Evaluation of climate change state, impact and vulnerability indicators

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Mikael Hildén & Andreas Marx,
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Author affiliation:

Mikael Hildén, Finnish Environment Institute (SYKE), Helsinki, Finland
Andreas Marx, Helmholtz Centre for Environmental Research (UFZ), Leipzig, Germany

EEA Project managers:

Hans Martin Füssel, European Environment Agency, Copenhagen, Denmark
André Jol, European Environment Agency, Copenhagen, Denmark

European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation
c/o *Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)*
Viale Aldo Moro 44
I-40127 Bologna, ITALY
Phone: +39 051 3782618
Email: sergio.castellari@cmcc.it
Website: http://cca.eionet.europa.eu/

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Summary

In November 2012 the EEA published the EEA Report *Climate change, impacts and vulnerability in Europe 2012 – An indicator-based assessment* (2012 CCIV report; EEA, 2012a)[1]. At the same time, about 40 EEA indicators on climate change and impacts were updated on the EEA website[2] and thus also in Climate-ADAPT. This ETC CCA Technical Paper provides further information on the selection of indicators included in the 2012 CCIV report.

The choice of indicators is a critical step in this assessment. Ideally indicators provide highly reliable information on the phenomena they are expected to illustrate, long temporal perspectives and sufficient spatial resolution. The main purpose of this technical paper on evaluation of climate change state, impact and vulnerability indicators is to present and discuss criteria that have been used in the evaluation of indicators. These criteria were developed in parallel and in interaction with the general work on indicator evaluation that the EEA has carried out in its review of the governance and use of environmental indicators in Europe.

This technical paper starts with a brief description of the purpose of the 2012 CCIV report (Chapter 1), followed by overviews of the different types and policy purposes of climate-related indicators presented therein (Chapter 2) and of related indicator sets (Chapter 3). The main part of this document describes the evolution of evaluation criteria for selecting climate-related EEA indicators (Chapter 4) and the application of those criteria to the indicators presented in the 2012 CCIV report. The technical paper concludes with some reflections on the application of the criteria to different groups of indicators in the 2012 CCIV report (Chapter 6). Two conference papers on the 2012 CCIV report that were presented at the conference *Impacts World 2013 (International Conference on Climate Change Effects, Potsdam, 27-30 May 2013)* are included as annexes.

[1] http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012
[2] http://www.eea.europa.eu/data-and-maps/indicators/

1 Introduction

Indicators are being developed in order to provide salient information on important societal issues in a condensed and easily understandable form. The EEA has specified environmental indicators to be "a measure, generally quantitative, that can be used to illustrate and communicate complex environmental phenomena simply, including trends and progress over time – and thus helps provide insight into the state of the environment" (EEA, 2005a). The Impact Assessment of the European Commission's 2009 White Paper on adaptation (EC, 2009) describes the purpose and scope of indicators, as to "build a structured information dataset to better understand the territorial and sectoral distribution of vulnerability to climate change impacts, vulnerability being defined as a function of 1) the exposure to CC impacts, 2) the sensitivity and 3) the adaptive capacity of a system or territory)".

Generally three main purposes can be identified for climate change impact, vulnerability and adaptation indicators at the European level. They should:

1. Support European assessments of observed and projected impacts and social, economic, and ecological risks/vulnerabilities in order to raise awareness and improve the knowledge base of policy development;
2. Support European policy development, specifically by contributing to the knowledge base of decisions on adaptation and funding allocations (this includes Impact Assessments of proposed EU policies and mainstreaming into existing or planned EU policies); and
3. Contribute to the monitoring in the progress of implementation of adaptation actions and effectiveness in reducing risks/vulnerability, or increasing resilience.

The recently adopted EU Adaptation Strategy (EC, 2013) also refers to indicators (e.g.in the context of the proposed adaptation preparedness scoreboard). The focus there is on adaptation actions (corresponding to point 3 above) rather than on climate change and its impacts.

The EEA report on *Climate change, impacts and vulnerability 2012* (2012 CC IV report; EEA, 2012a), which presents information on past and projected climate change and related impacts in Europe are based on a range of indicators that primarily fulfil the first purpose. The report was published in November 2012 with contributions from JRC, ECDC, WHO and a large number of research institutes, agencies and individual scientists. The main objectives of the 2012 report were to:

- present past and projected climate change and impacts through indicators;
- identify sectors and regions most at risk;
- highlight the need for adaptation actions;
- identify main sources of uncertainty;
- demonstrate how monitoring and scenario development can improve the knowledge base.

The 2012 CC IV report uses indicators to assess the vulnerability of society, human health and ecosystems in Europe and identifies, and, where the spatial resolution allows, regions in Europe most at risk under climate change. Furthermore, the report discusses how monitoring and scenario development can improve our understanding of climate change, its impacts and related vulnerabilities. EEA also published a separate report in March 2013 focusing entirely on adaptation (EEA, 2013). The report on adaptation is not based on indicators, because so far indicators on adaptation are not widely used. However, as mentioned above, the EU Adaptation Strategy foresees the development of indicators to assess the adaptation preparedness of its Member States.

The choice of indicators is a critical step for any of the purposes listed above. Ideally indicators provide highly reliable information on the phenomena they are expected to illustrate, long temporal perspectives and sufficient spatial resolution. In reality there are many practical obstacles in developing and using indicators. The 2012 CC IV report discusses principal sources of uncertainty that affect our knowledge of climate change. In addition to uncertainty a number of other criteria can affect the choice of indicators to be presented and followed.

The main purpose of this technical paper on evaluation of CC state, impact and vulnerability indicators is to present and discuss criteria that have been used in the evaluation of indicators for climate change state, impact and vulnerability and that contributed to the selection of indicators for the 2012 CC IV report. These criteria were developed in parallel and in interaction with the general work on indicator evaluation that the EEA has carried out in its review of governance and use of environmental indicators in Europe during 2011-2013.

2 Indicator context

Indicators have to be placed in a context that provides a base for an interpretative narrative. 'Climate change' needs to specified in order to identify meaningful indicators.

The IPCC has defined *Climate change* ('state of climate') to be any change in climate over time, whether due to natural variability or the result of human activity (IPCC, 2007b). *Climate change impacts* refer to observed or projected effects of climate change on natural and human systems. Projections often refer to the 'potential impacts', which are all impacts that may occur given a projected change in climate, without considering adaptation.

The selection of indicators for climate change also needs to consider the links to possible action. For climate change impacts, vulnerability and adaptation four broad types of indicators can be distinguished:

1. State of the climate
2. Biophysical impacts of climate change
3. Social, economic, and ecological vulnerability/risks
4. Adaptation actions

These categories of indicators have different purposes (see Table 2.1), and they are in different stages of development and usage. No country has yet specified a full set of 'adaptation indicators'. In UK[3], Germany[4], Finland[5] and a few other countries and through some work by EEA and its (former) ETC ACC[6] initial ideas on *monitoring of adaptation actions* have been developed, which might be called '*adaptation indicators*'. However, these are often only qualitative and not clearly defined. Therefore this technical paper focuses only on the three other main 'types' of relevant indicators: 'State of the climate'; 'Impacts'; 'Vulnerability/risks'.

[3] UK, 2010: Measuring adaptation to climate change - a proposed approach February 2010, http://www.defra.gov.uk/environment/climate/documents/100219-measuring-adapt.pdf;
UK ASC, 2011: Adapting to climate change in the UK – Measuring progress (Adaptation Sub-Committee progress report 2011), http://www.theccc.org.uk/publication/adapting-to-climate-change-in-the-uk-measuring-progress-2nd-progress-report-2011/;
UK ASC, 2012: Climate change – is the UK preparing for flooding and water scarcity? (Adaptation Sub-Committee progress report 2012), http://www.theccc.org.uk/publication/climate-change-is-the-uk-preparing-for-flooding-and-water-scarcity-3rd-progress-report-2012/
UK ASC, 2013, Managing the land in a changing climate (Adaptation Sub-Committee progress report 2013), http://www.theccc.org.uk/publication/managing-the-land-in-a-changing-climate/

[4] UBA, 2010: Establishment of an Indicator Concept for the German Strategy on Adaptation to Climate Change http://www.uba.de/uba-info-medien-e/4031.html

[5] MMM 2009: Evaluation of the Implementation of Finland's National Strategy for Adaptation to Climate Change. http://www.mmm.fi/en/index/frontpage/climate_change_energy/adaption/evaluation_of_strategy.html

[6] ETC ACC Technical paper 2010/15, ' Adaptation Indicators for Biodiversity '. http://acm.eionet.europa.eu/reports/ETCACC_TP_2010_15_Adap_Ind_Biodiv.
ETC ACC Technical paper 2009/6, Development of Adaptation Indicators, http://air-climate.eionet.europa.eu/reports/ETCACC_TP_2009_6_ETCACC_TP_2009_6_Adapt_Ind

Table 2.1 Categories of indicators related to climate change state, impacts and vulnerabilities and their main purposes.

Indicator category	**Main purpose**
State of climate change (e.g. temperature, precipitation, sea level rise)	Raise awareness and develop the knowledge base of the processes of climate change in order to justify action.
Climate change impacts (e.g. floods, droughts, change in biodiversity)	Raise awareness, develop the knowledge base on the nature and processes of impacts, help determine vulnerability in order to justify and focus action.
Social, economic, and ecological vulnerability/risks (determined by biophysical impacts, their relevance for a sector or region, and the available coping and adaptive capacity)	Identify adaptation needs and options, justify and focus decisions on funding and other resource allocation and monitor progress in adaptive capacity

One of the key concepts for action is vulnerability. *Vulnerability* is generally interpreted as an integrative concept that links the social and biophysical dimensions of climate change. Quantitative statements and indicators about vulnerability require clear specification of the vulnerable system, the hazard(s) it is vulnerable to, the attributes at risk (i.e., the adverse impacts) from exposure to this hazard, and the time horizon. Furthermore there are multiple interpretations, definitions and methods of what constitutes vulnerability and how to measure the concept 'on the ground', resulting in important differences between the dominant interpretation of this concept in the climate change and natural hazards contexts.

The IPCC Fourth Assessment Report has defined vulnerability (to climate change) as follows: "*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which as system is exposed, its sensitivity, and its adaptive capacity*" (IPCC, 2007a). This definition is not without problems. For example, a literal interpretation of the vulnerability definition from IPCC would assign low vulnerability to regions and sectors that are exposed to and sensitive to climate change as long as their adaptive capacity is high enough. Such an assessment of low (post-adaptation) vulnerability reflects the expectation that the residual impacts of climate change will be low if the adaptive capacity of the region is actually implemented. Somewhat different definitions of vulnerability (to climate change) and of (disaster) risk have been proposed in the IPCC SREX (IPCC, 2012).

The example shows that care is needed in interpreting indicators on climate change when they are used to guide decisions. One way to deal with this is to reflect on indicators in a risk framework. Thus the UK explicitly uses indicators together with a risk approach and a conventional definition of risk (the probability of an adverse event multiplied by its consequence) in their first national climate change risk assessment (DEFRA, 2012).

