Grow Green

Climate change, vulnerability and risk in urban areas

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The renaturing of cities through an increased emphasis on the use of Nature-based solutions (NBS) offers urban areas the opportunity to deliver multiple environmental and socio-economic benefits. In particular, approaches linked to NBS can limit the impact of climate change on vulnerable cities. In order to use NBS successfully to reduce and mitigate climate change, the existing environmental risk needs to be evaluated.

From the climate change adaptation perspective, risk is understood as a function of hazard, exposure and vulnerability, according to the Intergovernmental Panel on Climate Change in its Fifth Assessment Report, AR5 (IPCC (2014) AR5, WG-II, Ch. 19[1]).

Risk component	*Hazard: influenced by natural variability of climate variables and anthropogenic climate change* *Exposure to hazard* *Sensitivity (component of vulnerability)* *Capacity of response (component of vulnerability)*

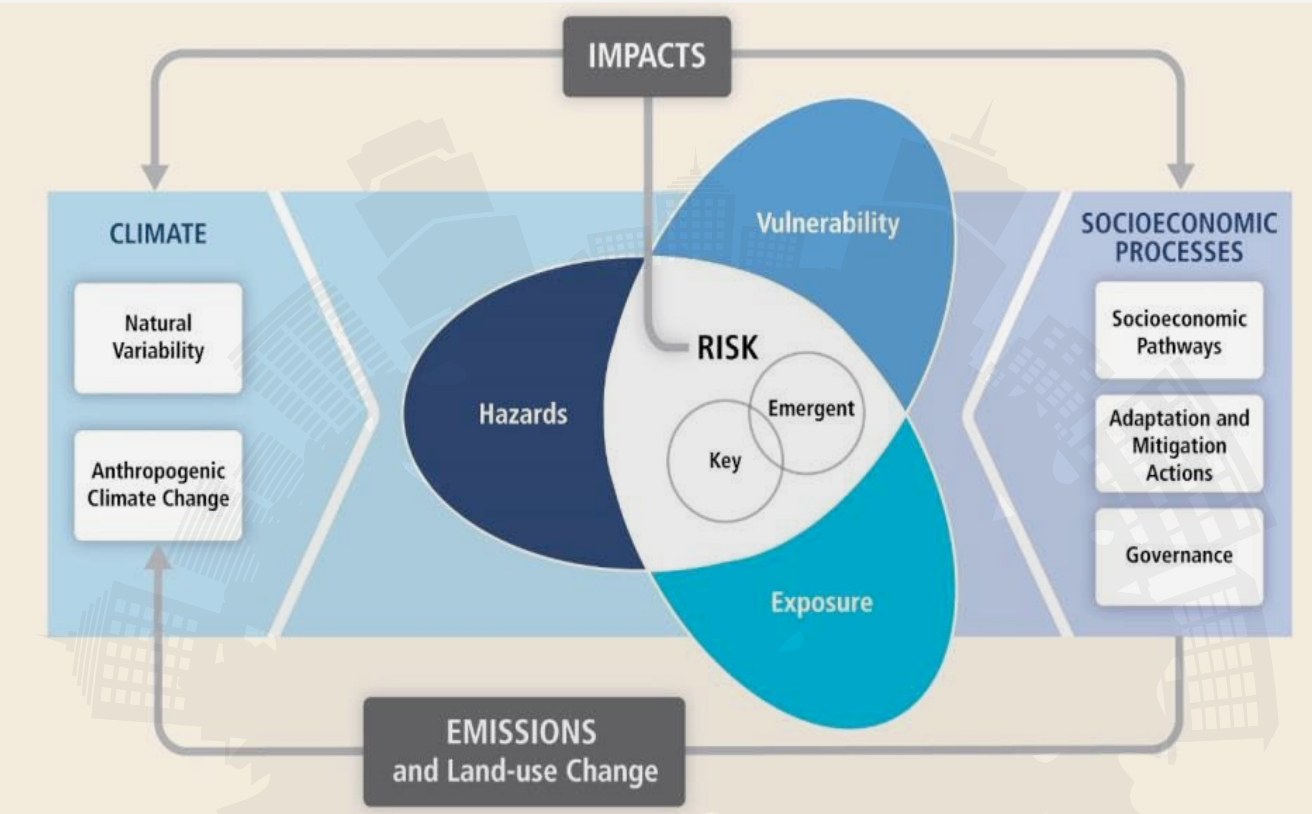

Figure 1. Risk Assessment Approach. Source: IPCC, 2014 Technical Report, Figure [TS.1]

Where:
Risk = f (hazard, exposure, vulnerability)
Risk = probability (hazard) x consequence f (exposure, vulnerability)
Vulnerability= f (sensitivity, capacity of response)

The IPCC's conceptualisation of risk also highlights the influence of climate and socio-economic processes on risk.

