ΕΡΓΑΣΤΗΡΙΟ ΛΙΜΕΝΙΚΩΝ ΕΡΓΩΝ

ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ
ΣΧΟΛΗ ΠΟΛΙΤΙΚΩΝ ΜΗΧΑΝΙΚΩΝ
ΤΟΜΕΑΣ ΥΔΑΤΙΚΩΝ ΠΟΡΩΝ ΚΑΙ ΠΕΡΙΒΑΛΛΟΝΤΟΣ

# Μάθημα: Περιβαλλοντική Διαχείριση Παράκτιας Ζώνης

## Τρωτότητα Ακτών & Λιμένων

Βασιλική Τσουκαλά | Καθηγήτρια ΕΜΠ

Βασιλική Χαλαστάνη | Υπ. Διδάκτορας ΕΜΠ

Χριστίνα Τσάιμου | Υπ. Διδάκτορας ΕΜΠ

Αθήνα 2022-2023

## Highlights

- Vulnerability of systems – Examples of vulnerable systems
- Threats – Hazards that affect systems' vulnerability
- Definition & description of vulnerability components
- Vulnerability assessment – Estimation of Vulnerability Index
- Climate change & relationship with systems' vulnerability
- Coastal vulnerability
- Port Vulnerability

## Educational scope

After this course the student will be able to:

- Familiarize with the complex concept of vulnerability
- Identify potential threats-hazards that affect the vulnerability of a system
- Understand  the components of vulnerability and their interaction to assess the vulnerability of a system
- Comprehend the relationship of climate change impacts and vulnerability
- Implement existing practices for coastal vulnerability assessment
- Implement existing practices for port vulnerability assessment

## Vulnerability

Vulnerability was introduced in **1970s** within the discourse on natural hazards and disaster (Keefe et al, 1976).

The concept is **relative** and **dynamic** (Iorhen et al, 2021).

Vulnerability refers to various **systems**:
individuals, households, communities (e.g. coastal), infrastructures (e.g. ports) etc.

If the system is unable to withstand, for example, an earthquake or a storm, or lack of attentiveness may result in a slower reply to a disaster, leading to better loss of life or protracted suffering.

The reverse side of the coin is **capacity**, which can be described as the resources available to systems to cope with a threat or to resist the impact of a hazard.

A system might be vulnerable to certain events but be resilient to others. Therefore, it is important to consider the specific risk and threat profiles to the area under analysis.

## Systems


## Systems


AIRPORT


Office system work
infographics
TRAINING
Lorem ipsum
75%
IDEA
SELECTION
Lorem ipsum
95%
CHATING
Lorem ipsum
TEAMWORK
MOTIVATION
to achieve success
100%
BREAK TIME
&COFFEETIME
To increase efficiency by 45%
ANALYSIS DATA
Lorem ipsum 35%
BRAINSTORMING
is a group creativity technique
by which efforts are made to find
a conclusion for a specific problem
INFORMATION
Lorem ipsum 85%

## Vulnerable systems

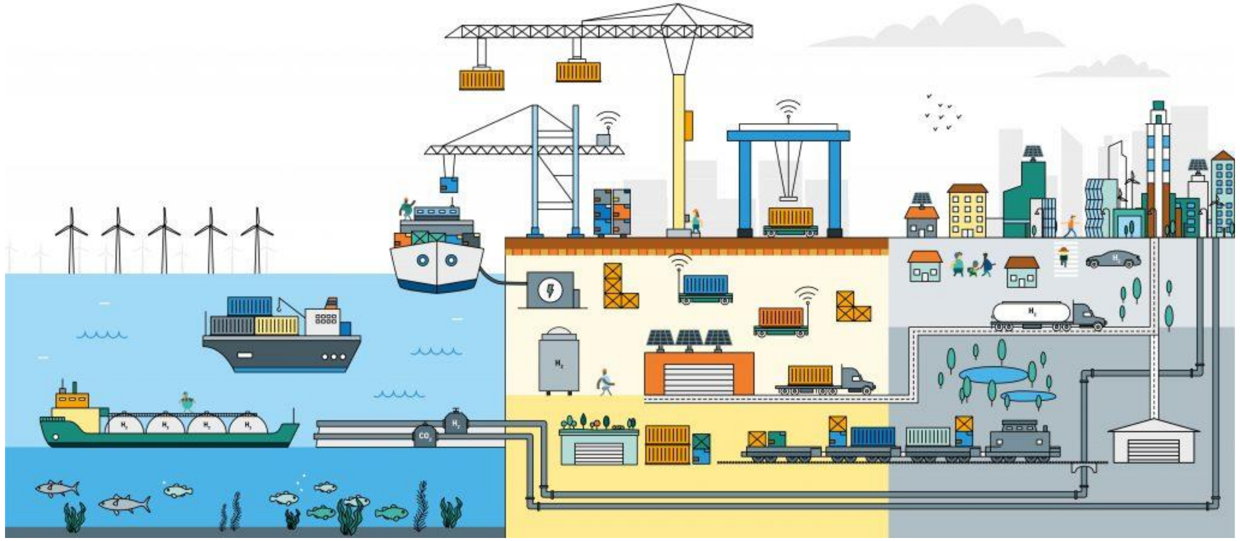
A system is a group of interacting elements (or subsystems) having an internal structure which links them into a **unified whole**. The boundary of a system is to be defined, as well as the nature of the internal structure linking its elements (physical, logical, etc.). A complex system is made by many components interacting in a network structure (Zio et al, 2016).

Most often, **the components are physically and functionally heterogeneous, and organized in a hierarchy of subsystems that contributes to the system function. This leads to both structural and dynamic complexity**, the former referring to the system design and the latter emerging from the system operation within its complex architecture.

**Heterogeneity** refers to the differences in the elements, their interconnections and roles within the system structure, often with high-connected core elements and low-connected periphery nodes.

## Indicative types of vulnerable systems (1)

- ❑ Societies
- ❑ Organizations
- ❑ Individuals
- ❑ **Coastal areas**
- ❑ **Ports**



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## Indicative types of vulnerable systems (2)

- **Societies**: These are nations across the globe that lack the coping abilities to overcome shocks, threats and risks being caused by environmental factors, lack of political rights and social amenities. Indicative factors of vulnerable societies include bad governance, poor economic growth and lack of natural disaster control and management system (Iorhen et al, 2021).
- **Organizations**: Flourishing organizations become weak to face threats, fierce competitions and risks among other forces, thus being restricted from competing at the domestic, international and global market. Indicative factors of vulnerable organizations include poor financial status, Covid-19 pandemic, shortsighted and poor leadership practices, failed policies and strategies, lack of required human capital, etc (Iorhen et al, 2021).
- **Individuals**: Persons being harassed and fragile or becoming immigrants etc. Indicative factors of vulnerable individuals are poverty in the developing countries, increase in population, unemployment, diseases, hunger, violence and crises, lack of social and infrastructural facilities (Iorhen et al, 2021).

## Indicative types of vulnerable systems (3)

- **Coastal areas**: Coastal landforms, affected by short-term perturbations such as storms, generally return to their pre-disturbance morphology, implying a simple, morphodynamic equilibrium. Many coasts undergo continual adjustment towards a dynamic equilibrium, often adopting different 'states' in response to varying wave energy and sediment supply (Nicholls et al, 2007).
- **Ports**: Seaports are interfaces between the various transport modes and are typically combined transport centers. In addition, they are also multi-functional trade and industrial areas where goods are not only in transit but also handled, manufactured and distributed. In fact, ports are multi-dimensional systems which, to function adequately, must be integrated into global logistic[s] chains. An efficient port requires not only adequate infrastructure, superstructure and equipment but also good communications and especially a dedicated and skilled management team with a motivated and trained work force (UNCTAD, 1996).

## Vulnerability definitions

- **Chambers (1989)** investigated vulnerability in terms of the external and internal side: the external approach constitutes risks, shocks and stress to which a system is subject to, while the internal approach is related with defenseless, lack of means to cope with damaging loss (becoming physically weaker, inexpensively insolvent, socially dependent, humiliated or expressively harmed etc.).
- **Clark et al (2000)** defined vulnerability as the risk of adverse outcomes to receptors or exposure units-systems in terms of relevant changes in climate, other environmental variables and social conditions.
- According to the **World Health Organization (2000)** vulnerability is the degree to which a system is unable to anticipate, cope with, resist and recover from the impacts of disasters.
- **Damas and Rayhan (2004)** claimed that vulnerability is exposure to contingencies and stresses, and difficulty in coping with them.

## Threats leading to vulnerability (1)

Various concepts are used in literature to express **threats**:

**hazards**, stresses, disasters, damages, contingencies, adverse effects.

Threats are a **potential forthcoming event** that a system may be vulnerable to.

To assess the threat, and consequently estimate how vulnerable is the system to the specific threat, it is necessary to (Ferreira, 2019):

i. identify and distinguish its typology, its type of expression, as well as and the shielding techniques and measures (existing or planned) associated with it,

ii. analyze the threat according to internal and external factors, and

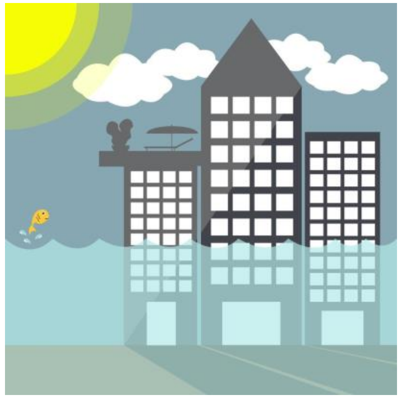
iii. to classify the threat according to the analysis made of its factors.