The EEA recognises the multiplicity of definitions and interpretations of important concepts (such as vulnerability) in climate change science and policy. The approach in the 2012 CC IV report has therefore been *not* to choose one specific definition of vulnerability and/or risk over others but to use these terms in line with their everyday use where possible and to provide further clarification where needed (for further information, see Section 1.7 in EEA, 2012a).

3 Existing European climate change indicator sets

EU-wide indicator-based assessment reports (EEA, 2008a, 2012a), and also EU research projects have developed and presented climate change and climate change impact indicators for the following broad categories:

- Atmosphere and climate
- Cryosphere (glaciers, snow and ice)
- Marine biodiversity and ecosystems
- Water quantity
- Freshwater quality and biodiversity
- Terrestrial ecosystems and biodiversity
- Soil
- Agriculture and forestry
- Human health

The 2008 EEA/JRC/WHO report (EEA, 2008a) covered about 40 indicators for observed and projected climate change, and observed and projected climate change impacts for these categories. The 2012 EEA report (EEA, 2012a) covered approximately the same number of indicators and topics with some revisions at the level of specific data sets.

Vulnerability information based on a combination of information on (potential) climate impacts and on socio-economic data (e.g. people affected and/or damage costs) were included in the 2008 EEA/JRC/WHO report only for a limited number of issues for which information was available. EEA updated analyses of climate change impacts, vulnerability and adaptation within Europe for its State of the Environment and Outlook report 2010 (EEA, 2010). These reports included the following vulnerability indicators (based mainly on the results from PESETA[7]):

- river floods (damage, people exposed)
- coastal areas (damage, people exposed)
- agriculture (crop yield changes)
- tourism (changed conditions for summer tourism)

Also one indicator was included from another source:

- energy (projected changes in hydropower production in Scandinavia)

Within *ESPON* several projects have been performed on vulnerability to climate change and on natural hazards (also trying to combine both aspects), usually at NUTS3 level of spatial detail. The ESPON-climate project "Climate Change and Territorial Effects on Regions and Local Economies in Europe" was finalised in May 2011 and the report (ESPON Climate, 2011) includes numerous indexes that aim at providing answers to the question "How and to which degree are sectors of regional and local economies and regional and local infrastructures going to be affected by climate change? The approach is based on aggregated indexes that are presented in a spatially explicit way using maps.

An indicator-based impact assessment framework has also been developed for the European Union NUTS-2 level that quantifies potential regional changes in weather-related hazards together with an index of regional adaptive capacity that identifies the potentially most vulnerable regions in Europe

[7] For the final results of the PESETA project and of the recently concluded PESETA II project, see http://peseta.jrc.ec.europa.eu/

(Lung et al., 2013). Such studies allow hotspot regions to be identified, which can guide efforts to increase adaptive capacity.

DG REGIO developed in 2009 within the Regions 2020 study a climate change vulnerability index (EC, 2008). It is one of four indices developed to inform discussions of future EU cohesion policy. This index focuses on the exposure of population and economic sectors to climate change, taking into account the sensitivity to various climate risks (riverine and coastal floods) and the importance of various climate-sensitive sectors (agriculture, fisheries, and tourism) for regional economies. The index was updated in the Fifth Cohesion Report (EC, 2010).

Further information on main EU indicator developments and on thematic and sectoral indicator sets is available in the 2012 CC IV report (EEA, 2012a, Section 1.4.3 and 6.1.2).

4 Evaluation criteria for indicators

4.1 General approach to evaluation criteria

The assessment of climate state, impact, vulnerability and adaptation can rely on indicators that characterize aspects of the environment as well as of the coupled human–environment system. Evaluation criteria need to be defined to ensure that indicators are scientifically credible and relevant for policy planning, implementation, and monitoring. Several sets of evaluation criteria have been developed to ensure that indicators fulfil their task (Niemeijer and de Groot, 2008). These include SMART (Schomaker, 1997) with five criteria (Specific, Measurable, Achievable, Relevant, Timebound) which is widely used in UN Organizations. Other evaluation criteria sets for environmental indicators vary in the total number of criteria and in criteria types. EEA (2005a) defined nine criteria for the EEA core set of indicators, where four were policy related, another four were data related and one criterion was related to them being scientifically accepted. Voigt and van Minnen (2007) worked on evaluation criteria which are presented further below together with the criteria for the SEBI process (EEA, 2012c). In the EEA indicator review process (2011-2012) four groups of criteria were used, i.e. relevance, method and process, coverage and user friendliness with a total of eight criteria. A new criterion relative to previous evaluations was the explicit recognition of the need to assess uncertainties.

The recognition of uncertainty is particularly relevant in the context of climate change, where uncertainties vary in type and magnitude. These uncertainties are often difficult to convey in simple indicators. Nevertheless, the acceptance of indicators is dependent on the transparency of their selection and on the availability of sufficient contextual information. Therefore, indicators should be contextualized and information on evidence, agreement, confidence or uncertainties should also be noted in the selection and presentation of indicators.

The final identification of indicators is usually a step by step procedure based on consensus on the evaluation criteria derived in a group discussion with experts. This was also the case for the indicators selected for the impacts and vulnerability report 2012. In the process an external Advisory Group consisting of representatives of European policymakers and international organizations provided additional advice. Hence, the selection criteria presented below were not normative in the sense that they could have been aggregated to a single quality measure for 'automatic' selection of indicators above a given quality threshold. Instead the criteria provided input into the discussions on what the indicators could and could not achieve, and contributed thereby to informed decisions on what to include in the final report and the indicator management system of the EEA.

4.2 Criteria previously used by EEA

The process for the selection and the development of the SEBI2010 indicators and the preparation of related reports was done in a formalized and transparent way (EEA, 2012c). The advantage of such an approach is the transparency and the fostering of common ownership, although it may mean substantial work, including a series of dedicated meetings. The aim of the SEBI was to establish a set of indicators for monitoring progress towards and helping achieve the biodiversity 2010 target, relevant at the European level. Subsequently countries on a voluntary basis could also use the set for their national purposes.

Voigt and van Minnen (2007) developed a set of criteria for the 2008 indicator report on climate change, impacts, vulnerability and adaptation. In addition to indicator specific criteria, the following general criteria were used to evaluate the set as a whole:

- Representative: the set of indicators provides a representative picture of relevant domains, including state of the climate system, biophysical impacts, and social, economic, and ecological vulnerability/risks.
- Small in number: the smaller the total number of indicators, the easier it is to communicate cost−effectively to policy-makers and the public.
- Aggregation and flexibility: aggregation should be facilitated on a range of scales.

The final result of the selection process was included and described in the 2008 report (EEA, 2008a). For the 2012 CC IVA report (EEA, 2012a) the approach resembled the SEBI2010 indicator selection and development which meant discussions and transparent documentation throughout the process.

The main criteria as used in 2007 for SEBI and for the 2008 CC IVA report were compared with the aim to establish an improved list of criteria for the 2012 report (Table 4.1). It was found that indicators including projections required partly different criteria from those that only provided information on the historical development (see below).

Table 4.1. Annotated comparison of the criteria of 2007 and the SEBI 2007 criteria

Criteria ETC ACC (Voigt et al., 2007)	**SEBI 2007** (EEA, 2012c)	**Comments**
1. Policy relevance	1. Policy relevant and meaningful: indicators should send a clear message and provide information at a level appropriate for policy and management decision-making by assessing changes in the status of biodiversity (or pressures, responses, use or capacity), related to baselines and agreed policy targets if possible. 2. Biodiversity relevant: indicators should address key properties of biodiversity or related issues as pressures, state, impacts and responses.	Two issues: 1) Relevance in terms of concern (such as temperature increase) but has no immediate relevance for decisions, i.e. instrumental use is not possible/meaningful. Conceptual and political use dominate[8]. 2) Relevance in terms of specific decisions such as allocation of funds for flood protection. Indicators can be used instrumentally in the design of policies.
2. Progress towards the target	3. Progress towards 2010: indicators should show clear progress towards the 2010 target.	Other than general global 2 ^{o}C target few if any targets at a European level. Europe 2020 strategy[9] qualitative objective: *'We must also strengthen our economies'*

[8] The study of the use of research and indicators has identified different categories of use. (1) Instrumental use refers to using indicators as a basis for changing behaviour or action, (2) conceptual use refers to slower changes in user attitudes or ideas as a consequence of information provided by the indicators, and (3) political or legitimising use occurs when indicators are used to convince others to support or defend a particular position. (Weiss, 1979; Rosenström, 2009)

[9] http://ec.europa.eu/europe2020/index_en.htm (Visited 14.7.2013)

		resilience to climate risks, and our capacity for disaster prevention and response'. EU Adaptation Strategy objective: '*The overall aim of the EU Adaptation Strategy is to contribute to a more climate-resilient Europe. This means enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels, developing a coherent approach and improving coordination.*'
3. Routinely collected data	6. Routinely collected data: indicators must be based on routinely collected, clearly defined, verifiable and scientifically acceptable data.	The criterion refers to the 'technical' quality of the underlying data such as the statistical base
4. Spatial coverage	8. Spatial coverage: indicators should ideally be pan-European and include adjacent marine areas, if and where appropriate.	Technical quality and underlying statistical base. Criterion somewhat limited as impacts and vulnerabilities are context and spatially specific
5. Time series	9. Temporal trend: indicators should show temporal trends.	Technical quality and underlying statistical base
6. National scale and representatives for countries	10. Country comparison: as far as possible, it should be possible to make valid comparisons between countries using the indicators selected.	Technical quality and underlying statistical base. Criterion somewhat limited as impacts and vulnerabilities are context and spatially specific, but adjacent countries or otherwise similar can be compared meaningfully
7. Easily understandable	5. Acceptance and intelligibility: the power of an indicator depends on its broad acceptance. Involvement of policy-makers as well as major stakeholders and experts in the development of an indicator is crucial.	Dissemination criterion, favours variables to which it is easy to relate as opposed to complex indexes. For example a change in phenology of specific selected species as opposed to a composite index giving a dimensionless number for the change in phenology of a wide range of different species.
8. Methodologically well founded	4. Well founded methodology: the methodology should be clear, well defined and relatively simple. Indicators should be measurable in	Technical quality – statistical base

	an accurate and affordable way, and constitute part of a sustainable monitoring system. data should be collected using standard methods with known accuracy and precision, using determinable baselines and targets for the assessment of improvements and declines.	
	7. Cause-effect relationship: information on cause-effect relationships should be achievable and quantifiable in order to link pressures, state and response indicators. These relationship models allow scenario analysis and represent the basis of the ecosystem approach.	General justification for the designation as an indicator as opposed to a simple statistical variable. A clarification of the "underlying story" but not necessarily the DPSIR-framework
9. Priority topics		Related to policy relevance.
10. Timeliness	11. Sensitivity towards change: indicators should show trends and, where possible, permit distinction between human-induced and natural changes. Indicators should thus be able to detect changes in systems in timeframes and on scales that are relevant to the decisions, but also be robust enough to measure errors that do not affect interpretation.	Related to the type of use, but also includes an element of technical quality. The relationship between the 'measuring of errors' and interpretation is not fully clear. For decisions robustness against measuring errors appears more important.
11.Transparency, clarity and quality of the process		Relates to the choice of indicators, not the maintenance. Also related to the type of use.

