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Orientation guide on concepts, terms and definitions in the context of Climate Services, Infrastructure Risk Assessment and Climate Risk Management

Responsible

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Overview on clustered terms

Climate

Weather

The state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity and barometric pressure (WMO 2011).

In the context of the PIEVC Protocol:

Weather refers, generally, to day-to-day temperature and precipitation activity. Climate refers to average atmospheric conditions over longer periods of time.

A *weather event* are specific atmospheric conditions related to temperature, moisture, wind velocity, and barometric pressure. Within the context of the risk assessment, a weather event is defined by a value for specific atmospheric conditions that could potentially exceed infrastructure threshold values.

A *weather forecast* is a prediction of individual weather elements on an hourly or daily basis. Forecasts are determined from a combination of weather model output, constrained by observed data every 12 hours, and local sources of information such as tracks of storms and precipitation from satellite and radar reports (Engineers Canada 2015).

Climate

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often-surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC_WG1 2013).

The statistical character of climate has significant consequences on climate information and its usability. The interpretation of climate data (statistics) is very much dependent on the choice of the temporal and spatial scale as well as on the object (variable, indices) of analysis. In the context of Climate Services, temporal and spatial scales as well as the object of analysis for CS-products should be chosen with care and in the context of decision-making. A discussion about the usability of standardized climatological products and the need of specialized products should take place.

Micro climate

The local climate as moderated by geographic or physical features. Large rivers or lakes can affect the local climate. Populated areas tend to see somewhat different weather than the surrounding regions (Engineers Canada 2015).

Climate change

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC_WG1 2013).

Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (IPCC_WG1 2013).

Climate variability

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC_WG1 2013).

Climate extreme (extreme weather or climate event)

Both, extreme weather events and extreme climate events are referred to collectively as 'climate extremes. From this definition, […] climate extremes can be defined quantitatively in two ways:

1) Related to their probability of occurrence
2) Related to a specific (possibly impact-related) threshold

Statistically, climate extremes relate to the occurrence of a value of a weather or climate variable above or below a threshold value near the upper or lower ends of the range of observed values of the climatic variable.

The distinction between extreme weather events and extreme climate events is not precise, but is related to their specific time scales:

- An extreme weather event is typically associated with changing weather patterns, that is, within periods of less than a day to a few weeks.
- An extreme climate event happens on longer time scales. It can be the accumulation of several (extreme or non-extreme) weather events (e.g., the accumulation of moderately below average rainy days over a season leading to substantially below average cumulated rainfall and drought conditions) (IPCC AR5 – SREX).

Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of moderate weather or climate events (this accumulation being itself extreme). Compound events, that is, two or more events occurring simultaneously, can lead to high impacts, even if the two single events are not extreme per se (only their combination).

Not all extreme weather and climate events necessarily have extreme impacts, It is the vulnerability to these extremes that reveal the degree of impact.

<u>In the context of the PIEVC Protocol:</u>

A climatic condition that the infrastructure could experience deemed relevant for consideration in the vulnerability assessment. This could include normal climatic events considered in the design, development and management of the infrastructure and also recent climatic trends and events that could potentially affect the infrastructure (Engineers Canada 2015).

Climate Services

GFCS	Global Framework for Climate Services: GFCS provides a worldwide mechanism for coordinated actions to enhance the quality, quantity and application of climate services. The framework provides guidance for action at national and sub-national scales.
Climate Service	Transformation of climate-related data — together with other relevant information — into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. As such, these services include data, information and knowledge that support adaptation, mitigation and disaster risk management (DRM) (EU 2015). The Global Framework of Climate Services (GFCS) envisages five components for an effective provision of climate information: (1) Observations and monitoring, (2) Research, modelling and prediction, (3) Climate Service Information System, (4) User interface platform and (5) Capacity development (WMO 2014). Dimensions and criteria for successful climate information provision: (1) technical dimension: provision of high quality data (credibility); (2) service dimension: provision of contextualized information and dissemination/ access of products (salience) and (3) institutional dimension: cooperation and trusted interaction of climate service providers to enable flow of data and its legitimacy.
User-Interface Platform	The User Interface Platform (UIP) provides a structured means for users, researchers and climate service providers to interact at the global, regional and national levels to ensure that user needs for climate services are met. The objective of the UIP is to promote effective decision-making in view of climate considerations. The need to make climate-related decisions will be the driver for providers and users to develop more useful climate information. All countries share that need and have a place in the GFCS. The UIP will strive to include all providers and users of climate services. A UIP can be defined further as a managed methodology, or a collection of methods, means, approaches, and processes of systematic and mutually beneficial collaboration. It enables interactions that help define user needs and provider capabilities, tries to reconcile the needs with those capabilities, and eventually promotes effective decisions based on climate information (WMO 2014) Yet, mechanisms that structures the operation of a UIP at national and sub-national levels are lacking.
Climate product	A derived synthesis of climate data. A product combines climate data with climate knowledge to add value (WMO 2014).
Climate Service Product	There is no official definition of 'climate service product'. However, referring to the definition of 'climate service' a discrimination of 'climate product' and 'climate service product' should be done including the 'service'-component of climate services. Hence, a climate [service] product is a management tool for all climate data that allows access to useful climate information that is suited to particular needs of

the end-users as well as practical guidance on how they can use it. It encompasses a range of activities that deal with generating and providing information based on past, present and future climate and on its impacts on natural and human systems (modified from WMO 2011).

A Climate Service Product is often a multi-data product which includes climate data but which is also undergone many value-adding processes. Thus, a CS product is often a cooperate product of various stakeholder.

Climate Outlook	A term referring to a scenario of climatic and economic and social conditions over a coming season or two, usually developed by consensus among a group of experts and mainly used in the context of Regional Climate Outlook Forums (WMO 2011).
Climate information	Climate data, climate products and/or climate knowledge (WMO 2014).

