change scenarios also play an important role. The obvious distinction is that indicators based on historical data are primarily driven by available observations whereas projections are based on model outputs. Validation of model output and bias correction methods provide links between the two types of indicators.

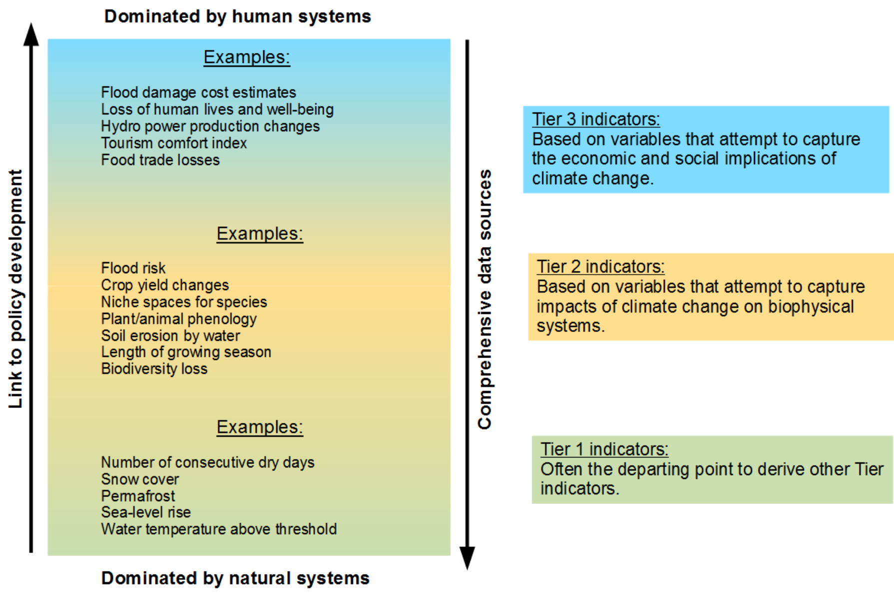

Figure 1 - Framework of climate impact indicator classification as used by CLIPC

In this categorization, Tier-1 indicators are intended to give information on the past and future evolution of the climate system. For example, mean temperature change, ice cover extent or sea-level rise provide indications of the impact on the climate system that are caused by anthropogenic interference with the global energy balance. Tier-2 indicators attempt to quantify the impacts of climate change in bio-physical systems. Flood risks, crop losses, changes in distributional ranges or phenology of organisms or soil erosion are examples of such variables that can be used as indicators. Tier-3 indicators primarily aim at providing information on the socio-economic systems affected by climate change. These indicators usually build on previous ones and make the bridge from a bio-physical change to social or economic loss/gain. For example, indicators based on the economic consequences of extreme weather events or morbidity during heat waves belongs to this group. It comes without saying that the classification is not free of inconsistencies as there are indicators that overlap the classes proposed. Nevertheless, this structuring of indicators is useful for the purposes of the CLIPC work, since it establishes a common framework of reference for communication with the consortium and wider climate-impact community.

For the sake of clarity, we provide some of the working definitions used in the elaboration of this deliverable. These do not yet constitute a comprehensive glossary, but are useful as clarification of some terms that populate this deliverable, especially since the use of the wording “climate indicator” or “impact indicator” is often used by scholars of very different disciplines.

- **Climate impact indicator** - an observed or projected measure that indicates a 'relevant' environmental/human/economic impact that can be linked to changes in the climate.

- **Tier-1 climate impact indicator** - A climate impact indicator primarily intended to give information on the past and future evolution of the climate system. Changes in temperature and precipitation extremes, artic ice coverage or sea-level changes are examples of such variables that belong to this indicator category.

- **Tier-2 climate impact indicator** - A climate impact indicator primarily intended to quantify the impacts of climate change in bio-physical systems. Flood risks, crop losses, changes in distributional ranges or phenology of organisms or soil erosion are examples of such variables that belong to this indicator category.

- **Tier-3 climate impact indicator** - A climate impact indicator primarily intended to provide information on the socio-economic consequences entailed by the changes in Tier1 and 2 indicators. Crop-value loss, human casualties and economic losses from floods or storm events are examples of such variables that belong to this indicator category. Several Tier-2 indicators can be converted into Tier-3 indicators provided that reliable estimates can be provided on the economic consequences of physical impacts.

- **Climate indices** - Calculated value that can be used to describe the state and the changes in the climate system. Indices are often used as synonyms for indicators.

- **Essential Climate Variable** - A physical, chemical, or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate.

II. Previous work on climate change and impact indicators

This section reviews a number of European initiatives (projects, reports, activities) that have produced climate and climate impact indicators. The search for these initiatives was done by making use of the Climate-ADAPT portal and it was restricted to the time period between the start of the FP6 program and today. In addition to the European-funded initiatives, the newest developments on climate impacts from the Intra-Sectoral Impact Model Intercomparison (ISIMIP) are also addressed (see Table 1).

Table 1 - Overview of investigated studies on climate change and impact indicators.

Project/report/activity		Objectives	Topics addressed
Climate change, impacts and vulnerability in Europe 2012: An indicator-based report.	EEA 2012a	Assess past and projected climate changes and their impacts, and the associated vulnerability to society and ecosystems in Europe.	• Climate system • Environmental systems • Socio-economic systems and health • Vulnerability
ESPON Climate: Climate Change and Territorial Effects on Regions and Local Economies.	ESPON 2011	Assess the degree of vulnerability of different European regions to climate change and the impact of climate change on the regions economic, social, and environmental dimensions of European regions.	• Physical • Environmental • Economic • Social • Cultural
Urban Vulnerability Indicators and Vulnerabilities, Vulnerability Assessments by Indicators and Adaptation Options for Climate Change Impacts (a Scoping Study). Urban 2010-2012	ETC/CCA 2010 2012	Propose a system of urban vulnerability indicators, for assessing where European cities stand in terms of vulnerability and adaptation.	• Heat waves • Floods • Droughts/water scarcity • Forest fires
ENSEMBLES: Climate change and its impacts at seasonal, decadal and centennial timescales	EU FP6 research project 2004 to 2009	Formulation of very high resolution Regional Climate Model Ensembles for Europe. Global mitigation scenarios.	• Climate system

ENSEMBLES 2009		Probabilistic projections of climate change. Impact analysis, both with RCM ad probabilistic projections.	
The Inter-Sectoral Impact Model Intercomparison Project.	ISIMIP - Research activity Potsdam Institute for Climate Impact Research	Quantitative estimate of impacts and uncertainties for different sectors and from multiple impact models.	• Agriculture* • Biomes* • Forestry • Energy • Health* • Coastal infrastructure* • Marine ecosystems • Water* *fast track
Quantifying projected impacts under 2°C warming IMPACT2C	FP7 EU research project 2011-2015	Identify and quantify the impacts and most appropriate response strategies of a 20C global warming for Europe and three selected vulnerable regions in other parts of the world	• Water • Energy • Infrastructure • Tourism • Agriculture • Forestry • Ecosystem services
Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis PESETA I and II	JRC/JES	Consistent multi-sectoral assessment of economic impacts of climate change in Europe for the 2071-2100 time horizon.	• Agriculture • Coastal systems • River floods • Tourism • Human health • Energy* • Transport infrastructure* • Forest fires* • Habitat suitability* *further included in PESETA II

1. Climate change, impacts and vulnerability in Europe 2012: An indicator-based report

1.1 Objective, data, coverage and scenarios

In 2012 the European Environment Agency (EEA 2012a) compiled information on past and projected climate change, and related impacts in Europe, based on a range of indicators. The report aimed at providing a strong knowledge base for the development and implementation of adaptation strategies and actions at both national and EU levels. Furthermore the report updates and improves earlier indicator-based assessments of climate change impacts and vulnerability published by the EEA, namely in 2004 and 2008. The indicators gathered are made accessible via the web-based EEA indicator management system[2] and the European Climate Adaptation Platform ClimateADAPT[3]. Approximately 40 indicators are included in

[2] http://www.eea.europa.eu/data-and-maps/indicators

[3] http://climate-adapt.eea.europa.eu

the EEA 2012a report. The indicators have been organized in three broad topics. These topics are: *Changes in the climate system*; *Impacts on environmental systems* such as the coastal zones, soil or inland waters; and *Impacts on socio-economic systems and health* such as agricultural systems, energy or transport. The report contains a chapter dedicated to indicators of vulnerability to climate change, such as indicators of damage costs, as well as integrated approaches to operate the concept of vulnerability taken from the ESPON project. A tentative matching of the indicators provided in the EEA 2012a report to the CLIPC Tier classification (Figure 2) shows the predominance of indicators associated with Tier-1 and 2, respectively 46 and 48% of the total indicator set. Tier-3 indicators comprise only about 6% of the indicator set reported in the EEA 2102a report.

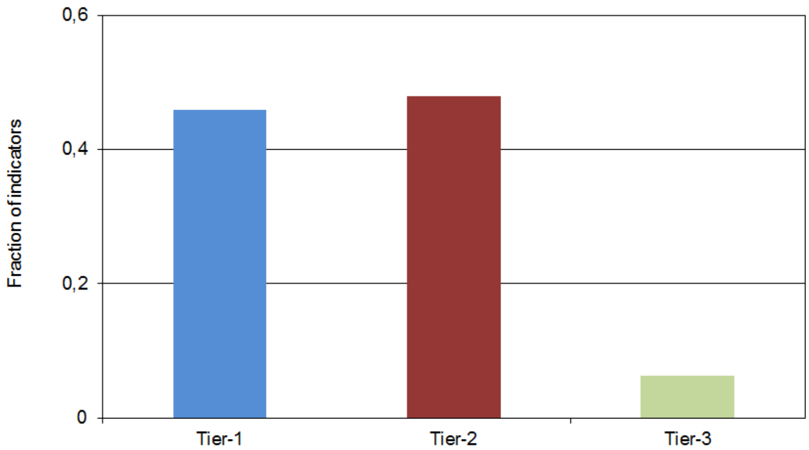

Figure 2 - Fraction of indicators provided in EEA 2012 tentatively allocated according the CLIPC Tier-1, -2 and -3 classifications.

The report included both observations and projections for the majority of the indicators. Indicators have been quantified using existing information; hence, the use of climate models, forcing scenarios, spatial resolutions and time frames for projections varied between indicators as the data were obtained from a large number of independent studies. Full harmonization of indicators with respect to models, climate scenarios, time frames or spatial coverage was therefore impossible. As a an example, while the indicators under the topic "Changes in the climate system" are usually derived from large ensembles of RCMs and GCMs, a substantial number of indicators belonging to the topic "Impacts on environmental systems" and "Climate impacts on socio-economic systems and health" are obtained from studies that have used a single or two climate models. This is the case for indicators providing information on agro-phenology, distribution and abundance of animal species, forest fires or water requirements. The use of socio-economic scenarios is also non-systematic; although in this case a considerable fraction of indicators are obtained for the IPCC SRES A1B scenario, see Figure 3 for details. For the indicators with spatially-explicit projections (in the form of a map), about 40% had been derived using the A1B scenario. Indicators that have been calculated according to one of the other SRES scenarios constitute about 20% of the indicators. For approximately 40% of the indicators included in the EEA report, there was no spatial representation (maps) of future projections. For these indicators the report provided concise text with information on projections available in the literature; many of these also used SRES scenarios.

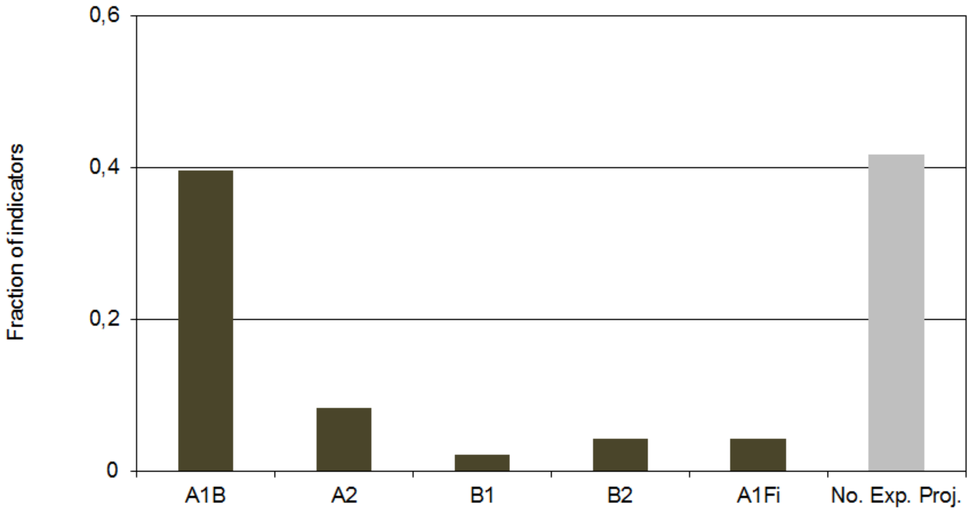

Figure 3 - Fraction of indicators with spatial-explicit representation (maps) provided in EEA 2012 according to the socio-economic scenario used.

The time frame for which projections are available is also rather variable across and within the investigated topics. The time frames of 2021-2050 and 2071-2100 were most commonly used for the indicators presented in a spatially-explicit manner.

1.2 Climate change and impact indicators

This report represents an extension of the EEA (2012a) in compiling indicators for the potential impacts of climate change. The set of indicators used for this purpose is based extensively on previous peer-reviewed as well as non-peer-reviewed work. Although it is mentioned in the report that the selection of indicators to be included adhered to criteria documented in an ETC technical paper published in 2013, the report falls short in making transparent how the selection process was carried. Although both preceding reports in 2004 and 2008 provide explicit criteria for indicator selections, specific details remain unclear. Examples of such criteria are: the policy relevance of an indicator, its strength in establishing the causal links between climate change and observed impacts, its methodological soundness, issues of data quality, the availability of the indicator for long periods of observations, and information on robustness and uncertainty.

The assessment of past and projected climate change and impacts is reported mostly for indicators belonging to the topics *Changes in the climate system* and *Climate impacts on environmental systems*. The indicator set under these two topics ranges from basic (Tier1) climate change indicators such as temperature averages and extremes, wind speeds or snow cover length; to more elaborated (Tier-2) indicators employing biophysical (e.g., river flow and flood return levels) or envelope models (e.g., distribution of plant and animal species). Regarding the investigation of *Climate impacts on socio-economic systems and health*, the report contains indicators that cover most of Europe’s economic sectors; including agriculture, biodiversity, forestry, energy, transport, tourism, fisheries and human health. Also here the indicators range from simple climate indices constructed via the use of basic climate variables (e.g., heating degree days or flowering date of winter wheat) to metrics that imply the use of biophysical or statistical modeling, such as agricultural yield.

Indicators that could be mostly related to the Tier-3 classification in CLIPC, such as people affected, are included in the EEA 2012a section referring to indicators of *Vulnerability to climate change*. Under this topic indicators are largely dominated by human systems such as costs of flood damages or other natural disasters or projected economic costs of climate change. The establishment of systematic indicators has proved to be challenging due to lack of systematic data collection and analysis. The report specifically noted that there is a need for enhanced and sustained monitoring in Europe of "environmental systems, socio-economic systems and health, and of costs of damages of extreme weather events" (EEA 2012a).

2. ESPON Climate: Climate change and territorial effects on regions and local economies in Europe.

2.1 Objective, data, coverage and scenarios

The ESPON Climate[4] project had the objective of assessing the degree of vulnerability of different European regions to climate change. In this light, it was not an explicit objective of ESPON Climate to collect, or elaborate, impact indicators. Instead, the project strived to operationalize the concept of vulnerability for European regions by using an adapted version of the Klein & Füssel (2006) vulnerability framework. In order to determine the vulnerability of a system a number of intermediate steps have to be fulfilled, among those, the determination of the potential climate change impacts. Potential impacts are framed as a combination of climatic exposure (Tier-1 indicators) and sensitivity. In this particular case sensitivity is assessed via socio-economic and bio-physical conditions of each system under analysis, for example, population, infrastructure or landscape. Thus, impact metrics in ESPON are, in theory, mainly related to Tier-2 and Tier-3 indicators in CLIPC. Individual impact metrics are divided into physical, environmental, social, cultural and economic dimensions. The project also devoted large efforts to the aggregation of impact metrics within and across each dimension.

[4] http://www.espon.eu/main/Menu_Projects/Menu_AppliedResearch/climate.html

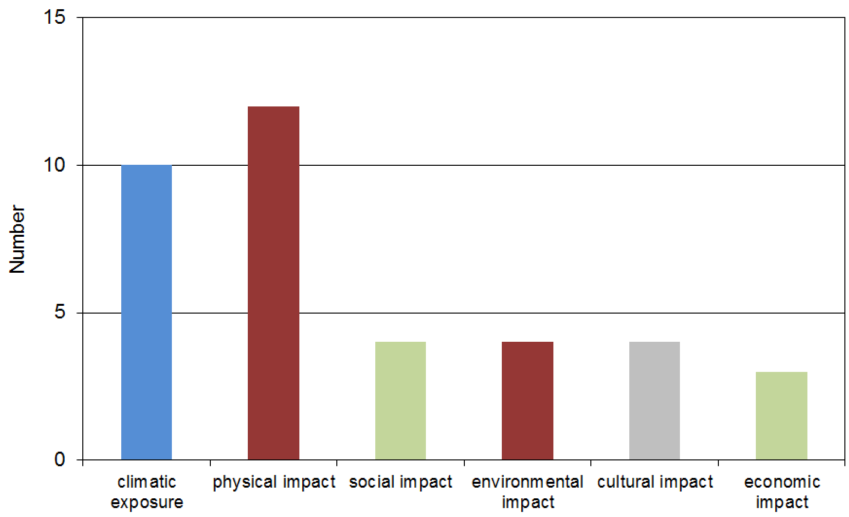

Figure 4 - Number of individual climatic exposure and potential impact indicators in ESPON 2011. ESPON climate indicators are tentatively coded according to CLIPC Tier classification. Blue for Tier-1 indicators; Red for Tier-2; Green for Tier-3. Indicators informing on cultural impacts have not been coded and are shown in grey.

Figure 4 illustrates the number of individual climate exposure and potential climate indicators, according to the five dimensions assessed, and available from ESPON Climate. Indicators of climatic exposure and those depicting the potential physical and environmental impact of climate change in European regions dominate the indicator set. Metrics informing on the potential social, cultural and economic impacts are the least represented in the indicator set, a characteristic also noted in the EEA 2012a study. We have coded, in a tentative manner, the indicators available from ESPON climate according to the Tier classification of CLIPC. Most of the indicators can primarily be classified as Tier-1 and 2 indicators. One of the most prominent characteristics of the ESPON Climate project has been to use , as far as possible, consistent socio-economic scenarios and time frames. The regional model COSMO-CLM[5] was adopted for climate change runs with three *realizations* for the time period 1961-1990 and two realizations for each scenario for the time frame 2001-2100 based on the IPCC A1B scenario. Indicators of climate exposure always indicate the change of climate conditions from the reference time period (1961-1990) to those expected in the time period 2071-2100. Also consistent across the study is the homogenization of indicators to the same administrative level, in this case NUTS-3 regions.