1 IPPC AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability

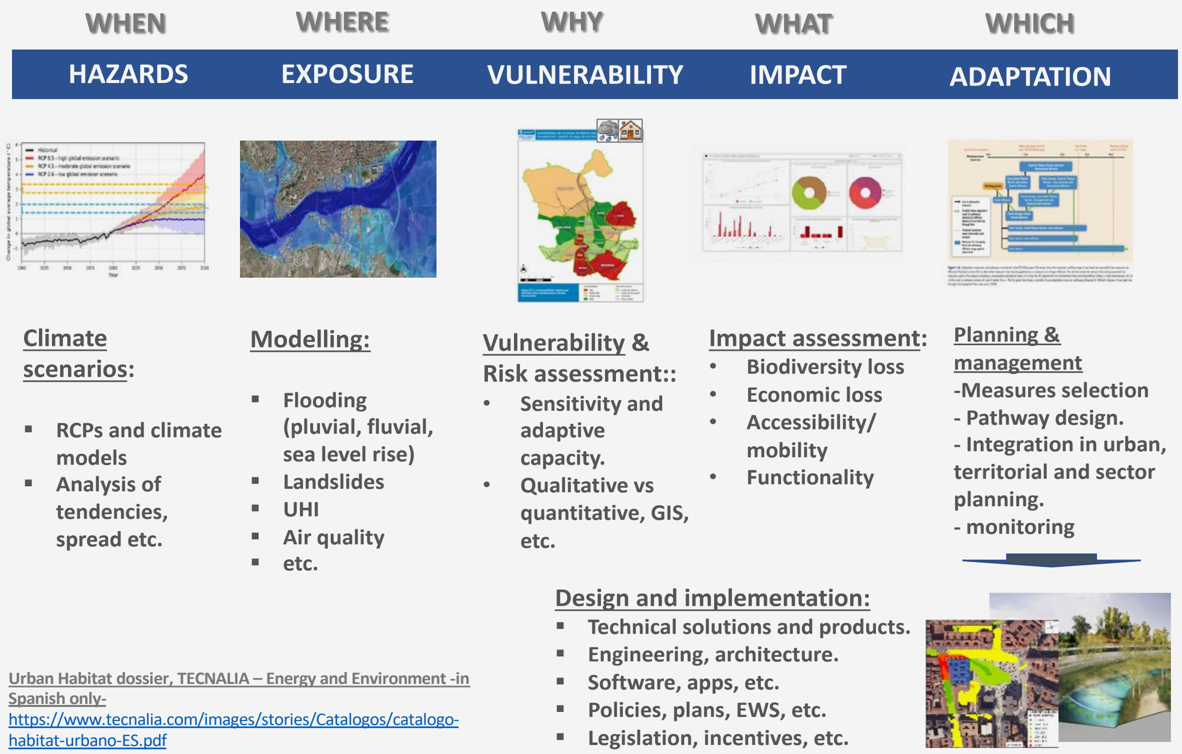

Figure 2. Sequential analysis of hazards, exposure and vulnerability assessment. Source own elaboration TECNALIA 2021. Adapted from Urban Habitat dossier, TECNALIA – Energy and Environment -in Spanish only-https://www.tecnalia.com/images/stories/Catalogos/catalogo-habitat-urbano-ES.pdf

The decision-making sequence shown in Figure 2, allows the identification of the most significant future climate hazards, the delineation of where those hazards would potentially have a spatial representation. It also explains why a city could be potentially vulnerable to these hazards, and what the expected impact is. With this tool, NBS can be identified to tackle hazards and to define adaptation measures to reduce exposure, vulnerability and risk of cities.

What are climate scenarios?

A **climate scenario** is a plausible representation of future **climate** that has been constructed for explicit use in investigating the potential impacts of anthropogenic **climate** change (IPCC).

The elaboration of climate scenarios provides insights into the future behaviour of phenomena such as floods, droughts, heatwaves, etc., and their potential impact on health, infrastructure, natural environment, economy. Projections of climate trends can be made periodically by means of global circulation models (GCM-General Circulation Models) under different scenarios. At an international level, this activity is coordinated by the IPCC, whose latest report (IPCC; AR5, 2014[2]), establishes four scenarios called representative concentration pathways (RCP-Representative Concentration Pathways).

[2] IPPC AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability

What are the Representative Concentration Pathways?