## Threats leading to vulnerability (2)

Examples of threats:

- ❑ Natural hazards (tsunami, earthquakes)
- ❑ Human-induced factors (terrorism)
- ❑ Climate-change impacts (extreme events, sea level rise)
- ❑ Accidents (explosion, fires)




## Threats leading to vulnerability (3) - Adger et al. (2006)

| Vulnerability approach | Objectives | Sources |
|---|---|---|
| *Antecedents* | | |
| Vulnerability to famine and food insecurity | Developed to explain vulnerability to famine in the absence of shortages of food or production failures. Described vulnerability as a failure of entitlements and shortage of capabilities. | Sen (1981); Swift (1989); Watts and Bohle (1993) |
| Vulnerability to hazards | Identification and prediction of vulnerable groups, critical regions through likelihood and consequence of hazard. Applications in climate change impacts. | Burton et al. (1978, 1993); Smith (1996); Anderson and Woodrow (1998); Parry and Carter (1994) |
| Human ecology | Structural analysis of underlying causes of vulnerability to natural hazards. | Hewitt (1983); O'Keefe et al. (1976); Mustafa (1998) |
| Pressure and Release | Further developed human ecology model to link discrete risks with political economy of resources and normative disaster management and intervention. | Blaikie et al. (1994); Winchester (1992); Pelling (2003) |
| *Successors* | | |
| Vulnerability to climate change and variability | Explaining present social, physical or ecological system vulnerability to (primarily) future risks, using wide range of methods and research traditions. | Klein and Nicholls (1999); Smit and Pilifosova (2001); Smith et al. (2001); Ford and Smit (2004); O'Brien et al. (2004) |
| Sustainable livelihoods and vulnerability to poverty | Explains why populations become or stay poor based on analysis of economic factors and social relations. | Morduch (1994); Bebbington (1999); Ellis (2000); Dercon (2004); Ligon and Schechter (2003); Dercon and Krishnan (2000) |
| Vulnerability of social-ecological systems | Explaining the vulnerability of coupled human-environment systems. | Turner et al. (2003a, b); Luers et al. (2003); Luers (2005); O'Brien et al. (2004) |

# Types of vulnerability

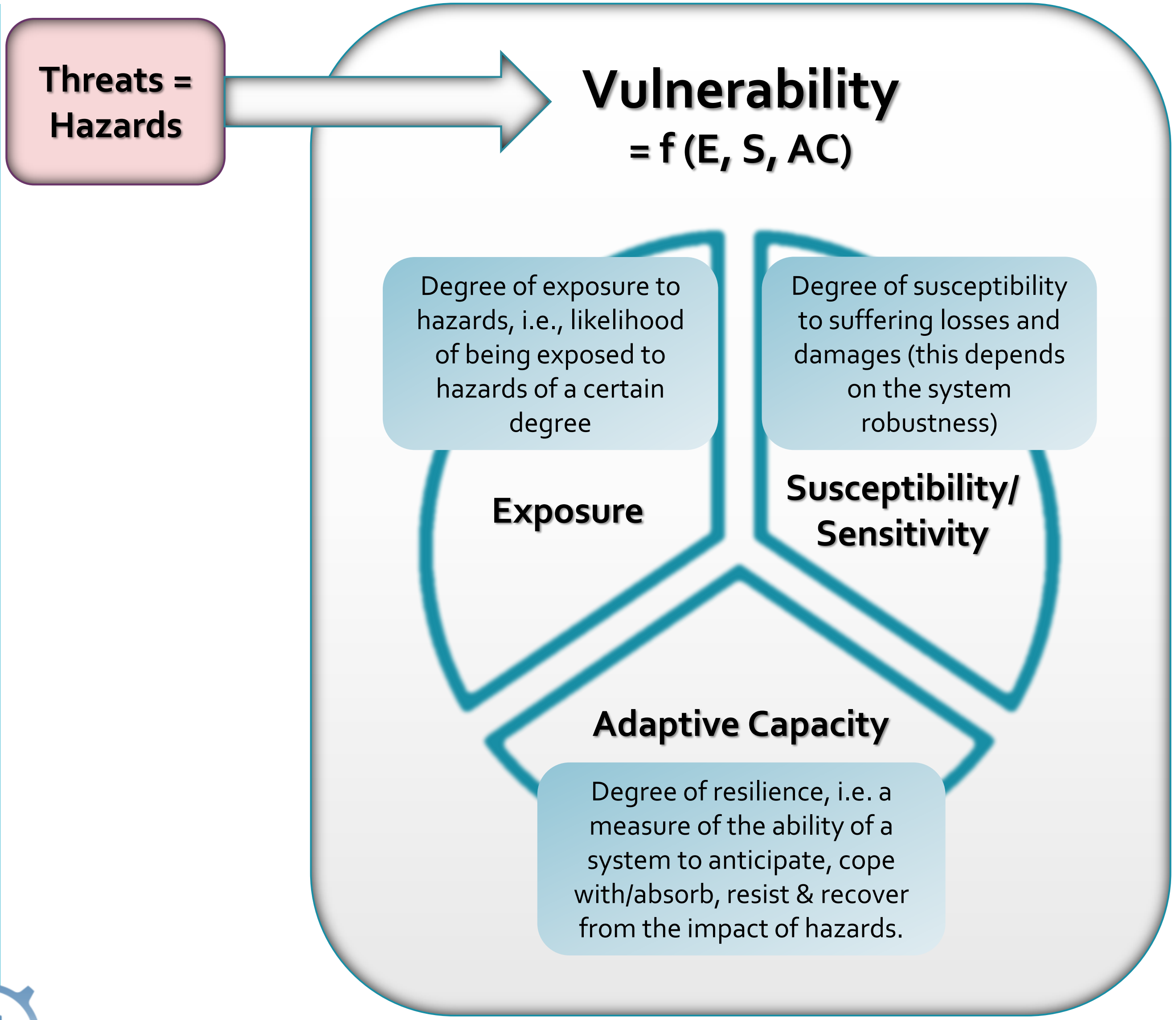
***(1/2) (Iorhen, 2021)***

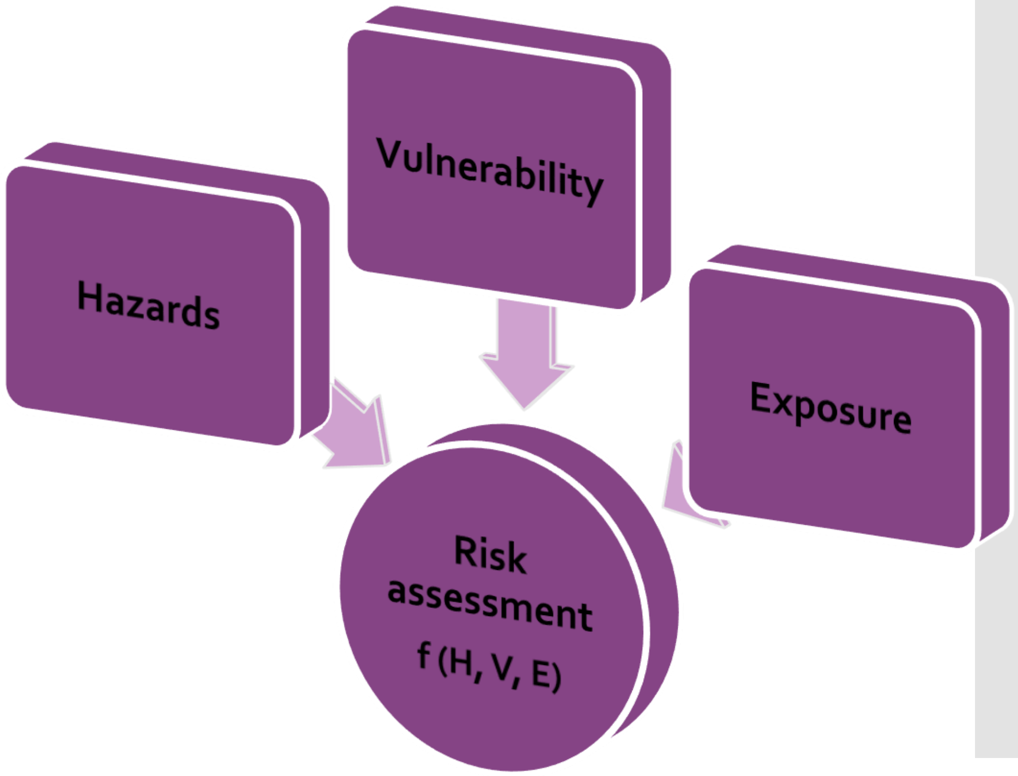
- **Physical Vulnerability**: It is related by the physical characteristics of the system. Depending on the type of the system it may refer to land degradation, typhoons, earthquakes, flood, hurricane, drought, storms.
- **Political Vulnerability**: It is prompted by the political status that the system may be related with (e.g. where there is no democratic and electoral process for the citizens to have access to political power and representation).
- **Social Vulnerability**: It arises as a result of rapid population growth, poverty and hunger, high level of ethnicity, low levels of education, gender inequality, lack of access to technological means and disintegration of social patterns. This can also include religion differences and marginalization.
- **Economic Vulnerability**: This can be determined by the income levels among individuals, the bargain power, price level, inflation rate, unemployment, Gross Domestic Product (GDP), Gross National Product (GNP) and exchange rate among others.

***(2/2) (Iorhen, 2021)***

- **Environmental Vulnerability**: It is related with the environmental characteristics of the system e.g. pollution, deforestation, fire disaster, critical habitats etc.
- **Academic Vulnerability**: This vulnerability arises due to lack of knowledge, expertise, conceptual experience in solving operational and routine problems at individual, group, organizational and national levels.
- **Attitudinal Vulnerability**: This type of vulnerability arises when individuals, organizations and nations have negative attitude to change and lack initiative and creativity of turning threats to opportunities.

# Vulnerability interactions



## Vulnerability components

- Degree of losses and damages due to the impact of hazards;
- Degree of exposure to hazards, i.e., likelihood of being exposed to hazards of a certain degree and susceptibility to suffering losses and damages (this depends on the system robustness, which is the antonym of vulnerability);
- Degree of resilience, i.e., a measure of the ability of a system to anticipate, cope with/absorb, resist and recover from the impact of hazards.

(Zio 2016)

# Vulnerability interactions

## Hazards

**Hazard** is defined as a **threat** that can potentially cause damage to systems (Dewan, 2013).

Hazards can take many forms (natural, human-induced, environmental)

Hazards may be characterized by location, time, intensity, and frequency.

| Groups | Sub-groups | Examples of main types |
|---|---|---|
| **Natural** | Geophysical | Earthquake, geophysically triggered mass movement, volcanic activity |
| | Hydrological | Flood, wave action, hydrometeorological triggered mass movement |
| | Meteorological | Storms, extreme temperature |
| | Climatological | Drought, wildfire, glacial lake outburst |
| | Biological | Air-, water-, and vector-borne diseases, animal and plant diseases, food-borne outbreaks, antimicrobial resistant microorganisms |
| | Extraterrestrial | Impact, space weather |
| **Human-induced** | Technological | Industrial hazard, structural collapse, fire, air pollution, infrastructure disruption, cybersecurity, hazardous materials (including radiological), food contamination |
| | Societal | Armed conflict, civil unrest, financial crisis, terrorism, chemical, biological, radiological, nuclear, and explosive weapons |
| **Environmental** | Environmental degradation | Erosion, deforestation, salinization, sea level rise, desertification, wetland loss/ degradation, glacier retreat/melting |

(Saulnier et al. 2021)

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# Vulnerability interactions

## Exposure

Systems need to be exposed to a hazard to be **directly or indirectly affected** by it (Saulnier et al. 2021).

**Direct** effects include injury, illness, other health effects, evacuation and displacement, and economic, social, cultural, and environmental damages.

**Indirect** effects refer to additional consequences over time that cause unsafe or unhealthy conditions from economic, infrastructure, social, or health and psychological disruptions and changes.

One of the major challenges in disaster research is measuring who has been affected and when. Determining which effects can be attributed to a disaster is complex, as there are multiple indirect pathways to an outcome.