Climate data, climate parameters and their characterization

Climate data	Historical and real-time climate observations along with direct model outputs covering historical and future periods. Information about how these observations and model outputs were generated (“metadata”) should accompany all climate data (WMO 2014).
Metadata	Information about meteorological and climatological data concerning how and when they were measured, their quality, known problems and other characteristics (IPCC_WG1 2013).
Observation	Observation, or observed data, refers to any information that has been directly measured. In climatology, this means measurements of climate variables such as temperature and precipitation (WMO 2011).
Variable	The name given to measurements such as temperature, precipitation, etc. (climate variables), sea level rise, salinity, etc. (marine variables) and cooling degree-days, days of air frost, etc. (derived variables) (WMO 2011).
Climate parameter (PIEVC)	A specific set of weather conditions or climate trends deemed to be relevant to the infrastructure under consideration. The parameter may be a single variable, such as mean monthly temperature, or a combination of variables, such as low temperature combined with rainfall. Within the context of a vulnerability assessment, climate parameter selection is tailored to the specific design, operational and maintenance characteristics of the infrastructure being assessed (Engineers Canada 2015).
Essential Climate Variable (ECV)	An ECV is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth’s climate. ECV datasets provide the empirical evidence needed to understand and predict the evolution of climate, to guide mitigation and adaptation measures, to assess risks and enable attribution of climate events to underlying causes, and to underpin climate services. They are required to support the work of the UNFCCC and the IPCC. (WMO)
Climate threshold	The point at which external forcing of the climate system, such as the increasing atmospheric concentration of greenhouse gases, triggers a significant climatic or environmental event which is considered unalterable, or recoverable only on

very long time-scales, such as widespread bleaching of corals or a collapse of oceanic circulation systems (IPCC_WG1 2014).

Extreme value distribution	A particular family of probability density functions used to describe the probabilities of extreme values, such as annual maximum (or minimum) daily temperature (UKCIP, 2003)
Probability	Probability is used to describe the chance or relative frequency of occurrence of particular types of event, or sequences or combinations of such events. These events may be discrete or described by a continuous variable. An example of a discrete event is the probability that a particular location experiences flooding on one or more occasions during any year. The maximum depth of flooding experienced during each such event is an example of a continuous variable, which can take a range of values with different probabilities. The nature of the probability may be determined by reference to an underlying theory, or be described based upon supporting observations (UKCIP, 2003). In the context of the PIEVC Protocol: In the PIEVC risk assessment, probability is the likelihood of a climate event occurring (Engineers Canada 2015).
Joint probability	The probability of specific values of one or more variables occurring simultaneously (or sequentially) to affect a particular consequence. For example, high water levels in estuaries can depend on the likelihood of particular river flows, tidal heights, and offshore cyclonic conditions. In order to estimate the likelihood of high water levels, the joint probability of these events will need to be considered (UKCIP, 2003)
Probability density function or distribution	A function that describes the probability that a variable will take a particular value across the entire range of possible values. For example daily rainfall, annual mean temperature, household flood damage loss (UKCIP, 2003).
Probability score factor (PIEVC)	A factor based on an arbitrary score (0 to 7) used to define the probability of a weather event or climate trend impacting a particular infrastructure component (Engineers Canada 2015).
Percentile	A percentile is a value on a scale of one hundred that indicates the percentage of the data set values that is equal to or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (10th) percentile may be used to refer to the threshold for the upper (lower) extremes (IPCC_WG1 2013).
Return period	The expected mean time between occurrences that equal or exceed a particular defined, usually extreme or unusual event. Often used to express the frequency of occurrence of the event (= 1/return period). Estimates of return periods are subject to uncertainty, such that consecutive events may occur at intervals greater or smaller than the average return period (UKCIP, 2003)

Climate Modelling, Simulations and Projections

Predictability	The extent to which future states of a system may be predicted based on knowledge of current and past states of the system. Since knowledge of the climate system's past and current states is generally imperfect, as are the models that utilize this knowledge to produce a climate prediction, and since the climate system is inherently nonlinear and chaotic, predictability of the climate system is inherently limited. Even with arbitrarily

accurate models and observations, there may still be limits to the predictability of such a nonlinear system (IPCC_WG1 2013).

<u>In the context of the PIEVC Protocol:</u>

An estimate of future climate quantities (means, statistics) over a defined time horizon.
This is in some ways similar to a weather forecast in that the skill depends the ability to initialize the climate model with observations, but the difference is that a large portion of the skill arises from initializing the ocean component of the prediction model. The result is typically known as a seasonal forecast and provides a prediction of conditions above or below some "normal" value (Engineers Canada 2015).

Climate model (spectrum or hierarchy)

A climate model is the numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity. Complexity will be increased by considering different physical, chemical or biological processes at various spatial scales: i.e. simple models only consider atmospheric processes most relevant for global circulation. Very complex models consider interactions between atmosphere, ocean and terrestrial systems (coupled models) or processes which only can be resolved at higher spatial resolutions (Regional Climate Models or empirical parametrizations). Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) provide a representation of the climate system that is near the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal and inter-annual climate predictions (IPCC_WG1 2013).

Parametrization within climate models

In climate models, this term refers to the technique of representing processes that cannot be explicitly resolved at the spatial or temporal resolution of the model (sub-grid scale processes) by relationships between model-resolved larger-scale flow and the area- or time-averaged effect of such sub-grid scale processes (IPCC_WG1 2013).

Global circulation model (global climate model)

Complex computer programs commonly used to simulate the atmosphere or ocean of the earth and project climate trends on a global scale. The mathematical models are based on general circulation of the planetary atmosphere and apply thermodynamics to calculate radiation and latent heat in order to establish a global mass and energy balance (Engineers Canada 2015).

Regional climate model

A regional climate model is a climate model of higher resolution than a global climate model. It can be nested within a global model to provide more detailed simulations for a particular location (WMO 2011).

Climate projection

A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty (IPCC_WG1 2013).

Downscaling

The two approaches, dynamical and statistical downscaling are not quite interchangeable alternatives, and there are many technical aspects to consider if one need to choose one of them. Here are some main characteristics listed.