2.2 Climate change and impact indicators

The indicators of climatic exposure in ESPON (Tier-1) were largely identical to those proposed in the EEA 2012a report. For example, *change in mean annual temperature*, *numbers of frost days*, *snow cover duration*, *mean precipitation and extreme precipitation* or *changes in the 100 year return flood level* are included in both studies. The main difference is a stronger focus of EEA 2012a on the indicators indicating the state and evolution of the cryosphere. Only the exposure indicators of river and coastal flooding required additional processing of the output given by COSMO-CLM. For the case of river flooding, flood heights from the LISFLOOD hydrological model were used (also used in EEA 2012a to evaluate river

[5] http://www.clm-community.eu/index.php?menuid=198

flows). For coastal flooding ESPON made use of a tailor-made approach combining storm-surge heights from the Dynamic Interactive Vulnerability Analysis tool and a global digital elevation model.

Regarding the metrics on potential impacts for the physical, environmental, societal, economic and cultural dimensions (Tier-2), all result from a deductive approach that is, using available scientific knowledge in form of frameworks, theories or models about the vulnerable system of interest in the selection and aggregation of indicating variables (Hinkel 2011). In ESPON Climate potential impacts were determined by combining climatic exposure indicators with the sensitivity of a system in a deductive fashion; in most of the cases using previous knowledge from analog work or specific case studies. As an illustrative example the metric depicting the *potential impact of climate change on airports and harbors* (due to floods) was determined by overlaying inundated areas (tailor-made approach, see above) and corresponding changes in inundation heights (LISFLOOD, see above) with a map of the infrastructure networks and facility locations. The logic in this case, and very much for all indicators of potential impact, is the following: if the same geographical region scores high in the intermediate indicators of exposure and sensitivity, then the potential impact is also expected to be high. The individual impact score for a region is normalized between 0 and 1 (although the ESPON project also provides the original scores) according to the maximum and minimum distribution of impact scores for the NUTS-3 regions. This normalization implies that all European regions are ranked between the lowest and highest absolute scores. An interesting feature of the ESPON project was the very high level of indicator aggregation of such normalized scores across the physical, environmental, social, economic and cultural impacts of climate change.

3. Urban Vulnerability Indicators & associated ETC scoping study

3.1 Objective, data, coverage and scenarios

The Urban Vulnerability Indicators study aims at proposing a system of urban vulnerability indicators, which would allow an assessment of European cities in terms of vulnerability and adaptation, and the areas where certain problems cluster. The study is a follow-up of the 2010 ETC/ACC[6] scoping study on vulnerabilities to climate change hazards in urban regions. It seems therefore sensible to analyze both together for the purposes of this review. Both reports focus on assessing vulnerability indicators for the urban space. This is a new feature in this short review since until now we have been mostly evaluating work that dealt with a large number of economic sectors. At the core of both works sits the same vulnerability framework as in EEA 2012a and ESPON Climate (see above). Both urban studies are preparatory work that is currently followed up by implementation of a selected number of indicators.by the European Topic Centers on Spatial Analysis and Information and on Climate Change Adaptation (ETC/SIA and ETC/CCA).

[6] http://acm.eionet.europa.eu/reports/ETCACC_TP_2010_12_Urban_CC_Vuln_Adapt

The Scoping study reviews a total of 26 vulnerability indicators for the urban space distributed across the topics of heat, decreased precipitation and drought, wildfires, fluvial flooding, intense precipitation, sea-level and coastal flooding. Vulnerability indicators are composed of exposure, sensitivity and, at times, adaptive capacity components. Figure 5 shows the distribution of climate exposure indicators across the investigated themes in the ETC Scoping study. Climate exposure indicators for heat, sea-level rise and coastal flooding dominate the (exposure) indicator set make up approximately 50%.

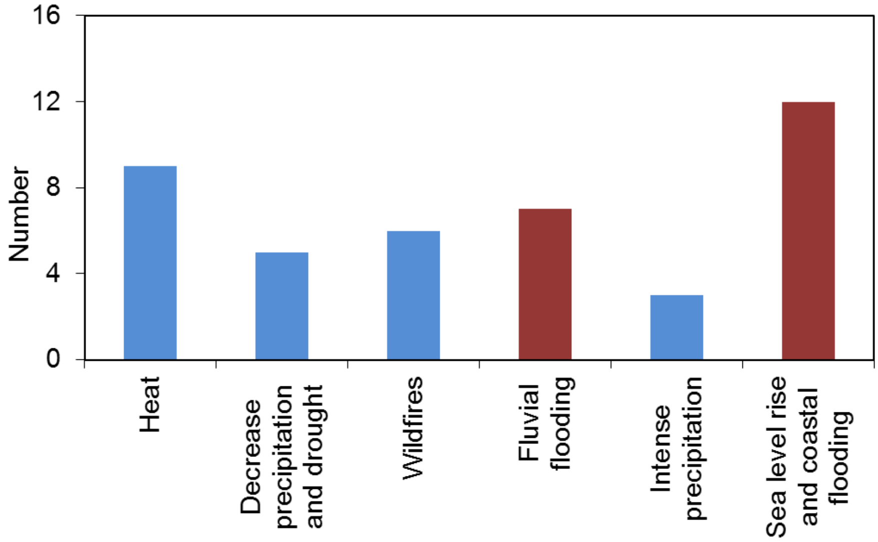

Figure 5 - Climate exposure indicators across the investigated themes of the ETC scoping study coded according the Tier classification of CLIPC.

The Urban Vulnerability Indicator study narrows the climate exposure indicator selection of the ETC Scoping study to 5 distributed across the themes of heat, foods (both fluvial and coastal), water scarcity/droughts and forest fires. With the exception of heat, for which two climate exposure indicators are considered, the remaining topics include a single climate exposure indicator. While most of the exposure indicators available can be related to the Tier-1 classification in CLIPC, some can be related to Tier-2. This is the case of indicators for fluvial and coastal flooding, which are, at times a, combination of a potential flood height and its propagation over the terrain.

3.2 Climate change and impact indicators

Examples of climate exposure indicators for the case of heat in the Scoping study are: Warm Spell Duration Index (WSDI), tropical nights, heat wave days, days > 30 °C or changes in average December, January and February maximum temperature by 2030. These indicators could be related to Tier-1 in the CLIPC classification, since they are selected or constructed from primary climate data without further impact modelling to capture a specific impact on biogeochemical human systems. Exposure indicators for pluvial flooding were found to be similar to those in EEA 2012a and ESPON Climate, namely, river flow and inundation depth, and coastal flooding, with emphasis on indicators such as inundated area and changes in storm surge height (Tier-2). Some of the exposure indicators use insights from vulnerability studies applied in urban regions outside the European space. As an illustrative case, the climate exposure metrics used in the case of wildfires refer specifically to those used in an Australian bush fire vulnerability indicator (see Preston el at, 2008).

The Urban Vulnerability indicator study narrows down the urban vulnerability indicators to a manageable number. The proposed set of indicators is derived from the Scoping study. The final set of indicators to measure climatic exposure is: heat: combined number of hot days and warm nights, and effective temperature; Floods: area prone to flooding (both from fluvial and coastal flooding); Water scarcity/droughts: standard precipitation index; Forest fires: fire probability index. The report neither provides details on how this selection took place nor which indicator criteria (e.g., methodology or coverage) were used.

4. ENSEMBLES: Climate change and its impacts at seasonal, decadal and centennial timescales

4.1 Objective, data, coverage and scenarios

The ENSEMBLES project aimed at providing researchers, decision makers, businesses and the public with climate information obtained through the use of the (at the time) latest climate modelling and analysis tools. The central feature of the project was the running of multiple climate models in order to improve the accuracy and reliability of results. The information was envisioned to help policy makers, at all levels, in determining future strategies to address climate change. From the many topics addressed in the ENSEMBLES project two are of particular interest to CLIPC: (i) the probabilistic estimate of uncertainty in future climate variables at seasonal to decadal and longer time-scales; and (ii) a linkage of outputs of the ensemble climate predictions to a range of sectoral impacts including agriculture, health, food security, energy, water resources, insurance and weather risk management.

Gridded observational datasets of daily precipitation and temperature have been developed using a European network of high-quality station series. The datasets cover the period from 1950 to 2008. A set of multi-model simulations was produced over the period 1860-2000 to simulate the long-term climate conditions. Subsequently, a multi-model set of coupled simulations over the 21st century was produced for the A2, A1B and B1 IPCC scenarios. ENSEMBLES made considerable efforts to construct probabilistic high-resolution regional climate scenarios and seasonal-decadal *hindcasts*. Results are available at 25km resolution. For particular climate variables and regions, downscaling methods where applied to GCM output in order to obtain both climate change projections extended up to 2100 as well as seasonal to decadal *hindcasts*. The downscaled climatic variables all belong to Tier-1: daily temperature and precipitation, minimum and maximum temperature, marine surface wind, drought indices, river discharge, solar radiation, vapor pressure, wind speed and relative humidity.

4.2 Climate change and impact indicators

The ENSEMBLES project did not aim, as a core objective, to provide climate change or impact indicators. It did nevertheless support 1) the integration of process models of impacts on the natural and managed global environment into Earth System Models and 2) the modelling of the extreme weather events to evaluate impact risks. For example, the Dynamic Global Vegetation Model[7] (DGVM) LPJmL was forced with the projected climatic patterns from seventeen general circulation models used in the ENSEMBLES project. A number of what we could call Tier-2 indicators were derived from the exercise and reported for the global scale: Tree cover, Net Primary Production (NPP), heterotrophic respiration, evaporation, river runoff and incidence of fire. Other DGVM's have been used providing comparable outputs.

With respect to extreme events, a number of impact models have been used in ENSEMBLES to define the nature of extreme events and their impacts. These impact assessments were carried out across a number of regions and topics, for example: potential changes in energy demand in the Mediterranean or changes of fire risk in *Fennoscandinavia*. To assess potential changes in energy demand a number of impact indicators were generated such as changes in cooling and heating degree days, mean change in cooling degree days and the standard deviation of change. To assess fire risk in *Fennoscandinavia* the Finnish Fire Index was used, using projections from a 100-year simulation with the SMHI-RCA Regional Climate Model. In addition to the more global/regional efforts in providing climate change impact assessments, the ENSEMBLES project elaborate 11 more detailed case studies (all located in Europe) for which both climate change and impact indicators where generated. These are summarized in Table 2.

Table 2 - Case study regions and downscaled indicators for the ENSEMBLES project

Study region	Indicator	Comment
Castilla Léon	Changes in phytoclimatic indices	Index represents the suitability of a certain species to live in a given region depending on its climate.
Spain	Mean and extreme precipitation.	Different ENSEMBLES RCMs used to reproduce the mean and extreme precipitation regimes in Spanish hydrological basins.
Andalucia	Changes in bioclimatic and drought indices	Percentage changes in four bioclimatic types (humid, semi-humid, dry and semi-arid) in Andalucía.
North sea	Decadal, monthly and daily means of 10m wind components (u & v),	Approach consisted of a multi linear regression (MLR) model for spatial downscaling and a multi-variate auto regression (mvAr) model to generate highly temporal time series of wind components.
Rhine basin	Annual maxima of *10-day precipitation sums*	Data to used in driving a hydrological model of the Rhine basin to study potential changes in the occurrence of extreme river discharges.
Alps	Changes in winter snow water equivalent	Ensemble mean, minimum and maximum based on six ENSEMBLES regional climate change scenarios assuming SRES A1B emissions
Northern Italy	Changes in temperature extremes	Statistical downscaling applied to several GCMs to construct probability density function (PDFs) of changes in temperature extremes over Northern Italy
Scandinavia	Frequency of second- and third-generations of bark beetles	Indicator resulted form impact modeling that used ENSEMBLES outputs of climate data as input.
Romania	Changes in extreme precipitation	Example: Mean frequency (number of days) of summer daily precipitation exceeding 15 mm/day at the Calarasi station (Romania)
Danube	Changes in river flow extremes	Changes in river flow extremes are associated to the atmospheric

[7] https://www.pik-potsdam.de/research/projects/activities/biosphere-water-modelling/lpjml

Mediterranean	Changes in temperature and rainfall extremes	predictors of sea level pressure (SLP), geopotential, temperature, specific and relative humidity Example of indices determined: frequency of hot days (Tmax>35ºC), tropical nights (Tmin>20ºC) and length of maximum dry spell

5. ISIMIP: The Inter-Sectoral Impact Model Intercomparison Project.

5.1 Objective, data, coverage and scenarios

ISIMIP is a community-driven modelling effort with the goal of providing cross-sectoral global impact assessments, based on Representative Concentration Pathways (RCPs) and socio-economic Shared Socio-Economic Pathways (SSPs) scenarios. Its aim is similar to those of model intercomparison initiatives that are sector-specific, for example AgMIP[8] or waterMIP[9] for the cases of agriculture and water respectively and which are included in the ISIMIP network. The first efforts of ISIMIP were devoted to the elaboration of a common climate dataset and bias correction to serve as input to the different impact models. This was achieved during the project fast track (until May 2013). During this phase a total of 5 GCMs has been used, as well as approximately 30 impact models covering the sectors of agriculture, biomes, water, health (restricted to malaria) and coastal infrastructure. In order to guarantee a minimum consistency of model outputs, a set of basic requirements was adopted by impact modelers during the fast track phase. All RCP concentration scenarios are to be run using data from one GCM. Four additional GCMs are only considered together with those RCPs producing the highest and lowest end-of-century forcing (RCP8.5 and RCP2.6 respectively). If applicable, only the middle-of-the-road socio-economic scenario (SSP2) is used in the minimal setting. Highly relevant sensitivities (e.g. to CO_2 fertilization) are also considered. Bias corrected climate data from the GCMs participating in CMIP5 are provided. Data cover the time period from 1950 to 2099. During ISIMIP-2 the suite of impact models will be extended as well as impact model results driven by RCMs added.

5.2 Climate change and impact indicators

The full output dataset of the ISIMIP fast track is available via an ESGS node[10]. Due to the large numer of impact models and sectors assessed, the outputs of ISIMIP that could be considered to be climate impact indicators are substantial. Figure 6 illustrates the diversity of impacts indicators (understood in this case as model output variables) provided by the ISIMIP initiative as classified according the CLIPC Tier framework. Output variables related to impact modeling in the water sector dominate the “indicator set”. These were found to be mostly dominated by Tier-2 indicators such as run off, soil moisture, irrigation demand, and land-use patterns. Tier-1 indicators include snowfall, rainfall, snow water equivalent and evapotranspiration. The biomes sector accounts only for Tier-2 indicators or model output variables (e.g., NPP, vegetation type or leaf area index). Output variables for the agricultural sector were divided into those emanating from biophysical modeling (Tier-2) and those resulting from agro-economic modeling (Tier-2 and 3). Regarding the latest, more than half

8 http://www.agmip.org/
9 http://www.eu-watch.org/
10 esg.pik-potsdam.de

were identified to be Tier-3 indicators, for example, average producer prices, total calorie consumption, water and land prices.

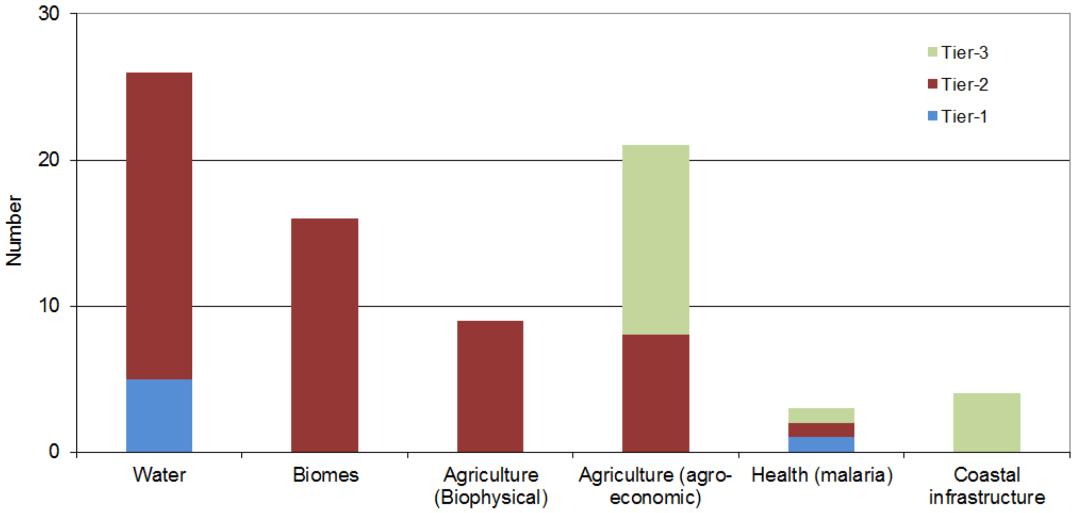

Figure 6 - Number of Tier-1, -2 and -3 indicators for sector specific output variables

The two least represented sectors in terms of number of output variables are the sectors of health (in ISIMIP fast track restricted to the malaria issue) and coastal infrastructure. For the latter, within the ISIMIP, only one model was used the output of which could be regarded as Tier-3 indicators: expected number of people flooded annually, expected sea-flood costs, adaptation costs of building, upgrading and maintaining dikes.

6. IMPACT 2C: Quantifying projected impacts under 2°C warming

6.1 Objective, data, coverage and scenarios

The ongoing project IMPACT2C provides information and evidence on the impacts of 2 °C global warming for Europe and other key vulnerable global regions. The project aims to consider the impacts from a cross-sectoral perspective, e.g. for particularly vulnerable areas that are subject to multiple impacts where cumulative effects may arise and in relation to cross-cutting themes. The work flows from climate information, its uncertainty processing, via the evaluation of impacts, vulnerabilities and risks, to cross-sectoral assessments and synthesis highlighting risks, trade-offs, synergies and costs at a pan-European level.

A global warming of 2 °C relative to pre-industrial climate has been proposed as a threshold which society should endeavor to remain below, in order to limit the dangerous effects of anthropogenic climate change. The IMPACT2C project started comparing the new RCP (Representative Concentration Pathways) model runs to the A1B scenario, looking at the possible changes in regional climate under this target level of global warming.