## Risk

**Risk describes an uncertain event or condition that, if it occurs, has an effect on at least one objective** (uncertainty about future changes) (PIANC, 2020).

Risk includes two dimensions to describe the **(future) consequences** potentially arising from the operation of the systems and their activities, and the **associated uncertainty** (Zio, 2016).

For purposes of decision making, it is necessary to provide a quantification of risk, i.e., of the consequences of the accident scenarios, e.g. measured in terms of losses, damages, injuries etc., and of their likelihood of occurrence quantified by some measure of uncertainty, e.g. in terms of probabilities (frequencies) (Zio, 2016).

**Risk assessment methodologies** are often employed to help understand what can go wrong, estimate the likelihood and the consequences, and to develop risk mitigation strategies to counter risk (Ezell 2007).

**Climate change** *(IPCC, 2018, Glossary)*

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 forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

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 makes a **distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.**

**Climate variability** *(IPCC, 2018, Glossary)*

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).**

## Climate crisis

In November 2019, a group of more than 11,000 scientists from 153 countries named climate change an "emergency" that would lead to "untold human suffering" if no big shifts in action takes place.

JOURNAL ARTICLE

### World Scientists' Warning of a Climate Emergency

FREE

William J Ripple ✉, Christopher Wolf ✉, Thomas M Newsome, Phoebe Barnard, William R Moomaw Author Notes

*BioScience*, Volume 70, Issue 1, January 2020, Pages 8–12,
https://doi.org/10.1093/biosci/biz088
**Published:** 05 November 2019

*We declare clearly and unequivocally that planet Earth is facing a climate emergency. To secure a sustainable future, we must change how we live. This entails **major transformations** in the ways our global society functions and interacts with natural ecosystems.*

# Climate change

## Climate crisis

COVID-19 lockdowns significantly diminished transportation and consumption, but had very little impact on reversing the trends negative trends of planetary vital signs including temperature and greenhouse gases.

“Only **profound changes in human behavior** can meet these challenges and emphasize the need to move beyond the idea that global heating is a stand alone emergency, and is one facet of the worsening environmental crisis. This necessitates the need for transformational system changes and to focus on the root cause of these crises, the vast overexploitation of earth rather than just addressing symptom relief”.

JOURNAL ARTICLE EDITOR'S CHOICE

**World Scientists’ Warning of a Climate Emergency 2021**

William J Ripple, Christopher Wolf, Thomas M Newsome, Jillian W Gregg, Timothy M Lenton, Ignacio Palomo, Jasper A J Eikelboom, Beverly E Law, Saleemul Huq, Philip B Duffy ... Show more

*BioScience*, Volume 71, Issue 9, September 2021, Pages 894–898, https://doi.org/10.1093/biosci/biab079
**Published:** 28 July 2021

**Six areas** where fundamental changes need to be made

*(Ripple, 2021):*

(1) *energy* — eliminating fossil fuels and shifting to renewables;
(2) *short-lived air pollutants* — slashing black carbon (soot), methane, and hydrofluorocarbons;
(3) *nature* — restoring and permanently protecting Earth's ecosystems to store and accumulate carbon and restore biodiversity;
(4) *food* — switching to mostly plant-based diets, reducing food waste, and improving cropping practices;
(5) *economy* — moving from indefinite GDP growth and overconsumption by the wealthy to ecological economics and a circular economy , in which prices reflect the full environmental costs of goods and services; and
(6) *human population* — stabilizing and gradually reducing the population by providing voluntary family planning and supporting education and rights for all girls and young women, which has been proven to lower fertility rates.

## Tackling Climate change

### Mitigation

*(IPCC, AR6,WGII, 2022)*

A human intervention to reduce emissions or enhance the sinks of greenhouse gases.

### Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

A response or a process of adjustment to accommodate the actual or projected climate or the effects of climate change.

*(PIANC, 2020)*

## Tackling Climate change

### Mitigation

*(IPCC, AR6,WGII, 2022)*

A human intervention to reduce emissions or enhance the sinks of greenhouse gases.

**Anthropogenic emissions:** Emissions of greenhouse gases (GHGs), precursors of GHGs and aerosols caused by human activities. These activities include the burning of fossil fuels, deforestation, land use and land-use changes (LULUC), livestock production, fertilisation, waste management and industrial processes.

**Greenhouse gases (GHG):** Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's ocean and land surface, by the atmosphere itself and by clouds. This property causes the greenhouse effect.

Primary GHGs in the Earth's atmosphere:
Water vapour ($H_2O$),
carbon dioxide ($CO_2$),
nitrous oxide ($N_2O$),
methane ($CH_4$) and
ozone ($O_3$)

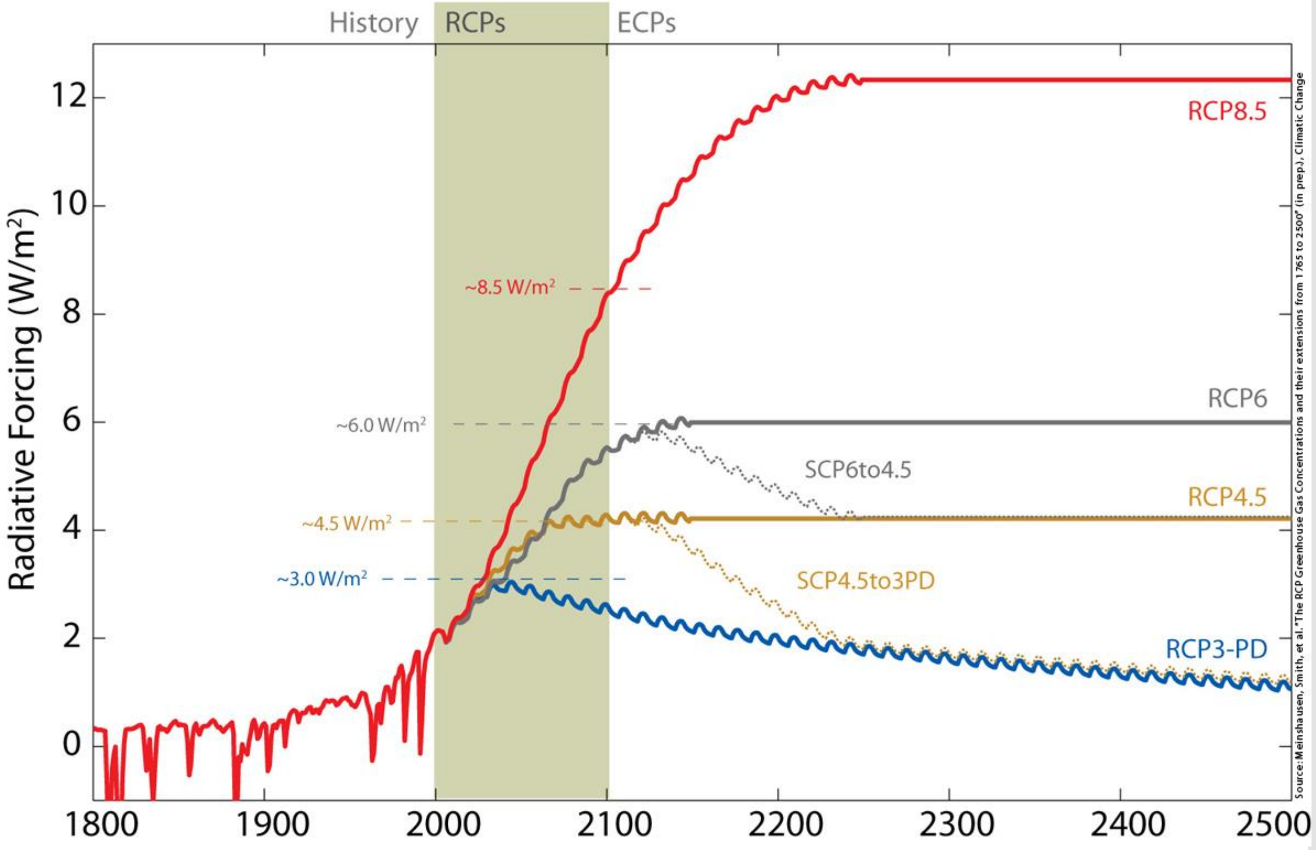
Human-made GHGs:
sulphur hexafluoride ($SF_6$),
hydrofluorocarbons (HFCs),
chlorofluorocarbons (CFCs) and
perfluorocarbons (PFCs)

## Representative Concentration Pathways (RCPs)

Each RCP defines a specific emissions trajectory and subsequent radiative forcing
*(a radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, measured in watts per square meter)*

***Moss et.al. 2010.*** *Median temperature anomaly over pre-industrial levels.*

| Name | Radiative forcing | $CO_2$ equivalent (ppm) | T anomaly (° C) | Pathway |
|---|---|---|---|---|
| RCP8.5 | 8.5 $W/m^2$ in 2100 | 1370 | 4.9 | Rising |
| RCP6.0 | 6.0 $W/m^2$ post 2100 | 850 | 3.0 | Stabilisation without overshoot |
| RCP4.5 | 4.5 $W/m^2$ post 2100 | 650 | 2.4 | Stabilisation without overshoot |
| RCP2.6 (RCP3PD) | 3 $W/m^2$ before 2100 declining to 2.6 $W/m^2$ by 2100 | 490 | 1.5 | Peak and decline |




***(Meinshausen et al., 2011)***

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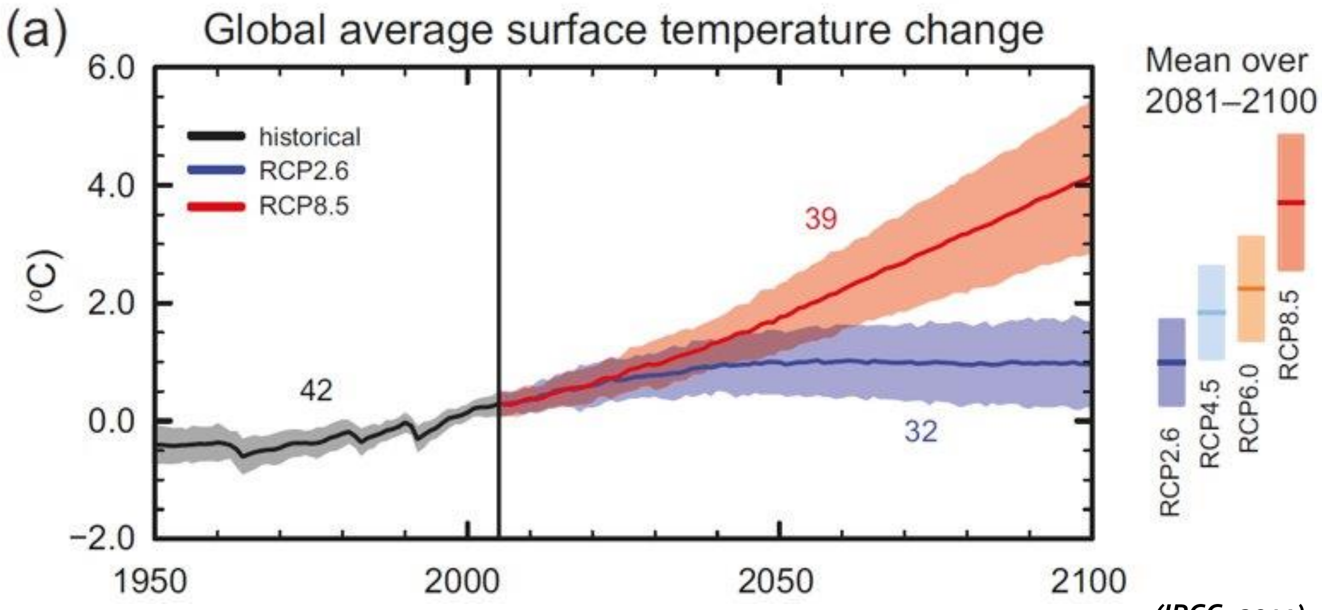
## Representative Concentration Pathways (RCPs)




*(IPCC, 2014)*

**2°C**

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

**Where do the RCPs come from?**

The RCPs were used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2014 as a basis for the report's findings. Previous IPCC assessment reports used a set of scenarios known as SRES (Special Report on Emissions Scenarios), which start with socioeconomic circumstances from which emissions trajectories and climate impacts are projected. In contrast, RCPs fix the emissions trajectory and resultant radiative forcing rather than the socioeconomic circumstances.