<u>Main advantages of dynamical downscaling (RCMs):</u>

- Individual variables are physically consistent in time and space, and the different variables are internally consistent. The same fundamental physical principles are used in both an RCM and a GCM.
- An RCM provides for large region a wealth of output data at high resolution compared to what can be obtained from a GCM.
- No specific calibration data is required.

<u>Main disadvantages of dynamical downscaling (RCMs):</u>

- RCMs are very complex and requires substantial computational resources, often at same level as required for GCM simulations (however, large datasets covering many regions are made freely available by modelling institutes).
- Near the boundary of the RCM domain artefacts and spurious effects occur.
- While removing much of the GCM bias that is related to the coarse resolution, an RCM also adds its own biases to the output data.

<u>Main advantages of empirical statistical downscaling(ESD):</u>

- The methods are computationally inexpensive.
- Many different statistical methods are available, allowing for substantial flexibility.
- ESD typically includes bias correction as an integral part of the process.

<u>Main disadvantages of empirical statistical downscaling (ESD):</u>

- A calibration dataset, typically a long meteorological record of high quality is required. Any quality problems in the calibration data will be transferred to the downscaled GCM/RCM data.
- The higher the requirements regarding spatial and temporal consistency, or inter-variable consistency are, the more complex and computationally demanding the statistical procedures become.
- The ESD approach requires/assumes stationary statistical relationship, the relationship must remain constant under climate change (climate4impact.eu)

Climate forecast (prediction)

A climate forecast (prediction) is a probabilistic statement about future climate conditions on timescales ranging from seasons to decades. It is based on conditions that are known at present and assumptions about the physical processes that will determine future changes (WMO 2016).

- <u>Deterministic forecast (prediction):</u> Forecasts (predictions) of an event of a specific magnitude at a specific time and place.
- <u>Probabilistic forecast (prediction):</u> Forecasts (predictions) of an event of a specific magnitude at a specific time and place (WMO 2016).

Climate baseline (PIEVC)

The condition against which changing climate is assessed. For most cases, this will be the design conditions assumed for the particular infrastructure or infrastructure component. In some cases, the baseline would be determined as the current conditions that the infrastructure or infrastructure component is experiencing. Changing climate is then compared with these baseline conditions.

In climate research, a baseline climate refers to a chosen tri-decade from climate history. The most common choice has been 1961-1990. Most recently, researchers have been using 1971-2000 (Engineers Canada 2015).

Climate scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate (IPCC_WG1 2013).
Business-as-usual scenario (PIEVC)	A pathway forward that encompasses actions that have already been determined through previous planning, or that are a normal part of the organization's practices. Vulnerabilities identified in Step 5 of the Protocol may not be addressed (Engineers Canada 2015).
Re-analysis	Re-analyses are atmospheric and oceanic analyses of temperature, wind, current, and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques. Using fixed data assimilation avoids effects from the changing analysis system that occurs in operational analyses. Although continuity is improved, global re-analyses still suffer from changing coverage and biases in the observing systems (IPCC_WG1 2013).
Uncertainty in climate modeling	Uncertainty refers to a state of having limited knowledge. Uncertainty can result from lack of information or from disagreement over what is known or even knowable. Uncertainty may arise from many sources, such as quantifiable errors in data, or uncertain projections of human behavior. Uncertainty can be represented by quantitative measures or by qualitative statements. Uncertainty in climate change projections is a major problem for those planning to adapt to a changing climate. Uncertainty in projections of future climate change arises from three principal causes: natural climate variability; modelling uncertainty, referring to an incomplete understanding of Earth system processes and their imperfect representation in climate models; and uncertainty in future emissions (WMO 2011).
Ensemble	A set of simulations (each one an ensemble member) made by either adjusting parameters within plausible limits in the model, or starting the model from different initial conditions. While many parameters are constrained by observations, some are subject to considerable uncertainty. The best way to investigate this uncertainty is to run an ensemble experiment in which each relevant parameter combination is investigated. This is known as a perturbed physics ensemble (WMO 2011).

System of Interest characterization (Infrastructure)

System of concern / interest	The social, economic and physical domain within which risks arise, produce consequences, and in which risks are managed. An understanding of the way in which a system may behave is an essential aspect of understanding and managing risk. In particular, it is important to identify mechanisms and thresholds by which the system may fail when loaded, and the processes that provide opportunities for risk management decisions (UKCIP, 2003).
Public infrastructure	Public infrastructure is defined as those facilities, networks and assets operated for the collective public benefit including the health, safety, cultural or economic well-being of the citizens, whether operated by government and/or non-government agencies (Engineers Canada 2015). The basic equipment, utilities, productive enterprises, installations and services essential for the development, operation and growth of an organization, city or nation (IPCC_WG2 2014).
Infrastructure owner	The corporate or government agency that has jurisdictional control over the infrastructure. In a risk assessment, a project manager normally acts as an agent of the infrastructure owner. However, the project manager may defer strategic or policy matters to key managers within the owner organization. Depending on the owner organization, these decisions may be referred to senior management staff or the political level of some municipal organizations (Engineers Canada 2015).
Infrastructure component	One of a number of physical features, processes, procedures and/or human resources that comprise the infrastructure (Engineers Canada 2015).
Design life	The period of time during which the infrastructure is expected to operate within the design parameters. Notionally, the length of time between commissioning and the onset of wear-out. Typically, design life is a shorter duration than the period between commissioning and the anticipated time of actual failure. In some cases, design life is stated in terms of the economic return period of an engineering project (PIEVC Engineering Protocol 2106).
Useful service life	The time between commissioning an infrastructure, or infrastructure component, and mandatory refurbishment or replacement. Useful service life is normally defined by the mean time between failures and is longer than the design life of the infrastructure or infrastructure component (Engineers Canada 2015).
Capacity	The load that an infrastructure component is designed to accommodate (Engineers Canada 2015).
Existing capacity - C_E	Existing capacity C_E is the current capacity of the infrastructure (Engineers Canada 2015).
Change in capacity - $C_{\Delta E}$	The projected change (loss) in capacity arising from aging and normal wear and tear of the infrastructure (Engineers Canada 2015).
Capacity deficit - C_D	Capacity deficit C_D is the amount of capacity that must be added to the infrastructure component to address the vulnerability identified by this procedure. $C_D = L_T - C_T$ $= L_T - (C_E + C_{\Delta E} + C_A)$

where:

C_D = Capacity deficit of the infrastructure component
L_T = Total load on the infrastructure component
C_E = Existing capacity of the infrastructure component
$C_{\Delta E}$ = Change in capacity of the infrastructure component
C_A = Additional capacity of the infrastructure component (Engineers Canada 2015).