4.3 Criteria for evaluating indicators for the 2012 EEA CC IV report

Twelve criteria, categorized into five groups, were used to evaluate indicators considered for inclusion in the EEA Report on Climate change, impacts and vulnerability in Europe 2012.

4.3.1 Groups of criteria

Some of the criteria set basic quality requirements on potential indicators such as the length of the available data series and methodological soundness whereas other criteria aimed to ensure that necessary background information was easily available in order to place the indicator in a proper context. The following groups of criteria were used

- Policy relevance
- Relevance for climate change
- Methodological validity (including uncertainty)
- Data availability
- Acceptability

Each group of criteria included two or three specific criteria. Operational interpretations and a scale were developed to provide indicative information for scoring how well an indicator met a particular criterion.

'Policy relevance' was a key group of criteria as indicators were expected to support policy development. In the EEA internal review of policy relevance two operational criteria were formulated: a) Is the indicator policy relevant, i.e. supporting EU policies' priority issues? and b) Does the indicator correspond to current EU Environmental Policy issues?

In a broad sense any indicator on climate change is policy relevant as climate change is a priority area for the EU. To be useful the relevance had to be indicatively scored. This could partly be done by linking the relevance more explicitly to policy targets. Thus the objective of the Europe 2020 strategy is to "*strengthen our economies' resilience to climate risks, and our capacity for disaster prevention and response"*. Similarly, the overall aim of the EU Adaptation Strategy (adopted after the publication of the 2012 CCIV report) is *"to contribute to a more climate-resilient Europe. This means enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels, developing a coherent approach and improving coordination.*'These documents provide some 'guidance' in judging the level of policy relevance. Unfortunately it is difficult to determine whether the EU is "on track" towards resilience to climate change due to methodological problems and the lack of data. There are no simple indicators for resilience and adaptive capacity. This is also shown by the EEA 2013 report on adaptation (EEA, 2013) which is primarily qualitative, based among others on information from national adaptation strategies, case studies and policy overviews, rather than quantitative indicators.

In addition to the policy targets relating specifically to climate change, it was feasible to address the policy relevance of potential indicators by indicating whether the indicator provided information on progress towards agreed policy targets in other key environmental themes such as:

- Nature and biodiversity (terrestrial and marine)
- Water stress and water quality (ecological)
- Air quality (acidification, eutrophication and human health)

In applying the criteria a distinction had to be made between (parts of) indicators that document a historical development ("past trends") and those that are based on future projections ("outlook indicators"). Although the same basic groups of criteria were relevant, the interpretation of specific criteria depended on whether the data referred to historical observations or to future projections. In the latter the focus of the evaluation are the models are used to provide the projections.

The weight and importance of different specific criteria depended on the nature and subject of the indicator. For example indicators of climate change state demand long time series. These were expected to cover climatological normal periods (30 years), especially for phenomena with high interannual variability. Climate impact indicators were more complex in terms of data demand and a preference was set for at least 20 years. Indicators of vulnerability in terms of the development of physical infrastructure, such as buildings in flood prone areas, were assumed to give reliable indications of development also over shorter periods of time.

4.3.2 Indicators of observed change

Each group includes two or several specific criteria that can be operationalized (Table 4.2). The explanations aim at providing a base for an indicative scaling that is developed in Chapter 5.

Table 4.2. Detailed criteria for the evaluation of indicators of observed change

Criteria	Explanation and comments
Policy relevance 1. Relevant for areas of EU policies and actions 2. Link to existing or emerging policy targets	1. The specific policies which the indicator is expected to serve can be identified. The indicator should provide a clear message and provide information at a level appropriate for European policy development and implementation by assessing changes in the status of relevant variables (or pressures, responses, use or capacity). 2. Indicators should be related to baselines and agreed policy targets to the extent possible. In the case of future targets, they should facilitate assessing the chances of achieving these targets. Relevant targets and objectives for climate change and adaptation include the 2 ^{o}C target and the qualitative Europe 2020 target ‘'We must also strengthen our economies' resilience to climate risks, and our capacity for disaster prevention and response'. Thematic specific objectives and targets such as the WFD and MSD objectives for inland waters and marine ecosystems respectively, the floods directive, the CBD and European targets for biodiversity, and targets and air quality targets can be referred to in evaluating specific indicators. Also general targets of the sustainable developments strategy and the Sixth Environment Action Programme of the European Community 2002-2012 indicate areas and issues of concern.
Relevance for climate change 3. Causal link to climate change 4. Sensitivity towards change	3. The direct causal chain or causal network that links an indicator to climate change and justifies its use in the context of climate change state, impact or vulnerability has been identified and adequately described, and preferably also quantified. 4. Indicators should be sensitive to changes in climate and/or climate policies. Indicators should be able to detect changes in systems in timeframes and on scales that are relevant to policy decisions. They should be robust enough to errors of measurement to avoid over-interpretation of spurious trends. Baselines and targets for the assessment of improvements and declines should ideally be known in advance. The signal to noise ratio should be considered at least at a qualitative level.
Methodological validity (including uncertainty) 5. Transparent methodology 6. Valid model base 7. Uncertainty assessment	5. The methodology for the indicator construction should be transparently described and well founded to allow for critical evaluations. 6. If an indicator is based on models these should be adequately documented and validated. This also applies to dynamic models as well as statistical models that are used to derive indicators from heterogeneous data sets (e.g. regional temperature averages). 7. Key uncertainties in the measurement of underlying data and key assumptions in the indicator construction have been identified and their implications for indicator values and trends assessed.
Data availability 8. Data availability	8. Indicators should be measurable in an accurate and affordable way, and constitute part of a sustainable monitoring system. Data should be

and regular updating 9. Spatial coverage and resolution 10. Length of time series and temporal resolution	collected using standard methods with known accuracy and precision, and data should be publicly available. Indicators should preferably be routinely updated without excessive time lags. 9. Indicators should cover an area that is meaningful for European policy making. The spatial resolution (e.g. the number of observation points) should be sufficient to detect relevant changes. 10. The length of the time series should be adequate for determining trends. Twenty years is generally a minimum but for variables with large interannual variability even longer time series should be used. The temporal resolution should be adequate for describing the relevant topic (e.g., monthly averages cannot illustrate floods).
Broad acceptability 11. Intelligibility 12. Participatory development	11. Indicators should preferably be intuitively comprehensible and easy to understand without deep knowledge of how the indicator has been constructed. 12. Policy-makers as well as major stakeholders and experts should have been involved in the development.

4.3.3 Indicators of projected change ("outlook" indicators)

The criteria for indicators of projected change differ from those based for observed change mainly when it comes to methodological aspects and in the interpretation of uncertainties (Table 4.3).

Table 4.3. Detailed criteria for the evaluation of indicators of projected change

Criteria	Explanation and comments
Relevance for policy 1. Relevance for specific policies 2. Links to existing or emerging policy targets	1. As for observed indicators. 2. As for observed indicators.
Relevance for climate change 3. Causal link to climate change 4. Attribution to climate change	3. As for observed indicators. 4. Sensitivity analyses of models used in projections reveal critical variables and allow attribution of projected changes to climate change and/or assessment of the relative importance of different drivers
Methodological validity (including uncertainty) 5. Transparent methodology 6. Valid model base 7. Uncertainty assessment	5. As for observed indicators (but the importance of documenting the model base, see separate point 6, is generally more important). 6. Models should be adequately documented and validated as appropriate for different types of models (for example emissions scenarios, climate models, climate impact models). 7. Relevant uncertainties that could affect the projections and their interpretation have been identified and ideally assessed. Climate impact projections should be based on a sufficiently wide range of global emissions or climate scenarios and of climate impact models where available. Availability of probabilistic results facilitates assessment of climate change-related risks.
Data availability 8. Data availability and regular	8. Models should be maintained and updated. Projections should include output in terms of variables that are routinely monitored to allow for

updating. 9. Spatial coverage and resolution 10. Length of projections and temporal resolution	future validation of projections. 9. As for observed indicators. 10. As for observed indicators. Length of projection(s) should correspond to policy targets and objectives where available.
Broad acceptability 11. Intelligibility 12. Participatory development	 11. As for observed indicators. 12. As for observed indicators.

5 Applying the criteria in evaluating indicators

5.1 Indicative scoring scales

The specified criteria were used to systematically evaluate proposed indicators. Guiding questions and scores were developed in order to help evaluators in assigning indicative numerical assessments of the indicator to be evaluated. The scales were intended to support consistency in the application of the specific criteria across indicators. The goal was not to specify values that could be summed over different criteria to form a grand total quality value for each potential indicator. Such a full "quantitative" evaluation was not considered meaningful because the weight of a particular criterion will vary depending on the specific indicator and its use.

5.2 Scales for scoring indicators of observed change

The following tables provide sets of questions that lead to an indicative scoring with respect to the criteria. The importance of the questions varied with the indicator. For a broad overview an average score at the group level gave hints of the general quality, but it was also found that it was often easier to score criteria individually. The detailed evaluation questions were useful in highlighting different aspects covered by a group of criteria.

Policy relevance

Criteria	Evaluation questions	Score (1-5)	
1. Relevant for areas of EU policies and actions **2. Link to existing or emerging policy targets**	**Questions**: To what extent can one identify specific European level policies that are directly served by the indicator? To what extent do specific target exist?	1	Relevance at the level of general climate change policy, not possible or meaningful to link to specific policy areas
		2	The indicator has some links to specific policy areas, but many confounding factors mean that it cannot be used in concrete choices between policy options
		3	The indicator guides the general setting of priorities in specific policy areas, but the indicator is not expected to provide information that can be used to guide the actual implementation of the policy(ies)
		4	The indicator guides the general setting of priorities in specific policy areas, and the indicator is expected to provide some guidance on the actual implementation of the policy(ies)
		5	The indicator is intimately linked to the development of specific policies. Choices are made and the implementation is tracked by following changes in the indicator values

Relevance for climate change

Criteria	Evaluation questions	Score (1-5)	
3. Causal link to climate change	**Questions**: How well are the relevant cause-effects	1	The indicator illustrates general climate related issues, but the links to anthropogenic climate change state, impact or vulnerability are

4. Sensitivity towards change	known and documented? Which aspects of climate change (state, impact or vulnerability) are covered? Are changes in the climate change state, impact or vulnerability reflected in the indicator? Do baselines and targets for the assessment of improvements and declines exist?		unproven. The variation in the indicator is probably almost independent of variation in the climate change state, impact or vulnerability.
		2	The indicator has been shown to have some links to anthropogenic climate change state, impact or vulnerability, but confounding factors make the links highly uncertain, contested and difficult to confirm. Some variation in the indicator can be tentatively attributed to variation in the climate change state, impact or vulnerability.
		3	The indicator has been shown to have links to anthropogenic climate change state, impact or vulnerability, but confounding factors make the links uncertain. Some variation in the indicator can be attributed to variation in the climate change state, impact or vulnerability.
		4	The indicator has been shown to have links to anthropogenic climate change state, impact or vulnerability, and have been confirmed in several independent studies. Some uncertainties concerning the generality of the links remain, but parts of the variation in the climate change state, impact or vulnerability is clearly reflected in the indicator values.
		5	The indicator has been shown to have links to anthropogenic climate change state, impact or vulnerability. The links are uncontested and strong so that specific changes in climate change state, impact or vulnerability are reflected in the indicator values.