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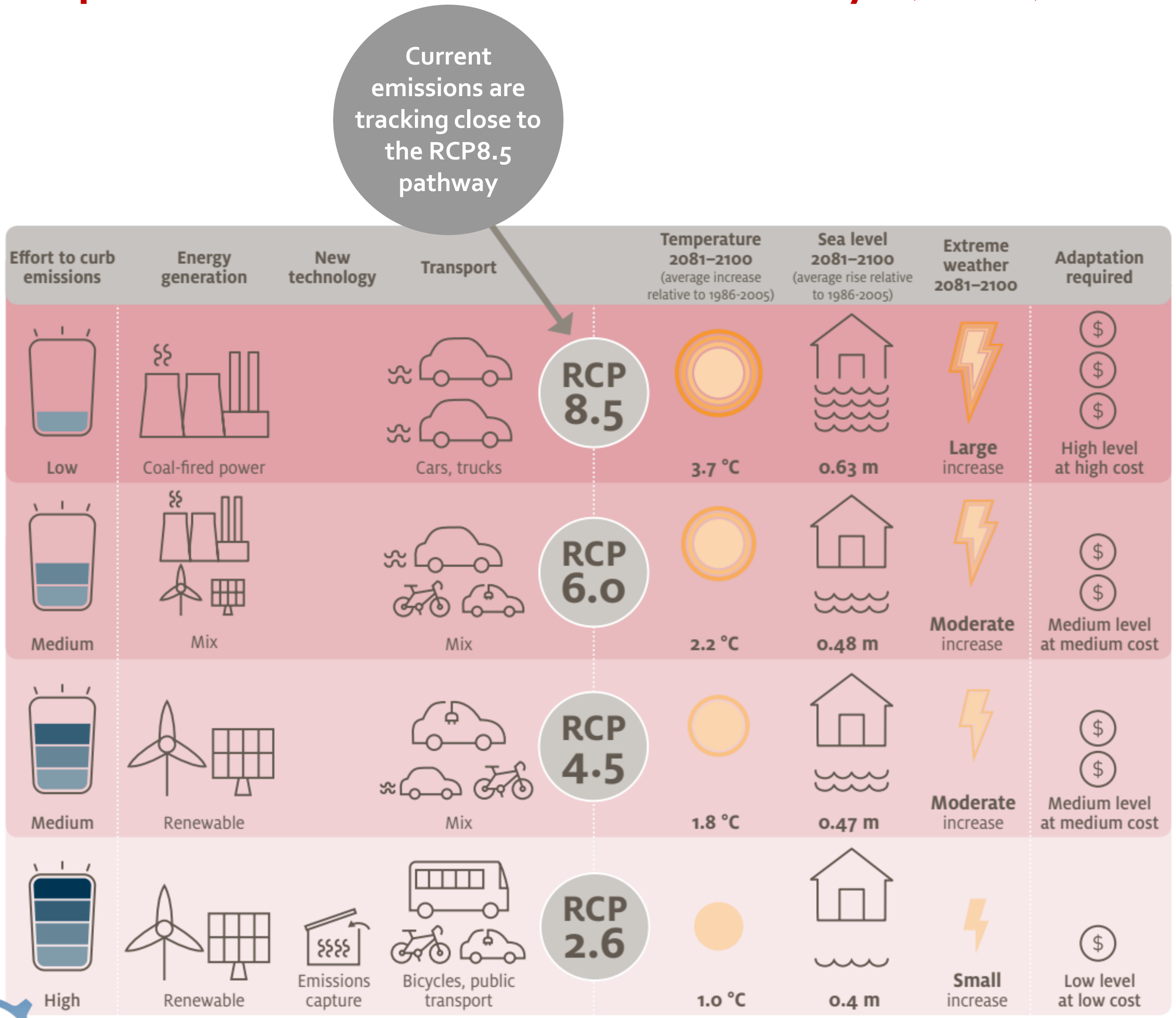
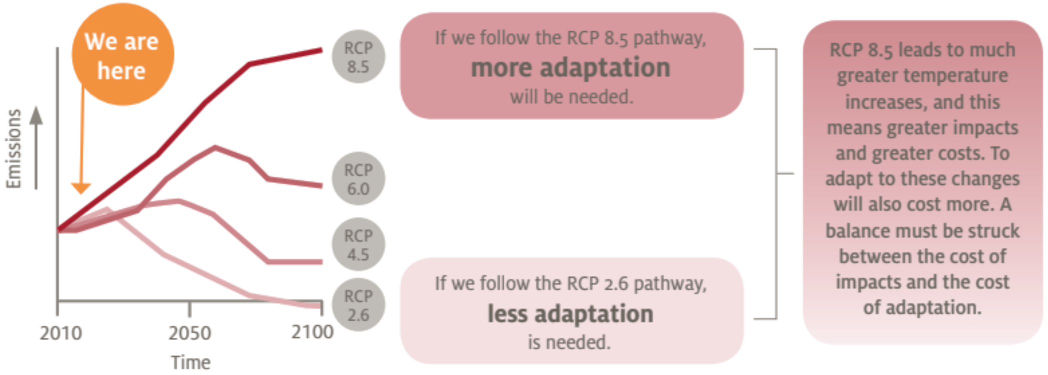
# Representative Concentration Pathways (RCPs)



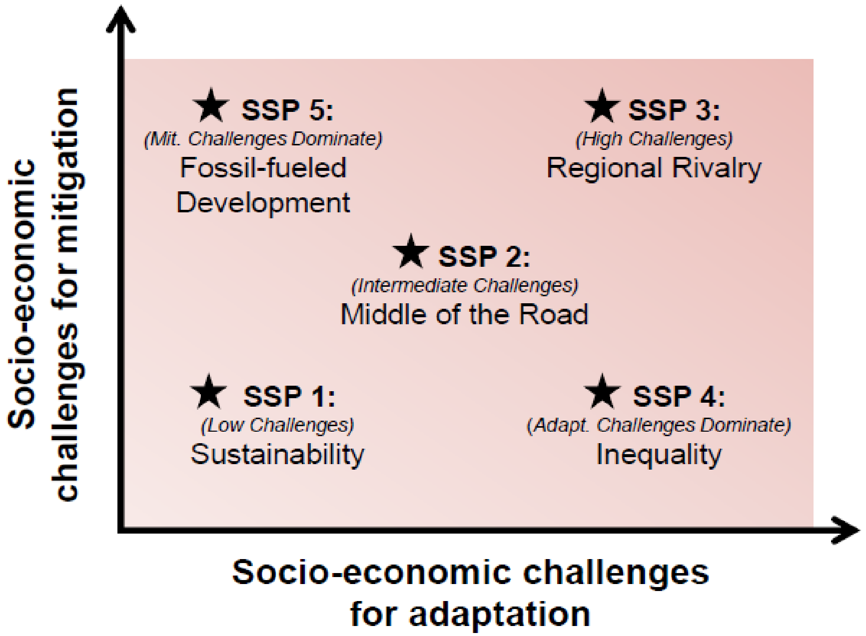

*(Coast Adapt, Australia)*

## Shared Socioeconomic Pathways (SSPs)

The idea of shared socio-economic pathways (SSPs) is developed as a basis for new emissions and socio-economic scenarios. An SSP is one of a collection of pathways that describe alternative futures of socio-economic development in the absence of climate policy intervention. The combination of SSP-based socio-economic scenarios and RCP-based climate projections should provide a useful integrative frame for climate impact and policy analysis.

**Socio-Economic Scenario**

A scenario that describes a possible future in terms of population, gross domestic product (GDP), and other socio-economic factors relevant to understanding the implications of climate change.




*(O'Neill et al., 2014)*

**SSP1:** The sustainable and "green" pathway describes an increasingly sustainable world. Global commons are being preserved, the limits of nature are being respected. The focus is more on human well-being than on economic growth. Income inequalities between states and within states are being reduced. Consumption is oriented towards minimizing material resource and energy usage.

**SSP2**: The "Middle of the road" or medium pathway extrapolates the past and current global development into the future. Income trends in different countries are diverging significantly. There is a certain cooperation between states, but it is barely expanded. Global population growth is moderate, leveling off in the second half of the century. Environmental systems are facing a certain degradation.

**SSP3**: Regional rivalry. A revival of nationalism and regional conflicts pushes global issues into the background. Policies increasingly focus on questions of national and regional security. Investments in education and technological development are decreasing. Inequality is rising. Some regions suffer drastic environmental damage.

**SSP4**: Inequality. The chasm between globally cooperating developed societies and those stalling at a lower developmental stage with low income and a low level of education is widening. Environmental policies are successful in tackling local problems in some regions, but not in others.