Additional capacity - C_A

Additional capacity C_A is the incremental infrastructure capacity resulting from anticipated maintenance, retrofit and refurbishment activities over the time horizon of the evaluation (Engineers Canada 2015).

Total capacity - C_T

Total capacity C_T is the total anticipated capacity of the infrastructure over the period of the evaluation.

$$C_T = C_E + C_{\Delta E} + C_A$$

where:

C_T = Total capacity of the infrastructure component
C_E = Existing capacity of the infrastructure component
$C_{\Delta E}$ = Change in capacity of the infrastructure component
C_A = Additional capacity of the infrastructure component (Engineers Canada 2015).

Exiting load -L_E

The current load on the infrastructure (Engineers Canada 2015).

Total load - L_T

The total anticipated load on the infrastructure over the evaluation:

$$L_T = L_E + L_C + L_O$$

where:

L_T = Total load on the infrastructure component
L_E = Existing load on the infrastructure component
L_C = Changing-climate load on the infrastructure component
L_O = Other change loads on the infrastructure component (Engineers Canada 2015).

Building code

A set of ordinances or regulations and associated standards intended to regulate aspects of the design, construction, materials, alteration and occupancy of structures that are necessary to ensure human safety and welfare, including resistance to collapse and damage (UNISDR 2009). Building codes can include both technical and functional standards. They should incorporate the lessons of international experience and should be tailored to national and local circumstances. A systematic regime of enforcement is a critical supporting requirement for the effective implementation of building codes (UNISDR 2009).

Impact & risk

Climate Disaster

A serious disruption of the functioning of a community or a society at any scale due to climate extreme events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts (UNISDR 2009).
The effect of the climate disaster can be immediate and localized, but is often widespread and could last for a long period. The effect may test or exceed the capacity of a community or society to cope using its own resources, and therefore may require assistance from external sources, which could include

neighboring jurisdictions, or those at the national or international levels (UNISDR 2009).

Climate (change) Impacts

Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts (Zebisch et al. 2017).
Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts.

- Potential impacts: all impacts that may occur given a projected change in climate, without considering adaptation.
- Residual impacts: the impacts of climate change that would occur after adaptation. See also aggregate impacts, market impacts, and non-market impacts (IPCC_WG2 2014).

Referring to the statistical character of climate a discussion on the definition of 'climate impacts' is required: if climate is the statistics of weather, is climate impact consequently the statistics of weather impacts?

In the context of climate services (contextualizing of climate information – making CS useful for decision-makers) it makes sense to discriminate 'climate impact types' to define and characterize scales of 'critical climate conditions' (CCC):

- <u>Systemic climate impact</u>*: The climate stimulus is buffered by an interconnected system (e.g. catchments, ecosystems, dams, etc.). The actual impact felt by the system of concern is the integrated climate forcing over time (and space).*
- <u>Statistical climate impact</u>*: impact of a single event is sub-critical. A critical magnitude-frequency relation for a specific time-period may exceed the resilience threshold.*
- <u>Organizational climate impact</u>*: impact and coping occurs on scale of weather events. Persistent CCC cause critical coping situation (exhaustion of resources, etc.)*
- <u>Decision-conditioned (pseudo) climate impact</u>*: temporal scale of the critical climate conditions is significant smaller than the lead-time of a related decision*
- (Funk et al. 2016)

Infrastructure response

The generally anticipated effects arising from the climate and other change parameters interacting with the infrastructure components (Engineers Canada 2015).

Consequence

The result or effect caused by some event or action. Consequences may be beneficial, neutral or detrimental. A detrimental consequence is often referred to as an impact. May be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected) (UKCIP, 2003).

Cumulative effect

Climate-infrastructure interactions that increase in severity when they combine, resulting in scenarios that are materially more severe than the events themselves. For example, an individual snowfall or rainfall event may not be significant. However, a snowfall immediately followed by a rainfall may result in very serious infrastructure responses (Engineers Canada 2015).

Risk

Risk results from the interaction of vulnerability, exposure, and hazard (...) (Zebisch et al. 2017) revealing a specific damage pattern in the cause of the occurrence of a hazardous event. Understanding the risks and thresholds, including uncertainties associated with climate, is one principle of good adaptation (WMO 2011).

As risk elimination is not possible in the context of climate risks, residual risk is the remaining unmanaged risk, even when effective disaster risk reduction has been accomplished. Managing residual risk implies making provisions for effective emergency services, preparedness, response and recovery, together with socioeconomic policies such as safety nets and risk transfer mechanisms, as part of a holistic approach of risk reduction (UNISDR 2009)

The concept of climate risk was adopted from the field of Disaster Risk Reduction (DRR). In DRR, the focus is on sudden hazardous events of a certain magnitude and with the potential to have immediate consequences, e.g. a flood event with impacts on humans or assets (such as death, injury or significant crop losses). In addition to sudden hazardous events, however, climate risks also comprise a broad range of trends steadily evolving over a longer timeframe. The adverse consequences of these trends manifest themselves in slowly increasing pressure on the environment and livelihoods rather than in immediate impacts. Examples for such trends and their consequences include an increase in pests and diseases in the agricultural sector due to a warmer and more humid climate or the loss of arable land due to slowly increasing saltwater intrusion.

RISK in the context of Infrastructure Risk (PIEVC)

Risk is the possibility of injury, loss or negative environmental impact created by a hazard. The significance of risk is a function of the probability of an unwanted incident and the severity of its consequence.
In mathematical terms:

$$R = P \times S$$

where:

R = Risk
P = Probability of a negative event
S = Severity (Impact) of the event, given that it has happened (Engineers Canada 2015).