Methodological validity (including uncertainty)

Criteria	Evaluation questions	Score (1-5)	
5. Transparent methodology **6. Valid model base**	**Questions**: To what extent is the methodology clear, well defined and transparent so as to allow critical evaluations of the indicator. Have models and statistical procedures been adequately described and validated?	1	Largely ad hoc based methodology that is weakly documented, lack of meta-data, not well specified statistical or other modeling methodology
		2	Methodology partly documented, documentation not easily available, ad hoc procedures used, meta data partially available. Modeling or statistical methodology described at a general level.
		3	Methodology documented but documentation not easily available, some ad hoc procedures used, meta data exist for key sources. Modeling or statistical methodology described but validation is missing.
		4	Detailed documentation of methodology available, all procedures are described and meta data exist for key sources. Modeling or statistical methodology described and validation is reported.

		5	Detailed documentation of methodology available, all procedures are described and meta data exist for key sources. Independent peer-reviewed analyses have confirmed soundness of methodology, models and statistical procedures.
7. Uncertainty assessment	**Questions**: To what extent is relevant information available to assist interpretation of changes in the indicator (e.g., key uncertainties, non-climatic confounding factors) to judge the reliability of the indicator concerning the relevant climate change state, impact or vulnerability?	1	Little or no information on uncertainties
		2	General indicative information on important uncertainties and possible confounding factors
		3	Structured information on important uncertainties and known confounding factors
		4	Structured information on important uncertainties and known confounding factors and indications of their consequences for the interpretation of the indicator.
		5	Consistent treatment of uncertainties following IPCC guidance[10] with clear and explicit specification of the consequences for the interpretation of the indicator.

Data availability

Criteria	Evaluation questions	Score (1-5)	
8. Data availability and regular updating	**Questions**: To what extent is the indicator measured in an accurate and affordable way, constituting part of a sustainable monitoring system? To what extent are data collected using standard methods with known accuracy and precision? How frequently and how rapidly are the data updated.	1	Separately acquired data, routine collection does not exist and data is not generally accessible. Lack of information on accuracy and precision. Updating at irregular intervals.
		2	Partly routine collection, and part of the data is accessible. Indicative information on accuracy and precision. Infrequent updating with considerable time lags.
		3	Mainly routine collection, most of the data is accessible and freely available. General information on accuracy and precision. Regular updating, but time lags may be significant (years).
		4	All data produced by routine collection, and the data is accessible and freely available through open sources. Information on accuracy and precision. Regular updating, moderate time lags.
		5	All data produced by routine collection and data production is maintained by an established monitoring system. Data is accessible and freely available through open sources. Independent analyses of accuracy and precision are available. Regular and rapid updating of data.

[10] Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties

Criteria	Evaluation questions	Scoring (1-5)	
9. Spatial coverage and resolution	**Questions**: To what extent does the indicator cover meaningful areas from the point of view of European policy making? To what extent is the spatial resolution sufficient for detecting relevant changes in climate change state, impact or vulnerability.	1	Local indicator that is of limited utility at a European level or indicator is due to coarse spatial resolution only able to register major changes in climate change state, impact or vulnerability.
		2	Indicator that may serve specific (regional) European level policies. Can register some regional changes related to climate change state, impact or vulnerability.
		3	Indicator serves important regional European level policies. Can register regional changes related to climate change state, impact or vulnerability.
		4	Indicator serves European wide policies. Can register regional changes related to climate change state, impact or vulnerability.
		5	Indicator serves European wide policies. Can register European wide changes related to climate change state, impact or vulnerability.
Criteria	**Evaluation questions**	**Score (1-5)**	
10. Length of time series and temporal resolution	**Questions**: To what extent is the temporal resolution adequate for describing the relevant state, impact or vulnerability? To what extent is time series adequate for determining trends, considering the interannual variability.	1	The indicator gives crude information of temporal variability and the length of the data series is too short (<<20 years) to give reliable indication of trends.
		2	The indicator can capture adequately short term variability but the length of the data series is too short (<<20 years) to give reliable indication of trends.
		3	The indicator gives somewhat crude information of short term variability but the length of the data series is reasonably long (around 20 years or more) to give indication of trends.
		4	The indicator gives information of short term variability (or short term variability is not relevant) and the length of the data series is reasonably long (around 20 years or more) to give indication of trends.
		5	The indicator gives information of short term variability (or short term variability is not relevant) and the length of the data series is adequate (well above 30 years) to give reliable information of trends.

Broad acceptability

Criteria	Evaluation questions	Score (1-5)	
11. Intelligibility **12. Participatory development**	**Questions**: To what extent is the indicator intuitively comprehensible and easy to understand without deep knowledge of how the indicator has been constructed? To what extent is the indicator accepted by important stakeholder and the public? To what extent have stakeholders had an opportunity to participate in the development of the indicator?	1	The indicator requires expert knowledge to be understood and has been developed by and for experts within a restricted field.
		2	The indicator requires expert knowledge to be properly understood but it has been used publicly to the extent that there is a general understanding of what it means. Specialist users refer to it.
		3	The indicator can be understood without expert knowledge, but its relationship with climate change state, impact or vulnerability and the meaning and magnitude of a change may remain obscure. Limited use among stakeholders.
		4	The indicator can easily be understood without expert knowledge, and its relationship with climate change state, impact or vulnerability is intuitively obvious and the magnitude of a change can be perceived with reference to everyday experience. Stakeholders follow the indicator routinely.
		5	The indicator can easily be understood without expert knowledge, and its relationship with climate change state, impact or vulnerability is intuitively obvious and the magnitude of a change can be perceived with reference to everyday experience. Stakeholders have contributed to its development and actively participate in the interpretation of the results.

5.3 Scales for scoring indicators of projected change ("outlook" indicators)

Policy relevance

Criteria	Evaluation questions	Score (1-5)	
1. Relevant for areas of EU policies and actions **2. Link to existing or emerging policy targets**	**Questions**: To what extent can one identify specific European level policies that are directly served by the indicator? To what extent do specific target exist?	1	Relevance at the level of general climate change policy, not possible or meaningful to link to specific policy areas
		2	The indicator has some links to specific policies areas, but many confounding factors mean that it cannot be used in concrete choices between policy options
		3	The indicator guides the general setting of priorities in specific policy areas, but the indicator is not expected to provide information that can be used to guide the actual implementation of the policy(ies)

		4	The indicator guides the general setting of priorities in specific policy areas, and the indicator is expected to provide some guidance on the actual implementation of the policy(ies)
		5	The indicator is intimately linked to the development of specific policies. Choices are made and the implementation is tracked by following changes in the indicator values

Relevance for climate change

Criteria	Evaluation questions	Score (1-5)	
3. Causal link to climate change **4. Sensitivity to climate change**	**Questions**: How well do the models reflect relevant and known cause-effects known? Which aspects of climate change (state, impact or vulnerability) are covered? Do projections reflect changes in the climate state, impact or vulnerability?	1	The projections illustrate general climate related issues, but the projection model is based on links to anthropogenic climate change state, impact or vulnerability that are speculative. The projections are practically independent of variation in the climate change state, impact or vulnerability.
		2	The projections are based on some known links to anthropogenic climate change state, impact or vulnerability, but confounding factors make the model subject to high uncertainties, and difficult to verify. Some variation in the projections can be attributed to variation in the climate change state, impact or vulnerability.
		3	The projections are based on known links to anthropogenic climate change state, impact or vulnerability, but confounding factors introduce uncertainties. Part of the variation in the projections can be attributed to variation in the climate change state, impact or vulnerability.
		4	The projections are based on well known links to anthropogenic climate change state, impact or vulnerability, and confounding factors introduce at modest uncertainties at most. Variation in the projections can be attributed to variation in the climate change state, impact or vulnerability.
		5	The projections are based on well known links to anthropogenic climate change state, impact or vulnerability, and the effect of confounding factors can be adequately modelled. Variation in the projections can be attributed to variation in the climate change state, impact or vulnerability.

Methodological validity (including uncertainty)

Criteria	Evaluation questions	Score (1-5)	
5. Transparent methodology **6. Valid model**	**Questions**: To what extent is the methodology clear, well defined and	1	Largely ad hoc based projection methodology that is weakly documented, without well specified statistical or other modeling methodology

base	transparent so as to allow critical evaluations of the indicator. Have models and statistical procedures been adequately described and validated?	2	Methodology partly documented, documentation not easily available, ad hoc procedures used. Modeling or statistical methodology described at a general level.
		3	Methodology documented but documentation not easily available, some ad hoc procedures used. Modeling or statistical methodology described but validation is missing.
		4	Detailed documentation of methodology available, all procedures are described. Modeling or statistical methodology described and validation is reported.
		5	Detailed documentation of methodology available, all procedures are described and openly available. Independent peer-reviewed analyses have confirmed soundness of methodology, models and statistical procedures.
7. Uncertainty assessment	**Questions**: To what extent is relevant information available to assist interpretation of changes in the indicator (e.g., key uncertainties, non-climatic confounding factors) to judge the reliability of the indicator concerning the relevant climate change state, impact or vulnerability?	1	Little or no information on uncertainties
		2	General indicative information on important uncertainties and possible confounding factors
		3	Structured information on important uncertainties and known confounding factors
		4	Structured information on important uncertainties and known confounding factors and indications of their consequences for the interpretation of the indicator.
		5	Consistent treatment of uncertainties following IPCC guidance[11] with clear and explicit specification of the consequences for the interpretation of the indicator.

Data availability

Criteria	Evaluation questions	Score (1-5)	
8. Data availability and regular updating	**Questions**: To what extent is the projection based on data that are regularly updated in a sustainable monitoring system? To what extent are input data used in projections based on standard methods with known accuracy and precision? How frequently and how rapidly are the	1	Separately created projections not supported by routine collection of data. Lack of information on accuracy and precision. Updating at irregular intervals.
		2	Projections use partly routinely collected and accessible data. Indicative information on accuracy and precision. Infrequent updating with considerable time lags.
		3	Projections use mainly routinely collected data, most of the data is accessible and freely available. General information on accuracy and precision. Regular updating, but time lags may be significant

[11] Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties (Mastrandrea, Field, Stocker, Edenhofer, Ebi, et al., 2010)

	projections updated.		(years).
		4	Projections use only routinely collected data, most of the data is accessible and freely available. General information on accuracy and precision. Regular updating, moderate time lags.
		5	Projections use only routinely collected data. Data used for projections is delivered by an established monitoring system. Data is accessible and freely available through open sources. Independent analyses of accuracy and precision are available. Regular and rapid updating of data.