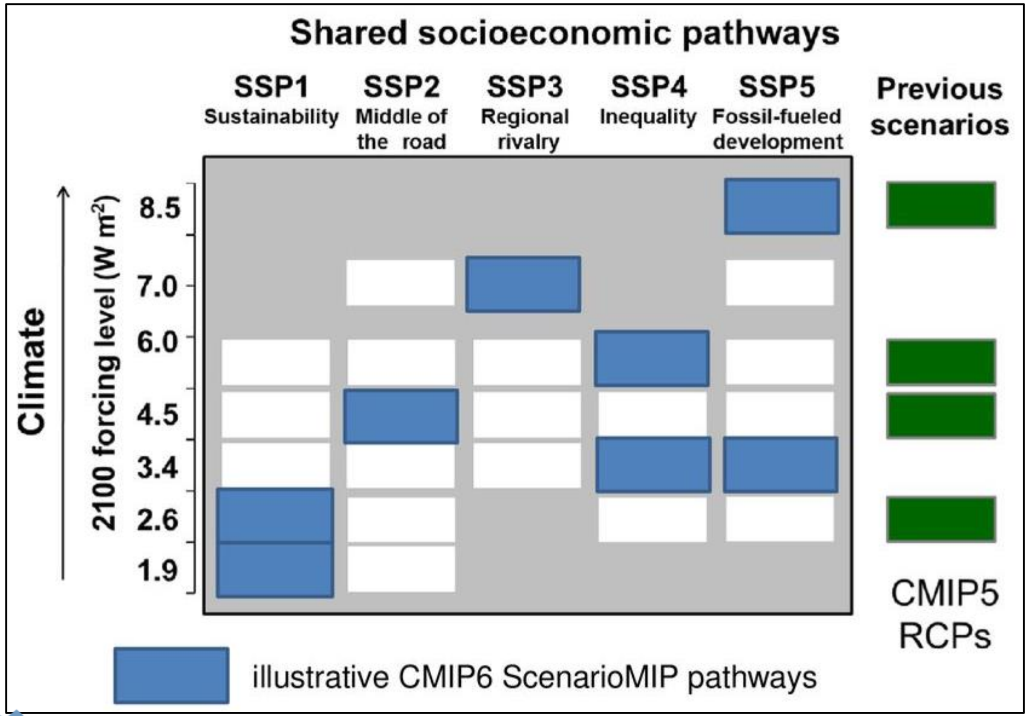
**SSP5**: Fossil-fueled Development. Global markets are increasingly integrated, leading to innovations and technological progress. The social and economic development, however, is based on an intensified exploitation of fossil fuel resources with a high percentage of coal and an energy-intensive lifestyle worldwide. The world economy is growing and local environmental problems such as air pollution are being tackled successfully.

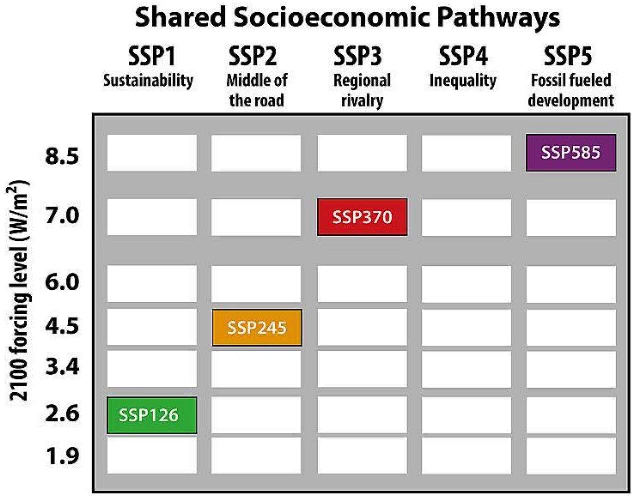
***(in brief; from www.dkrz.de)***

## RCPs and SSPs

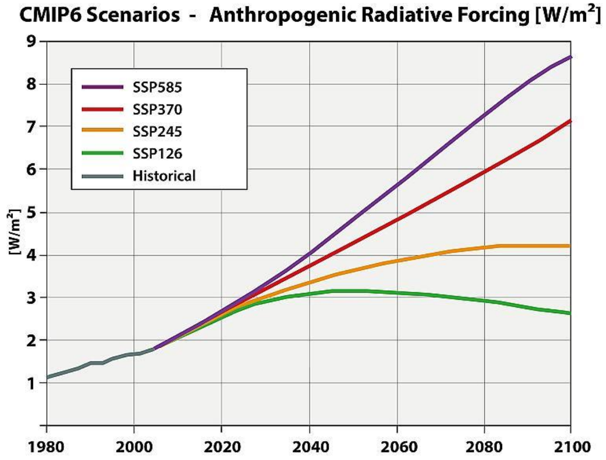
The SSPs contain a range of baseline scenarios spanning between 5.0 and 8.5 W/m2 of radiative forcing by 2100. They also specifically consider mitigation scenarios where forcing is limited to 6.0, 4.5, 3.4, 2.6 and 1.9 W/m2. As computational limitations prevent scientists from running all the SSPs through every climate model, a number of "marker" scenarios were chosen at different forcing levels to be used in CMIP6 – the global climate modelling exercise being undertaken by IPCC AR6.

CMIP6 will include the same four forcing levels found in the RCPs – 8.5, 6.0, 4.5, and 2.6 – in addition to new 1.9, 3.4 and 7.0 forcing scenarios.
Both the 8.5 and 7.0 scenarios are taken from no-policy baseline emission scenarios in the SSP database, while all the other forcings use emissions scenarios where some level of mitigation is employed.




(O'Neill et al., 2016)



## Tackling Climate change

*(IPCC, AR6,WGII, 2022)*

**Adaptation**

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

A response or a process of adjustment to accommodate the actual or projected climate or the effects of climate change.

*(PIANC, 2020)*

**Vulnerability**

**Resilience**

## Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. *(IPCC, AR6,WGII, 2022)*

Vulnerability indicates the degree to which a system is susceptible to, and unable to cope with, adverse climate change effects, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which an asset, operation or system is exposed, its sensitivity and its adaptive capacity.

*(PIANC, 2020)*

## Resilience

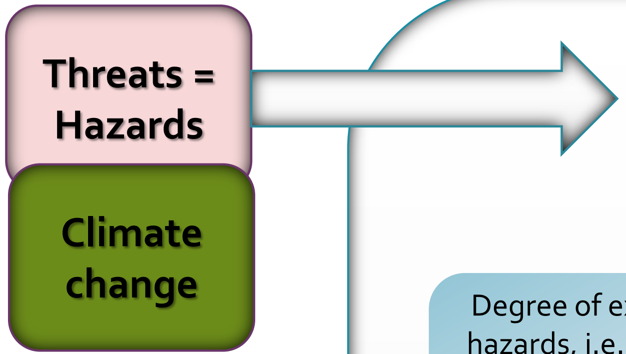
The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation (Arctic Council, 2016).

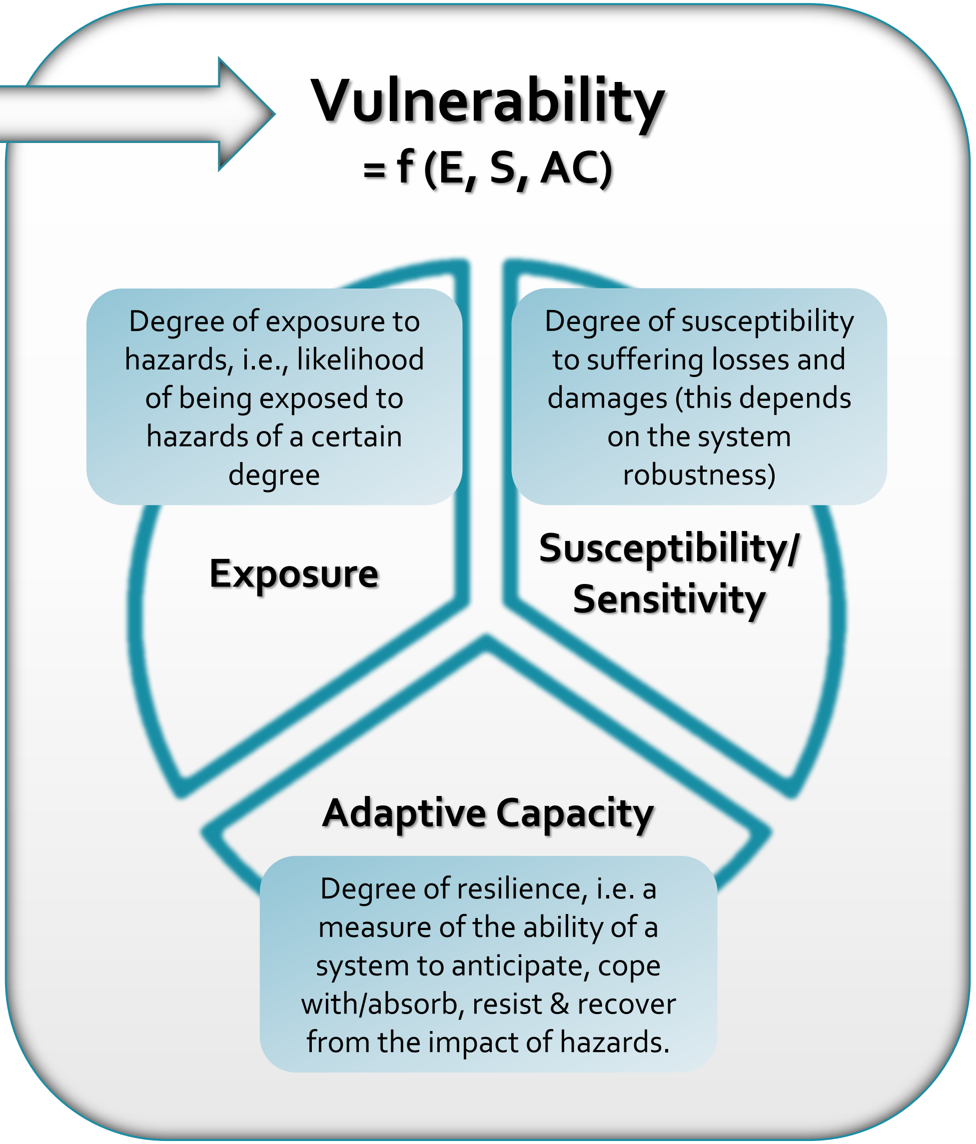
*(IPCC, AR6,WGII, 2022)*

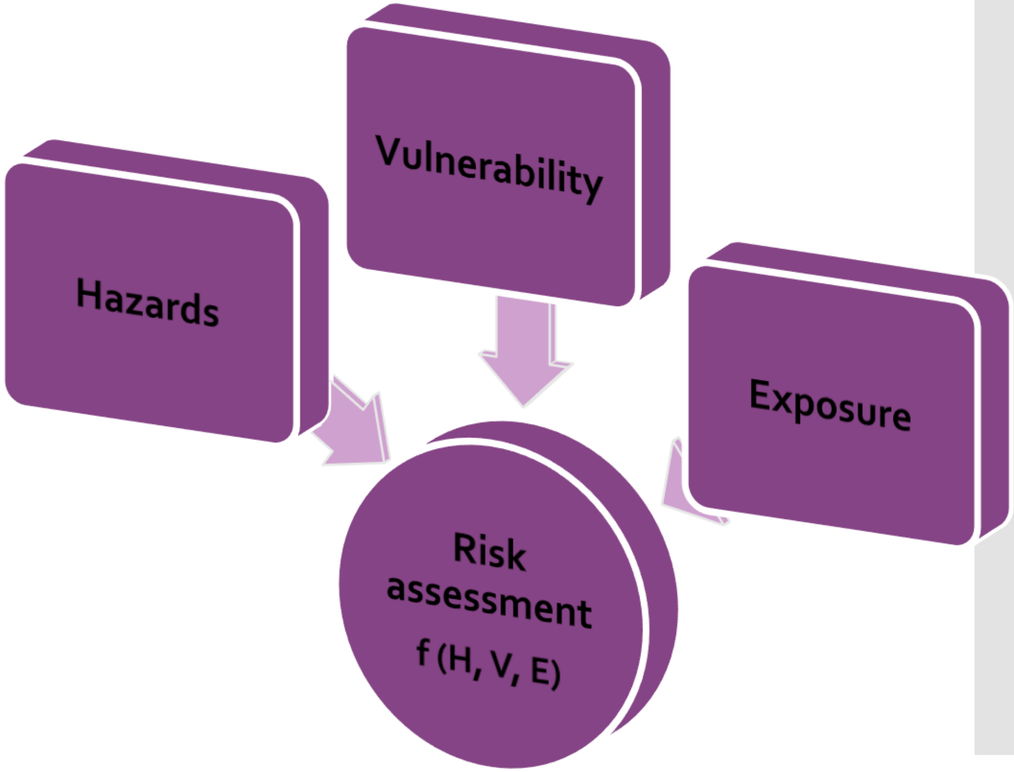
## Vulnerability factors (Havko et al, 2017)