Peripheral Risk (PIEVC)

A peripheral risk may occur when local geographical features result in secondary events following a climate incident. For example, a minor culvert failure resulting from a rainfall event could result in loss of slope stability leading to a mudslide. The practitioner, i.e. the individual or team executing the Protocol, may judge the culvert failure to be a low risk but the contribution to the secondary event may be quite significant. Practitioners are encouraged to consider the sequence of events arising from projected failures as one element of the risk assessment (Engineers Canada 2015).

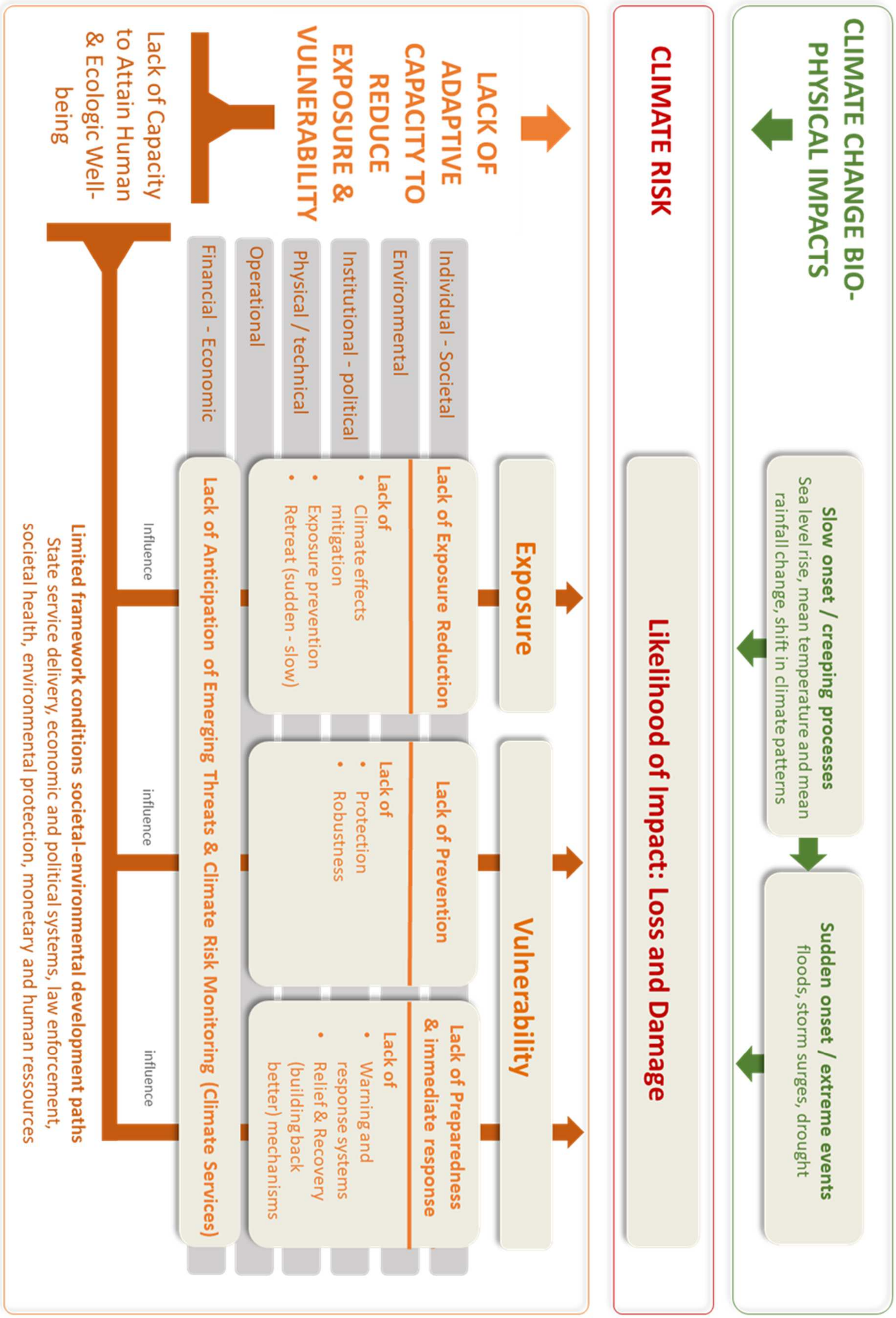
Special case risk (PIEVC)

AS defined by the owner’s risk tolerance thresholds, very low risk scores that are nonetheless of particular concern. Typically these represent cases with:

- very low probability and very high severity; or
- very low severity and very high probability

(Engineers Canada 2015).

Components of risk & risk causality



Hazard	'A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage' (WMO, 2011). In [the IPCC] report, the term hazard usually refers to climate-related physical events or trends or their physical impacts (Zebisch et al. 2017).
Hazardous event	The manifestation of a hazard in a particular place during a particular period of time (UNISDR 2009). Severe hazardous events can lead to a disaster because of the combination of hazard occurrence and other risk factors (UNISDR 2009).
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (Zebisch et al. 2017).
Interaction	The interface between weather events and/or climate trends and infrastructure components. When an infrastructure component experiences a weather event and/or climate trend it may respond. This interrelationship between the infrastructure component and the weather event and/or climate trend may cause an infrastructure response (Engineers Canada 2015).
(Climate) Vulnerability	Vulnerability is 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 a system is exposed, its sensitivity, and its adaptive capacity. Vulnerability to climate change refers to the propensity of human and ecological systems to suffer harm and its ability to respond to stresses imposed because of climate change effects. The vulnerability of a society is influenced by its development path, physical exposures, the distribution of resources, prior stresses and social and government institutions. All societies have inherent abilities to deal with certain variations in climate, yet adaptive capacities are unevenly distributed, both across countries and within societies. The poor and marginalized have historically been most at risk, and are most vulnerable to the impacts of climate change (WMO 2011).
Engineering vulnerability (PIEVC)	Engineering vulnerability is defined as the shortfall in the ability of public infrastructure to absorb negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure. It is a function of: - character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed; - sensitivities of infrastructure to changes, in terms of positive or negative consequences of changes in applicable climatic conditions; and - built-in capacity of infrastructure to absorb any net negative consequences from the predicted changes in climatic conditions (Canadian Council of Professional Engineering 2008). When the infrastructure has insufficient capacity to withstand the climate change loads placed on it, it is considered to be vulnerable; it is resilient when the capacity is sufficient. See also vulnerability ratio (Engineers Canada 2015).
Vulnerability ratio – V_R (PIEVC)	The vulnerability ratio (V_R) is calculated by dividing the total loading of an infrastructure (L_T) by the total capacity of the infrastructure (C_T): $V_R = L_T / C_T$

When $V_R > 1$, the infrastructure component is vulnerable
When $V_R < 1$, the infrastructure has adaptive capacity (Engineers Canada 2015).