To understand how our climate may change in the future, we need to predict how society will behave. For example, will the burning of fossil fuels continue at an ever-increasing rate, or will there be a shift towards renewable energy?

The RCPs try to capture these future trends. They make predictions on how concentrations of greenhouse gases (GHG) in the atmosphere will change in the future as a result of human activities.

Previous IPCC assessment reports used a set of scenarios known as SRES (Special Report on Emissions Scenarios), which start with socio-economic circumstances from which emissions trajectories and climate impacts are projected. In contrast, RCPs fix the emissions trajectory and resulting radiative forcing[3] rather than the socio-economic circumstances.

The four RCPs (Figure 3) range from very high (RCP8.5) to very low (RCP2.6) future GHG concentrations. The numerical values of the RCPs (2.6, 4.5, 6.0, and 8.5) refer to the concentrations in the year 2100.

RCPs are characterised by their approximate calculation of the total radiative forcing in the year 2100 in relation to the year 1750, which can be 2.6 W m – 2, 4.5 W m – 2, 6.0 W m – 2, or 8.5 W m – 2. These correspond to scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5, respectively CO_2 equivalent concentrations –including CH_4 and N_2O of approximately 475, 630, 800 and 1313 ppm.

What do RCPs consist of?

An RCP scenario consist of a huge ammount of data. RCP data is in tables. For each category of emissions, an RCP contains a set of starting values and the estimated emissions up to the year 2100, based on assumptions about economic activity, energy sources, population growth, and socio-economic factors. The data also contain historic, real-world information. While socio-economic projections are drawn from the literature in order to develop the emission pathways, the database does not include socio-economic data. Modelers download the database sets to initialise their models, which jump-starts what would otherwise be very lengthy. RCPs and previous scenarios were created to avoid such duplication and the inevitable initialisation inconsistencies that would emerge.

	FR	Tendencia del FR	$[CO_2]$ en 2100	
RCP2.6	2,6 W/m^2	decreciente en 2100	421 ppm	Decreasing – low emission scenario
RCP4.5	4,5 W/m^2	estable en 2100	538 ppm	Stable- moderate emission scenario
RCP6.0	6,0 W/m^2	creciente	670 ppm	Increasing- high emission scenario
RCP8.5	8,5 W/m^2	creciente	936 ppm	

Figure 3. RCPs according to AR5 of the IPCC. Source: IPCC, AR5, 2014[4]

3 **Radiative forcing** is a measure of how the energy balance of the Earth–atmosphere system is influenced. The word '**radiative forcing**' is used because these factors change the balance between incoming solar **radiation** and outgoing IR **radiation** within the Earth's atmosphere.

4 IPPC AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability

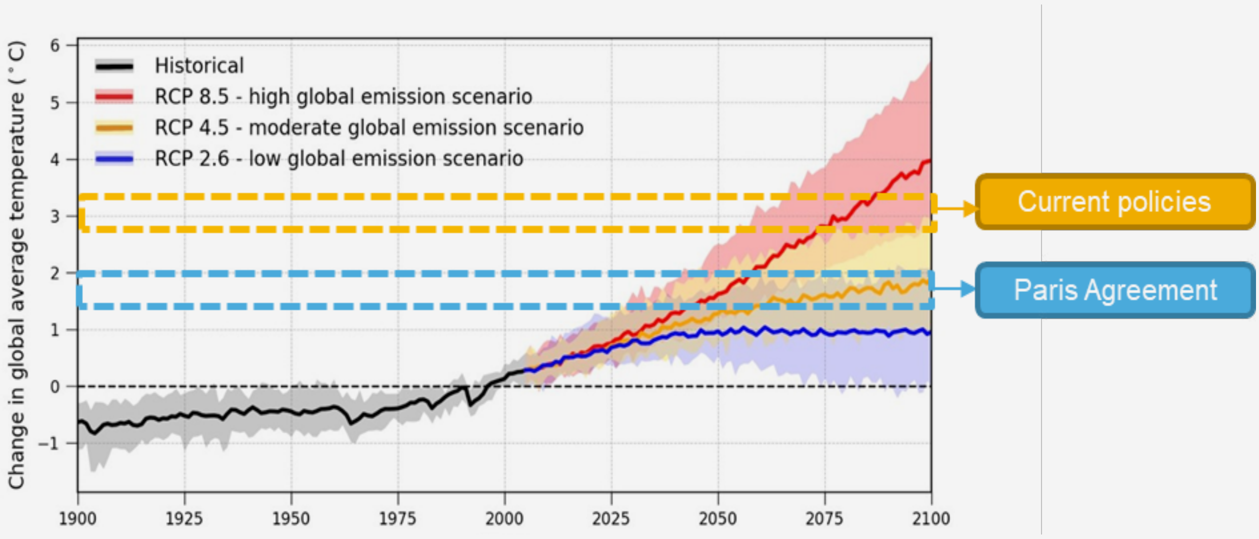

Figure 4: Change in global average temperature from 1900 to 2100 considering historical data evolution and the RCPs 2.6, 4.5 and 8.5.