- Disasters' particularities and their impacts (ability of disasters cause dysfunction of system elements)– **exposure**,
- Characteristics of the system elements and its susceptibility to effects of a disaster – **susceptibility/sensitivity**,
- Ability or capacity of the system in conjunction with society to adapt to changing conditions –**adaptive capacity**

# Vulnerability interactions

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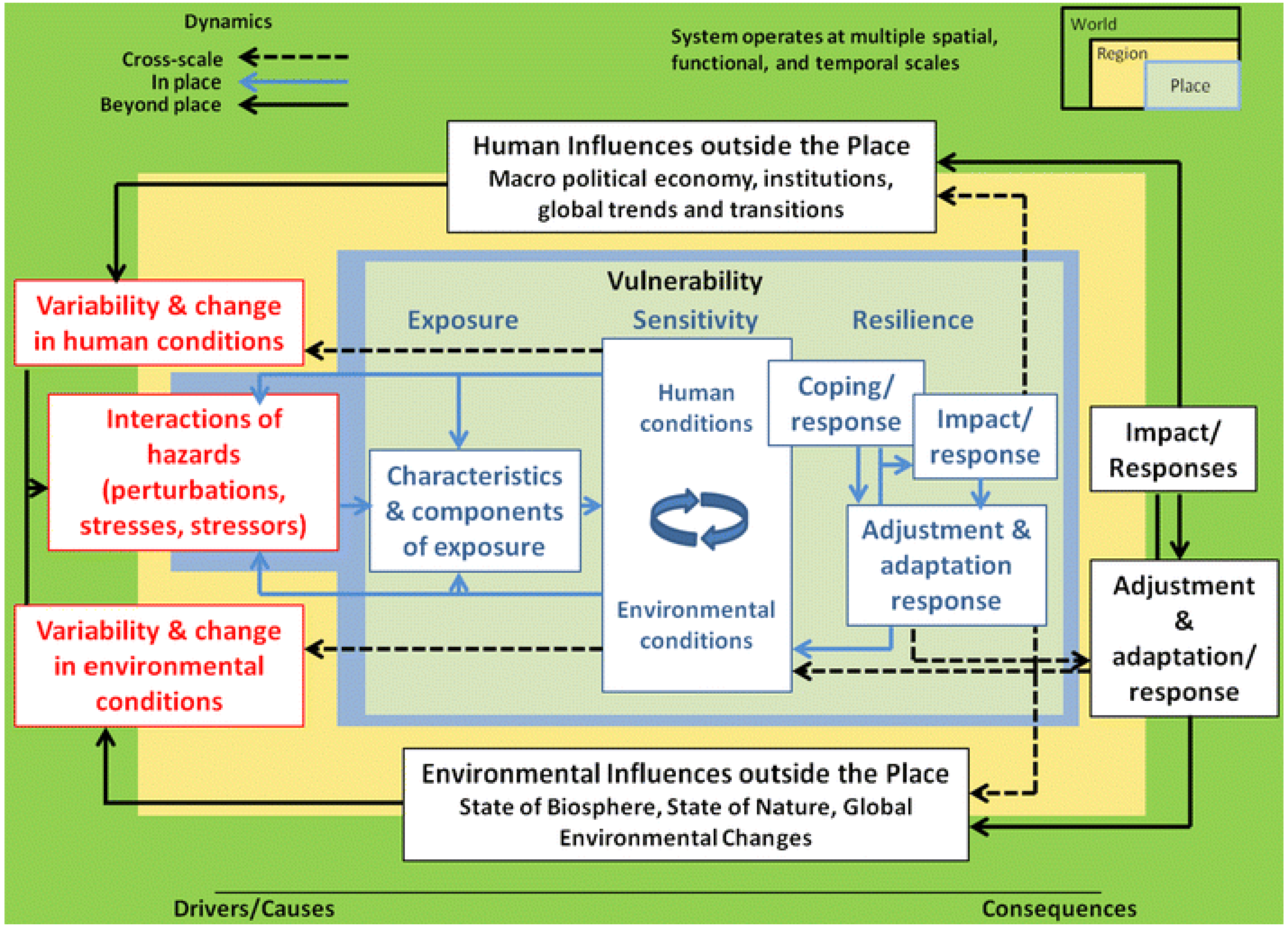
# Vulnerability framework

**(Turner et al, 2003)**

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## Exposure (Havko et al. 2017)

- **Ability to cause damage** which is associated with an occurrence of particular crisis event and its intensity, type, mode of action, range and in overall with its destructive effects. E.g. earthquake with different intensity may have various destructive impacts.
- **Duration of a disaster** which is the expected period of exposure to the effects of a disaster. It is also a period necessary to restore the required level of operational state of the system.
- **Activatability** which is the time necessary for threat activation. The longer this time period is, the less devastating a disaster could be. In cases with longer activation period it is possible to adopt some mitigation measures (e.g. warning, evacuation, etc.).

# Vulnerability components

## Susceptibility (Havko et al. 2017)

- **Sensitivity** which refers to the tendency of a system to be functionally damaged by effects of particular disaster. This characteristic is related to the ability of the system to resist to and cope with expected negative effects on its own.
- **Protection** which can be seen as additional feature to the "sensitivity". "Sensitivity" is about own ability of an element to handle situation On the other hand "protection" takes into account external measure which are already applied inside or outside the system to protect it, mainly with aim of decreasing the negative effects of a disaster.
- **Accessibility** which is the level of simplicity with which the system can be affected by a disaster. (e.g. location)

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## Adaptive capacity (Havko et al. 2017)

- **Redundancy** which is the ability of other elements of the system take over the functions of failed elements. Redundancy is closely linked to the density of the system and its structure. For example, there is a remarkable difference in redundancy of road and rail transportation network. From such point of view is rail network and its elements more vulnerable than the road elements.
- **Availability of resources** which refers to the access to the sources required
- **Capability of rapid response** which is the ability of responsible authorities and rescue services (professional and voluntary) effectively (1) prevent effects of disasters by adoption of rapid measures or (2) remove impacts of such events in short period of time and recovery to the previous state.

# Vulnerability components

**Vulnerability = Exposure + Sensitivity + Adaptive capacity**

**Susceptibility**

## Sensitivity

The **degree** to which a system or species is affected, either adversely or beneficially, 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, AR6,WGII, 2022)*

## Susceptibility

Susceptibility indicates whether an asset, operation or system is **prone to** harm, disruption or other adverse effects as a result of changes in meteorological, oceanographic or hydrological characteristics. *(PIANC, 2020)*

## 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. *(IPCC, AR6,WGII, 2022)*

## 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. (MA, 2005),*(IPCC, AR6,WGII, 2022)*

Adaptive capacity means having the **ability to adjust** to change. For example, there may be redundancy or resilience within the system that means a change or impact can be accommodated. Having adequate adaptive capacity can make the difference between an incident or event being inconvenient and potentially catastrophic. *(PIANC, 2020)*

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## Definition

A vulnerability assessment means **comparing potential future threats to existing capacities and desired protection levels** (Pursiainen, 2018; Silvast et al., 2021).

Vulnerability assessments can take many forms dependent on the field from which they are drawn (i.e., climate change adaptation, disaster risk management, or poverty and development) (Weis et al. 2016).

The bigger the system is and the more interconnected is to other systems, the more difficult it may be to recognize its vulnerabilities.

## Example – Seaport Vulnerability assessment (PIANC, 2020)

| Port Example Climate Change Vulnerability Assessment<br>SCENARIO 1 of 3 | Compared to the baseline, <u>how does exposure</u> to the potential climate hazard <u>change</u> within the planning horizon?<br>↑↑ Significant increase<br>↑ Increase<br>→ No change<br>↓ Reduction<br>↓↓ Significant reduction | | | | | Considering relevant thresholds and existing adaptive capacity, <u>how is vulnerability</u> likely to be <u>affected</u>?<br>↑↑ Significant increase<br>↑ Increase<br>→ No change<br>↓ Reduction<br>↓↓ Significant reduction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Examples of relevant parameters or processes →<br>Examples of critical assets, operations or systems ↓ | Extreme heat | Sea level rise | Wind speed | Wave conditions | Seasonal rainfall | Extreme heat | Sea level rise | Wind speed | Wave conditions | Seasonal rainfall |
| Berthing and loading, offloading cargo | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | ↑ |
| Access to berth (e.g. navigation channels) | ↑↑ | ↑ | → | → | ↑↑ | → | ↓ | → | → | ↑ |
| Maritime structures | ↑↑ | ↑ | → | → | ↑↑ | → | ↑ | → | → | → |
| Quay equipment (e.g. cranes, ship loaders/unloaders, marine loading arms) | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | ↑ |
| Trucks/in-terminal vehicles | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | ↑ |
| Onshore structures | ↑↑ | ↑ | → | → | ↑↑ | → | → | → | → | → |
| Storage areas | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | ↑ |
| Onshore equipment (e.g. stacking or reclaiming machines, conveyors, rubber-tyre gantry cranes) | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | ↑ |
| Electrical power systems | ↑↑ | ↑ | → | → | ↑↑ | → | → | → | → | → |
| Drainage systems | ↑↑ | ↑ | → | → | ↑↑ | → | → | → | → | ↑↑ |
| Fuel systems | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | → |
| Road/rail access and internal road network | ↑↑ | ↑ | → | → | ↑↑ | ↑ | → | → | → | ↑ |
| Facilities for workers | ↑↑ | ↑ | → | → | ↑↑ | ↑↑ | → | → | → | → |