Sensitivity

Sensitivity is the degree to which a system is affected, adversely or beneficially, either by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC_WG2 2014). Sensitivity may include physical attributes of a system (e.g. building material of houses, type of soil on agriculture fields), social, economic and cultural attributes (e.g. age structure, income structure) (Zebisch et al. 2017).

➔ **Threshold**

The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels (IPCC_WG2 2014).

➔ **Climate Impact threshold**

An Impact threshold defines critical climate conditions at which a system of interest in sensitive to and hence damages are likely to occur. Hence, its definition and calculated value is based on the system of interest's characteristics to experience harm. The definition of impact thresholds is key for climate risk assessment and requires the inclusion of end-users for developing climate service products.

➔ **Infrastructure threshold value (PIEVC)**

A value representing an infrastructure specific weather event or climate trend that triggers an undesirable infrastructure response.

In a vulnerability assessment, the climate parameter establishes the general weather or climatic conditions while the infrastructure threshold denotes a specific value of those conditions that must not be triggered. Thresholds may be maxima or minima depending on the climate parameter.

In some cases, an assessment may contemplate a number of threshold values for a specific climate parameter. This would be done to identify the impact of a range of weather events or climate conditions that may elicit different, notionally more severe, infrastructure responses (Engineers Canada 2015).

Changing-climate load – L_C

The anticipated load placed on the infrastructure resulting from changing climate over the period of the evaluation (Engineers Canada 2015).

Sensitivity analysis (PIEVC)

Systematically changing input values to determine the effects of such changes. In risk assessment, adjusting probability and/or severity score values to determine if the adjustments result in triggering risk tolerance thresholds. For example, adjusting a severity score by one unit may result in shifting an interaction from medium to high risk (Engineers Canada 2015).

Severity score factor (PIEVC)

A factor based on an arbitrary score (0 to 7) used to define the severity of the consequences of a weather event or climate trend impacting a particular infrastructure component (Engineers Canada 2015).

Risk Assessment

Risk assessment	In order to grasp all relevant impacts of climate change on the system of concern, climate risk assessments therefore need to consider both sudden hazardous events and slowly evolving trends. This has certain implications on how likelihoods are determined and reflected in assessment (Zebisch et al. 2017). - The process by which hazards are recognized and characterized. In the case of climate change risk assessment, risk identification is a deliberate procedure to review, and it is hoped, anticipate possible hazards. Risks associated with climate variability can in general be identified from past experience of climate (UKCIP, 2003). - The process by which risk assessment is used to develop risk management options to reduce, mitigate or compensate for the risk (UKCIP, 2003). The process by which hazards and consequences are identified, characterized as to their probability and magnitude, and their significance assessed (UKCIP, 2003).
Risk profile (PIEVC)	The pattern of high, medium and low risks established through a risk assessment. The risk profile is based on the risk scores calculated by the assessments placed within the context of the risk tolerance thresholds established by the infrastructure owner. Through the profile the practitioner can identify the infrastructure-climate interactions that generally lead to higher levels of risk. Each infrastructure will have a unique risk profile within a specified time horizon (Engineers Canada 2015).
Risk evaluation & Risk tolerance threshold (PIEVC)	The risk score values established by the infrastructure owner that define high, medium, low and special-case risk scores (Engineers Canada 2015) serving the evaluation of risk.

Infrastructure risk assessment

Boundary condition	The set of conditions that establish the limits of the scope of the assessment. Boundary conditions include the definition of the time horizon, geographic boundaries, jurisdictional authority, and features of the infrastructure that are within the mandate of the vulnerability assessment (Engineers Canada 2015).
Data sufficiency	Data availability and/or quality. Data must be both available and of high enough quality to meet the needs of the assessment (Engineers Canada 2015).
PIEVC Risk assessment	The process whereby practitioners answer three questions: 1. What can happen? 2. How likely is it to happen?

	Given that it has happened, what are the consequences?
Infrastructure exposure assessment (Yes/No analysis)	Analysis executed as part of the Protocol that requires the practitioner to assess if an identified climate parameter could potentially interact with an infrastructure component. Where the practitioner identifies that no interaction is possible, the interaction is eliminated from further analysis (Engineers Canada 2015).
Risk assessment workshop	A face-to-face working session conducted to complete the risk analysis outlined in the Protocol. The Protocol allows practitioners to conduct the workshop as a series of one-on-one meetings in lieu of a larger group session. However, the recommended process is to conduct a larger in-person working session to generate synergies that cannot be achieved through one-on-one discussion (Engineers Canada 2015).
Engineering analysis	Establishing the relationship between remaining useful service life, performance demands and other relevant factors of the infrastructure and changing-climate impacts, in order to calculate a numeric representation of vulnerability, adaptive capacity and infrastructure resiliency (Engineers Canada 2015).
Engineering vulnerability assessment	Executing the PIEVC Engineering Protocol to establish the engineering vulnerability or resiliency of the specified infrastructure (Engineers Canada 2015).
Table-top risk assessment	A risk assessment conducted with a smaller, more focused, group. Practitioners may execute the Protocol within the confines of the practitioner team prior to the risk assessment workshop in order to inform discussions or draw preliminary conclusions (Engineers Canada 2015).
Material/Materiality	The level of affect of a piece of information used in the vulnerability assessment. Information is material when the omission or misstatement of that information may affect the opinion, recommendations and/or conclusions resulting from the study. Conversely, information is not material when the omission or misstatement of that information will have no or negligible affect on the opinion, recommendations and/or conclusions resulting from the study (Engineers Canada 2015).
Surrogate information	Information from other models, regions or assessments used to compensate for information gaps in the current assessment. The Protocol allows practitioners to use information from regions with similar climatic and geographic conditions as a surrogate for information not currently available for the region of the assessment (Engineers Canada 2015).
Time horizon	The period in time that the assessment considers. Time horizon will usually look forward a number of years determined by the practitioner. Often this horizon will be the remaining useful life of the infrastructure that is being assessed (Engineers Canada 2015).
Multi-factor analysis	The term multi-factor analysis (MFA) is used when describing the technique to be used to compare adaptation scenarios in this triple-bottom-line analysis. The term is synonymous with multi-criteria-analysis, the term more commonly employed by operational research literature. MFA was created in order to distinguish between factors and criteria, which is necessary for the development of the triple-bottom-line analysis in Step 7 (Engineers Canada 2015).