Criteria	Evaluation questions	Score (1-5)	
9. Spatial coverage and resolution	**Questions**: To what extent does the indicator cover meaningful areas from the point of view of European policy making? To what extent is the spatial resolution sufficient for detecting relevant changes in climate change state, impact or vulnerability.	1	Local indicator that is of limited utility at a European level or indicator is due to coarse spatial resolution only able to project major changes in climate change state, impact or vulnerability.
		2	Indicator that may serve specific (regional) European level policies. Can project some regional changes related to climate change state, impact or vulnerability.
		3	Indicator serves important regional European level policies. Can project regional changes related to climate change state, impact or vulnerability.
		4	Indicator serves European wide policies. Can project regional changes related to climate change state, impact or vulnerability.
		5	Indicator serves European wide policies. Can project European wide changes related to climate change state, impact or vulnerability.

Criteria	Evaluation questions	Score (1-5)	
10. Length of time series and temporal resolution	**Questions**: To what extent is the temporal resolution adequate for describing the relevant state, impact or vulnerability? To what extent is time series adequate for determining trends, considering the interannual variability.	1	The projection model crudely temporal variability and the length of the projection is too short (<20 years) to give signals of change.
		2	The projection model can cover some significant temporal variability but the length of the projection is too short (<20 years) to give signals of change.
		3	The projection model covers sufficiently significant temporal variability. The length of the projection is too short (<20 years) to give signals of change.
		4	The projection model covers all significant temporal variability although the length of the projection is too short (<20 years) to give signals

			of change.
		5	The projection model covers all significant temporal variability and the length of the projection is long enough (>20 years) to give signals of change.

Broad acceptability

Criteria	Evaluation questions	Score (1-5)	
11. Intelligibility **12. Participatory development**	**Questions**: To what extent is the indicator intuitively comprehensible and easy to understand without deep knowledge of how the indicator has been constructed? To what extent is the indicator accepted by important stakeholder and the public? To what extent have stakeholders had an opportunity to participate in the development of the indicator?	1	The indicator requires expert knowledge to be understood and has been developed by and for experts within a restricted field.
		2	The indicator requires expert knowledge to be properly understood but it has been used publicly to the extent that there is a general understanding of what it means. Specialist users refer to it.
		3	The indicator can be understood without expert knowledge, but its relationship with climate change state, impact or vulnerability and the meaning and magnitude of a change may remain obscure. Limited use among stakeholders.
		4	The indicator can easily be understood without expert knowledge, and its relationship with climate change state, impact or vulnerability is intuitively obvious and the magnitude of a change can be perceived with reference to everyday experience. Stakeholders follow the indicator routinely.
		5	The indicator can easily be understood without expert knowledge, and its relationship with climate change state, impact or vulnerability is intuitively obvious and the magnitude of a change can be perceived with reference to everyday experience. Stakeholders have contributed to its development and actively participate in the interpretation of the results.

6 Summary of indicator evaluation

The scoring of the proposed indicators was originally carried out by the author(s) of the draft indicator assessment in the 2012 CC IV report The findings were reviewed by the EEA/ETC CCA "core team" (Füssel, Hildén and Marx) to increase consistency in the interpretations of the criteria scores. Some indicators, notably those related to forestry, were included at a later stage in the production of the report and did not go through the same structured review. Full consistency in the scoring was thus not achieved. The application of the criteria did nevertheless reveal some important differences between the indicators (Table 6.1).

The work with the choice of indicators for the 2012 IV report demonstrated that it is feasible and useful to develop criteria for the ex-ante assessment and also ex-post evaluation of indicators of climate change although some criteria proved to be more difficult than others (Table 6.2). The degree to which the process of evaluation and review should be formalized is also open to debate. A strictly formal process with an independent review team and rigorously specified scoring criteria could produce a maximally coherent overview of the indicators. Such a "blind" review is likely to emphasize criteria related to data and methods. A more informal review based on self-assessment by authors is likely to emphasize criteria of relevance, paying attention to context and practical data availability.

Initially it was considered necessary to treat indicators of past development and projections separately. However, in reporting and providing scores most contributors delivered an aggregate that gave a general score for the indicator, covering both observations and projections. Conceptually the main differences between observed data and projected data arise at the level of methodological validity and in the uncertainty assessment. Rather than going through two separate scoring exercises for observed and projected indicators, the experiences from the scoring process suggest that it is better to add an explicit note of widely divergent scores between observations and projections where relevant.

The ultimate choice of indicators for a report such as the 2012 EEA report have to be based on a pragmatic weighting of the different criteria. Potential indicators scoring consistently low (1-2) on many criteria should clearly be discarded, but a low score on some criteria should not lead to automatic rejection. There can be some compensation across criteria, but not in an automatic mathematical sense. The criteria represent genuinely different dimensions of factors that affect the usability and usefulness of the indicator and therefore the assumed use should also enter into considerations of what compensation is acceptable. Indicators intended for broad conceptual use, contributing to the general understanding of an issue may be allowed weaknesses in the quantitative estimation that would be unacceptable for an indicator needed in operational work on, for example, dam safety in flood prone areas.

For this report a total of 12 criteria were developed distributed into five groups. In hindsight, one might ask whether a more limited number might have been sufficient as well. However, such a discussion is beyond the scope of this Technical Paper.

Table 6.1. Evaluation of the different groups of indicators in the 2012 CC IV report

Indicator group	Reflections on the application of the criteria
Key climate variables	Generally high scores for all criteria. Interpretation of policy relevance for indicators such as storms and precipitation for which there are no specific policy targets was affected by the weight given to the general policy debate on climate change.
Cryosphere	The cryosphere variables are easy to understand and they have general policy relevance, but there are no specific targets. The available data series tend to be shorter than those for the key climate variables and there is also still on-going methodological development work. Quantitative projections are non-existent or very uncertain for many variables. Cryosphere projections scored lower than the projections of key climate variables.
Oceans and marine environment	Oceans and the marine environment provide indicators reflecting chemical and physical change (acidification, temperature and heat contents) and impacts on biota (phenology and distribution). All of these indicators provide relevant information on the progress of climate change, some of them also support the development of maritime and fishery policies (including funding priorities). Many of the indicators are methodologically demanding and still in a phase of active development, which led to low or intermediate scores on methodology and uncertainty assessment.
Coastal zones	Coastal regions are politically highly relevant, and events in the coastal zone have significant impact on European economies. Awareness of sea level rise plays an important role in the development of climate policies on mitigation and adaptation although no specific targets have been set. Concerns about storm surges and coastal erosion are important, in particular for Integrated Coastal Zone Management (ICZM) and for maritime spatial planning.
Freshwater quantity and quality	Indicators on water availability and management scored high on nearly all criteria. Projections based on modelling are available for both floods and drought whereas water temperature and ice cover follow general temperature projections.
Terrestrial ecosystems and biodiversity	Several indicators track climate change impacts on terrestrial ecosystems, but the scores varied. Policy targets are related to the conservation of biodiversity, independent of climate change, although the links are recognised. Projections have been made for biodiversity related indicators but the uncertainties are significant.
Soil	Soil variables are closely linked to climate variables and soil protection is a concern in Europe. However, currently there is no EU Soil Directive. Low scores on data availability limited the use of these indicators. Projections for soil are based on inferences from climate variables. No specific quantitative projections were included in the 2012 EEA report.
Agriculture	Agriculture provides examples of the impacts on socio-economic systems and their vulnerability to climate change. Indicators related to agriculture are generally easy to understand, they reflect important policy areas and there is extensive research and monitoring, hence scores on all criteria were medium to high. Model based projections are available for crop production, yield and irrigation.
Forests and forestry	Forestry and climate change is an emerging policy area in the EU (see the Green Paper "On Forest Protection and Information in the EU: Preparing Forests for Climate Change"[12]). Furthermore, climate change impacts in forests also affect many other aspects of society. Indicators were not scored as the indicators were added late in the process.
Fisheries and aquaculture	No quantitative indicators were included in the 2012 IV report.
Human health	Indicators on the impacts of climate change on human health are based on heterogeneous data sources. For some indicators, notably those related to disasters and extreme events, the scores on data availability were low due to rather short and incomplete time series.
Energy	The only indicator that scored sufficiently high to be included in the 2012 IV report was an indicator on the development of the energy need for heating.
Transport services and infrastructure	No quantitative indicators were evaluated for the 2012 IV report.
Tourism	No quantitative indicators were evaluated for the 2012 IV report.
Vulnerability	Vulnerability indicators have not been evaluated for inclusion in the EEA indicator management system[13], with the exception of an indicator of damage costs. This indicator is based on the best available data (based on historical data of Munich Re[14]) but the underlying data are not publicly available.

[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0066:FIN:EN:PDF
[13] http://www.eea.europa.eu/themes/climate/indicators#c10=CLIM&c5=all&c7=all&c13=50&b_start=0
[14] http://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-1/assessment

Table 6.2. Criteria used in the technical paper and comments on their use

Group of criteria	Specific criteria	Comments
Policy relevance	**EU-policies**	The separation into two criteria was in principle logically clear, but in practice difficult. The question of how specific a target should be to justify a claim that the indicator directly serves it remained partly unresolved, especially since also other policy areas than those strictly considered to be part of climate change policies came into play
	Targets	
Climate change	**Causal links**	The separation into two criteria is natural, but the temporal scale is an issue. A variable such as sea level rise is sensitive to climate change but the temporal change is very slow compared with, for example, changes in phenology.
	Sensitivity	
Methodological validity (including uncertainty)	**Transparency**	The criteria highlight different aspects of the methodological quality and reliability of the indicator. Transparency is a somewhat subjective/context dependent criterion as well as the degree of model validation. The assessment of uncertainties and the robustness of the indicator is partly dependent on the subject area. Flood forecasting has emphasized these aspects for a long time whereas ecological studies have recognized it more recently.
	Validated model	
	Uncertainty assessment	
Data availability	**Availability and updating**	The criteria on data availability are generally straightforward and easy to score. Spatial coverage obviously depends on context: some indicators such as those based on glacier data, are naturally restricted in space, but may nevertheless be significant for a wider area. In other cases spatial coverage is restricted due to lack of data.
	Spatial coverage	
	Time series	
Acceptability	**Intelligibility**	The two criteria are in principle clearly separate, but intelligibility often has to be based on subjective judgment. The issue of participation turned out to be somewhat unclear, especially concerning public participation. Few, if any, of the indicators have include participation by the public in the development stage, but some such as temperature are part of common knowledge and also provide anybody the opportunities to participate in the analysis that the indicator has become "participatory". Other indicators remain more abstract or in the hands of a small community, where nevertheless the development of the indicator has been open and participatory
	Participation	

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Annex A: What do we know about climate change and its impacts – conclusions from a comprehensive European-wide assessment

The following annex was presented at the conference *Impacts World 2013, International Conference on Climate Change Effects, Potsdam, 27-30 May 2013* and published in the online conference proceedings at http://www.climate-impacts-2013.org/files/wism_fuessel.pdf.