6.2 Climate change and impact indicators

The possible changes have been investigated by analyzing Tier-1 climate change impact indicators for Europe, i.e. robust changes in mean and extreme temperature, precipitation, winds and surface energy budgets. The project results (Vautard et al 2014) indicate a large likelihood that most of Europe will experience a greater increase in heat extremes in Southern Europe, a robust increase in heavy precipitation and an increase in extreme winds in winter in Central Europe. The findings of the analysis of Tier-1 climate change indicators revealed also strong distributional patterns across Europe, which will be important in the subsequent impact assessments. As a second step, the project will use a range of models to assess the 2°C global warming effects on water, energy, infrastructure, coasts, tourism, forestry, agriculture, ecosystems services, and health and air quality-climate interactions. These finding will be dominated by Tier-2 and Tier-3 indicators.

7. PESETA I and II: Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis

7.1 Objective, data, coverage and scenarios

The objective of the JRC PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) is to make a consistent multi-sectoral assessment of the impacts of climate change in Europe for the 2071-2100 time horizon. The project methodology has two distinctive features. Firstly, it is based on bottom-up biophysical impact models results. Bottom-up models take into account the relationship between climate change and biophysical impacts in a structural way, modelling all the relevant interactions and mechanisms. Secondly, the assessment is made in a consistent way, where all biophysical impact models use the same climate data.

For the JRC PESETA II study climate simulation runs were obtained from the ENSEMBLES project (see above). Runs were driven by the SRES A1B emission scenario and the so called E1 emission scenario in Tol (2006). The E1 scenario was developed within ENSEMBLES as an attempt to match the European Union target of keeping global anthropogenic warming below 2 °C above pre-industrial levels. Climate change runs were available for two resolutions, 25 and 50 km. A total of 7 Regional Climate Models (RCM's) and 6 GCM's (Global Circulation Models) are used to obtain climate change runs. As for the resolution of biophysical and economic impacts, these are largely variable. In case of agriculture (using the JURC owned BioMA model) results are available for a 25km grid cell, for the case of impacts on tourism the output resolution is the NUTS2 level. Economic impacts of climate change are only available for a highly aggregated level such as major European regions (e.g., Northen Europe or Central Europe).

7.2 Climate change and impact indicators

The PESETA I and II projects have determined climate change and impact indicators across all the Tiers considered in CLIPC. Most of the Tier-1 indicators have been calculated on a daily basis, although some are also available on monthly (in regard to Forest species habitat suitability) and year (in particular in case of forest fire analysis). The indicators are basically several variations of temperature, precipitation, humidity and wind variables. Of particular interest for CLIPC are results from the PESSETA project regarding the biophysical impacts (Tier-2) resulting from the projected changes in climate. These are summarized in Table 3 and serve as inputs to the determination of economic impacts (Tier-3) using the GEM-E3 model.

Table 3 - Biophysical output used to run the GEM-E3 model by sector/theme investigated

Sector/theme	Biophysical model output
Agriculture	Yield change
Energy	Heating and cooling demands
River floods	Residential building damages Production activity losses
Forest fires	Burnt area Reconstruction costs
Transport infrastructure	Changes in cost of road asphalt binder application and bridge scouring Net change in costs related to extreme flooding and winter conditions
Coastal areas	Migration costs Sea-flood costs
Tourism	Tourism expenditure
Human health	Hours lost due to morbidity and mortality Additional health expenditures Warmer temperature Mortality

In a CLIPC context, the outputs of biophysical models are linked to the Tier-2 indicators. The consistency of climate models and scenarios used allows for inter-indicator comparability. The economic estimates of climate impacts (Tier-3) produced by PESETA are in principle very valuable since it is rather uncommon to find such a comprehensive and extensive sectoral coverage in economic impact assessments of climate change. The main disadvantage of the PESETA results in the context of CLIPC is the highly aggregated spatial nature of Tier-3 indicators.

8. Differences between indicators

8.1 Differences across tiers of impact indicators

As noted in the introduction, there is no fully unambiguous definition of what a climate change impact indicator is. A dictionary definition that an indicator is "a sign that shows the condition or existence of something" or "a pointer or light that shows the state or condition of something" is generally fulfilled by all the variables and metrics that have been explored in the previous sections. An Essential Climate Variable (ECV) has been specified as a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of the Earth's climate (Bojinski et al, 2014). The EEA specifically includes the narrative that provides the wider context for the "something" in the indicator definition (EEA 2012a) whereas for example EMSEMBLES and ISIMIP primarily provide scientific data and outputs of models that can be used in exploring climate change impacts by others in a non-scientific context, e.g., policy context. For ESPON Climate, an impact indicator is the combination of an exposure (mostly climatic) and a sensitivity indicator (mostly of socio-economic character).

The review in Sections 1-7 has given an overview of the current state and availability of climate change and impact indicators. Indicators at Tier-1 are abundant and there are several parallel data sets that are good indicators of climate change as a phenomenon. The ECV's have been selected by virtue of their reliability and systematic quality controlled monitoring. From an impact perspective, one of their main roles is that they provide indication on the pressures that climate change exerts on natural and human systems.

Tier-2 indicators have been developed in numerous research projects that have aimed at linking observed changes in the climate with changes in biophysical systems. The review has shown that there is less fully standardized data that can be used to derive indicators that provide standardized information across wide geographical scales although there are numerous studies of particular regions and cases that link observed or projected changes in the climate to corresponding changes in the biophysical environment. One of the challenges lies in the geographical and temporal differences in the links between climate and the biophysical systems. Some systems may be sensitive to, for example, winter extremes whereas the duration of particular conditions may be more important for other regions.

There is a definitive lack of Tier-3 indicators. This is not primarily due to a lack of data on human systems in general. Statistics of societal changes are abundantly available, but the difficulties lie in identifying and verifying causal relationships between climate and societal changes. The data on human systems is systemic in the sense that it reflects changes in numerous different driving forces, only some of which are related to climate change. Even when there appears to be a fairly direct link between a particular set of observations and climatic conditions there are a number of confounding factors that may question the validity of the indicator as a sign of the impacts of climate change. For example monetary damage caused by floods and storms are clearly linked to extreme weather events. The monetary damage, as measured by the level of compensation paid by insurance companies, does not, however, reflect only impacts of climate change, but also the value of assets in affected areas, which may increase independently of climate change (Barredo 2010, Visser et al. 2012, Smith and Katz 2013). Therefore it appears that Tier-3 indicators are often more useful when they are framed in terms of vulnerability or adaptive capacity rather than in terms of actual impacts, which require detailed site specific analyses to deal with the question of attribution.

Table 4 - Understanding of climate change and impact indicators in the context of the evaluated studies.

Study	Indicators of climate change:	climate impact:
EEA 2012a	Climate variables aggregated either in time or according to a given threshold	Combination of an exposure indicator (mostly a climate variable) and a sensitivity indicator (mostly a socio-economic variable).
ESPON 2011	Exposure indicator (mostly climate variables)	Combination of an exposure indicator (mostly a climate variable) and a sensitivity indicator (mostly a socio-economic variable).

ETC/ACC 2012-2012		Combination of an exposure and sensitivity indicators.
ENSEMBLES 2009	Climate variables aggregated either in time or according to a given threshold	Output of biophysical modeling.
ISIMIP		Output of a biophysical or coupled biophysical and economic model.
IMPACT2C		Output of a biophysical or coupled biophysical and economic model.
PESETA I and II		Output of a biophysical or coupled biophysical and economic model.

8.2 Challenges of defining Tier-3 indicators and suggestions to improve the societal relevance of Tier-1 and Tier-2 indicators

The efforts in CLIPC to identify indicators revealed that there were fewer Tier-3 indicators than Tier-2 and Tier-1 indicators. A similar distribution of indicators classified into Tiers 1, 2 and 3 was also seen in the review of existing indicator studies by the EEA and ISI-MIP (see sections 2 and 5). Yet it can be expected that Tier-3 indicators are the most appealing for those potential CLIPC portal users who are engaged in developing concrete policies and measures for adaptation (and mitigation). This is a challenge for the development of the portal, although we cannot set aside that the expertise of the participating institutions in CLIPC is mainly focused on Tier-1 and 2 indicators and thus the search for Tier-3 indicators may have been partially incomplete.

One reason for the smaller number of indicators that describe socio-economic impacts of climate change is that these often require an analysis "further down the chain" combining information on purely bio-physical conditions with those describing the society and their effects on human activities. These entail more sources of uncertainty and tend to be restricted to smaller regions, although some Europe-wide analyses for example on estimating the costs of climate change impacts in selected sectors has been conducted (ClimateCost project – Watkiss 2011). Possible Tier-3 indicators that attempt to project conditions to the future ideally require detailed scenarios of specific socio-economic variables.

An example that illustrates some of these challenges can be taken from the projections of flood risks and their effects on society (see Flörke et al. 2011 for a Europe-wide analysis). Models have been developed that simulate the risk of floods in a specific area for present-day and future climatic conditions (which could be based on a Tier-2 indicator). Future flood projections are dependent on assumptions about adaptation in the water management. Combining projections of flood areas with information on infrastructure, housing and population would allow defining a Tier-3 indicator; however, spatially detailed data on the latter is required to allow a spatial matching with projected flood zones. Projections of future floods would ideally be matched with scenarios of infrastructure, housing and population, again on a spatial scale that allows the matching with projected flood zones.

To overcome the possible underrepresentation of Tier-3 indicators in CLIPC, two approaches can be considered to increase the societal relevance of Tier-1 and Tier-2 indicators, without directly defining new indicators that would fall in the Tier-3 category:

- The societal relevance of indicators (including Tier-1 and 2) can be described in a text section accompanying the indicator data, maps and graphs. This has been done for the EEA's impact indicators (see section 1 – EEA 2012a), in which the text description for each indicator starts with a few paragraphs that outline the background and explains in general terms in which way an indicator is important. For example, for the Tier-1 indicator of snow cover, one can mention its relevance for transport and tourism/recreation.

- Spatially explicit Tier-1 and Tier-2 indicators can be overlaid with information about socio-economic conditions to identify regions where a high exposure to a bio-physical impact coincides with e.g. low regional financial resources or a large proportion of elderly. This has been done in indicator-based vulnerability assessments Europe-wide (e.g. ESPON-Climate, Greving et al. 2011 – see section 2 above) and for European regions (e.g. for selected sectors in the Nordic region Carter et al. 2014). Developing a web-based mapping tool that would allow users themselves to do this overlaying is one of the directions that CLIPC WP8 could take. An example of such a web-based mapping tool has been presented by Carter et al. (2014)[11].

One of the main challenges in linking Tier-1 and Tier-2 indicators to socio-economic data is attribution of changes to climate change. As long as the linking is exploratory and user driven, it can be seen as a search for possible connections between climate change and socio-economic conditions. If one wishes to formalize a possible relationship and call it a Tier-3 indicator that expresses socio-economic consequences of climate change, the demands on rigorous evidence for the relationship increases considerably. The uncertainties need to be recognized and properly dealt with and this may not yet be possible. There is also a need to identify ownership and interest in regular updating of the indicator and the underlying data, meaning that any European socio-economic indicator should most likely rely on information that is produced by, for example, Eurostat.

8.3 Impact indicators and decision making

One of the justifications for developing indicators is that they should support decision making. The EEA (2012a), the ESPON Climate (ESPON 2011) and the Urban vulnerability study (ETC/ACC 2012-2012) make this link explicit whereas research based projects such as ENSEMBLES, ISIMIP or IMPACT2C implicitly assume that the indicators that they produce or that can be derived from their output also serve decision making. The relationship between the decision making and indicators varies among the tiers (Table 5). Tier-1 indicators have been designed to provide information that is relevant for operational decisions or to give

[11] See http://www.iav-mapping.net/U-C-IAV

general background information for policy development. Tier-3 indicators can help focusing risk management strategies justifying policy initiatives, but are less useful for specific decisions. For example, indicators of overall average economic losses associated with climate change can support the planning and implementation of adaptation policies, but do not provide particularly useful guidance for specifying specific subsidies that increase adaptive capacity. Tier-2 indicators can justify action, but can also partially guide specific decisions. For example, the indicators of flood risk can be used to prioritize investment opportunities within river basins.

The context determines the demand for indicators, but also how an indicator should be interpreted and displayed. Thus there is a demand for very specific and spatially disaggregated Tier-1 indicators to support concrete decisions. General Tier-3 indicators are in greatest demand at a national or European aggregate level, where they can guide policy development. Tier-2 indicators are demanded both at a detailed level to guide design and at a general level to justify policies..

Table 5 - The use of information from different Tiers in decision making

Type of decision making	**Use of indicator**		
	Tier-1	**Tier-2**	**Tier-3**
Implementation of specific measures	Use to determine standards or thresholds, for example resilience of buildings or other infrastructure to extreme weather events, sea level rise etc.	Focus, design and prioritization of measures	General contextual understanding and justification, little direct use at the level of individual measures
Implementation of programmes	Design and focus of programmes	Design, focus and evaluation of programmes	Design, focus and evaluation of programmes
General policy development	General contextual understanding and justification for climate policies	General contextual understanding and sector specific justification for focus and design of policies including targets or threshold values as well as policy evaluation	Justification for focus and design of policies, possibly targets or threshold values for policies and their evaluation

III. Criteria for examining climate impact indicators

9. Description of indicator criteria

9.1 General development of criteria

Indicators have been developed in many fields and a number of criteria have been presented to determine the usefulness of indicators. These include the “SMART” (Doran, 1981) criteria list where an indicator should satisfy the following criteria:

- Specific,
- Measurable (and also reliable, comparable and contextually appropriate),
- Achievable (i.e. cost effective),
- Relevant
- Time-bounded and sensitive.

More elaborate checklists have also been introduced (MacDonald, 2013). These include criteria such as (i) Clarity of Focus and Meaning, i.e. the degree to which a single indicator is unambiguous and reflects or represents what is to be examined accurately or (ii) Opportunity to Detect Unexpected or Unintended Findings, i.e. the degree to which an indicator (or set of indicators) allows for documentation of unexpected or unintended consequences.

Niemeijer and de Groot (2008) proposed a conceptual framework to select environmental indicators. They reviewed previous criteria commonly used to identify environmental indicators and found the criteria used in four or more cases to be: Analytically soundness (strong scientific and conceptual basis); availability of historical record (existing historical record of comparative data); time-bound (sensitive to changes within policy time frames); measurability (measurable in qualitative or quantitative terms); resource demand (achievable in terms of the available resources) and relevance (relevance for the issue and target audience at hand).

Donnelly and colleagues (2007) focused on the development of environmental indicators and other methods for the provision of information as required under the EU Strategic Environmental Assessment (SEA). The list of criteria for indicator selection was found to be rather similar to the cases described above, comprising criteria such as: policy relevance, covering a range of environmental receptors, relevance to the plan, showing trends, understandable, well founded in scientific terms, enables to prioritize key issues, adaptable and able to identify conflicts.

For earth observation data, the principle “Data and derived products shall have associated with them an indicator of quality to enable users to assess their suitability for particular applications, i.e., their “fitness for purpose” is a key requirement that leads to many of the criteria listed. Concerning some specific data sets, the Quality Assurance Framework for Earth Observation developed for the GEOSS Global Earth Observation System of Systems provides a basic set of criteria that all published earth observation data should fulfill. There have also been made operational for climate related data.

The CLIPC Toolbox is intended to allow users to rank and aggregate climate change and impact indicators (WP8). In addition, particular user groups will have particular needs (WP2) which the toolbox will have to recognize and take into account. The different requirements imply the adoption of a common framework within the CLIPC consortium to scan, examine and evaluate indicators in a consistent way. Such framework should 1) ensure the appropriate documentation of the scientific and methodological details required to reproduce, rank and aggregate indicators, and 2) help to identify which climate change or impact indicator is better suited to which type of user group or purpose.

CLIPC will not only develop such a framework but also test it in practice with its internal suppliers and external users of data/indicators. The framework can also be considered to form an important step in organizing the meta-data for indicators for the toolbox. Such information will not only help to improve the transparency of the indicator provided by CLIPC, but also help users to select which indicator they think might fit their purpose. User needs and the tailoring of indicators have so far not been made sufficiently explicit, although it is well known from studies of indicators of sustainable development that the use of indicators is significantly enhanced when users can contribute to the development and thereby increase the salience of the indicators (Rosenström 2009).

Previous work on criteria for the evaluation of climate change impact indicators includes: the Environment Protection Agency (EPA) report on Climate Change indicators in the USA, the EEA report on climate change, impacts and vulnerability (EEA 2012a) whose criteria are described in Hildén & Marx (2013), the Streamlining European Biodiversity Indicators also published by the EEA (2012b), and the Indicators of Climate Change in California (ICCC) 2013 report (see Table 6).

Table 6 - Collection of criteria used to evaluate climate indicators from existing reports.

EEA(2012a) and Hildén & Marx (2013)*	***SEBI and EEA (2012b)***	***ICCC (2013)***	**EPA (2012)**
Relevance for climate change Casual link to climate change Sensitivity towards change	Cause-effect relationship Information on cause-effect relationships should be achievable and quantifiable in order to link pressures, state and response indicators.	Data quality Data are collected using scientifically valid data methods and can support sound conclusions	Connection to climate change The relationship to climate change is easily explained.
Methodological validity (including uncertainty) Transparency Valid model base Uncertainty	Methodological well founded Clear Well defined Relatively simple Cause-effect relationships should be achievable and quantifiable	Representativeness Indicator reflects the issue it is intended to characterize.	Transparent, reproducible, and objective The data and analysis are scientifically objective and methods are transparent.
Data availability Availability and regular updating Spatial coverage/resolution Time series	Routinely collected data Routinely collected Verifiable Scientifically acceptable	Sensitivity Indicator Can distinguish meaningful differences in conditions.	Broad geographic cover The spatial scale is adequately supported with data that are representative of the

length/temporal resolution			region/area.
Broad acceptability Ineligibility Participatory development	Spatial coverage Indicators should ideally be pan-European and include adjacent marine areas	Decision-support Indicator provides useful information for decision-making.	Peer-reviewed data The data are credible, reliable, and have been published and peer-reviewed.
Policy relevance For EU policies Policy targets	Time series Indicators should show temporal trends		Uncertainty Information on sources of uncertainty is available.
*Criteria identified for observed and projected data	Country comparison As far as possible, it should be possible to make valid comparisons between countries		Trends over time Long term data are available to show trends over time.
	Timeliness Able to detect changes in systems in timeframes and on scales that are relevant to the decisions		Feasible to construct The indicator can be constructed or reproduced/allows for routine updates.
	Acceptance and intelligibility The power of an indicator depends on its broad acceptance.		Understandable to the public Depiction of observations and are understandable to the average reader.
	Policy relevance Relevance in terms of general concern Relevance in terms of specific decisions		Usefulness Informs issues of national importance and addresses issues important to human or natural systems.
	Biodiversity relevant Address key properties of biodiversity or related issues as pressures, state, impacts and responses.		Actual observations The data consist of actual measurements (observations) or derivations thereof.
	Progress towards target Indicators should show clear progress towards the 2010 target.		