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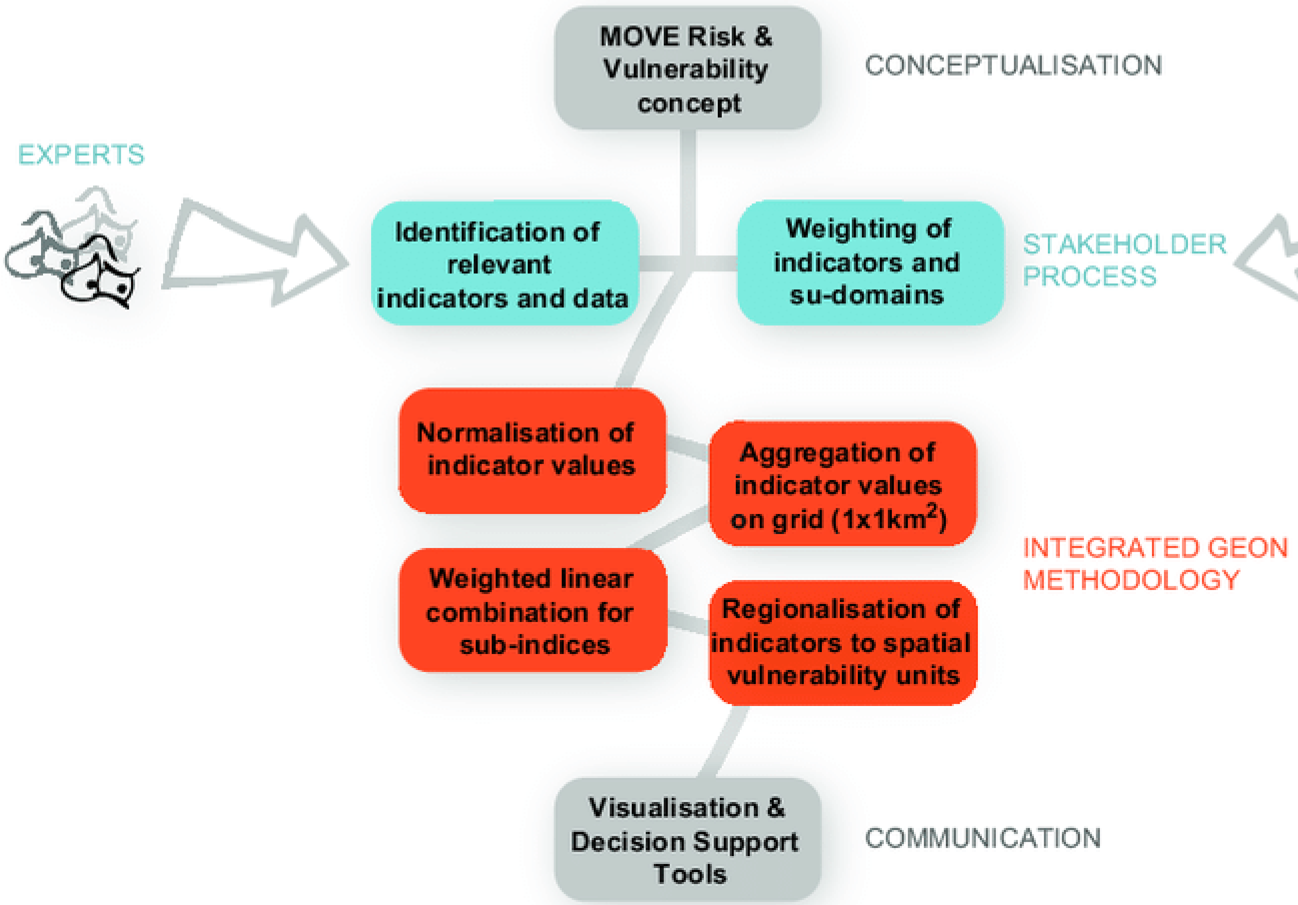
**(Kienberger et al. 2014)**



**Vulnerability Index (Havko et al, 2017)**

$$VI = f(E, S, AC) = f[f(CH_{ACD}, CH_{DD}, CH_{Ac}), f(CH_S, CH_P, CH_{Acc}), f(CH_R, CH_{AR}, CH_{CRR})]$$

where:

VI: Vulnerability Index
E: Exposure
S: Susceptibility
AC: Adaptive Capacity
$CH_{ACD}$: Characteristic – Ability to Cause Damage
$CH_{DD}$: Characteristic – Duration of a Disaster
$CH_{Ac}$: Characteristic – Activatability
$CH_S$: Characteristic – Sensitivity
$CH_P$: Characteristic – Protection
$CH_{Acc}$: Characteristic – Accessibility
$CH_R$:Characteristic – Redundancy
$CH_{AR}$: Characteristic – Availability of Resources
$CH_{CRR}$: Characteristic – Capability of Rapid Response

# Coping mechanisms

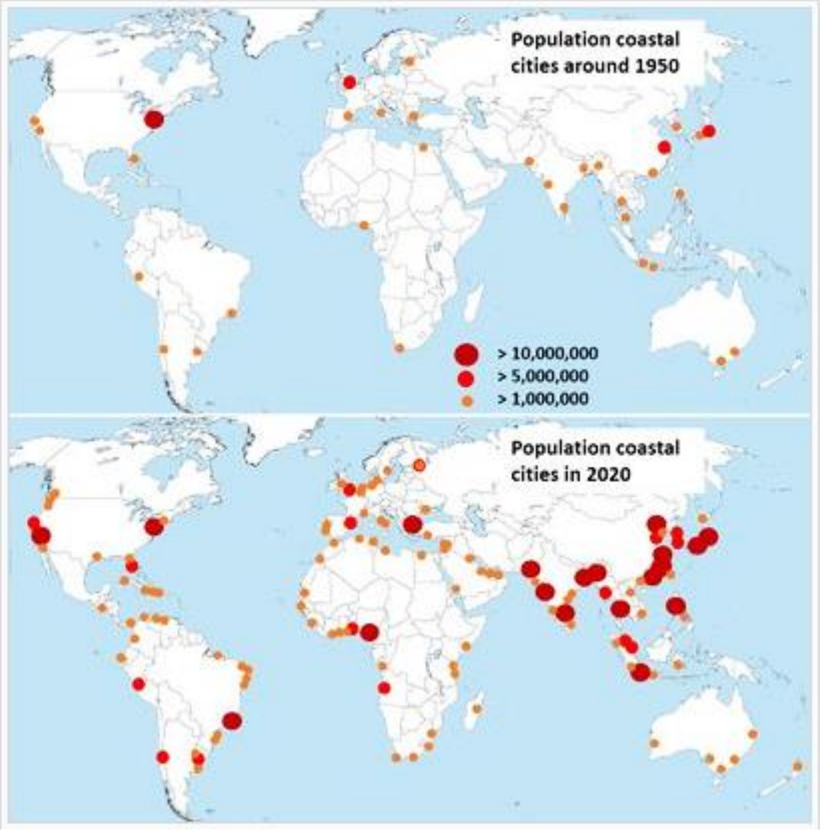
**(Iorhen, 2021)**

- **Functional Socio- Economic and Political Institutions** ensuring that services like education, water, roads, health care, investment, production and diversification among others are available and effective to provide safety nets.
- **Effective Natural Disaster Control and Management Programs** for natural disaster issues like earthquake, flood, typhoons, hurricanes, explosions and fire in line with the climatic, environmental and man-made disaster of a particular region
- **Effective Educational System** to provide citizens with the basic knowledge, skills and experience, the weapon to fight and overcome ignorance
- **Technological Expansion** for employing advanced technology tools
- **Strategic Leadership** to drive the systems in the right direction with a futuristic mindset.

## Coastal systems

# Coastal vulnerability


*(https://eclass.hua.gr/modules/document/file.php)*




Population of coastal cities around 1950 and in 2020.

*(Barragan et al., 2015)*

- Today, approximately 3 billion people — **about 50% of the world's population** — live within 200 km of a coastline.
- **In Greece, almost 85% of the population** live within 50 km of a coastline.
- Greece: 13.676 km of coastline ($11^{th}$ globally)

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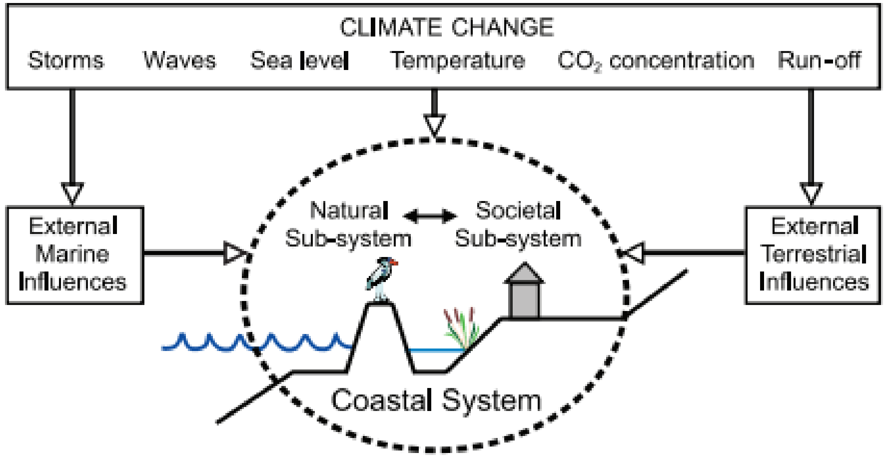
## Protocol for Mediterranean Sea: Integrated Coastal Zone Management

**Coastal zone**: the geomorphologic area either side of the seashore in which the interaction between the marine and land parts occurs in the form of complex ecological and resource systems made up of biotic and abiotic components coexisting and interacting with human communities and relevant socio-economic activities.