The screenshot below (Figure 5) shows how many emissions categories are addressed by the RCPs. Each RCP contains the same categories of data, however the values vary a great deal, reflecting different emission trajectories over time as determined by the underlying socio-economic assumptions (which are unique to each RCP).

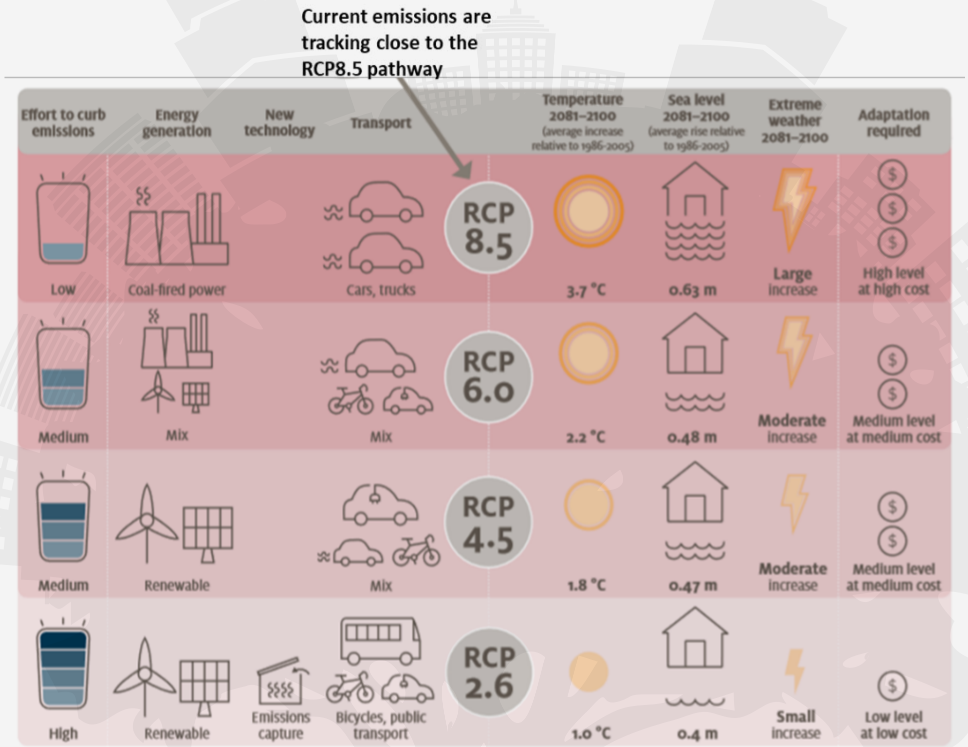

Figure 5. Summary of RCPs pathways. Source: Coastal Adapt https://coastadapt.com.au/sites/default/files/infographics/15-117-NCCARFINFOGRAPHICS-01-UPLOADED-WEB%2827Feb%29.pdf

2 °C increase in temperature is recognised as the threshold at which climate change becomes dangerous

The spatial resolution of the GCMs is hundreds of kilometres and does consider regional heterogeneities. There are however techniques of regionalisation (down-scaling) that allow increasing its spatial resolution, such as dynamic regionalisation based on the use of regional Climate Models (RCM). Each of these process steps (scenarios, GCM, RCM) carries uncertainties.

Which climate scenario to adopt in an urban context?

Scientists use the RCPs to model climate change and build scenarios about the impacts. These scenarios can be used by cities to plan for the future. RCP 8.5 leads to much higher temperature increases, and this implies greater impacts and costs. To adapt to these changes will also cost more. A balance must be struck between the cost of impacts and the cost of adaptation.

In Europe the EEA, Copernicus programme works with RCP 4.5 & 8.5. As the most plausible ones, The RCP4.5 being the most optimistic scenario and the RCP8.5 the most pessimistic one, disregarding the other two RCPs available. At the European level, regional climate change projections have been produced and updated by various research projects that have incorporated the results of the GCMs from successive IPCC reports:

Initiative	Spatial resolution	IPCC associated report
PRUDENCE	50km x 50km	AR3
ENSEMBLES	25km x 25km	AR4
CORDEX	12km x 12km (and 50km x 50km)	AR5

Currently, under the Euro-CORDEX initiative, which is the European branch of the CORDEX initiative (COrdinated Regional Downscaling EXperiment), we work with RCMs with a resolution of 0.11º (about 12x12 km2) and 0.44º (50x50 km2).