The criteria used in the different frameworks presented in Table 6 are very similar, suggesting that it is possible to identify a set of basic criteria that climate change impact indicators should fulfill. For example, the criterion described as *policy relevance* is shared by the EEA and the SEBI frameworks and also in the ICCC (2013) under the term *decision support*. Issues of data quality and availability are also naturally part of all the frameworks. In an attempt to guarantee the quality of the indicators used EPA (2013) restricts the use of indicators to only those that have been through a peer-reviewed process. EEA (2012b) relaxes somehow this condition while imposing that indicators used have to be available for long time-series in order to capture temporal trends. Other types of criteria are rather unique to a particular framework, driven by the objectives and scope of the reports. For example, lists of criteria proposed by the Hildén & Marx (2013) highlight the need for climate indicators to be relevant for EU policies. The same can be observed in the EEA (2012b) and ICCC (2013) reports. Although this criterion appears to be important when selecting impact indicators, it is not expected to be easy to evaluate, unlike for example a quality criterion or the existence of long time-series of data.

Policy relevance can be determined by the extent to which an indicator serves the design and implementation of specific policies. All climate change indicators may be relevant for climate change policies at a general level (awareness, fostering public support for measures, see Table 5, section 8.3), but some indicators can also be used in guiding the implementation or judging the effectiveness of specific policies. For example, a Tier-2 indicator defined as the number or proportion of buildings subject to severe flood risk can be used to guide land use policies and to evaluate the success of such policies.

One way to ensure that indicators fulfill the *Policy relevance* criterion would be to make the selection of indicators a participatory process, where relevant audiences and users of indicators are invited to participate. It is worth mentioning the bias of the investigating frameworks towards the identification of indicators focused either on broad audiences (EPA 2012) or decisions makers and general public (EEA 2012b). For some data such as earth observations there have been efforts to develop criteria that seek to ensure the validity and 'fitness-for-purpose' of different sensors' products for climate change (Bates and Privette, 2012). The suggested approach focuses in particular on a 'maturity matrix' that offers a systematic means of assessing a Climate Data Record's (CDR's) 'usability' for long term monitoring of the climate and it stresses technical data quality, but also access and software readiness.

The indicators that the CLIPC project deals with are expected to attract attention both from the policy and science community - either via the exploration of the indicators themselves or via an interest in the underlying data. In such a case, the needs of scientific audiences should also be a matter of some reflection when searching for adequate criteria to evaluate indicators. For example, a researcher might be interested in finding how a particular indicator of impact performs against the observed impact it tries to capture, or if the indicator proposed has gone through some process of validation. Other science-oriented users might be more interested in discovering details about the methodology behind the calculation of the indicators. Detailed input on user requirements emerge from WP2 and will complement/sharpen the establishment of evaluation criteria.

We cluster the criteria in Table 6 in two broad groups. The first is *scientific adequacy and feasibility,* and it refers to the methodological details as well as data availability (marked orange). The second group we call *relevance, usability and scope of use* (marked in blue), and deals with the informative power of the indicator, its data availability, accessibility and the easiness to inform on particular uses. The first set of criteria can be understood to primarily examine the scientific base, while the second emphasizes different aspects of use. The separation of criteria into these broad dimensions is useful as it highlights that indicators should be evaluated from several perspectives that demand different approaches. For example, while judgments on the scientific criteria of an indicator can be made by checking to what extent the underlying methodology corresponds to accepted practice, the usefulness or the policy relevance an the indicator can only be judged using some measure of the user demand.

9.2 Scientific adequacy and feasibility

Criteria under *scientific adequacy and feasibility* are used to evaluate issues such as the methodological transparency and scientific soundness of the approach (see Table 7). The most straightforward way to ensure that these demands are satisfied is to use only methods and data that have gone through peer review processes (see EPA 2012). The drawback of such a strict criterion is the reduction of potential indicators. There are also border line cases, for example not all statistical data collections have necessarily gone through peer review. The criterion *methodological transparency* is used to evaluate the method underlying a particular climate change or impact indicator. One of the key issues is the scientific documentation of the relationship, i.e. is the relation between the indicator and the impact aims to portray scientifically established and documented.

Table 7 – Description of the scientific adequacy and feasibility criteria for climate change and impact indicators.

Criterion	Specification
Methodological Description MD	**This criterion is used to assess the methodology to produce a climate change and impact indicator. A publication or report in which the methodology is described should be available. Optimally the required methodology should be present in peer review publications and be public available. This nevertheless is not always the case, and therefore some flexibility is required.**
Conceptual framework of the indicator SC	**Climate change and impact indicators are expected to differ considerably in terms of their complexity. Some will be obtained via relatively simple mathematical operations; others will be a product of complex process modeling. It is useful to document the complexity according to five pre-established categories:** **1 - Transformation of a single climate variable** **2 - Metric combining several climate variables** **3 - Metric aggregating climate and non-climate data** **4 - Metric derived from bio-physical data other than climate** **5 - Output of biophysical or economic model** **Other - free text** **The simplicity/complexity information provides background (meta)information, but cannot as such be used to judge the merit or worth of an indicator. Generally simplicity is to be preferred, but some of the relevant processes may be so complex that a too simple indicator would provide spurious information.**
Scientifically documented relationship SDR	**Usually and indicator of impact or change is a proxy measure that provides information on a more complex phenomena. For example, global mean temperature is used as a widely accepted metric to assess the state of the climate system. This criterion is used to judge the strength of the assumed relationship between the indicator and the impact according to 4 pre-established categories. Scientific soundness (SDR1) can be categorized into** **1 - A solid, agreed theoretic framework linking indicator and a statistical correlation between indicator and impact has been established.** **2 - A solid, agreed theoretic framework linking indicator and impact is agreed, but the statistic relationship is poor.** **3 - A statistical correlation between indicator and impact has been established but an agreed scientific explanation is yet missing.** **4 - Circumstantial evidence about the relationship is known and accepted within the scientific community.** **Other – free text**
Treatment of uncertainty (data and method of the indicator). TU	**Since the evolution of the climate systems is uncertain, it is relevant to assess the extent to which an indicator is able to deal with uncertainty. There is uncertainty in both the input data and the methods. This criterion is used to evaluate the ability of the indicator to deal with uncertainty. We note that "uncertainty" is used in a broad manner, including statistical data**

	and modeling uncertainties. The evaluation of the criterion is therefore based on qualitative considerations. In general indicators that are able to recognize and deal with uncertainty are preferred to those that neglect uncertainty altogether.

The matrix intends also to clarify the potential sources of uncertainty of a given indicator. The uncertainty issue is transversal to the datasets used to calculate and indicator as well as the method employed. Other archetypical questions to be answered during the evaluation of the scientific adequacy and feasibility are, how complex are the indicators (e.g, are indicators derived from one simple formula applied to a standard climate variable, are they products of a combination of different climate variables and social-economic data, are they a result of an impact modeling exercise), can the indicator be directly applied to different geographic regions and still keep its informative power.

9.3 Usability, relevance and scope of use

The second group of criteria is related to the usability, relevance and scope of use of an indicator. The criteria in Table 8 summarize the aspects to be investigated. The evaluation of the usability, relevance and scope will depend on the intended audience. For example, indicators that are good for raising public awareness may not be the same as indicators that assist implementation of adaptation action.

An evaluation based on criteria such as data availability or updating frequency, provides information on the ease of producing the indicator. The criteria also allow judgments to be made on what the indicator illustrates and how intelligible it is, i.e. to what extent it is intuitively understandable without auxiliary descriptions.

Table 8 - Description of the usability, relevance and scope of use criteria for climate change and impact indicators.

Criterion	Specification
Input data , source, availability and type ISAT	The criterion is based on details of the underlying data that is used to derive a climate change or impact indicator, the data sources required, the availability of the data and the type of data. Of particular interest is the availability status of the data. The following options have been identified: PD - Public domain CO - Within consortium PU - Through purchasing RE – Restrictions The CLIPC will have strong preference for indicators that are based on data in the public domain. For development and testing purposes consortium owned data can be valuable. Another important aspect is the type of data that the indicator is based on. The following options have been identified: OBC - Observed in-situ bio-physical data OBE - Observed in-situ socio-economic data MOP - Model projection MOR - Model reanalysis SAT - Satellite data Other – Free text. The type of data mainly serves to classify the indicator, there is no particular preference for the type of data, although ideally indicators based on different types of data can be used to develop broader indicator based descriptions of topics, for example by combining observations and model

	projections on the same topic.
Updating frequency, time frame, resolution, ensemble details and spatial extent of underlying data UTRS	These criteria are used to examine the updating frequency of the underlying data required for deriving and indicator, the time frame for which the data is available, its temporal and spatial resolution and spatial extent. The spatial extent of the data-set are classified into categories G - Global E - Europe SE - Sub-European Other - free text In general there is a preference for indicators that build on long data series with frequent updating, good spatial resolution and wide geographical coverage. Such ideal indicators are very rare, and the criteria can be used to determine acceptable trade-offs. Ensembles: 1 - Multi-model-ensembles (one scenario and multiple models) 2 - Multi-scenario-ensembles (one model and multiple scenarios) 3 - Multi-parameterization-ensembles (one model and multiple parametrizations) 4 - Multi-member-ensembles (one model and one scenario and multiple realizations) 5- Others
Fitness for purpose of time-series length of underlying data FPID	This criterion is used to judge how well the available times series fits the purpose of the indicators. For example, a time series that only captures climatic variability over a decade is insufficient for indicating climate trends. The following categories have been identified: 1 – Data allows to discern inter-annual variability only of climate or impact 2 – Data adequate to discern decadal variability of climate or impact 3 – Data allows for statements on the long-term evolution of climate or impact 4 – Data provides only a snapshot for a particular point in time or between particular time slices Other – free text
Indicator availability and storage IAS	In addition to the input data used for deriving the indicator, one can judge the databases in which the climate change or impact indicator is already available with respect to availability, updating frequency, time frame, resolution and spatial extent of the indicator. Some pre-calculated indicators may be based on aggregation of original data to a particular administrative or other geographic region.
Fitness for purpose of time-series length of indicator FPI	Similar to the criterion FPID, it is relevant to examine the fitness for purpose of already calculate indicators as available in databases. The categories for the criterion follow those of the FPID criterion.
Scope of use SU	An indicator, being a climate change or impact, can serve several purposes and users. The scope of use of the indicator is thereby important to consider. This criterion thus mainly serves the classifying of indicators so that their merits can be considered in their appropriate contexts. The sub-criteria recognize four basic uses and four groups of users. Uses: 1 - Research 2 - Planning 3 - Policy development 4 - Awareness raising 5 - Others, which Users: CS - Climate scientists IR - Impact researchers IO - Intermediate organizations SU - Societal end users In general indicators that are widely applicable and that correspond to the needs of many types of users are preferable to those serving a very narrow use and limited user groups. However, there may be special operational indicators serving for example concrete flood management that are highly important despite their very focused and restricted use.

Focus on adaptive/coping capacity dimensions CF	**This criterion is used to assess to what extent the methodology used to derive the indicator includes factors that are relevant for adaptive or coping capacity. Key words indicating this in the methodological description of the indicator are: coping, adaptive, adaptation, capacity, and any mention of technological or physical 'defenses' that mediate or prevent the occurrence of e.g. extreme events like flooding.** **The criterion can be used to group indicators rather than make a judgment of their merit although there is a great demand for indicators that are able to support conclusion about the evolution of adaptive/coping capacity. Judgments on the fulfillment of the criterion are based on qualitative considerations.** **Inclusion of adaptive capacity:** **Yes** **No** **Not sure** **Conceptual framework of the indicator:** **1 - Methodology basically follows hazard/risk approach. (hazard+vulnerability = risk)** **2 - Methodology basically follows IPCC climate change approach. (exposure+sensitivity = impact)** **3 - Not clear which basic approach is underlying the methodology.** **4 - Methodology follows another basic approach. (name it below in "Other")** **5 - The previous options are not applicable to the indicator.**

A workshop hosted at the European Environmental Agency (EEA) between the 13^{th} and 14^{th} May served to refine, and agree on, preliminary lists of criteria. The form to document climate change and impact indicators can be accessed online[12]. All of the WP7 contributing partners were present together with relevant EEA representatives and external guests. The elaboration of the workshop constituted milestone 29 of the CLIPC project. The complete report of the conducted workshop can be found in section 144 of the Annex.

[12] https://docs.google.com/forms/d/1SSWYuMdYPK1WdY9uOANDZPqUJjwJYrcCKPN9qajt1KE/viewform

IV. Strengths and weaknesses of documented indicators

A key objective of this deliverable is to evaluate strengths and weaknesses of the documented indicators. This is of course partly a subjective endeavor in the sense that a judgment of a particular strength of an impact indicator generally refers to criteria, only some of which can be measured fully objectively.

10. Indicator database

The efforts of CLIPC returned a total of 81 climate change and impacts indicators consistently documented according to the criteria in section 9. Figure 7 shows the number of indicators documented according the Tier classification of CLIPC. The bulk of the indicators documented have been documented as Tier-1, that is, those informing mostly on changes of the climatic system. Next on the list are Tier-2 indicators, although already in substantially lower numbers. Tier-3 indicators constitute the least documented types of indicators in CLIPC. In general, the frequency of Tier-1 to 3 indicators resembles that of comparable efforts deriving impact metrics on societal and economic systems from indicators of change in the climate system. This reflects partly the availability of data sets in a form that allows calculation of indicators (easily accessible, standardized methods, long data series and wide spatial coverage). As noted in Section 8 there are also numerous socio-economic data bases that meet similar criteria. The main reason that they have not lead to a comparable number of climate change impact indicators is likely to be the difficulties in attributing changes in the data to climatic variables. Potential indicators thus often fail on the criterion "Scientifically documented relationship".

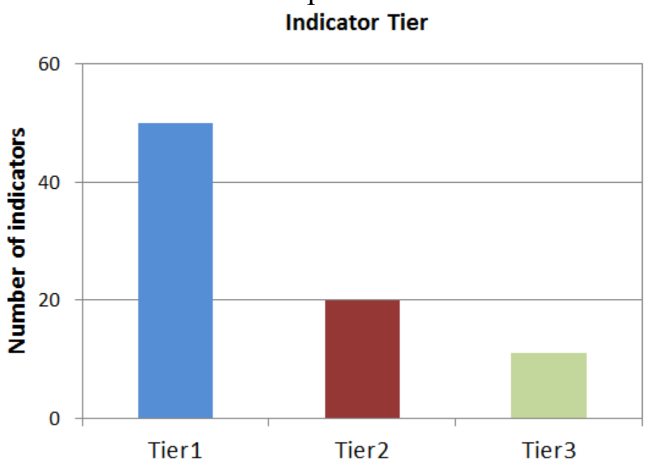

Figure 7 - Number of indicators documented according to CLIPC Tier classification.

In all investigated projects, Tier-3 indicators were most hard to find. As for the distribution of indicators across investigated themes, Figure 8 shows the number of indicators allocated to each CLIPC theme. Most of the documented indicators were identified for the water theme, followed by the urban and rural themes. About 43 indicators have been documented as exclusive for one theme (mostly Water). 19 indicators have been documented as touching two themes, the same amount of indicators that has been recorded as useful for all the three themes. This shows that cross-thematic indicators emerged from the documentation without the need for having a specific theme dedicated to that purpose. Tier-1 indicators have been documented as belonging to two or more themes but also as unique to a particular theme. In terms of indicators allocated specifically to one theme, the most numerous were found for the water theme followed by the rural theme.

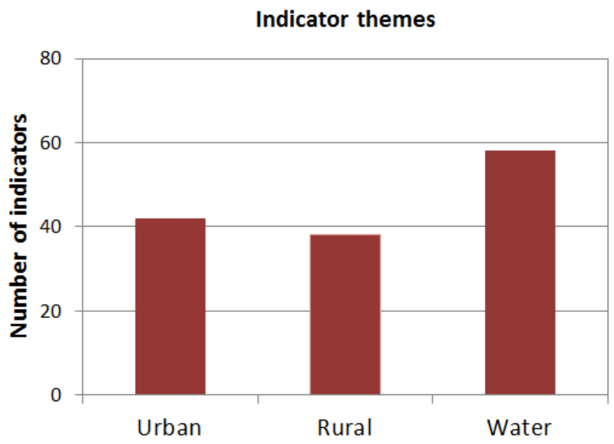

Figure 8 - Number of indicators documented according to CLIPC themes.

Figure 9 shows the following data categories: Model projections, Model reanalysis, Observed in-situ biophysical data, Satellite data and Observed in-situ socio economic data. Model projections dominate the data types, followed by observed in-situ biophysical data model reanalysis. Satellite observations, and to a greater extent, datasets from socio-economic in-situ observations, constitute a rather small fraction of data required for the indicators. The complete list of indicator documented can be found in Table 9.

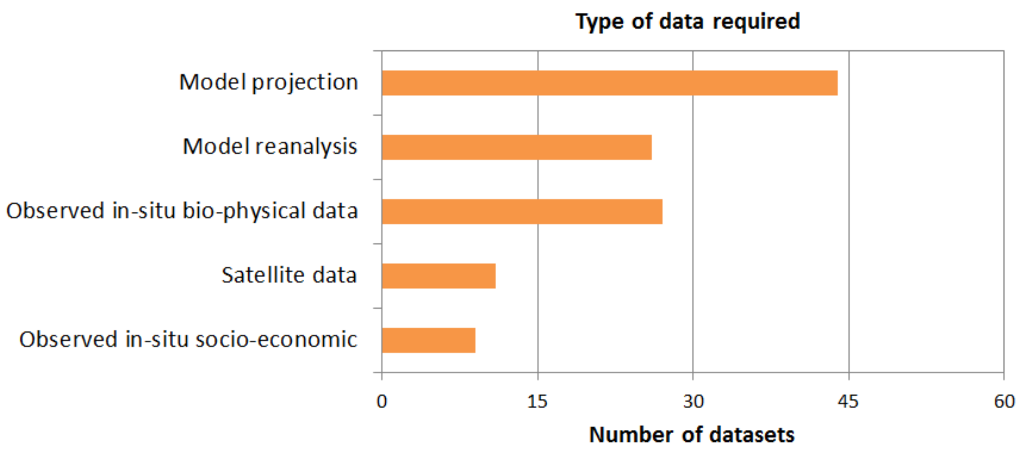

Figure 9 – Data types underlying the calculation of indicators.

11.Scientific and technical evaluation of indicators

The evaluation of indicators is done using the information gathered according to the two groups of criteria detailed in Section 9. The first is about basic strength and weaknesses related to the quality and characteristics of the indicator with particular reference to criteria of scientific adequacy and feasibility (Section 9.2) but also criteria such as availability and length of time series (Section 9.3). These can be considered to be scientific and technical strengths and weaknesses and the strengths should clearly outweigh the weaknesses for an indicator to be included in a portal. The second group of questions concerns strengths and weaknesses in terms of the applicability of the indicators for specific purposes that have been identified among user groups. The criteria that inform this assessment will depend on the specific uses being considered. These strengths and weaknesses can guide user to choose the indicators that best suit their purposes.