What do we know about climate change and its impacts – conclusions from a comprehensive European-wide assessment

Hans-Martin Füssel[a], Mikael Hildén[b], André Jol[a]

Abstract — In November 2012 the European Environment Agency (EEA) published its third indicator-based report on climate change, impacts and vulnerability in Europe. This report presents more than 40 quantitative indicators on observed and projected climate change and its impacts, most of them with European-wide coverage. These indicators are also a major source of information for the European Climate Adaptation Platform (Climate-ADAPT). However, some important impact domains are not covered because information is not readily available at the European level, impacts are hard to quantify or to measure, and/or because the influence of climate change is hard to disentangle from socio-economic, technical, cultural and political developments. This paper summarizes the availability of consistent information on observed and projected climate change and its impacts across climate-sensitive sectors and systems in Europe and identifies major knowledge gaps. The paper argues that the improvement of indicators and assessments is not simply a question of increasing monitoring and data collection, but also a task of deepening the theoretical and practical understanding of underlying processes.

Index Terms — assessment, climate change impact, Europe, indicators, vulnerability.

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1 Introduction

The European Environment Agency (EEA) is an agency of the European Union (EU) with the task of providing relevant, objective and up-to-date information on the environment to public decision-makers in Europe. So far the EEA has published three reports specifically devoted to climate change (EEA, 2004, 2008b, 2012a). These reports rely heavily on indicators, which EEA defines as *"a measure, generally quantitative, that can be used to illustrate and communicate complex environmental phenomena simply, including trends and progress over time – and thus helps provide insight into the state of the environment"* (EEA, 2005b). The EEA maintains an indicator management system (IMS) that presents indicators in a structured way on the EEA website. The selection of indicators to be included in the IMS is based on a review process, which applies eight selection criteria from four groups: relevance, method and process, coverage, and user friendliness (EEA, 2012b).

The climate change reports provide numerous indicators on different aspects of climate change. Owing to the complexity of climate change and the inertia of the climate system, most indicators comprise quantitative data about observed changes and projections of future changes, together with information on key uncertainties.

[a] European Environment Agency (EEA)
[b] European Topic Centre for Climate Impacts, Vulnerability and Adaptation (ETC/CCA); Finnish Environment Institute (SYKE)

The EEA climate change reports have attracted significant public attention, with tens of thousands of hits in internet search engines (Table 3). The number of Google hits of the 2012 report is remarkable in comparison with the previous reports, considering that the report had been available on the internet for just over three months at the time of the search. While this increase in Google hits is likely to be partly explained by the growth of the internet, it also shows that there is a strong demand for accessible information on climate change. In comparison, the reports are not very widely cited in the academic literature (Table 3). A detailed analysis of how the indicator reports are used in practice is beyond the scope of this paper. However, a rapid scan of the websites citing the reports suggests a great diversity, including government reports, popular journals and news items.

Table 3. References to the 2004, 2008 and 2012 EEA climate impacts reports on the internet (search 6 March 2013).

Search term	Google hits	Google scholar hits[15]
"Impacts of Europe's changing climate: An indicator-based assessment"	67 800	97
"Impacts of Europe's changing climate - 2008 indicator-based assessment"	41 300	117
"Climate change, impacts and vulnerability in Europe 2012"	96 900	6

All EEA indicators included in the 2012 climate change report are available online on the EEA website[16] and on the European Climate Adaptation Platform, Climate-ADAPT[17]. Climate-ADAPT is a web portal hosted jointly by the European Commission and the EEA that intends to support governmental organisations in developing adaptation strategies and plans. It includes among others an Adaptation Support Tool, country-specific information on national climate impact assessments and adaptation strategies, and a large database of adaptation case studies. Key impact maps for Europe are visualised in a map viewer that includes additional maps (e.g. from ClimWatAdapt, ESPON Climate and JRC-IES) compared to the more limited number of maps in the report. Climate impact researchers are invited to provide further impact maps, provided these are relevant for Europe and have undergone peer review. EEA will review and decide which maps to include, in close consultation with the researchers.

2 Contents of the report

The EEA report on climate change, impacts and vulnerability (2012 CC IV report) (EEA, 2012a) was published in November 2012 with contributions from JRC, ECDC, WHO, a large number of research institutes and

[15] Note that Google scholar reports a total of 275 citations for „Impacts of Europe's changing climate", which is more than the sum of citations of the 2004 and 2008 reports. This difference suggests that some of the 275 citations did not include the full title of the 2004 and 2008 reports.
[16] http://www.eea.europa.eu/promoproducts/indicators
[17] http://climate-adapt.eea.europa.eu/

government agencies (including from three European Topic Centres contracted by the EEA) and individual scientists. The 2012 CC IV report is an updated and extended version of the 2008 report (EEA, 2008b), which itself was an update and extension of the 2004 report (EEA, 2004).

The main objectives of the 2012 CC IV report were to:

- present past and projected climate change and impacts through indicators;
- identify sectors and regions most at risk;
- highlight the need for adaptation actions;
- identify main sources of uncertainty; and
- demonstrate how monitoring and scenario development can improve the knowledge base.

The 2012 CC IV report presents a range of indicators and supporting information that highlight past and projected climate change and related impacts in Europe. The report also brings together information to assess the vulnerability of society, human health and ecosystems in Europe and to identify those regions in Europe most at risk from climate change. As uncertainty is a key factor in climate change projections, the report discusses the principal sources of uncertainty for the indicators and notes how monitoring and scenario development can improve our understanding of climate change, its impacts and related vulnerabilities.

The 2012 CC IV report paints a broad picture of climate change and impacts (Fig. 1). It starts with changes in the climate system and their effects on environmental systems. Both of these have impacts on socio-economic systems and sectors, including human health. Vulnerability to climate change in the context of socio-economic changes is explored by presenting key results from relevant European research projects, but these are not included in the EEA IMS. The basic idea underlying the reports has remained unchanged from 2004 to 2012. The 2004 report was based on 22 indicators, divided into eight different categories. In 2008 the number of indicators had increased to about 40 indicators, and in 2012 approximately the same number of indicators was used. All reports have covered roughly the same issues and topics (see Fig. 1). The expansion of the indicators from 2004 to 2008 was achieved by adding additional indicators for nearly all sectors, but in particular by adding 6 new indicators on agriculture and forestry and 9 new indicators on impacts in economic sectors and health.

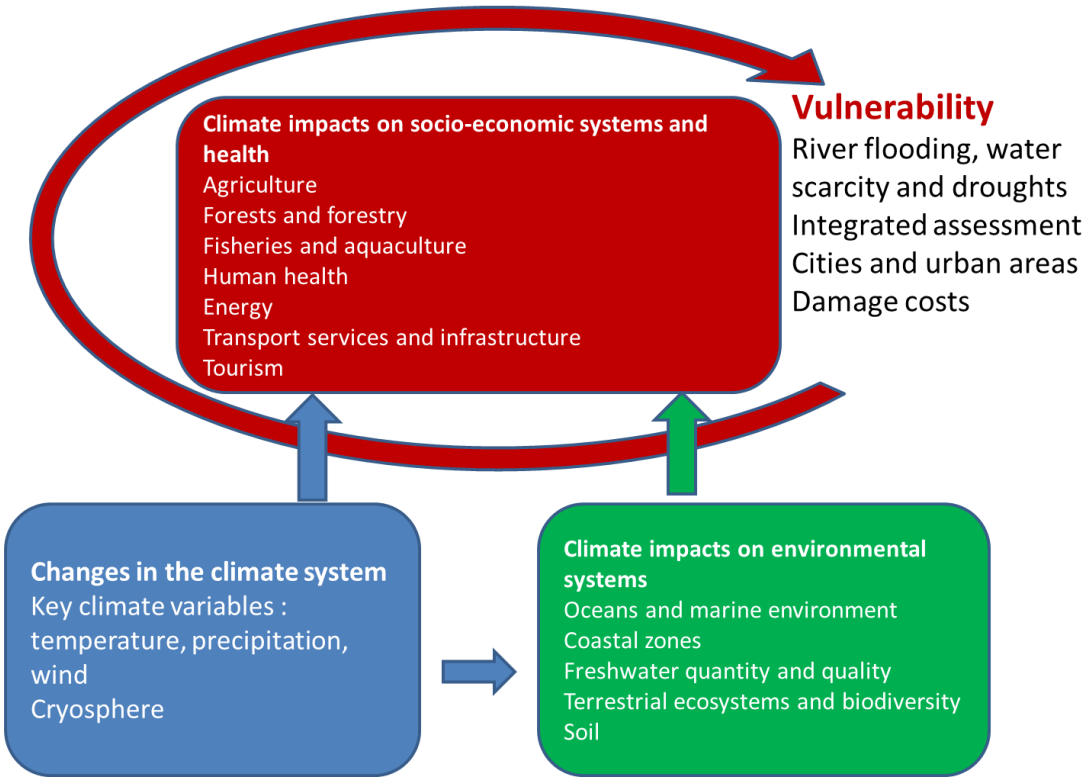

Fig. 1. Basic structure of the 2012 CC IV report. EEA indicators cover the following main groups: changes in the climate system, climate impacts on environmental systems, and climate impacts on socio-economic systems and health.

The main change in the reports over time is a growing emphasis on societal impacts, vulnerabilities and adaptation. For example, the issue of resource efficiency was hardly mentioned in the 2004 report and recognised but not elaborated in the 2008 report. In the 2012 report, however, several aspects of resource use effiency are highlighted. The growing importance of societal aspects can also be seen in the decision to produce a separate assessment report on adaptation. In the 2004 and 2008 reports, adaptation was dealt with in one short chapter only. This time, EEA decided to expand the treatment of adaptation into a full report (EEA, 2013) which is scheduled for publication in parallel with the launch of the EU Adaptation Strategy (on 29 April 2013).

3 Indicator selection and coverage

Ideally environmental indicators provide quantitative measures that illustrate and communicate complex environmental phenomena simply, including trends and progress over time. The EEA indicator review process (see Section 1) aimed at ensuring that the EEA indicators in the IMS are policy-relevant, methodologically valid and user-friendly.