The generation of climate scenarios with adequate spatial resolution is the required initial step to improve knowledge about climate change and advance in the identification and evaluation of impacts, weaknesses, and possible adaptation pathways.

The regional climate scenarios constitute a piece of cross-sectional reference information for subsequent studies of the impact of climate change on various sectors, such as health, agriculture, water resources, the natural environment, with the aim of identifying the best adaptation measures to climate change.

Time periods for the climate scenarios

In Europe 30-year periods are used in climate change scenarios, considering near future the period 2011-2040, Mid-range century 2041-2070 and late century 2071-2100[5]

5 EU use of time periods.

How to address climate change related hazards?

Hazard group	Main biophysical/weather/climate determinants	Hazard main type
Geophysical Originating from mass movement of solid earth.	Mass movement	Subsidence
		Landslide
		Earthquake
Meteorological Short-term or small-scale weather conditions (e.g., minutes to days).	Precipitation	Rainstorm
	Wind	Severe wind/storm
	Temperature trends and patterns hot and cold	Heat wave
		Extreme hot weather
		Cold wave
		Extreme cold weather
Climatological Long-term or large-scale atmospheric processes (e.g., intra seasonal to multi-decadal).	Water scarcity (lack of precipitation and or seasonal melt)	Drought
	Wildfire	Forest fire and land fire
Hydrological Mass movement of water influenced by meteorological	Flood	Surface flood/runoff
		River flood
		Coastal flood/ sea level rise
	Wave action	Storm surge
	Chemical change	Saltwater intrusion
		Ocean acidification
Biological A change in the way living organisms grow and thrive, which may lead to contamination and/or disease.	Insects and micro-organisms	Different diseases for humans, animals and plants under extreme events

Table 1 TECNALIA's proposal for clustering hazards linked to the main biophysical drivers/ determinant. Source: Own elaboration TECNALIA 2021.

The parameters used to classify climate change related hazards and their characteristics are:

- Location and spatial dispersion.
- Intensity /severity of the natural or human induced physical ones. - including extreme events.
- Duration of the event.
- Frequency how often this event is repeated.
- Probability.

Climate change may affect the main characteristics of the hazards in terms of the intensity, duration and frequency of these events, which is crucial when assessing vulnerability and risk.

Evaluation of climate change vulnerability and risk

There are different approaches and methods in the risk analysis related to climate change related hazards (see Figure 7):

- Quantitative risk analysis: Hazard scenarios and cost of elements at risk are used.
- Event tree analysis: A number of hazards may occur in chains: one hazard causes the next.
- Risk Matrix approach: They permit to classify risks based on expert knowledge with limited quantitative data.
- Indicator based approach: Social, economic and environmental vulnerability considered.