The key criteria for judging the fundamental strengths and weaknesses of indicator are the strength of the scientifically documented relationship between the indicator and what it is expected to indicate, the methodological transparency, the recognition of and ability to deal with uncertainty, the (public) availability of relevant data, the updating frequency, the length of the time series and the spatial resolution and coverage of the indicator. These scientific and technical aspects are to be covered in the metadata of each indicator to be included in the CLIP-C-portal.

11.1 Scientifically documented relationship

Arguably one of the most important criteria regarding impact indicators is the one of "Scientific documented relationship" (see also sections defining the indicator criteria to be documented). A *strong scientifically documented relationship* means that there is scientific evidence of a process that links the indicator to climate change as opposed to, for example, a weak correlation that upon closer examination may turn out to be spurious. In this particular respect most of the potential indicators examined by CLIPC are based on a solid agreed theoretic relationship between impact and indicator, and a statistical relation has been established (Figure 10). For some of indicators only circumstantial evidence about the relationship between indicator and impact is documented. There are also indicators for which a solid theoretical relationship between indicator and impact has been established, although there is yet only poor evidence of a statistical relation between indicator and impact.

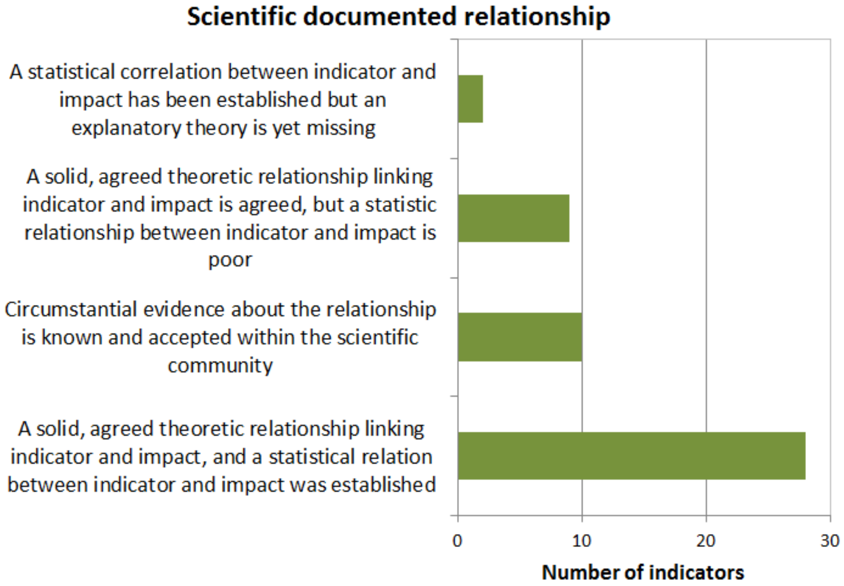

Figure 10 - Scientific documented relationship between impact indicator and impact.

Examples of indicators for which the relationship with impact is both theoretic and statistically established include: water-limited crop productivity, length of thermal growing season, moth Phenology Index, distribution of marine species. Indicators for which only circumstantial evidence with the impact is reported are: water scarcity, land elevation below projected sea-level or standardized snow pack index. Information on this criterion is as yet not available for all indicators. This can mean that either the chosen classes do not capture the full extent of the potential relationships between indicator and impact, or, more likely, that the understanding of impact and indicator is very different across the persons providing the information.

11.1Methodological transparency

A *sufficient methodological transparency* means that the way the indicator is being produced is traceable and published in such a way that all relevant aspects of the method can be scrutinized and reproduced independently. In the indicators examined it has been possible to trace the methodological base (see Figure 11) as well as relevant publications describing the calculation methods of an indicator. The methodological basis to derive climate change and impact indicators shows great variability. Most indicators (about 40% of the total number of indicators) are based on the use or transformation of a single climatic variable. The second most common methodological basis of indicators is that of combining several climatic variables. In some cases the combinations of particular climatic variables are called indices (see Introduction). For the purposes of the CLIPC project we maintain the wording indicator. Combining these two methodological bases would mean that about 60% of the documented indicators would only require climate data for their reproduction, which corresponds to the dominance of the Tier-1 indicators.

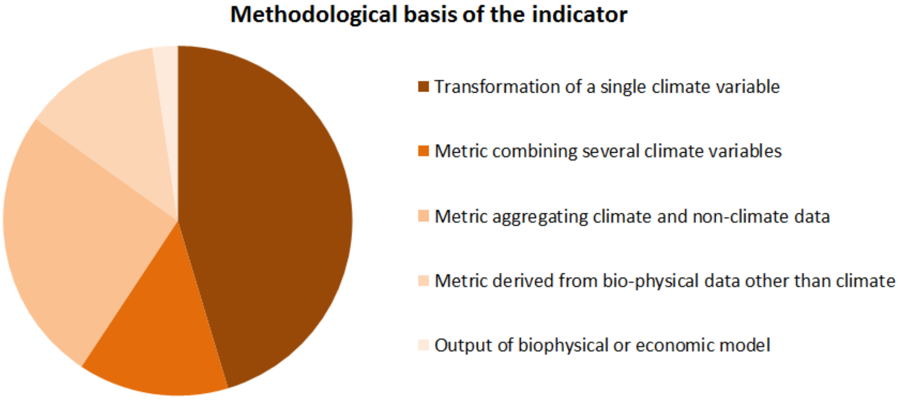

Figure 11 - Methodological basis of the documented indicators

Indicators with a methodological basis (Figure 11) that require the combination of climate and non-climate data constitute only about 24% of the indicators. Indicators derived from data other than climate, for example, moth phenology observations or water quality, represent about 12% of the cases. Few (2%) of the examined indicators are based on bio-physical or economic models The collected information also shows that there is a need to document this aspect in detail in metadata for indicators as the methodological base varies considerably and efforts to aggregate and or rank indicators must take into account the methodological and epistemological base of the indicators.

Table 9 - Catalog of potential impact and climate change indicators for CLIPC. The color coding reflects the indicator Tier. Blue for Tier-1; Green for Tier-2; Red for Tier-3.

Indicators	
Arctic and Baltic Sea ice extent	River flow change
Bathing water quality	100 years flood return level
Chlorophyll-a concentration	Water-limited crop yield
Cold days	River flood occurrence
Cold nights	River flow
Cold spell duration index	Water scarcity
Consecutive dry days	Water temperature
Consecutive wet days	Water-limited crop productivity
Diurnal temperature range	Intensity of urban heat island with city size
Frost days	Heating degree-days
Mass balance of glaciers	Rainfall Deciles
Sea level change	Reconnaissance Drought Index
Greenland ice sheet mass balance	Growing Degree Days
Grow season length of vegetation	Chilling Units
Hazardous substances in marine organisms	Climatic favorability of tree species
Heavy precipitation days	Distribution of marine species
Ice days	Freshwater biodiversity and water quality
Lake and river ice cover duration	Growing season for agriculture
Lake and river ice phenology	Land-cover extension below projected sea-level
Lake Ice extension	Moth Phenology Index
Max 1 day precipitation	Coastal flood damage and adaptation costs

Max 5 day precipitation	People affected by floods
Maximum of daily minimum temperature	Irrigation water requirement
Maximum of daily maximum temperature	Annual average damage from river floods
Mean precipitation	Average annual heat-related deaths per 100,000 habitats
Minimum of daily minimum temperature	Potential impact of river flooding on major roads
Minimum of daily maximum temperature	Potential impact of river flooding on railways
Number of wet days	Potential impact of river flooding on settlements
Nutrients in transitional, coastal and marine waters	Percentage change in arrivals/departures due to global warming
Ocean heat content	Annual olive-crop yield
Permafrost thickness	Natural disasters
Precipitation extremes	
Ocean acidification	
River flow drought	
Sea surface temperature	
Simple daily precipitation intensity	
Spring snow cover extension	
Snow cover extension	
Standardized SnowPack Index	
Snow Water Equivalent	
Storm surges	
Summer days	
The length of thermal growing season	
Total precipitation	
Tropical nights	
Very heavy precipitation days	
Very wet days	
Warm days	
Warm nights	
Warm spell duration index	

11.2 Recognition of and ability to deal with uncertainty

An *appropriate recognition of, and ability to deal with, uncertainty* means that there is a description of relevant uncertainties that may affect the interpretation of the indicator. The description of uncertainty was separated in those introduced by the method for calculating the indicator, and the uncertainty that is "inherited" by the databases used for indicator calculation. Regarding the first, it was observed that for 30 of the indicators documented the information is missing. For the remaining the descriptions provided help to frame the potential user on key uncertainties of the indicator method and data. A problem faced is that the description need now to be further homogenized in terms of language and aspects covered. Below we provide an example of a description discerning on the uncertainty of the indicator "Land elevation below projected sea-level (observations)".

There are largely two sources of uncertainty. The first is anchored in the detail of elevation model used. There are several products available and can vary considerably in their vertical accuracy. The most common global digital elevation model available (STRM90) and widely used can have considerable. For example about 7m in *regions of Thailand and 4m in coastal regions of USA, see Gorokhovich, Y., and A. Voustianiouk. "Accuracy assessment of the processed SRTM-based elevation data by CGIAR using field data from USA and Thailand and its relation to the terrain characteristics." Remote Sensing of Environment 104.4 (2006): 409-415.*

The second source of uncertainty is found on the rules used to obtain the flood extent. For example, it is arguable to assume that a land cell is flooded if its neighbor cell is also flooded. In order to account for this drawback, two types of connectivity are usually considered. A so called 4-side rule assumes that a land cell will be flooded if at least 4 of its neighboring cells are also flooded. A so called 8-side rule is similar to the one before but only assumed that a land cell will be flooded if all the neighboring cells are also flooded.

Harmonizing the heterogeneous descriptions of uncertainty across documented indicators will better inform potential CLIPC users and clearly an item that needs to be included in any metadata on indicators.

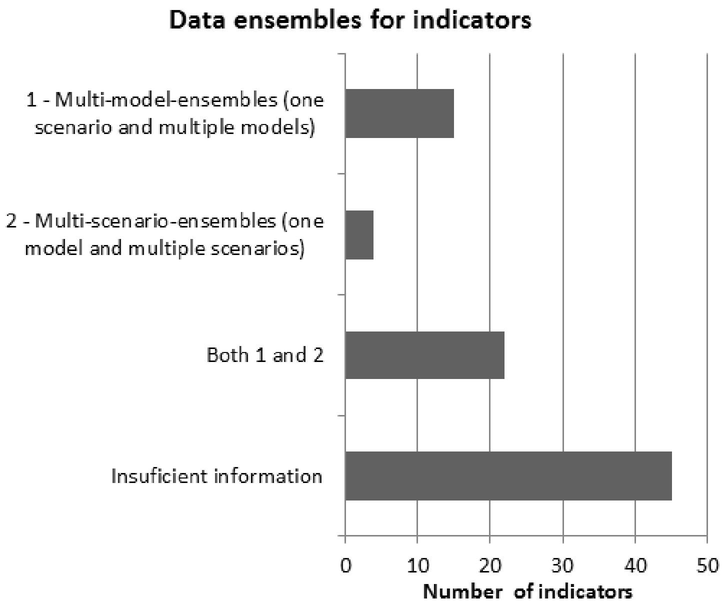

Figure 12 - Number of indicators for which ensemble input data is available

As for the issue of data uncertainty for indicator calculation (Figure 12), it was observed that for about 25% of the indicators data is available in the form of multi-model and multi-scenario ensembles ("Both 1 and 2" bar in Figure 12). For about 18 and 5% of the indicators, only multi-model and multi-scenario ensemble data is available respectively. There is a large bulk of indicators for which the information on the existence of ensemble data for their calculation is missing, which will need to be rectified in forthcoming updates of the indicator documentation.

11.3 Public availability of relevant data

The *public availability of relevant data* is closely linked with the methodological transparency. Indicators which use data that is publicly available are clearly superior to indicators that partly or fully depend on data that can only be accessed by a limited research team or obtained at great costs. For an operational portal open access to underlying data is important. The documentation of indicators allows us to understand to what extent data availability poses a serious constraint to the purposes of the CLIPC project. In Figure 13 it is shown the fractions of indicators whose data required for calculation can be found in the public domain, the fractions of indicators with at least one dataset required for publication not in the public domain, and the fraction of indicators with incomplete information on data availability. Approximately 70% of the indicators can be calculated with data that is publicly accessible, while 17% of the indicators would require the purchase/negotiation of at least one dataset for their calculation. As for the remaining indicators, information gathered until now does not allow for a statement on the status of data availability. Non-public data can be used in exploratory phases and indicator testing.

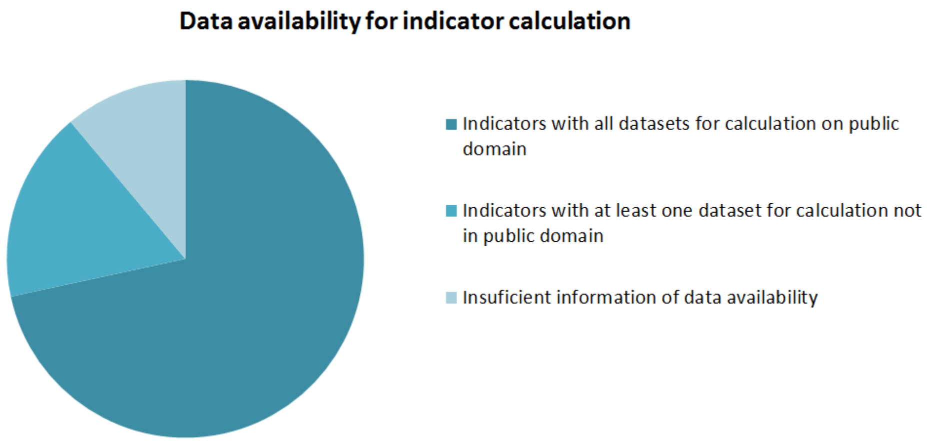

Figure 13 – Availability of data for indicator calculation in the public domain.

11.4 Updating frequency of relevant data, length of time series and spatial resolution

The *updating frequency* is relevant for ensuring that indicators are maintained and provide up to date information on the phenomena they indicate. A regular (yearly) update based on standardized monitoring is to be preferred over an indicator that is occasionally updated depending on, for example, availability of (irregular) funding for dedicated research projects. Of the examined indicators many suffer from less than regular updating. This is particularly the case when the indicators are developed and presented as the output of specific research projects and not maintained by organizations responsible for monitoring or statistical data.

The length of the time series is related to questions of attribution and uncertainty. A short time series is generally insufficient for making conclusive inference on the links between climate change and the indicator. A short time series can be accepted when the indicator is considered to be exploratory and a generator of hypotheses rather than an indicator supporting decision making. Of the examined indicators several Tier 1 indicators show time series that span many decades, even more than a century and projections are also commonly presented until 2100. Historical data for Tier 2 indicators are in many cases shorter and Tier 3 indicators even shorter. This suggests a need to develop, and in some cases reconstruct, data in order to be able to document long term changes in Tier 2 and 3 indicators as this affects possibilities to examine attribution to climate change.

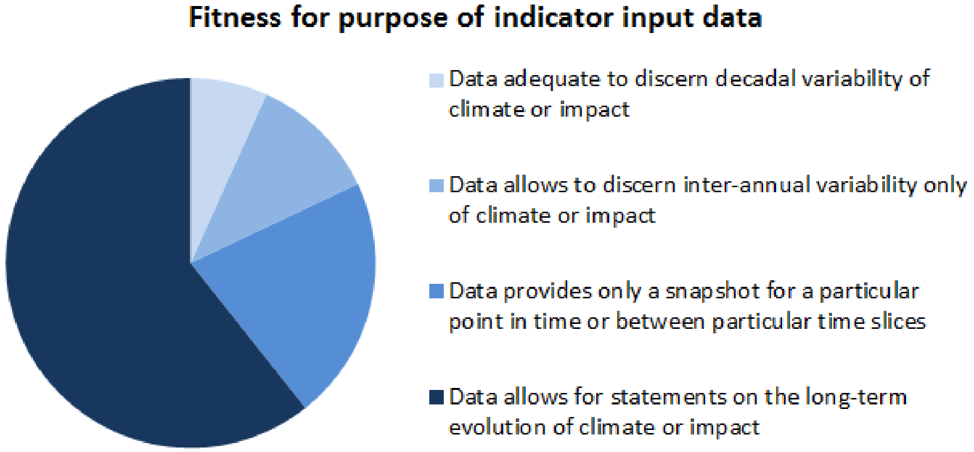

Figure 14 - Fitness for purpose of indicator input data

Figure 14gives an overview of the fitness for purpose of data time series required for indicator calculation. A large majority of the data is documented as being available in a length that is adequate to make statements on the long-term evolution of climate and climate impacts. It is nevertheless interesting to note that a considerable amount of input data for indicator calculation (about 20%) only allows for a snapshot of the impact between two particular time slices.

The *spatial resolution* and coverage of an indicator is also related to questions of attribution and uncertainty. In general a wide coverage is to be preferred as many potential users of the CLIPC portal are likely to look for indicators that are relevant or a European or at least regional scale. High spatial resolution is expected to be demanded by users who consider using the indicator for specific context dependent decisions or further detailed analyses of specific processes, whereas it is less important for those who look for broad overviews. The examined indicators display a wide range of variation with respect to spatial resolution, with some available at a fine scale (Table 10). Documented indicators presented a very heterogeneous picture in regard to the spatial resolution on which the underlying data is available. Of those indicators available in a grid format, average resolution ranges from 234 to 0.004km. Some indicators result from point measurements or are derived by making use of station data information and do therefore not have a well-defined spatial resolution. A very small set of indicators had a resolution that matched a particular administrative region.

Table 10 - Top 5 indicators with the lowest documented average resolution

Indicator	Average resolution[13]
Land elevation below projected sea-level (observations)	0.004km
Lake Ice Extent (observations)	0.08km
Intensity of urban heat island with city size (observations)	0.5km

[13] Average resolution means in this case the average spatial resolution of the data sources required for the calculation of the indicator.

Chlorophyll-a concentration (observations)	0.7km
Sea surface temperature (observations)	1km

In Table 10 we show the top 5 indicators in terms of average spatial resolution, which are mostly derived from satellite imagery. The remaining documented indicators are defined at spatial resolution greater than 1 km.