The selection of indicators for the 2012 CC IV report started with the indicator set of the 2008 report and suggestions by thematic experts for potential new indicators. All existing and suggested indicators were then evaluated according to 13 criteria from 5 groups (Hildén and Marx, 2013). These criteria are similar to the criteria used in the EEA-wide indicator review mentioned above, which started after the review of

indicators for the CC IV report. However, there are also some differences that stem from the differences in policy purpose and data collection between the CC IV indicators and most other EEA indicators. In particular, the emphasis of CC IV indicators on supporting policy planning rather than reviewing policy effectiveness results in a stronger focus on future projections and on spatially explicit reporting (rather than nationally aggregated information) than for most other EEA indicators. Somewhat different evaluation criteria were applied to past trends and future projections. Guiding questions were developed to help experts to consistently assess potential indicators. Different aspects of uncertainty, which are particularly relevant in the context of climate change, were also emphasized although uncertainties are difficult to convey in simple indicators.

The 2012 CC IV report covers 16 systems, sectors or topics with large differences in the availability and the quality of the underlying data (Table 4). The longest data series and the most elaborate projections are generally found for climatic variables and some indicators related to ecosystems. For many other topics, the historical data series are short and the projections indicative at best, underlining the importance of a proper treatment of uncertainty. Table 2 shows that the indicators of climate impacts on socio-economic systems and health suffer from the greatest uncertainties. In this area there are problems related to data availability, adequate modelling, and attribution. The difficulties may not lie primarily in the lack of data as such, but the in the lack of data that is assembled in standard form over large geographical areas and that can be linked to climate change.

Several climate-sensitive impact domains are either not covered at all or only through narratives without formal indicators. Climate impacts on industry and manufacturing, insurance, infrastructure (except for transport infrastructure), livestock production and cultural heritage are not covered due to the lack of available information. Climate impacts on personal well-being, aesthetic changes and other immaterial impacts are not systematically covered because they are hard to quantify or meaningful indicators are not available. Finally, information on changes in migration of people within and to the EU is not included because of a lack of evidence of the relevance of climate change.

Table 4. Overview of the material presented in the 2012 CC IV report: availability of data on past trends and projections, and main gaps. The colour scheme refers to Fig. 1: changes in the climate system (blue), climate impacts on environmental system (green) and climate impacts on socio-economic systems and health (red).

Topic and indicators	Availability: past trends	Availability: projections	Main gaps
Key climate variables: Global and European mean temperature; temperature extremes; mean precipitation; precipitation extremes; storms	Five indicators based on actual observations (also reconstructions and reanalysis); available time series from several decades to >100 years.	Projections for all indicators based on different models and scenarios.	**Past trends:** Only long-term trend provided, little discussion of decadal variation **Projections:** Little discussion of co-variation in climate variables.
Cryosphere: Snow cover, Greenland ice sheet; glaciers; permafrost; Arctic and Baltic Sea ice; lake and river ice	Six indicators based on actual observations with time series ranging from a little more than a decade to >100 years.	Projections for most of the indicators based on individual studies.	**Past trends:** Short data series for permafrost; lake and river ice data only available for a few sites. **Projections:** Only indicative and uncertain projections for most indicators

Topic and indicators	Availability: past trends	Availability: projections	Main gaps
Oceans and marine environment: Ocean acidification; ocean heat content; sea surface temperature; phenology of marine species; distribution of marine species	Five indicators based on observations with time series of a few to several decades, but often restricted to limited sea areas. Ocean acidification indicator based on proxy data from Hawaii.	Generally qualitative projections or individual studies	**Past trends:** Somewhat fragmentary information on trends; data is sparse for acidification and long term changes of species distribution and phenology. **Projections:** In most cases highly uncertain projections
Coastal zones: Global and European sea-level rise (SLR); storm surges	Two indicators based on observations. SLR observations up to >100 years depending on data set. Storm surges based on individual studies of events rather than comprehensive time series.	SLR based on a range of quantitative projections. Highly uncertain projections for storm surges.	**Past trends:** Lack of comprehensive data on storm surges. **Projections:** Significant uncertainty for SLR and very high uncertainty for storm surges.
Freshwater quantity and quality: Mean river flow; river floods; river flow droughts; water temperature of rivers and lakes; lake and river ice	Five indicators based on observations of several decades. Except for mean river flows and floods, and to some extent droughts, data are based on singular local data series rather than comprehensive coverage of large regions or the whole of Europe. For individual locations time series extend >100 years. In addition a narrative on freshwater ecosystem and water quality.	Model-based quantitative projections for river flow, floods and droughts. Projection based on inferences from air temperature for water temperature, and single study for ice. Narrative on freshwater ecosystems and water quality	**Past trends:** Lack of empirical and regional analyses/modelling of changes in freshwaters and freshwater ecosystems; thin spatial coverage and poorly harmonized data. **Projections:** Lack of regional projections on scales relevant to decision making
Terrestrial ecosystems and biodiversity: Plant and fungi phenology; animal phenology; distribution of plant species; distribution and abundance of animal species; species interactions.	Five indicators. Phenology and distribution patterns based on two to several decades of observations of selected species groups and habitats. Narrative description of species interactions based on review of individual studies.	Phenology projections based on inferences from climate projections. Model-based projections for selected species distributions. Narrative description of potential changes in species distribution.	**Past trends:** Partly fragmented view of changes due to non-standardized data and limited availability. **Projections:** High uncertainty, lack of alternative models and ensemble studies. Lack of data on species interactions (including alien species).
Soil: Soil organic carbon; soil erosion; soil moisture	Three indicators based on snapshot observations of variables. No comprehensive trend data, except a proxy for wind erosion over several decades. Narrative on biomass production and recurrent negative precipitation anomalies ("droughts") as proxy for soil degradation.	Qualitative projections based on a conceptual model of relevant processes	**Past trends:** No comprehensive compilation of soil data. **Projections:** Highly uncertain projections, lack of relevant modelling.
Agriculture: Growing season for agricultural crops; agrophenology; water-limited crop productivity; water requirement for irrigation	Four indicators based on two to several decades of observations of actual variables or relevant determinants.	Model-based projections for growing season, agrophenology, and water-limited crop productivity.	**Past trends:** Partly fragmented and non-standardised data; filtering of climate signal from observed data. **Projections:** Missing information on uncertainty related to modelling impacts of climate change on crop yield considering effects of possible adaptation options; lack of projections of the possible role of extreme events and pests.
Forests and forestry: Forest growth; forest fires	Two indicators based on two decades of observation for 17 EU countries on forest growth and three decades of forest fire observations.	Model projection of tree species composition using several scenarios; projection of fire danger under one scenario.	**Past trends:** Lack of harmonised and comparable data on forests across countries. Difficulties in filtering climate signal from data. **Projections:** Lack of separation of the impacts of climate change on forests and forestry in combination with other factors.
Fisheries and aquaculture	General narrative with information on temperature response of fish stocks in the north-eastern Atlantic	General narrative on possible consequences	**Past trends:** Disentagling and filtering climate effects from other changes. **Projections:** Lack of data on the impacts of climate change on fisheries and aquaculture in combination with other factors.

Topic and indicators	Availability: past trends	Availability: projections	Main gaps
Human health: Floods and health (addressing both coastal and river floods); extreme temperatures and health; air pollution by ozone and health; vector-borne diseases.	Four indicators that include several data series with coverage of one to two decades. For several vector borne diseases periodic snapshots rather than full data series. Narrative on water- and food-borne diseases	Narrative based on climate projections and review of individual studies.	**Past trends:** Fragmentary data, incomplete and short data series, difficulties in attribution. **Projections:** Lack of process-verification and scenario modelling
Energy: Heating degree days	Three decades of observations. Narrative description of electricity demand and production.	Narrative based on climate projections and review of studies on electricity demand	**Past trends:** Limited data, current indicator provides only one aspect of the relationship between climate change and energy. **Projections:** Limited picture of energy use and production in a changing climate.
Transport services and infrastructure	Narrative on impacts focussing on inland water transport and impacts of changes in extreme weather events. No data series or actual indicator	Narrative based on reviews	**Past trends:** Lack of data compilation to detect changes. **Projections:** Lack of systematic work on projections and scenario modelling
Tourism	No indicator, Narrative on general tourism and winter sport tourism.	Projections for general tourism using the tourism climatic index as a proxy	**Past trends:** Lack of data to examine change, filtering of climate effect **Projections:** Lack of understanding of preferences and reactions to climate change
Damage costs: Direct losses from weather disasters	One indicator on damages due to natural disasters in EEA member countries	Narrative projection, supplemented with quantifications based on model studies of the research project ClimateCost	**Past trends:** Difficulties in attribution. Projections: Not possible to cover all cost categories, cross-sectoral cost estimates are lacking

4 Discussion

The 2012 IV report demonstrates that there are great differences in the availability of data underlying climate and impact indicators (Table 4). The best information is available on climate variables (temperature, precipitation and some aspects of the cryosphere), for which long historical data series as well as projections are available. Indicators on climate change impacts on environmental systems include some well-researched areas where impacts of climate change have already been observed and where attribution studies have been made. However, data availability for some environmental systems (e.g., soil) is rather limited. Time series on climate impacts on socio-economic systems and health are generally limited, and the attribution of observed changes to changes in climate has proven to be difficult.

EEA indicators on climate change and impacts are primarily intended to inform the development of adaptation policies that address future climate risks. Quantitative projections of future developments exist for most (but not all) climate variables and for some impact indicators, although uncertainties are often large. The greatest “white spots” relate to future climate impacts on socio-economic systems and health where projections are often based on statistical modelling or on qualitative narratives inferred from projections of climate variables. Obviously, adaptation planning would benefit from deeper knowledge about societal impacts under different policies.

It is easy to demand more data and monitoring using harmonized methods in order to fill the gaps. Progress might be achievable to some degree by making greater use of available statistical data. For example, the ESPON Climate project combined spatially explicit data on the distribution of climate-sensitive

infrastructure and other assets with one climate projection to obtain indications of vulnerability at the NUTS-3 level (Greiving et al., 2011). There is, however, a need for more process-oriented studies that set climate change in a wider context of societal change and that can identify the climatic component in observed and projected changes. For example, studies have shown that the increasing trend in economic damages caused by natural hazards is driven primarily by socio-economic factors and not by climatic events (Visser et al., 2012; Barredo, 2010). Carefully designed analyses are therefore needed for a correct interpretation of indicators because a simple compilation of observed data or a presentation of projections can easily lead to flawed conclusions.

Further improvement of indicators and indicator-based assessments requires a reflection on the primary use of the information. If the aim is to monitor and understand the sensitivity of environmental systems to large-scale changes, detailed data from a few geographically limited systems may provide valuable information. If the the aim is to inform the development of European adaptation policies, there is a greater need to embrace the diversity of conditions throughout Europe. For such indicators, comprehensive geographical coverage is important, and the related assessment must include a narrative reflection on the diversity, uncertainties and caveats in the information provided.

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Annex B: Improved consideration of uncertainties in a comprehensive assessment of climate change impacts in Europe

The following annex was published in the online proceedings of the conference *Impacts World 2013, International Conference on Climate Change Effects, Potsdam, 27-30 May 2013* at http://www.climate-impacts-2013.org/files/hcaw_fuessel.pdf.