Practitioner	For the purposes of this assessment, the individual or team executing the Protocol (Engineers Canada 2015).
Professional judgement	The application of training, knowledge, experience, and skills gained over a prolonged period of professional practice. Within a vulnerability assessment, professional judgment refers to the combined judgment of the practitioner team and infrastructure owner and staff. Individuals can contribute a unique perspective regarding climate-infrastructure interactions based on their history of dealing with similar or analogous situations (Engineers Canada 2015).
Site visit	A tour conducted to inspect and familiarize the practitioner with the infrastructure being assessed. The site visit should include both observation of the facilities and discussions with maintenance, operations and management staff, as appropriate (Engineers Canada 2015).
Simple multi-attribute rating technique	A computational and aggregation technique based on a weighted summation of performances across factors under consideration (Engineers Canada 2015).
Statement of vulnerability/resiliency	A declaration by the practitioner outlining their professional opinion regarding the overall vulnerability or resiliency of the assessed infrastructure. The statement would normally outline boundary conditions and limitations of the assessment and provide the owner with a global understanding of the infrastructure's vulnerability to the changing-climate conditions considered in the assessment (Engineers Canada 2015).
Limitations of the PIEVC risk assessment	Uncertainties introduced into the vulnerability assessment related to the assumptions, sufficiency of data, and/or methodologies used to execute the Protocol. Limitations may, or may not, be material. The practitioner would normally comment on, and suggest additional work to address, material limitations (Engineers Canada 2015).

Adaptation and Climate Risk Management

Adaptation	Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC_WG2 2014). Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation: - Anticipatory adaptation: Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation. - Autonomous / spontaneous adaptation refers to a non-conscious response to climatic stimuli, but that is triggered by ecological changes in natural systems and by market or welfare changes in human systems. - Planned adaptation: Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (IPCC_WG2 2014).
Adaptive capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC_WP2 2014). In the context of the PIEVC Protocol: The Protocol predicts the adaptive capacity of the infrastructure component strictly from an engineering perspective. It identifies where loads may exceed the capacity of a structure and threaten failure. There may be social, operational or management strategies that could affect the resiliency of the infrastructure or provide alternative perspectives regarding the adaptive capacity of the infrastructure. These other factors are outside of the scope of this analysis but may be relevant considerations in establishing the conclusions and recommendations arising from the vulnerability assessment. Analysis of these additional factors is dependent on the professional judgement of the practitioner and input from the infrastructure owner (Engineers Canada 2015).
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management (UNISDR 2009). In the context of the PIEVC Protocol: The ability of an infrastructure, or infrastructure component, to absorb a projected weather event or climate condition and still maintain a level of service within design or operational tolerances (Engineers Canada 2015).
Climate Risk Management	Climate risks have to be continuously analyzed, reduced, addressed and transferred. Comprehensive Climate Risk Management (CRM) is a systemic approach that seeks to anticipate, avoid, prevent, and finance risks as well as absorb remaining impacts from extreme weather events and slow onset changes. It thus builds on lessons learnt from climate change adaptation (CCA) and disaster risk management (DRR), embedded in a sustainable development framework (www.adaptationcommunity.org). Precautionary principle: Where there are anticipated threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation' (Rio declaration, 1992).
Climate proofing	In general, the climate-proofing concept is used to ensure that planning, both on a strategic level as well as for specific investment and construction projects, is in-

line with efforts to increase resilience to climate change. In other words, climate proofing ensures that investment objectives are met under conditions of climate change. With the tool, elements and objectives of strategies and planning processes that are affected by climate change and in need of adaptation are identified in order to incorporate climate-change considerations into them.

Climate Risk Management Decision Making Process

A climate risk management process seeks to navigate through the diverse set of options available, by the means of various diverse decision-support tools such as Multi-Criteria Analysis and Cost-benefit analysis. The concept of comprehensive climate risk management encompasses the following mutually reinforcing steps and should build on the participation of stakeholders from different sectors and scales:

Step 1: Scoping: In this initial phase of climate risk management the system of interest is defined, whether it be an infrastructure, an ecosystem, a city or entire country. Based on such definition, the actors to be involved in the climate risk management process need to selected.

Step 2: Assessing needs of adaptation: Climate risk assessments build the foundation for this step. Based on risk assessment, which entails exposure, hydro-meteorological hazards and creeping processes and vulnerability assessment, the needs for investing in adaptation are clarified, e.g. through risk evaluation. Risk evaluation is a component of risk assessment in which judgments are made about the significance and acceptability of risk (UKCIP, 2003).

Step 3: Option generation: This stage of decision-making refers to brainstorming within a multi-stakeholder environment about all possible options available and worth to be considered. The open character, meaning putting less concern on feasibility or other aspects, is relevant to allow multiple perspectives and thinking “out of the box” when identifying potential adaptation solutions (adapted from Renn 2008, OECD 2009).