11.5 Indicator-by-indicator evaluation

The criteria used in the previous section also allow for discerning the strengths and weaknesses of individual or group of indicators. In the following we make this kind of informed judgment based on the available information that we have gathered on the individual indicators with respect to the criteria. Table 11 suggests that all indicators have strengths and weaknesses, but their nature varies. Thus an overall view of the impacts of climate change will benefit from a simultaneous use of indicators of different tiers in the same way as is done in, for example, the EEA indicator report (2012a). Such collections serve general awareness-raising in particular, and help to attract attention to specific topics. More specific uses are likely to require the use of several closely related indicators. Examples of indicator-by-indicator evaluation in the light of the fundamental aspects described before are shown in Table 11.

Table 11 - Examples of judgment on main strengths and weaknesses of indicators

Indicator/tier	Strengths	Weaknesses	Comment
Global long-term anomalies of average temperature/Tier1	Scientifically sound and technically sophisticated procedure for providing information on progress of climate change.	Highly aggregated information that is difficult to relate to any specific impacts of climate change.	Spatial disaggregated information on temperatures are available for regions/countries
Consecutive dry days/Tier-1	Transparent calculation based on available information, detailed spatial resolution for observations gives overview of situation	The effects of the length of a drought depend among other things on the region and season of its occurrence. Therefore it is difficult to compare across regions.	Relative changes within each region provide an indication of the direction of development.
Growing season for agriculture/Tier-2	Well defined basic concept that has clear general relationship to agricultural production. Transparent calculation based on easily accessible data at different spatial	Provides overview but does not alone indicate the actual development of agriculture as confounding factors, notably precipitation, influences it.	Can be combined with other indicators to identify the conditions for the development of agriculture.

	resolutions.		
Economic losses related to natural disasters/Tier-3	Based on insurance payments, reflects actual costs incurred and therefore easy to link to costs of conceivable measures to reduce vulnerability.	Underlying data not fully publicly available, more detailed analyses of indicator and factors affecting it are therefore seriously hampered. Issues of attribution arise as economic conditions affect development of indicator.	More detailed information is available for individual countries/regions, but have so far not been standardized and made available for the whole of Europe.
Annual heat-related deaths/Tier-3	Statistical relationship identified for many cities based on physiological considerations. Data increasingly available at different geographical scales.	Available data series are generally relatively short. Significant uncertainties exist and relationship appears to vary between regions/localities. Projections therefore highly uncertain.	Projections can be used for general indication of vulnerability rather than indications of actual deaths.

A detailed documentation of all relevant aspects of an indicator is time consuming and requires iteration between persons that are involved in calculating and maintaining the indicators in order to achieve coherence in the interpretation and judgment of the criteria. CLIPC will continue the documentation of the indicators beyond the time frame of this deliverable and maintain it throughout the lifetime of the project. A particular purpose is to ensure that the metadata on the indicators in the portal is systematically assembled. In addition it is meaningful to make aggregate judgments on the strengths and weakness of indicators in order to identify areas where there is a need of further development.

12.Match and mismatch with user expectations

The scientific and technical aspects of an indicator can be complemented with considerations of the needs of specific users. A quick reading of Scope of Use criteria (see SU criterion in Table 8) returns that mostly climate impact indicators can be used for research purposes and for awareness raising, see Figure 15. The remaining possible categories of uses rank substantially lower and account approximately for the same number of indicators. One should mention here that double counting of indicators was allowed, in the sense that the same indicators can have different uses.

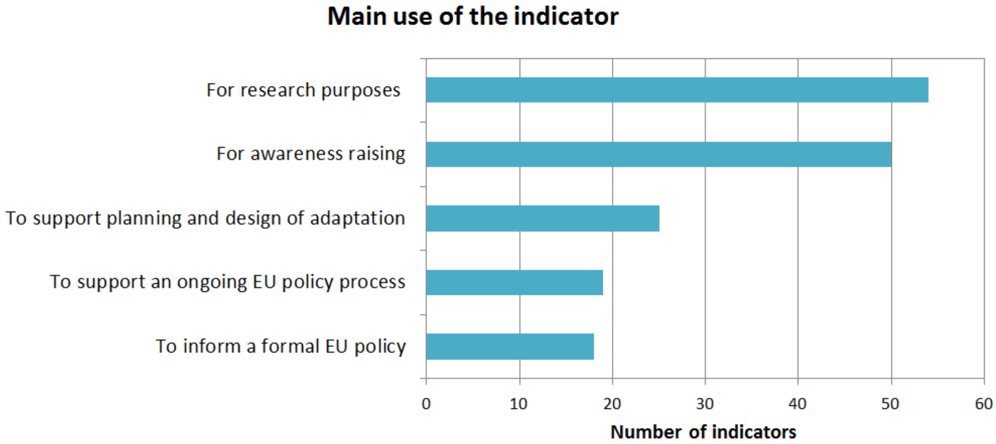

Figure 15 - Number of indicators documented by main use.

This insight of the main uses of the indicators in our database can now be contrasted with the preliminary results on user requirements from WP2. Based on an online survey that returned 60 responses from *climate scientists*, *impact scientists*, *intermediary organizations* and *societal end users*, work on WP2 provides the first indications of particular user requirements for climate change and impact indicators for the investigated user groups. Despite several user groups being involved in answering the questionnaire, three main purposes for climate data and impact indicators were identified to be common for the user groups. These are:

1. To give advice on climate data and climate impact indicators to others.
2. To support the development of adaptation strategies and plans.
3. To preform risk and vulnerability assessments.

These purposes are general and do not suggest a direct preference for any particular kind of indicators, although purposes 2 and 3 above underline the importance of Tier-2 and Tier-3 indicators (see Figure 7). Some purposes appear to be more specific for particular user groups. For example intermediary organizations see raising awareness as a specific use of climate data and impact indicators, whereas impact and climate researchers wish to use climate data and indicators as input for research on climate change. Table 12 shows the matrix of the top three purposes of data and impact indicators according to user group, constructed from WP2 outputs. Some of the uses put quite distinct requirements on the available data and indicators. Indicators that are used to raise awareness should preferably be easy to understand with general knowledge and visual. Indicators that are used for (impact) research purposes often need to be available in a spatially disaggregated form to allow linking with other variables that include spatial information.

Table 12 - Top purposes for data and indicators according to potential CLIPC users identified in the WP2 user consultation questionnaire.

User groups	**Top three purposes for climate data and indicators** **1st**	**2nd**	**3rd**
Societal end users	Support the development of adaptation strategies and plans	Create awareness	Make risk and vulnerability assessments

Intermediary organizations	Give advice on data and climate impact indicators to others	Support the development of adaptation strategies and plans	Create awareness
Impact researchers	Make risk and vulnerability assessments	Input in research on climate change	Support the development of adaptation strategies and plans[14]
Climate scientists	Give advice on data and climate impact indicators to others	Input in research on climate change	Mix of awareness raising, adaptation and risk assessment[15]

In addition, expert judgment of the consortium partners places indicators documented as being mostly of potential use for "Impact researchers". Almost every indicator gathered was perceived as potentially useful for impact research. "Societal end user" is the user category for which the smaller faction, although substantial (about 30%), of indicators is documented as potentially useful.

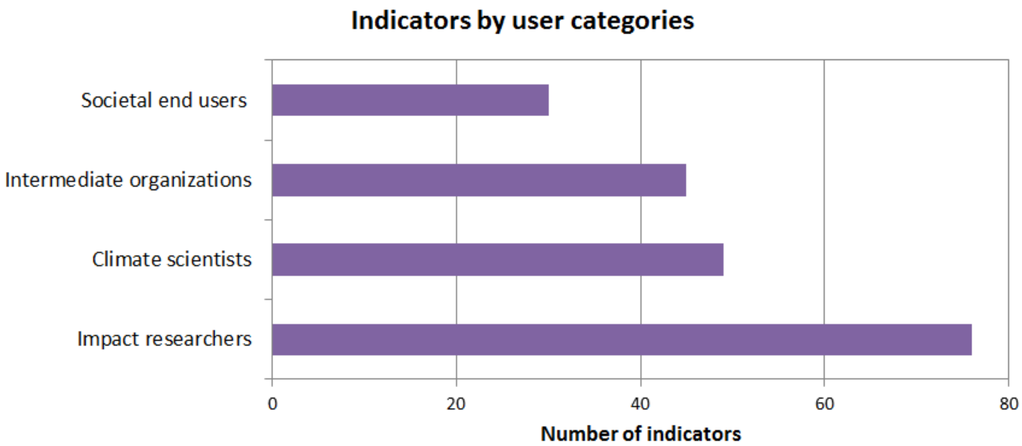

Figure 16 - Number of indicators documented by potential main user category identified in WP2.

Attending both to the results of the indicator documentation and the main uses of indicators gathered in WP2, the current database of indicators already makes good progress in meeting the demand of indicators to be used for research purposes and awareness raising (shaded boxes in Table 12). Regarding other envisioned uses of indicators by potential users, these can at some extent be also addressed by the indicator sample in the current database. Nevertheless, due to the non-existence at this point of better details of what the use of an indicator for the development of adaptation plans entails, it is hard to make more concrete judgments of the potential miss-match between the indicators gathered and the envisioned uses of indicators by potential users.

A potential way-out from the lack of detailed information from users is to think about what criteria from Table 7 and Table 8 are relevant for and indicator to be used for the top-purposes in Table 12. For each use in Table 12 we have identified criteria that can be useful in judging indicators from a user perspective. Examples are provided in Table 13, together with a brief

[14] The second and third purposes in the user category "Impact Researchers" presented the same number of answers, meaning that the placement of the 2nd or 3rd purposes is in this case arbitrary.

[15] The same number of answers for purposes "Create awareness"," Make risk and vulnerability assessments" and "Support the development of adaptation strategies and plans".

explanation on how the criteria relate to the rationale of the indicator being used for a top-purpose identified in WP2. Furthermore, since this deliverable is interested with the strengths and weaknesses of indicators, an additional column in Table 13 is added with suggestions on how documented criteria could help discerning strengths and weaknesses of indicators in the context of a particular use.

For the use *supporting the development of adaptation strategies and plans,* criteria such as the ability to display *adaptation/coping capacity* can be expected to be significant. Indicators that can be readily used in assessments, or easily adapted/altered to suit the specificities of assessment, have particular strengths. **Error! Reference source not found.** shows how indicator fares in regard to the inclusion of the adaptive/coping capacity dimension. The potential impact indicators examined by CLIPC appear to be weak in accounting explicitly for adaptive capacity. Only about 15% of the documented indicators have been coded as incorporating adaptive capacity. Half of the indicators do not account directly for adaptive capacity. This is understandable since many of the indicator belong to Tier-1 indicators, which mostly (although not without exceptions) do not usually incorporate a measure of the capacity of society or ecosystems to sustain change.

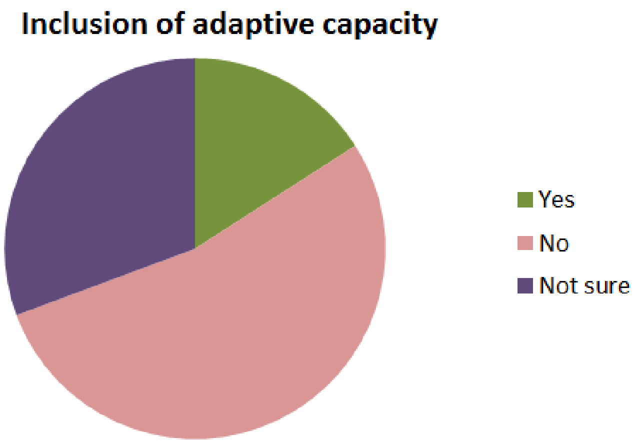

Figure 17 - Fraction of indicators that account for adaptive capacity.

The results indicate that there is a demand for indicators that provide ways to measure adaptive capacity. The availability of such indicators would strengthen adaptation planning.

Table 13 – Examples of criteria used to evaluate strengths/weaknesses of indicators with respect to a specific use.

Top-purpose of the indicator	Selected criteria from Table 7 and Table 8	Rationale	Strength (1) & Weakness (0) (evaluation pairs)
Supporting the development of adaptation strategies and plans	Presence/absence of adaptive/coping capacity	An ability of the indicator to include a dimension of adaptive/coping capacity makes it useful for this top-purpose is a comparative strength	(1) If indicator documented with "Yes" in criteria CF (Table8) or (0) If indicator documented with "No" in criteria CF (Table8)
Production of risk and vulnerability	Length of time series	A long time-series of the indicator	(1) If indicator documented with "3" in

assessments		makes it useful for this top-purpose and gives information on its strength.	criteria FPI (Table8) or (0) If indicator documented with “1, 2 or 4” in criteria FPI (Table8)
Input in research on climate change	Data availability	The accessibility and availability of input data and indicators for further analysis and manipulation determines a basic usefulness and strength for use in research.	(1) If indicator documented with “PD” in criteria ISAT (Table8) or (0) If indicator documented with other than “PD” in criteria ISAT (Table8) --
	Ensembles details	For projected indicators the availability based on ensemble modelling and/or multiple scenarios is a strength.	(1) If indicator documented with both with “1” and “2” in criteria UTRS (Table8) or (0) If indicator documented other than “1” and “2” in criteria UTRS (Table8)
Creating awareness	Main use of the indicator	The degree to which the documented indicators have been used to raise awareness suggests makes it useful for this top-purpose and highlights a strength.	(1) If indicator documented with “4” in criteria SU (Table8) or (0) If indicator documented with “1,2 or 3” in criteria SU (Table8) --
	Indicator allocated to two or more themes	The ability of an indicator to be relevant across several themes is assumed to reflect a strength.	(1) If indicator documented in more than one theme or (0) If indicator documented as being exclusive to 1 theme

In *elaborating risk and vulnerability assessments* the availability of long time series is considered to be a particular strength as it allows consideration of, for example, return times based on empirical evidence.

The use of data and indicators as *input in research to climate change* generally requires possibilities to manipulate the data or indicators further, at the very least in the form of customized graphical display. Thus a key strength is the availability of the data and indicator values in the public domain. Indicators that are not openly available can be referred to but not used as input. Research focusing on future impacts of climate change is dependent on projections. The availability of the data and the indicator is thus vital also here. In addition data and indicators that are available based on ensembles of models and scenarios are to be preferred over indicators that are based on single models and single scenarios. The ensemble data allows an exploration of variability and uncertainties that remain largely hidden in single data series.

The purpose of using indicators for *raising awareness* is in one sense the most general one, but at the same time very demanding, as these indicators have to resonate with a diverse audience that does not necessarily have the expertise to judge the validity of indicator based claims or to understand the underlying processes. The first criterion is somewhat circular, but assumes that an evolutionary process has operated so that indicators whose *main use has been to raise awareness* have particular strengths in this regard. Since awareness raising should focus on key messages and not cause information overload, parsimony is a particular strength. Thus indicators that are relevant across multiple themes are likely to have strengths relative to more focused indicators that are relevant for a narrow theme.

Following the rationale exposed, it is now possible to proceed with a tentative match of a particular indicator and a very tentative evaluation of the relative strengths and weaknesses in regard to a particular use, and, in parallel to what user category might be more interested in the indicator. **Error! Reference source not found.** shows the summary of applying Table 13 to the indicator "Growing Season for Agriculture".

Table 14 - Preliminary evaluation of the strengths and weaknesses based on the potential use for the " Growing season for agriculture" indicator.

Use of the indicator	Strength (1 or 2), Weakness (0), insufficient data (NA)
Supporting the development of adaptation strategies and plans	1
Production of risk and vulnerability assessments	1
Input in research on climate change	1/NA
Creating awareness	1/0

The identified criteria in Table 13 do not provide an exhaustive view of the strengths and weaknesses of indicators from a user perspective. A user perspective on the strength and weaknesses ultimately needs to be based on a holistic view of the indicator, weighting the different criteria in a suitable, partly subjective, way.

Nevertheless, we do find the exercise useful as a starting point to identify how to better match the user-groups perspectives on the *use* of climate impact indicators, and their adequacy for a specific use in the light of particular strengths and weaknesses. Accordingly, Table 14 highlights that the indicator "Growing Season for Agriculture" is adequate for the uses of "Supporting the development of adaptation strategies and plans" and the "Production of risk and vulnerability assessments". Its use as input for research score 1/NA, meaning that while the input data sources are all in public domain, there is insufficient data in the documentation regarding the existence of ensemble–projections of the underlying databases for the calculation of the indicator. In regard to the use of “Creating awareness”, the indicator has been perceived as specific for one of the investigated themes (rural).

The complete table of examined indicators can be found in Section 155 of the Annex. It is important to mention that the current classification with respect to use specific strengths is only indicative i) because the statements on potential uses of indicator by users are only general and ii) the existence of some lack of harmonization in the documentation, the mapping between evaluation criteria for a particular use cannot (at the moment) be used to make very specific statements on the strengths and weaknesses of individual indicators. Additional criteria and a stronger emphasis on context related uses such as the development of adaptation measures for specific locations would probably strengthen the differences.

Most of the indicators have been used in raising awareness of climate change. Noticeably, no substantial differences across Tiers are observed in this regard. We do, however, lack information on which indicators have been the most compelling ones although several authoritative sources have tried to identify the characteristics of ‘good indicators’.[16] For example, the Lowell institute underlines relevance, understandability, and usability at the level of communities.[17] Such characteristics are particularly important for local awareness-raising. As such, many of the Tier-3 indicators are relevant and understandable and would also be useable, but are often hampered by the lack of community specific data, which may explain why they have not yet been used extensively in awareness raising, compared with, for example, many Tier-1 indicators.

The sample of indicators gathered at the time of writing have been observed to match the user needs for using indicators as input for climate research and for the purposes of awareness raising. The uses of supporting the elaboration of adaptation strategies and vulnerability studies can already be supported by the indicators gathered, although in these cases it is still preliminary to make definitive judgments in the light of draw backs previously highlighted. Further interaction with users and subsequent updates of indicator documentation will help to clarify this.

[16] http://www.rscproject.org/indicators/index.php?page=what-are-the-characteristics-of-a-good-indicators-or-indicator-sets [December 8 2014]

[17] http://www.sustainablemeasures.com/Training/pdf/HEDTrMan.pdf

V. Towards new indicators and the development of impact functions

The climate impact indicators documented in this deliverable provide the basis material for future indicator selection. The selection of indicators will be a continuous process during the lifetime of the project and beyond. An operational service for climate change impact indicators will have to have a systematic way of screening potential indicators in order to ensure minimum quality.

In tandem with the exploration of existing climate impact indicators, CLIPC was also entrusted with the creation of new ones. In order to pave the way for the creation of new indicators an initial exploration was conducted for two examples. The impact of climate change on the phenology of species is potentially important. CLIPC will link observations of phenology with climate information by combining different indicators. The goal of the outlined Moth Phenology Index (MPI) is to prepare tools for predicting how climate change may influence the activity (i.e. flight period) of one central group of natural species diversity, herbivorous insects, as exemplified by nocturnal moths. The observations of moth phenology gathered through the Finnish national moth monitoring scheme (*Nocturna*) constitute the basic phenology data for the index. Moth data are gathered using light traps that are run every night from the early spring to the late autumn, and the traps are usually emptied and the moth specimens identified on a weekly basis.