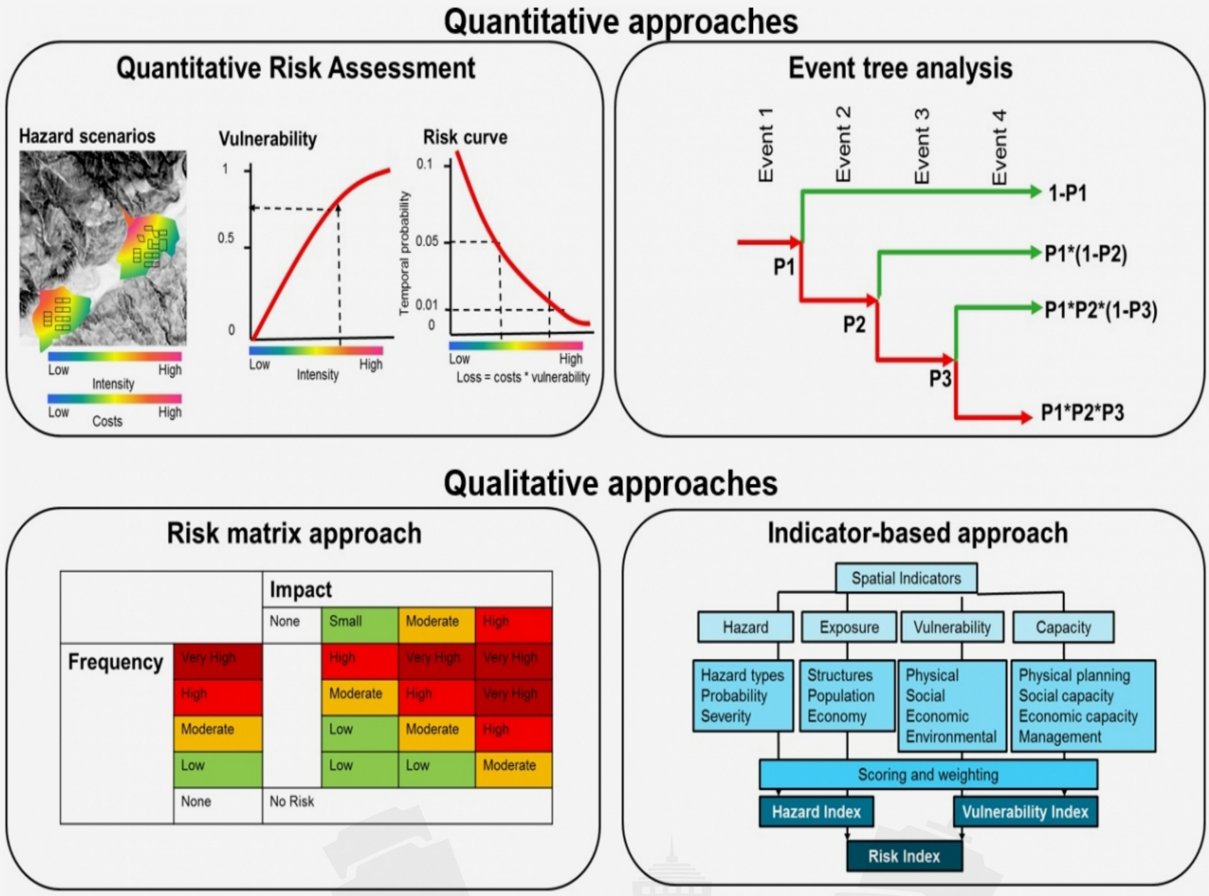

Figure 6 Different approaches to assess risk of hazards. Source: Caribbean Handbook on Risk Management (https://www.cdema.org/virtuallibrary/index.php/charim-hbook/what-is-charim)

Method	Advantages	Disadvantages
Quantitative risk assessment (QRA)	Provides quantitative risk information that can be used in Cost-benefit analysis of risk reduction measures.	Very data demanding. Difficult to quantify temporal probability, hazard intensity and vulnerability.
Event-tree analysis	Allows modelling of a sequence of events, and works well for domino effects.	The probabilities for the different nodes are difficult to assess, and spatial implementation is very difficult due to lack of data.
Risk matrix approach	Allows to express risk using classes instead of exact values, and is a good basis for discussing risk reduction measures.	The method doesn't give quantitative values that can be used in cost-benefit analysis of risk reduction measures. The assessment of impacts and frequencies is difficult, and one area might have different combinations of impacts and frequencies.
Indicator-based approach	Only method that allows to carry out a **holistic risk assessment**, including social, economic and environmental vulnerability and capacity.	The **resulting risk is relative** and doesn't provide information on actual expected losses.

Table 2 Advantages and disadvantages of risk approaches. Source: own elaboration TECNALIA, 2020. Adapted from Caribbean Handbook on Risk Management (https://www.cdema.org/virtuallibrary/index.php/charim-hbook/what-is-charim)

Definition of the vulnerable system: impact chains linking hazards with elements at risk

In order to define a vulnerable system there must be an analytical unit such as; municipality, district, planning zone areas, or other units which are not necessarily administrative areas. The definition of impact chains is the next step.

What is an impact chain?[6]

An impact chain describes a cause-effect relationship among elements that contribute to the consequences of a given combination of hazard and exposed object of a system.

- **Climate variables** are by definition impossible to control.
- **Non-climatic drivers** (biophysical and socio-economic) could be:
    - Contextual (difficult if not impossible to define the action to change) or
    - Controllable (those over which we could define actions to mitigate the risks).

Why is it important to characterise impact chains?

The impact chains are important in systematising the assessment of vulnerability against climate change towards NBS as adaptation measures. It is good practice to identify the relevant indicators that describe the system in order to perform an indicator-based vulnerability and risk assessment.

How to build impact chains?

Based on the identified climate stimuli, including its impacts on the behavior of natural hazards affecting the territory, the potential direct and indirect impacts to the various receptors such as built-up/physical assets or functions/services in a system can be identified (Figure 7).