Step 4: Assess adaptation options: Each of the options generated can have intended, but also unintended consequences that influence the climate risks. Moreover, some options are mutually exclusive others work complementary. Here, an assessment is necessary that guides decision makers through a process of how to evaluate alternative options, i.e. whether options that are available are effective, efficient, costly, sustainable, have side effects, or are fair and ethically acceptable (adapted from Renn 2008, OECD 2009)

Step 5: Select adaptation option: Once, the different options are assessed, it has to be decided upon, which options are to be selected and which rejected. This decision is obviously necessary if one or more options turn out to be the dominant. A legitimate decision can be made on the basis of formal balancing tools (cost-benefit analysis).

Step 6: Integrating adaptation options into relevant planning and implement options. This option relates to ensure that selected options become part of planning and are being implemented.

Step 7: Monitoring and evaluation of option performance. The final step is to monitor and evaluate the success of the adaptation strategy implemented. Evaluating the success of an adaptation process is not a straightforward task and may take a long time because the benefits of adaptation may not be realized until the climate changes significantly. Evaluating the success of adaptation should be based on measuring the benefits against the policy objectives used in effectiveness analysis. Quantitative indicators of success should be used when available (Smith, Lenhart 1996)

Climate Risk Management Options

Comprehensive climate risk management aims to reduce and address the negative consequences of climate change along the entire risk continuum: averting climate risks through the reduction of greenhouse gas emissions, minimizing climate risks through adaptation and risk management to managing residual climate risks.

Options
Ways of achieving objectives. Options might be policies, programs, projects, schemes, systems, technologies or anything else presenting a choice, about which a decision is needed. Options may be mutually exclusive (A or B), or could be implemented individually or in combination (A and/or B) (UKCIP, 2003).

Low regret options
Options for which the implementation costs are low while, bearing in mind the uncertainties with future climate change projections, while the benefits under future climate change may potentially be large (UKCIP, 2003)

No regret options
Adaptation options (or measures) that would be justified under all plausible future scenarios, including the absence of man-made climate change. A no regret option could be one that is determined to be worthwhile now (in that it would yield immediate economic and environmental benefits which exceed its cost), and continue to be worthwhile irrespective of the nature of future climate (UKCIP, 2003)

Climate risk management options and assessment

Adaptation domain	Adaptation component	Adaptation tasks	Adaptation measures
Anticipation	Forecast	Current R&V and future R&V scenarios	Technical capacity development, research
		Institutionalized mechanisms for anticipating future R&Vs	Cross-institutional coordination
Prevention	Hazard mitigation	Global Co2 Emission reduction	Mitigating anthropogenic hazard triggers (green economy, transport system, energy supply)
		Local / regional hazard mitigation	Mitigating anthropogenic hazard triggers (land degradation, pollution, ecosystem changes, land use change, sealing) , retention areas, restoring ecosystem functions
	Accommodation	Protection	Protected infrastructures and assets, e.g. dykes, green houses for crops, irrigation systems, window protection against storms
		Resistance (long-term functional exposure reduction)	Multi-hazard building codes for lifelines and housing, altering farming practices and planting dates, crop diversification
	Retreat	Redirection of development away from hazardous places	Incentives (insurance, economic development) and regulation (land use policies etc.)

		Relocation of settlements, socia and economic assets	Sustainable livelihood restoration of the affected population in less risky environments according to standards
	Exposure prevention	Development restriction potentially hazardous areas	Insurance, land use regulation
Managing residual climate risks	Early warning mechanisms	Real time hazard detection (time of arrival, magnitude)	Building instrumentation networks, institutionalization, decision support systems
		Warning dissemination	SOPs: institutionalization and infrastructure planning, education and socialization
	Immediate response mechanisms to warnings	Short-term exposure reduction	Hazard control mechanisms and measures
			Evacuation: SOPs / Evacuation Infrastructure: Spatial planning, shelter planning, labelling and socialization, provision of basic services
		Short-term resistance building	Measures that protect infrastructure and assets in the short-term from a hazardous event: e.g. housing protection
	Search and Rescue, Relief	Contingencies	Search and rescue infrastructure provision (shelter, direct aid, sanitation, food) & market interventions
	Recovery	Contingencies	Insurance: R&V transfer, micro-insurance for reconstruction
		Disaster resilient recovery planning	R&V zoning, R&V-R infrastructure planning, integration of R&V-R in recovery planning to account for returning and new hazards

Cost-benefit analysis

Monetary measurement of all negative and positive impacts associated with a given action. Costs and benefits are compared in terms of their difference and/or ratio as an indicator of how a given investment or other policy effort pays off seen from the society's point of view (IPCC_WG3 2014).

Uncertainty (CRM)

According to the ISO 31000 standard is 'the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood.' 4 Climate risk assessments are subject to various sources of uncertainty, which need to be carefully addressed. In the framework of these assessments, uncertainty can be regarded in terms of confidence and likelihood (Zebisch et al. 2017).
Confidence is a qualitative measure for the uncertainty of knowledge and information and the validity introduced by the IPCC. It is a combination of the level of evidence of a finding and the agreement (e.g. between experts or models). Confidence could be used in a risk assessment to give an indication on the validity of a statement such as in 'high risk for food insecurity in 2020 (medium confidence)'.

Likelihood in the risk assessment context is the chance of a specific adverse event (hazard) or consequence (impact) occurring. According to ISO 31000, likelihood can be determined objectively or subjectively, qualitatively or quantitatively, and described in general terms or mathematically (such as a probability or a frequency over a given time period). Probability is one possible measure for likelihood, expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty (Zebisch et al. 2017).

Over confidence

A potentially vulnerable state of underestimating uncertainty. There is a large body of evidence from cognitive psychological experiments and surveys showing that decision-makers and technical experts overestimate their own abilities, knowledge, and the precision of the information used to justify a particular choice or decision (UKCIP, 2003).

Worst-case	An assessment of risk based on pessimistic attitude to uncertainties concerning probability and impacts or opportunities. Sometimes used when assessing the risk associated with low probability, high consequence events (possible catastrophes and disasters). Used to provide an upper bound to estimates of risk (UKCIP, 2003).