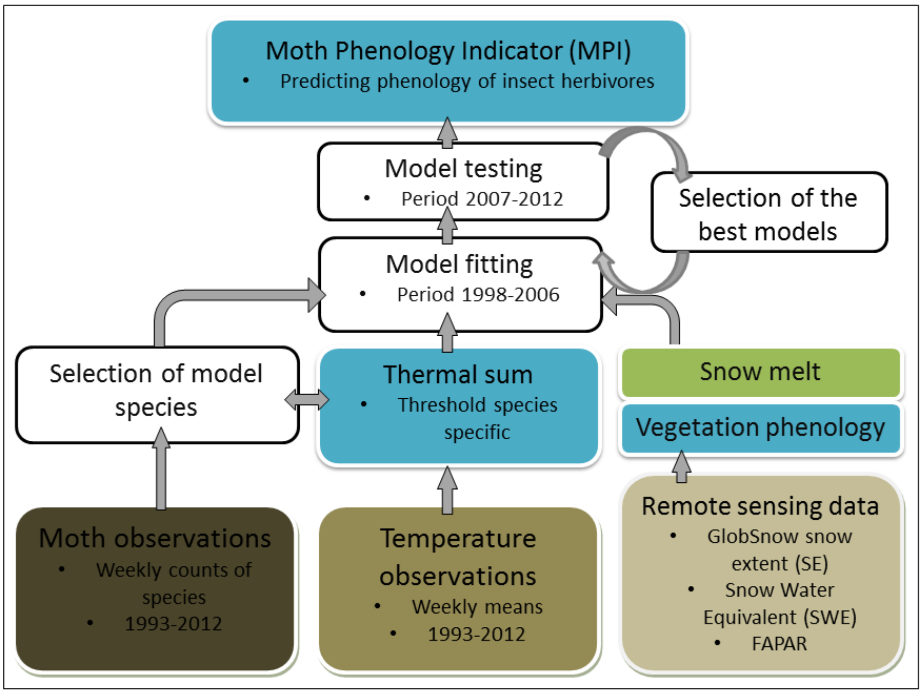

Figure 18 - Draft chart of datasets and steps used in deriving the Moth Phenology Index (MPI).

The MPI index will relate moth observations to climatic observations and remote-sensing data on phenomena such as snow melt in spring, greening and autumn senescence of deciduous trees using statistical modelling methods. A number of representative (i.e. wide-spread and abundant) moth species differing in timing of the peak flight period will be selected for modelling and deriving the index. The resulting MPI index is placed in the Tier-2 of the CLIPC project.

An outline of the steps needed in deriving the MPI index is presented in Figure 18.Three kinds of data will be used in preparing the MPI: (1) Weekly observations of approximately five selected moth species; these will be chosen from the total dataset (consisting of observations for 732 species) using the following criteria: the species need to be wide-spread and sufficiently abundant to allow statistical modelling and their peak flight period should occur at different times of the season. Moth data are available for the period 1993-2012. (2) Records of weekly accumulation of the thermal sum and weekly mean temperatures at the monitoring locations derived from gridded daily observations from the Finnish Meteorological Institute (FMI) will be used here (data with 10-km resolution are available for 1961-2013). Different threshold values for calculating thermal sums will be tested following previous modelling studies of moth phenology by Valtonen et al. (2011, 2014). (3) Remote-sensing data on snow melt in the spring, greening and autumn foliage of deciduous trees; available datasets include GlobSnow snow extent [18](SE; available with 1-km resolution for 1997-2012), Snow Water Equivalent[1] (SWE; 25-km resolution for 1979-2012) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR, 1-km resolution for 1998-2011)[19] including derived phenological dates.

Weekly observations of the selected moth species will be related to climate variables using statistical modelling methods. Thus e.g. generalized linear models (GLM) and generalized additive models (GAM) will be fitted to records of weekly accumulation of the thermal sum at monitoring locations and remote-sensing data on descriptors of seasonal progress such as snow melt in the spring, greening of forest vegetation and autumn foliage of deciduous trees. Models will be fitted using data from the period 1998-2006 and validated using data from the period 2007-2012. Alternative model versions using climate-only and remote-sensing-only predictor variables and a combination of both will be compared. Models with the best validation performance will be selected for the indicator.

Potential applications of the indicator include e.g. the prediction of the phenology of herbivore insect species, including potential forest pest species, in time (i.e. using regular updates of climate and remote-sensing predicator variables) and space (i.e. using gridded data over a spatial extent, e.g. the whole of Finland, that offers comparable environmental conditions than those of the locations of the moths observations). In the future the indicator

[18] GlobSnow data are available from www.globsnow.info
[19] FAPAR data are available from fapar.jrc.ec.europa.eu

may be tested extending its predictions of phenology to new geographical areas and to predictions of the future phenology based on climatic scenarios.

The second exploration was done for the case of heat impact in the urban theme (see Figure 19). In this case, the departing point is a Tier-1 indicator of daily apparent temperature, a widely used indicator in the field of epidemiology research related with heat-mortality (see Hajat & Kosatky 2010 for a meta-review). This Tier-1 indicator can nevertheless be supplemented with additional data. An example of this is the use of *satellite data* on surface temperature to convene an idea of the magnitude of the Urban Heat Island (UHI) potential (Tier-2). Additionally, very few impact indicators will attempt bridging the climate stimuli from Tier-1 indicators to a metric of danger to human societies (Tier-3) without a dimension introducing the sensitivity of that society to tolerate heat. This will be done by the elaboration of a sensitivity function driven by past climatic variables currently being developed. The data for the function is taken from published case-studies quantifying temperature-mortality relationships for a number of cities (in situ data).

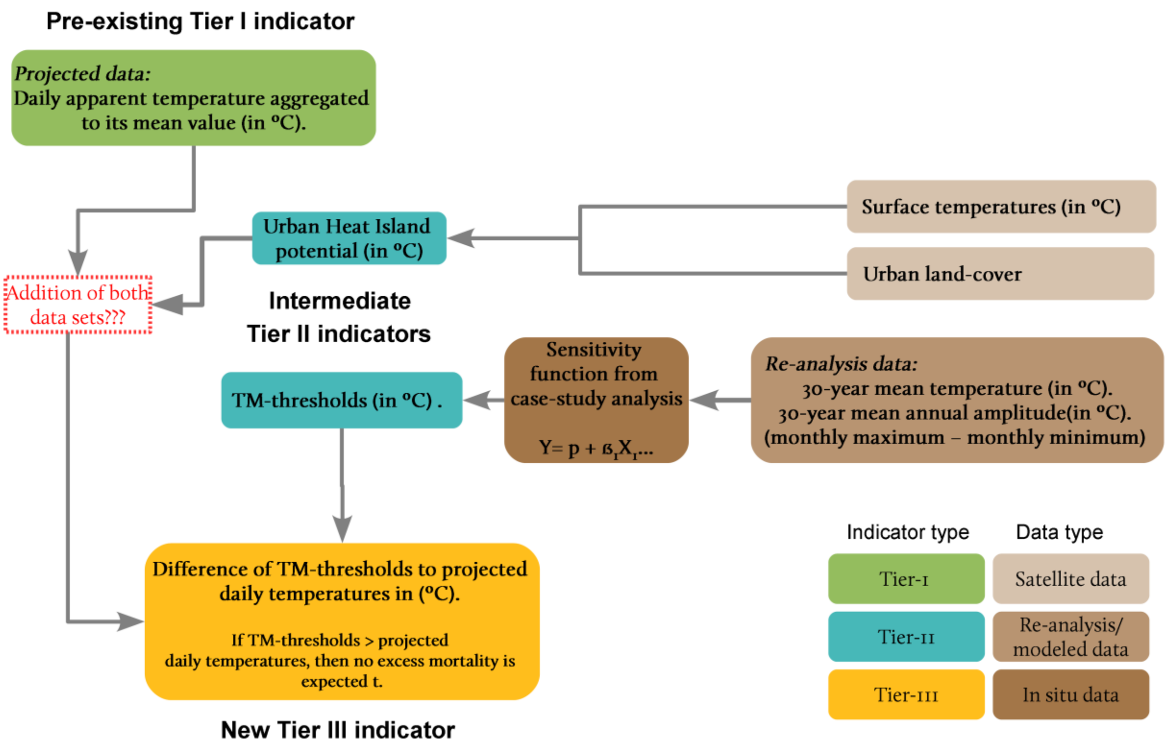

Figure 19 - Prototype of data integration for the elaboration of a new impact indicator

The final Tier-3 indicator would be a metric illustrating by how much the future temperatures deviate from the TM-threshold and thus what is the changes in risk of mortality.

VI. Conclusions and perspectives for further work in CLIPC

The main conclusions and perspectives for further works can be summarized as follows:

The analysis of strengths and weaknesses of indicators has used a grouping into three tiers. In this categorization, Tier-1 indicators provide information on the past and future evolution of the climate system. Tier-2 indicators quantify the impacts of climate change in bio-physical systems. Tier-3 indicators primarily provide information on the socio-economic systems affected by climate change. Tier-3 indicators usually build on Tier-1 and Tier-2, and make the bridge from bio-physical change to social or economic loss/gain. This grouping served to highlight the relative scarcity of indicators that explicitly link climate change to socio-economic consequences.

The criteria that were used to identify strengths and weaknesses build on commonly used indicator criteria. Climate change indicators are special in that an important part of the indicators are also used to project future development. This implies a heavy reliance on modelling and puts special demands on, for example, the treatment of uncertainty.

The large collection of information on criteria for climate change and impact indicators across the CLIPC themes and tiers has identified general strengths and weaknesses of indicators. The key criteria for judging the fundamental strengths and weaknesses of indicator are the strength of the scientifically documented relationship between the indicator and what it is expected to indicate, the methodological transparency, the recognition of and ability to deal with uncertainty, the (public) availability of relevant data, the updating frequency, the length of the time series and the spatial resolution and coverage of the indicator.

A general strength is that there is an abundance of Tier-1 indicators that are based on publicly available data, well-established scientific theories, long time series, high spatial resolution and the availability of projections based on the results of ensembles of models calculated for several different scenarios. Good Tier-2 indicators are less well available, but several exist, and they are also based on high quality open source data that are regularly updated. It is a priority to develop new Tier-2 indicators that are based on regular monitoring and that can explore novel data sources such as those based on earth observations. In CLIPC such efforts will be undertaken.

The poor availability of Tier-3 indicators is an obvious general weakness. One of the main reasons for the lack of Tier-3 indicators is that it is difficult to quantitatively attribute economic and wider societal development to climatic factors. This is natural as climate is only one of numerous factors affecting societal development. Therefore it appears that Tier-3 indicators are currently often more useful when they are framed in terms of vulnerability or adaptive capacity rather than in terms of actual impacts, which require detailed site specific analyses in order to deal with the question of attribution.

There is an obvious need to continue with exploratory work that can establish links between societal conditions and climatic factors. This can be achieved by examining socio-economic statistical information as dependent variables in the light of information from Tier-1 and Tier-2 climate indicators. Such studies demand sufficient spatial resolution in order to display the variation that is needed to explore possible relationships. Eventually the studies may lead to new Tier-3 indicators, but such studies will in any case improve the base for modeling and projections of impacts.

In the scanning work conducted for this deliverable it was not possible to fully harmonise the use of the evaluation criteria across indicators. For specific indicators there was also missing or incomplete information on some criteria. Further elaboration of strengths and weaknesses of indicators has to expand beyond the time frame of this deliverable and become an overarching objective of WP7 supporting the production of the CLIPC portal.

The sample of indicators gathered at the time of writing have been observed to match the user needs for using indicators as input for climate research and for the purposes of awareness raising. The uses of supporting the elaboration of adaptation strategies and vulnerability studies can already be supported by the indicators gathered, although in these cases it is still preliminary to make definitive judgments

By fine-tuning the criteria and the process for collecting relevant information of potential indicators, requirements will be developed for the meta-data of the impact indicators. Such meta-data will be included in the CLIPC portal and subsequent operational services. The meta-data will thus provide users with basic information on the reasons for the inclusion on the portal and also general information of the quality of the indicators.

As long term perspectives, the work of WP7 will be focused on the completion and expansion of the review of indicators made in this deliverable. The completion will benefit from a longer time frame for filling missing relevant criteria information via more interactions with the partners. In addition, more detailed insights from ongoing user consultation will hopefully allow for a better matching of the indicator list collected to the user needs. The expansion of the indicator list will be focused on expanding the Tier2 and 3 samples of indicators.

In the short term WP7 will identify a restricted set of impact indicators (from those already documented) to be calculated and used in the interactions with WP 3, 4, 5, 6 and 8 to provide ‘proofs of concept’ for the portal and its functions.

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VII. ANNEXES

14. Expert workshop report as part of MS29

Joint CLIPC - EEA meeting 13th to 14th May Copenhagen
Venue: EEA facilities at Copenhagen (Adress: *Kongens Nytorv 6, 1050 Copenhagen K*)

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Background

The CLIPC project will provide access to climate information of direct relevance to a wide variety of users, from scientists to policy makers and private sector decision makers. Information will include data from satellite and in-situ observations, climate models and re-analyses, transformed data products and climate change impact indicators.

This particular workshop focused on criteria to be used for evaluating and screening climate and climate impact indicators to be included in the CLIPC toolbox. An agreement on criteria is a required outcome of deliverable D7.1: *A review of climate impact indicators across specific themes and description of strengths, weaknesses and technical requirements.* In addition, the workshop discussed the envisioned functionalities of the CLIPC toolbox using as a starting point the identification of key users/user groups undertaken in D2.1: *Synthesis of user requirements from past efforts and user involvement strategy on providing climate (impact) data)*.

In developing requirements for CLIPC indicators the workshop reflected on ongoing and planned activities by the European Environmental Agency (EEA), the Joint Research Center (JRC), Copernicus Climate Services and the IPCC Task Group on data and scenario support for Impact and Climate Analysis (TGICA) and the IPCC Data Distribution Center (DDC) in order to make sure that both functionalities and data/indicator requirements can be harmonized with those developed elsewhere. The work will also reflect on related and relevant EU-projects projects such as CLIMSAVE, IMPRESSIONS and other pre-operational Copernicus projects addressing projections of climate change (and impacts). Experiences of indicator development and presentation will be fully used to avoid duplication of work.

This report is organized in the order in which the topics were dealt with at the workshop. The first half was devoted to the general expectations and ways of developing and using criteria for indicators of climate change and impacts of climate change. The second half of the workshop was devoted to a discussion on functionalities of the toolbox.

The Objectives of the workshop

The objectives of the workshop were to:

1. Discuss and agree on criteria to screen, evaluate and assess the strengths and weaknesses of climate and climate impact indicators and underlying data to be included in the CLIPC toolbox.
2. Discuss the functionalities of the CLIPC toolbox and how it will bring added value relative to other indicators and indicator tools.

To achieve its objectives the workshop was initiated with presentation from different perspectives on what CLIPC could achieve with respect to indicators of climate change.
The EEA's expectations on the CLIPC indicator toolbox
André Jol, EEA

The EEA's expectations were presented by André Jol who noted that the new multiannual work programme 2014-2018 guides EEA's activities and focal areas. Among these societal transitions have received particular attention and will be central in the work. In the State of the Environment Report of 2015 climate change will be one thematic issue. The portal Climate-ADAPT includes indicator information mainly from EEA (report on CC impacts, published in 2012) and maps (map viewer) and by 2016 climate indicators are expected to be updated closely linked with a new report due in 2016, building on the content and experiences with the 2012 report. This provides opportunities to link directly with the work in CLIPC . The Tier-1 indicators are fairly well placed and operational, but there is great interest in achieving progress in Tier-2 and Tier-3 indicators.

Climate-ADAPT is central for the EEA and it will link to work of JRC on CC impacts and adaptation and in the future also to the Copernicus climate services. On June 23 a expert meeting will be held on climate adaptation portals as part of EEA's work with member countries.

He summarised the main expectations from EEA towards the CLIPC project :

- Contribute to the EEA climate change impact indicators (on EEA web site) and 2016 indicator-based assessment report
- Contribute to Climate-ADAPT (e.g. map viewer)
- Help define the future linkages between the Copernicus climate change service and Climate-ADAPT
- Make effective use of linkages between CLIPC consortium and ETC CCA lead and partner organisations
- Participation by EEA in CLIPC advisory group and expert group meetings

Overview of the CLIPC project
Martin Juckes, CLIPC /STFC

Martin Juckes provided an overview of the CLIPC . He noted that CLIPC can be seen as a prototype for part of the future activities of the Copernicus Climate Change Services. The CLIPC will follow the Earth System Grid Federation (ESGF; http://esgf.org/) that develops, deploys and maintains software infrastructure for the management, dissemination, and analysis of model output and observational data. Another important connection is the IS-ENES climate4impact portal (http://climate4impact.eu/impactportal/general/index.jsp), which is oriented towards climate change impact modellers, impact and adaptation consultants, and other experts using climate change data. Specific goals are to provide

- harmonized access to data from many sources
- information on data value and limitations
- indices of climate change & impacts
- a knowledge base of authoritative information
- a toolkit to update indices and indicators

CLIPC makes assessment and data available for assessments but will not make its own assessment. A brief discussion noted the need to be clear about distinctions between indicators and indices.

The TGICA and the DDC: How to guarantee a consistent set of up-to-date scenarios for use in climate impacts assessments: Relevance for indicators of climate change?
Tim Carter, SYKE
Tim Carter described The Task Group on Scenarios for Climate and Impact Assessment (TGCIA) and the Data Distribution Centre (DDC) noting that TGICA covers all WGs and that the information needs are catered for through the DDC, for which rigorous quality control has been set up. An important task is to provide technical guidelines, interpretation of data, with all guidance rigorously peer reviewed and transparent criteria for linking data sets. TGICA has Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) on its agenda, but DDC not yet covered impact model information.

Tim Carter noted that the interest in data is expanding as the expert community is widening; also utilities and other users are increasingly requesting information, but users may not find the data sufficiently detailed. The link to Copernicus Climate services will thus be important for a wider user community.

The possibilities to share insights on user needs and user surveys were discussed, along with possibilities for organizing a meeting partly joint TGICA – CLIPC meeting for southern Europe.