Improved consideration of uncertainties in a comprehensive assessment of climate change impacts in Europe

Hans-Martin Füssel*

Abstract— In November 2012 the European Environment Agency (EEA) published its third indicator-based report on climate change, impacts and vulnerability in Europe. This report aimed among others at improving the assessment and reporting of uncertainties in observed and projected climate change and its impacts. EEA decided not to copy the IPCC approach for using calibrated uncertainty language, due among others to differences in the purpose and process between IPCC and EEA reports. Instead, authors were requested to consider the following aspects when writing their assessment and in particular when formulating key messages: choosing the appropriate type of statement, choosing the appropriate level of precision, considering all relevant sources of uncertainty, and reporting explicitly on the lack of information where appropriate. The treatment of uncertainties in the report was described in a dedicated section in the introduction. This paper presents the experiences with improving the consideration and reporting of uncertainties in the 2012 EEA climate impacts report.

Index Terms—climate impacts, European Environment Agency, indicators, uncertainty.

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1 Introduction

The European Environment Agency (EEA) is mandated by its founding regulation[18] *"to provide the Community and the Member States with the objective information necessary for framing and implementing sound and effective environmental policies"* and *"to publish […] indicator reports focusing upon specific issues"*. One topic where EEA activities have increased in recent years is climate change impacts and adaptation. The increased information demand is driven, among others, by the commitment in the European Commission's 2009 White Paper *"Adapting to climate change: Towards a European framework for action"*[19] to develop a comprehensive EU Adaptation Strategy by 2013[20]. Furthermore, 16 EEA member countries have developed National Adaptation Strategies and/or National Adaptation Action Plans in recent years, and many others are currently doing so.[21]

In response to the policy demands, EEA has so far published three indicator-based reports dealing with climate change (EEA 2004; EEA 2008; EEA 2012). The main target group of the reports are European and national policy-makers but they also serve academic scientists, non-governmental organisations, the press and the public at large. Within 3 months of its publication, the 2012 report already had around 100 000 Google hits and more than 500 media citations.

* European Environment Agency (EEA)

[18] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31990R1210:EN:HTML, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:126:0013:0022:EN:PDF

[19] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF

[20] http://ec.europa.eu/clima/events/0069/index_en.htm

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

2 EEA reports vs. IPCC reports

All environmental information managed by EEA is subject to some uncertainties, and EEA is working actively with its member countries to improve the consistency and accuracy of data reported from countries to EEA. The assessment and communication of uncertainty related to climate impacts faces particular challenges:

1. EEA indicators on climate impacts generally do not rely on data reporting from countries. Instead, data stems from international organizations, European research projects, research networks and individual institutions.
2. EEA indicators on climate change are primarily used to inform adaptation policies, which in turn are largely driven by anticipated changes in climate. Hence the importance of future projections is much more important for EEA indicators on climate impacts than for most other EEA indicators.

EEA has paid considerable attention to uncertainties in climate impact indicators already in its first and second indicator-based reports. The importance of this topic increased further in the preparation of the third indicator-based report for two main reasons:

1. The substantially increased activities around climate change adaptation at the European and national level resulted in higher demands on the underlying knowledge base, including relevant EEA indicators.
2. The discovery of an erroneous statement about the melting of Himalayan glaciers in a chapter of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change in December 2009 (dubbed "Glaciergate") resulted in strong public and political criticism of the IPCC. In response, the UN Secretary-General and the IPCC Chair asked the InterAcademy Council (IAC) in March 2010 to carry out an independent review of IPCC processes and procedures.[22]

The IPCC has considerable experience in assessing and communicating uncertainties in its assessment reports. Over a period of 10 years, the IPCC has developed and refined a 'calibrated language' to express the confidence in and/or likelihood of specific findings, which is applied in most key messages of IPCC reports (Moss and Schneider, 2000; IPCC, 2005; Mastrandrea, Field, Stocker, Edenhofer, Ebi, et al., 2010). This author had been involved in the preparation of the IPCC AR4 as an author, review editor, expert reviewer and government representative in IPCC plenary meetings. The increased efforts to describe the accuracy and robustness of the data underlying indicators in the 2012 EEA report was facilitated by his close familiarity with relevant IPCC practices.

EEA reports share some similarities with IPCC assessment, including a mandatory review by EEA member countries. However, there are also some important differences:

1. IPCC assessment reports aim to assess all information available in the relevant (academic) literature whereas the EEA climate impact reports focus on the presentation of selected indicators.
2. The writing team of a chapter in an IPCC report typically consists of 20 or more authors supported by at least two review editors. For example, the writing team of the chapter on Europe in the Working Group II contribution to the IPCC AR4 consisted of 3 convening lead authors, 7 lead authors, 12 contributing authors and 2 review editors. In contrast, most chapters of the

[22] https://www.ipcc.ch/pdf/IAC_report/iac_letter.pdf, https://www.ipcc.ch/organization/organization_review.shtml#.UTnrPCJZxqE

EEA climate impacts report are written by only one or two authors supported by a small number of contributors.

3. IPCC reports receive very strong attention from the media world-wide, including from countries where climate change is a very contentious issue. Their publication is regularly covered in the main evening news. The EEA climate impacts reports also receive considerable attention in the media (e.g. the 2012 report was cited more than 500 times in newspapers and websites), but this is still much less than for an IPCC report. Furthermore, EEA reports have not (yet) faced such a hostile reception by parts of its target audience as the IPCC reports.

Copying the IPCC approach for assessing and communicating uncertainty appeared neither feasible nor necessary for the EEA climate impacts report. Most importantly, the small number of experts involved in each indicator assessment prohibits quantitative expert assessments of confidence and uncertainty. Additionally, key messages would have become rather cumbersome and difficult to interpret for the target audience, without providing readers with substantial relevant information. It is important to emphasize that this decision does not in any way imply a criticism of the IPCC approach. It simply reflects the different needs and capacities between EEA and IPCC.

3 Consideration of uncertainty in the 2012 EEA climate impacts report

In the 2012 climate impacts report, uncertainty was addressed by the following elements, which were applied in particular in its key messages:

1. Dedicated uncertainty section
2. Careful choice of the type of statement
3. Careful choice of the appropriate level of precision
4. Explicit information on the pedigree of information and uncertainty
5. Explicit reporting of knowledge gaps
6. Central editing of uncertainty language
7. Extended expert review

These elements are further explained below.

Dedicated uncertainty section

A dedicated uncertainty section was included in the report that outlines the relevant key sources of uncertainty and explains how they are addressed and communicated in the report.

Appropriate choice of type of statement

Most key messages related to indicators can be categorized into a limited number of “types” of statements. The following types of statements are distinguished in key messages related to climate and impact indicators in the EEA report (based on IPCC, 2007c, Table SPM.2):

1. Observation of a climate variable or a climate-sensitive ‘impact’ variable
2. Observation of a statistically significant (change in) trend of a climate or impact variable
3. Attribution of a change in a climate or impact variable to a particular cause
4. Projection of a climate or impact variable into the future

Different types of statements are subject to different sources of uncertainty. As a general rule, the (sources of) uncertainty increases from observations to attributions and projections and from climate indicators to climate impact indicators. For example, observations of a climate or climate impact variable can be made for short time series whereas statements about statistically significant trends require availability of longer time series and the consideration of natural interannual variability. Authors were advised to formulate key messages so that it is clear what type of statement they make, and to avoid the combination of different types of statements in a single message.

Careful choice of the appropriate level of precision

Statements in key messages can be made at different levels of precision (or quantification), which are ordered here from least to most precise (based on IPCC, 2005):

1. Existence of effect (but the direction is ambiguous or unpredictable)
2. Direction (of change or trend)
3. Order of magnitude
4. Range or confidence interval
5. Single value (implying confidence in all significant digits)

Authors were advised to formulate key messages at the highest level of precision justified by the underlying data, and to separate statements with different levels of precision (e.g. related to observations vs. projections) in order to clearly indicate the precision of each individual statement.

Explicit information on the pedigree of information and uncertainty

Authors were advised to state explicitly whether and how key sources of uncertainty have been considered in the underlying dataset, and what this implies for the confidence that can be put in a specific data set or conclusion (where relevant and feasible). For example, a message on future climate change would indicate which emission scenarios and how many climate models are considered in this projection.

Explicit reporting of knowledge gaps

Authors were advised to report explicitly on the availability of data related to past trends as well as future projections. Explicit statements on knowledge gaps can inform future efforts for data collection and research. Additionally, they ensure the reader that a lack of reporting on an issued does not reflect a lack of consideration.

Central editing of uncertainty language

Some authors of the 2012 report had previously contributed to IPCC assessments and were prepared to pay particular attention to uncertainty assessment and communication whereas others felt less comfortable assessing the merits and robustness of research results reported in the academic literature that they were not directly involved in. As a result, the degree to which the recommendations above were followed differed substantially across chapters. In the end, central editing by EEA lead authors was needed to

improve the consistency of uncertainty reporting across the report.

Extended expert review

All EEA reports are reviewed by experts from so-called National Focal Points and thematic National Reference Centres from all EEA member countries. These experts are generally employed by government institutions, such as national Environmental Protection Agencies. For this report, the review was extended to an advisory group of about 20 thematic experts that had supported the report production from the beginning and to about 20 further scientific experts from academic institutions that were not involved as authors.

4 Discussion and conclusions

The clear communication of the state of knowledge on a particular subject, including associated uncertainties, is relevant in all work areas of the EEA. EEA reports and indicators addressing climate change and its impacts face particular challenges due to the large importance of future projections for informing present adaptation planning. For more than a decade, the IPCC has been guiding its authors on the consistent assessment and reporting of relevant uncertainties. While the efforts of the IPCC have been inspiring for the EEA, application of the IPCC uncertainty guidance to the EEA report was not feasible, largely due to the small number of authors working on a particular topic.

Instead of applying a calibrated uncertainty language, EEA efforts focussed on clarity about the type of statements (e.g. observation of a trend vs. attribution to a particular cause), careful choice of the level of quantification, and explicitit discussion of key uncertainties and of knowledge gaps. The efforts at improved consideration of uncertainty in the 2012 EEA climate impacts report have also inspired a wider discussion on uncertainty communication in EEA assessment reports.

Feedback from academic readers on the uncertainty reporting in the 2012 EEA report has generally been very positive. EEA has only received limited feedback from policy makers on this specific topic. However, key uncertainties relevant for climate change adaptation are clearly referred in the EU Strategy on adaptation to climate change[23] adopted in April 2013 as well as in national adaptation strategies. Hence, we feel confident to conclude that European and national decision-makers have accepted that adaptation planning involves decision-making under uncertainty, and that they do appreciate efforts by EEA (and others) to communicate the scope and source of these uncertainties as clearly as possible.

[23] http://ec.europa.eu/clima/policies/adaptation/what/documentation_en.htm

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