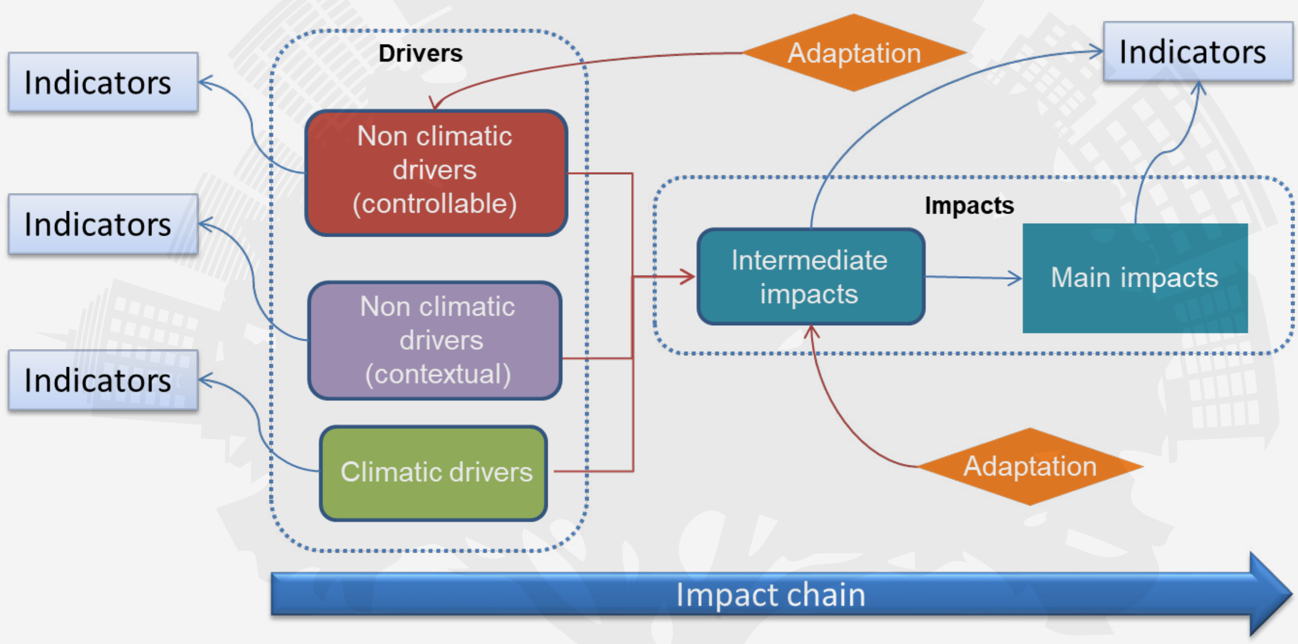

Figure 7. Visualises an impact chain. Source FPVII Project: RAMSES Reconciling Adaptation, Mitigation and Sustainable Development for Cities", FP7. 2012-2017

6 http://wiki.resin.itti.com.pl/supporting-tools/ivavia-guideline/module-2-developing-impact-chains/

Example of impact chains that could be defined in the context of a NBS Strategy:

- Fluvial Flooding on built environment.
- Heat stress on human health, comfort and well-being.
- Heat stress on agro-economic activities.
- Wildfires on agro-economic activities.