JRC's strategy regarding climate change impact data and services: Prospects and developments
Nadine Gobron, CLIPC /JRC

JRC's current work on climate change impact data were presented by Nadine Gobron who noted that JRC's key areas include:

- Development of the knowledge base Climate-ADAPT
- Estimating costs of future climate change
- Developing coherent integrated assessments

JRC is, in particular, the key map provider for Climate-ADAPT. New tools are also being developed including time series based on earth observation data. JRC has carried out the

Peseta II project (http://ftp.jrc.es/EURdoc/JRC87011.pdf), which has led to additional work on climate change impacts to be carries out in 2014-2015 on topics such as:

- costs of droughts
- impacts in coastal areas
- impact on ecosystems & services
- global impacts with implications for Europe

On earth observations development work continues on:

- Mitigation and adaptation
- Quality control

For quality control the project: QA4ECV – quality control for ECV (http://www.qa4ecv.eu/) attempts to bridge the gap between end-users of satellite data and the satellite data products by developing an internationally acceptable Quality Assurance (QA) framework that provides understandable and traceable quality information for satellite data used in currently evolving climate and air quality services.

General indicator requirements and the experience of using criteria to evaluate indicators by the EEA with special attention to climate and climate impact indicators
Hans-Martin Füssel, EEA

Hans-Martin Füssel presented the EEA approach to indicators and the requirements that emerge from the chosen approach. In the context of climate change key interests are to:

- present climate change– providing the general context
- present climate related hazards
- assess the impacts of climate change on society, human health and ecosystems
- assess the effectiveness of climate risk management (with a focus on adaptation)

This leads to demands on spatial coverage and resolution. The spatial coverage should be as wide as possible (taking into account the EEA member countries), and the resolution sufficient to identify relevant changes. In addition indicators should be relevant for EU policies. Indicators should thus meet the following criteria.

- Thematic and policy relevance
- Full geographic coverage of relevant variables
- Appropriate geographical aggregation
- Long time series
- Reliable data series
- Clear methodology

As far as possible indicators should provide observations of historical development, projections for future development, and information on uncertainties.

In 2016-2017 the EU is likely to revise its adaptation strategy leading to specific demands in the accompanying ‘impact assessment’ of the strategy according to EU procedures for all new proposed policies. The planned 2016 EEA report on CC impacts will be one input to this ‘impact assessment’.

It will be beneficial for CLIPC to further explore work that has been going on in projects such as Impact2c, PesetaII/III and to reflect on the question of attribution to climate change in considering indicators. He also stressed the importance of narratives that are an integral part of the EEA indicators.

For the development of indicators the EEA sees a need to link with many expert communities and to consider users involved in country level risk assessments. For future work it will be relevant to consider possibilities to expand the number of indicators and develop links to future Copernicus climate services. There is also ongoing development between JRC and EEA to ensure consistent approaches in their assessments and indicators, including easier access to data.

Development is also going on under Eurocordex regarding high resolution data with different bias correction methods but at the same time introducing some new uncertainties in bias correction.

Finally in the discussion it was noted that going through the past indicators and earlier data with a new framework can provide useful additional information.

A first set of criteria for CLIPC indicators: Example of how the CLIPC criteria could work in practice
Luis Costa, CLIPC /PIK

Luis Costa presented the application of the preliminary criteria for indicators. The main idea is to have a systematic framework that can be used to arrive at clear conclusions in D 7.1 on strengths and weaknesses of climate and climate impact indicators and underlying data. The aim is to provide a proof of concept of indicator criteria. A general starting point is the grouping of indicators into three tiers and the grouping of the criteria into two main groups: Scientific adequacy and feasibility and Usability, relevance and scope of use. In addition there is a consideration of impact functions which can be seen to relate indicators of different tiers to one another, or be used to develop new composite indicators.

General discussion on criteria

The discussion raised as a particular issue the link between the impact functions and the criteria and how to deal with that link. The need to consider some form of a numerical scale for the criteria was also raised.

In CLIPC there will be a need to consider possibilities to combine indicators thereby possible producing new indicators. It was, however, noted, that these user driven combinations should not be considered as “indicators” in the sense of those that have been evaluated using the criteria.

For the input variables there is a need to achieve specificity with standard reference names ensuring traceability and transparency. The criteria to be stressed in particular are those that related to the quality of underlying data [thresholds, standard disclaimer, benchmarks and “references to authoritative sources”]. It was noted that verifiability should be emphasized for impact indicators and also the recognition of limits impact/indicator functions with respect to time interval and geographical region especially in the context of impact functions which have been developed for specific locations with specific data. The (limits of) transferability should be flagged through criteria. Based on criteria a distinction can be made between research/exploratory work that may contribute to future indicators as opposed to “real indicators” that fulfill selection criteria.

Priority users/user groups for CLIPC and what preliminary demands they may put on data and impact indicators to be provided
Annemarie Groot, CLIPC /Alterra

Annemarie Groot presented the priority user groups and the user consultation strategies and user requirements that have been employed in other projects. She concluded that a pragmatic approach is needed in selecting priority user groups. Potential users can be placed in three circles dependent on the involvement in the CLIPC project and related projects. The inner circle consist of those already involved in projects of CLIPC partners, the second of users already involved in other similar European and national projects and finally the potential users of interest recognised by various partners but not necessary involved in any projects that has direct links with CLIPC . The user needs can be specified by identifying four categories, according to expected requirements and capabilities to handle climate change information:

1. Climate Scientists
2. Biophysical impact researchers
3. Boundary workers (or intermediary organizations) and socio-economic impact researchers
4. Societal end-users

The conclusion had been reached that the focus in identifying user need should on the first three categories.

Brainstorming envisioned key features the CLIPC toolbox
Mikael Hildén (facilitator), CLIPC /SYKE

Using the priority user groups as guideline the workshop discussed what functionalities should be developed in CLIPC for the toolbox.

The discussion identified a number of general requirements and technical features that should be considered in developing the toolbox. In addition key features for the specific user groups were identified.

General requirements

User friendliness should be a basic starting point. Users could achieve guidance by registering according to the focus of their interest and the expressed interest would guide the user to relevant parts of the toolbox. There should also be opportunities for providing feed-back.

One way of guiding users is to take policy needs as a base for supporting the users' selection of topics in the toolbox; for example energy/bioenergy; climate data/impacts. The specific entry points should be supported by transparent meta-data explaining the base for the work.

The credibility of the contents of the toolbox needs to be ensured through:

- appropriate quality control and quality control procedures, including bench marking of quality with other related services and products
- verifiability of information and data provided
- disclaimers on data/indicators as appropriate

The toolbox should preferably include exploratory tools for analyzing the indicators that would allow comparison of indicators: across topics; across different time intervals and across different areas. It could also allow users to bring in their "own" data to compare with what is available in the toolbox. This will require standards for data input and comparison but also disclaimers on the use of data for such comparisons. A distinction has to be made between 'indicators that have been approved by the project to be included in the portal based on QA/QC procedures and "User indicators & indexes", which are only exploratory products, not "approved indicators" even if they use information and data included in the toolbox.

In order to guide users there is a need to reflect on what limitations should be built into the toolbox that would stop users from creating combinations and analyses that are scientifically unjustified and potentially misleading. This is closely related to the question on what post processing opportunities CLIPC will provide. With extensive post processing opportunities there is a need for built in "warnings" on combinations of data or explanations for recommended combinations.

Different types of tools have different demands in this respect. Thus visualisations can be largely predefined giving users "controlled" ability to modify data through spatial and temporal aggregation. Opportunities for statistical analysis and overlay of, for example, uncertainties are more challenging in that they require the user to be experienced and aware of caveats.

The toolbox should provide free and open access to the available material and ensure its traceability and transparency. A review team is needed for checking al data and indicators that are proposed to be included in the toolbox.

Technical requirements

The amount of data and type of indicators should be taken into account in selecting server for the toolbox. The server must be able to cope with numerous simultaneous users requesting downloads of indicator information and data.

Registration of users according to needs could also lead to different user interfaces which are based on user profiles/areas of interest. There could also be a system for flexible data discovery (search function) but also (partly) predefined selection of products and indicators from the portal which the user can reach by specifying broad themes (see general requirements, user friendliness).

A help desk function should be included in the design of the portal. This could also include a general wish list for the management of tool box, and information on updates and new developments. Informing regular users can be considered. For example MyOcean regularly sends out information on new developments and products to registered users.

The toolbox should be able to automatically inform users of processes, in particular, it could provide information on processing time for “heavy requests” involving large amounts of data.

Specific characteristics serving particular user groups:

Climate scientists

Need for specific and detailed data; will wish to have maximum options to explore data further by analysing it using different user driven tools for treating the data, including scatter plots, free choice of timelines and other technical treatment. Flexibility with many choices in examining the data is a key to usefulness from the climate scientists point of view.
Climate scientists are also likely to wish opportunities that allow sharing of files, and the extraction of subsets of data for areas & issues

Impact scientists

Impact scientists are likely to benefit from partly predefined analyses of particular data and indicators, and to wish to have explanations and visualisations of climate data (Tier-1) indicators in particular. They could also wish to see pointers to similar/related data starting from some topic. This can be achieved by clearly labelling specific information according to areas/topics of interest.

Impact scientists are dependent on good metadata when reporting analyses involving the combination of different indicators to get insights into Tier-2 and 3 of the indicators, and should also be required to contribute to the development of metadata.

Impact research will have a particular interest in considerations of links between impacts and adaptation action, and how to monitor measures improving adaptation or adaptive capacity. Therefore indicators or tools that allows the exploration of the available information in the light of, for example, the EU-adaptation strategy at Tier-2 and 3, will be of particular interest for impact scientists.

Intermediaries

Intermediaries are particularly likely to benefit from a toolbox that provides as many finalized products as possible. This means for example:

- Predefined maps/graphs of specific indicators with explanations and interpretations of plots provided.
- Predefined time slices (with possibilities for users to easily adjust them to their own preferences; or with time sliders to view changes over time)
- Possibilities to zoom different geographical levels: Regional (NUTS3), national, European wide aggregation
- Predefined aggregations of indicators developed by experts; possibly allowing users ti define weights by users;
- Some (limited) possibilities for developing “indicators on the fly” to allow exploratory work with respect to relationships between indicators.
- Vivid examples based on/linked with the indicators, narratives and success stories and interesting cases

Intermediaries are also likely to benefit from information of (causal) links between indicators, but also from social/cognitive links (“those who viewed this also looked for…”) and indicators that can guide and inform steps towards adaptation.

Processes for user engagement

The workshop noted that there is a special need to develop processes for user engagement in the toolbox. An important function will be to include features that engage users, allowing them to make their feedback visible and to directing and guide user feedback with, for example FAQs.

CLIPC should link with activities such as CharmE that has focused on how to allow users to view or create annotations that describe how climate data has been used and what has been learned. For CLIPC the analogue is to describe the use impact data and indicators.

The point noted under general and technical requirements concerning category specific user registration can provide different entry points that take user need into account, and in so doing guiding users to key topics of her/his interest, and providing specific avenues for engagement.

In the discussion it was noted that the EIONET is a specific forum where the CLIPC can be marketed in particular to "intermediaries", but it will require concrete examples of what the toolbox can provide.[20]

Next steps

It was noted that CLIPC can be seen as a prototype for services that Copernicus will develop further. Particular attention will have to be devoted to QA/QC procedures. There is thus a need to organize meetings between CLIPC and organisations with relevant tasks in Copernicus where the contents of climate services and the links to the development of CLIPC can be discussed further. Relevant discussion partners are also the other pre-operational climate change service projects21, in particular those developing projections and/or predictions and that already have experience of user involvement activities. Lessons learnt should be assessed from these activities in order to be more focused and effective in CLIPC (and for the CCCS as a whole). There are also opportunities to identify and talk with EU-wide 'sectoral' organisations that maintain many relevant indicators including WHO, ECDC, ISDR but also those related to water and ecosystem issues. EEA can facilitate, through networks and systems managed by EEA colleagues, including WISE and BISE such discussions.

There is also a need to initiate the processes for integration /convergence between CLIPC and EEA activities. This will call for user meeting and smaller specific meetings on necessary steps in 2015 to track progress in CLIPC and to identify opportunities for establishing more formal links between CLIPC and the EEA Climate-ADAPT and indicator work.

There will also be a need to consider widely links to different activities that are potentially relevant for the production of indicators, for example the ISI-MIP (http://www.isi-mip.org/) which brings together impact models across sectors and scales to create consistent and comprehensive projections of the impacts of different levels of climate change. Also the outcomes of several finalized EU-projects such as CLIMSAVE and ongoing EU projects such as ToPDAd, IMPRESSIONS and BASE need to be considered.

[20] CLIPC was presented at the annual EIONET workshop on CC IVA held 24 June, EEA, Copenhagen. Interested countries were asked to contact CLIPC .

[21] http://www.copernicus.eu/pages-principales/projects/other-fp7-projects/climate-change/

List of participants

Surname	First name	Organisation
Bärring	Lars	SMHI
Carter	Tim	SYKE
de Groot	Annemarie	Alterra
Fons-Esteve	Jaume	UAB
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Gobron	Nadine	JRC
Hildén	Mikael	SYKE
Jol	André	EEA
Juckes	Martin	STFC
Kurnick	Blaz	EEA
Luojus	Kari	FMI
Lückenkötter	Johannes	TUDO
McCormick	Niall	JRC
Swart	Rob	Alterra
Teichmann	Claas	CSC
Thépaut	Jean-Noël	ECMWF

15. Investigation indicators according to the potential uses identified in WP2

Table 15 - Investigation of indicator according to the potential uses identified in WP2. The number 1 and 0 (zero) are a preliminary indications of indicator strength (1) or weakness (0) to a given use. NA's highlight that information is incomplete.

Identified uses of indicators	Supporting the development of adaptation strategies and plans	Production of risk and vulnerability assessments	Input in research on climate change		Creating awareness	
Criteria used from Tables 7 and 8	Presence/absence of adaptive/coping capacity	Length of the time series	Ensemble details	Data availability	Main use of the indicator	Indicator allocated to two or more themes
Arctic and Baltic Sea ice	0	1	0	1	1	0
Bathing water quality	0	0	NA	1	0	0
Chlorophyll in transitional, coastal and marine waters	0	0	NA	1	0	0
Chlorophyll-a concentration (observations)	0	0	NA	1	1	0
Climatic favourability of tree species (projections)	1	0	1	NA	0	0
Coastal flood damage and adaptation costs (projections)	1	NA	NA	0	0	1
Cold days	NA	1	0	NA	0	1
Cold nights	NA	0	0	NA	0	1

Cold spell duration index	NA	1	1	NA	0	1
Consecutive dry days	NA	1	0	NA	1	1
Consecutive wet days	NA	1	1	NA	0	1
Distribution of marine species	1	1	NA	0	0	0
Diurnal temperature range	NA	NA	1	NA	0	1
Extremely wet days	NA	NA	1	NA	1	1
Floods and health	0	0	NA	0	0	0
Freshwater biodiversity and water quality	0	1	NA	1	1	0
Frost days	NA	NA	1	NA	1	1
Glaciers mass balance	0	1	0	1	1	0
Sea level change	0	NA	NA	1	1	1
Greenland ice sheet	0	1	NA	1	1	0
Grow season length	NA	NA	1	NA	1	0
Growing season for agriculture	1	1	NA	1	1	0
Hazardous substances in marine organisms	0	0	NA	1	1	0
heavy precipitation days	NA	NA	1	NA	1	1
Ice days	NA	NA	1	NA	1	1
Lake and river ice cover	0	0	NA	0	1	0
Lake and river ice phenology	0	1	NA	1	1	0
Lake Ice Extent	0	0	NA	1	0	0
Land elevation below projected sea-level	0	NA	NA	0	1	1
Max 1 day precipitation	NA	1	1	NA	0	1
Max 5 day precipitation	NA	NA	1	NA	0	1
Maximum of daily minimum temperature	NA	1	1	NA	0	1
Maximum of daily maximum temperature	NA	1	0	NA	0	1
Mean precipitation	0	0	0	1	1	1
Minimum of daily minimum temperature	NA	1	1	NA	0	1
Minimum of daily maximum temperature	NA	1	1	NA	0	1
Moth Phenology Index	0	NA	NA	NA	1	0
Number of wet days	NA	NA	1	NA	0	1
Nutrients in transitional, coastal and marine waters	0	NA	NA	1	0	0
Observed development of ocean acidification	1	1	NA	1	0	0
Ocean heat content	0	1	NA	1	1	0
Permafrost	0	1	0	1	1	0
Precipitation extremes	0	1	NA	1	1	1
Projected change in average annual and seasonal river flow	0	1	0	1	0	0
Projected change in river floods with a return period of 100 years	0	0	0	1	1	0
Projected changes in water-limited crop yield	1	1	0	1	0	0
Projection of ocean acidification	0	1	NA	1	0	0
River floods	0	0	NA	1	1	0
River flow	0	1	NA	1	1	0
River flow (projected)	0	0	NA	1	0	0
River flow drought	0	1	NA	1	0	1
Sea level change (observations)	0	1	NA	1	1	0
Sea level change (projections)	0	NA	NA	NA	0	0

Sea surface temperature (observations)	0	0	NA	1	1	0
Simple daily intensity	NA	NA	1	NA	1	1
Snow cover (observations and projections)	0	1	NA	1	1	0
Snow extent (observations)	0	0	NA	1	0	1
Standardized SnowPack Index	0	0	NA	1	1	0
Snow Water Equivalent	0	0	NA	1	1	0
Storm surges	0	NA	NA	NA	0	0
Summer days	NA	NA	1	NA	0	1
The length of thermal growing season	0	0	NA	1	0	0
Total wet-day precipitation	NA	1	1	NA	1	1
Tropical nights	NA	1	1	NA	1	1
Very heavy precipitation days	NA	1	1	NA	1	1
Very wet days	NA	1	1	NA	1	1
Warm days	NA	0	0	NA	0	1
Warm nights	NA	0	0	NA	0	1
Warm spell duration index	NA	1	1	NA	1	1
Water scarcity	0	NA	NA	NA	0	1
Water temperature (observations)	0	1	NA	0	1	0
Water temperature (projections)	0	0	NA	0	1	0
Water-limited crop productivity (projections)	1	NA	0	1	1	1
Irrigation water requirement	0	1	0	1	1	1
Ocean acidification	0	1	NA	1	1	0
Intensity of urban heat island with city size	0	NA	NA	0	0	0
Heating degree-days	1	0	NA	1	1	0
Rainfall Deciles (observations)	1	NA	NA	NA	0	1
Reconnaissance Drought Index	1	NA	NA	NA	1	1
Annual average damage from river floods	0	NA	NA	0	1	0
Average annual heat-related deaths per 100,000 habitats	1	0	1	0	1	0
Growing Degree Days	1	NA	NA	NA	1	0
Chilling Units (observations)	1	NA	NA	NA	0	0
Potential impact of river flooding on major roads	0	1	0	1	0	0
Potential impact of river flooding on railways	0	1	0	1	0	0
Potential impact of river flooding on settlements	0	1	0	1	0	0
Percentage change in arrivals/departures due to global warming	0	1	0	0	1	0
Annual olive-crop yield	1	NA	NA	NA	0	0
Natural disasters	0	0	NA	1	1	1