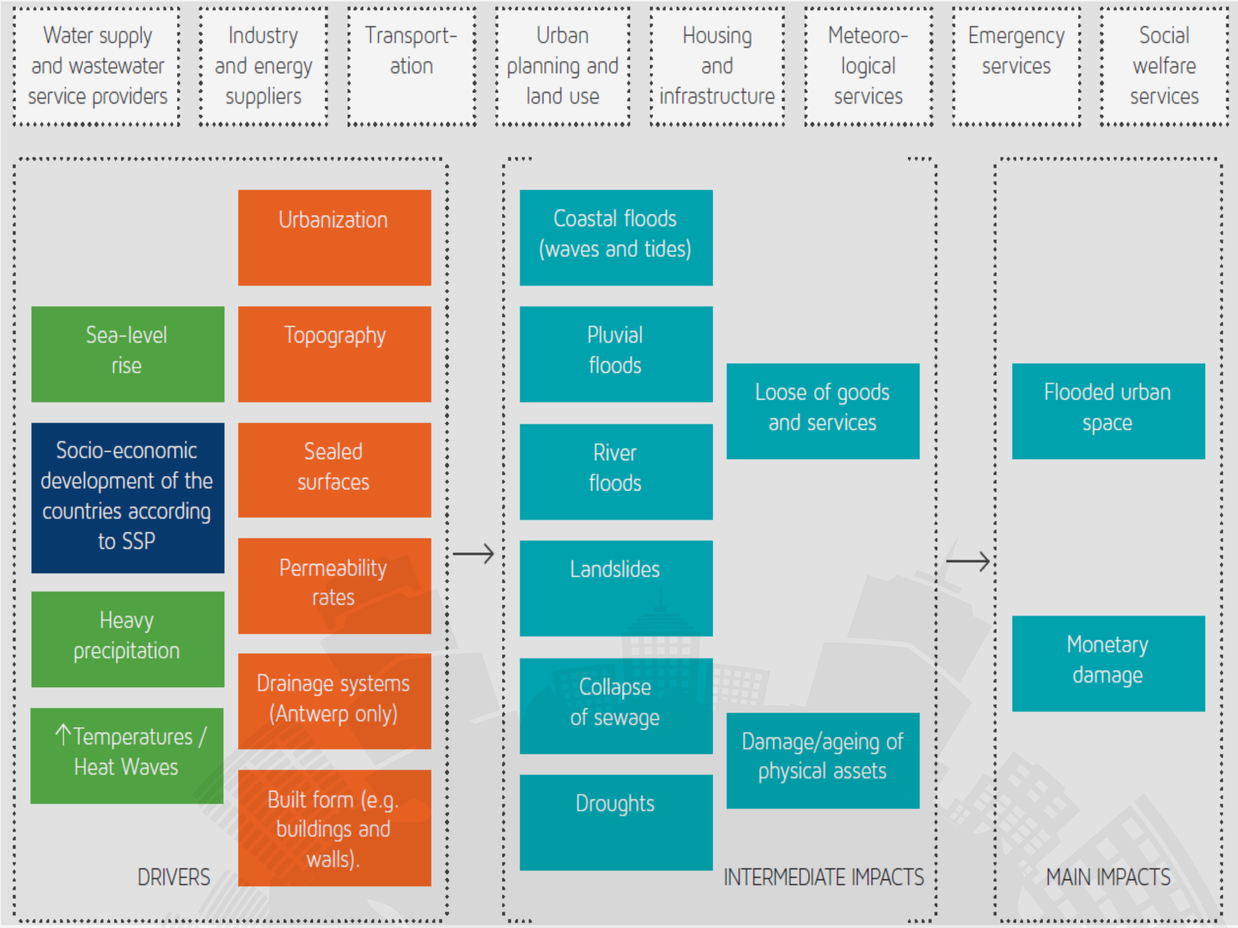

Figure 8 Example of an impact chain of flooding on urban areas. Source FPVII Project: RAMSES Reconciling Adaptation, Mitigation and Sustainable Development for Cities", FP7. 2012-2017

Most recent reference cases delivered by TECNALIA

Tapia et al 2017 Profiling urban vulnerabilities to climate change: An indicator-based vulnerability assessment for European cities. Ecological Indicators 78 (2017) 142–155

Territorial Impacts of Natural Disasters – ESPON TITAN (2019- 2021)

Evaluación de la vulnerabilidad y riesgo de los municipios vascos ante el cambio climático (2019)

Concluding remarks

The methodological resources offered in this factsheet can allow better informed territorial planning and urban planning decisions, in order to anticipate the possible impacts of climate change, as well as act proactively, to increase the efficiency and resilience of the territory.

The resources allow for the identification of priority intervention areas in need of targeted adaptation measures based on their significant vulnerability and risks as well as opportunity areas for the deployment of NBS.

Global information on vulnerability, risks and adaptation needs at the municipal level can serve as starting information for:

- The possible development of local adaptation plans, establishing a common approach that allows harmonizing and comparing concepts and indicators that can be incorporated into the monitoring of adaptation plans.
- Its consideration in processes and sustainability plans or Local Agendas 21 integrating the vulnerability and risk component of climate change, associated with management tools and monitoring of sustainability policies
- Its consideration in key local sector policies and plans to face the effects of climate change, such as risk management in emergency plans, or other municipal plans such as public health, to help update them by incorporating climate aspects.
- Compliance with and monitoring of international commitments such as the Global Covenant of Mayors for Climate and Energy.
- Requirement of specific studies in our municipality (thermal maps, floods, etc.) for use in urban development plans, urban regeneration plans, investment projects, etc.
- Identification of opportunities for collaboration and action at the regional level, to work together, in order to reduce the impact associated with impact chains that affect supra-municipal spaces such as basins or coasts.

Finally, the potential use both in the academic and research fields, as well as by private agents, making decisions about the preparation of studies, the adoption of investment criteria, etc. should be noted.

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