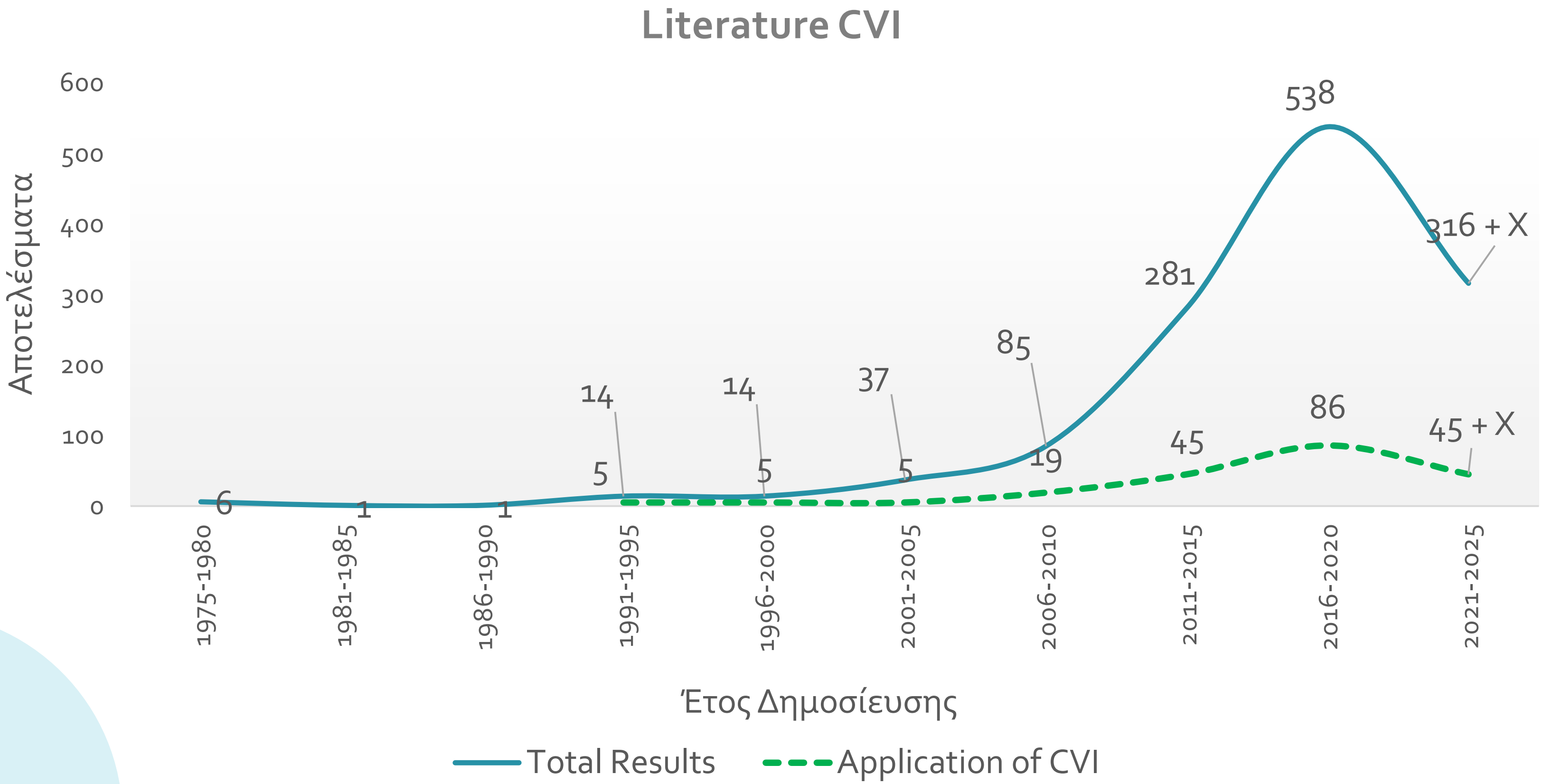



*(Nicholls et al, 2007)*

*Coastal flooding at Rio (https://www.patrasevents.gr/)*

*Coastal flooding at Norther Crete (https://www.aera.gr/)*

**1292**
*results*
*in Scopus*




*(Koulouri, 2022)*

*Search term:*
*"coastal vulnerability index"*

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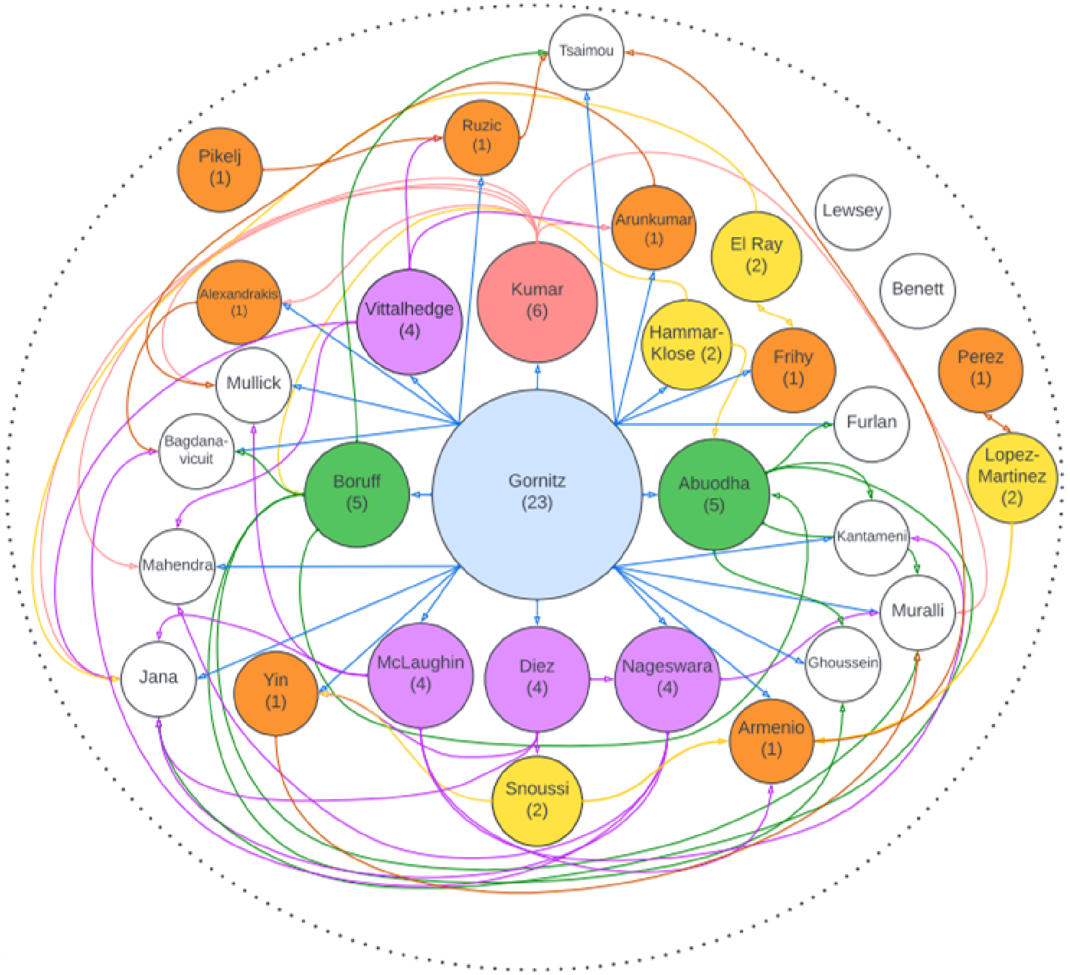
## Vulnerability in terms of climate change




**Thieler & Hammar-Klose, 1999; Gornitz et al., 1994:**

$$CVI = \sqrt{\frac{a*b*c*d*e*f}{6}}$$

Where:

a: the geomorphology

b: the coastline erosion-deposition rate

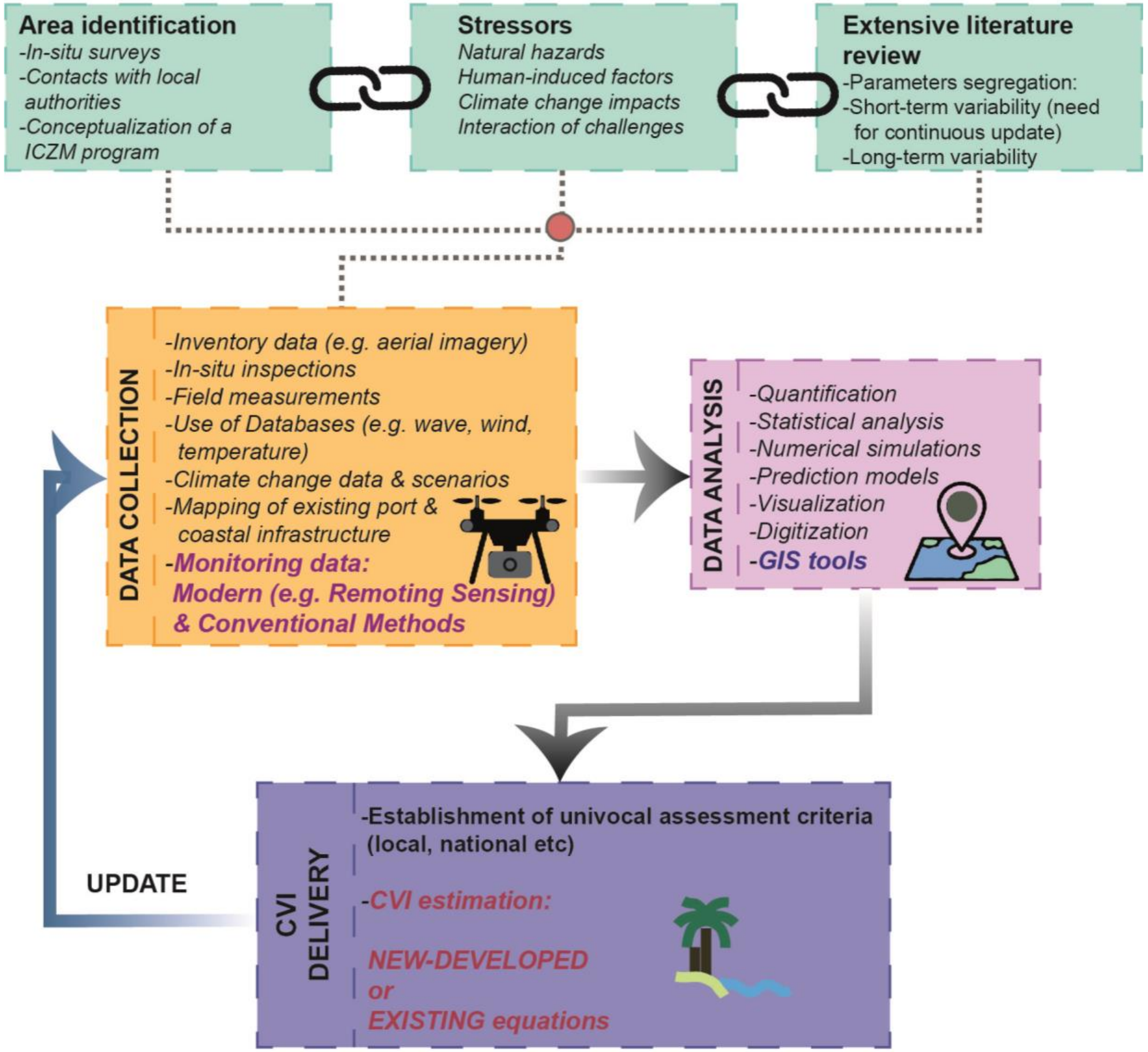
c: the coastal slope

d: the relative sea-level rise rate

e: the mean wave height

f: the mean tide range.

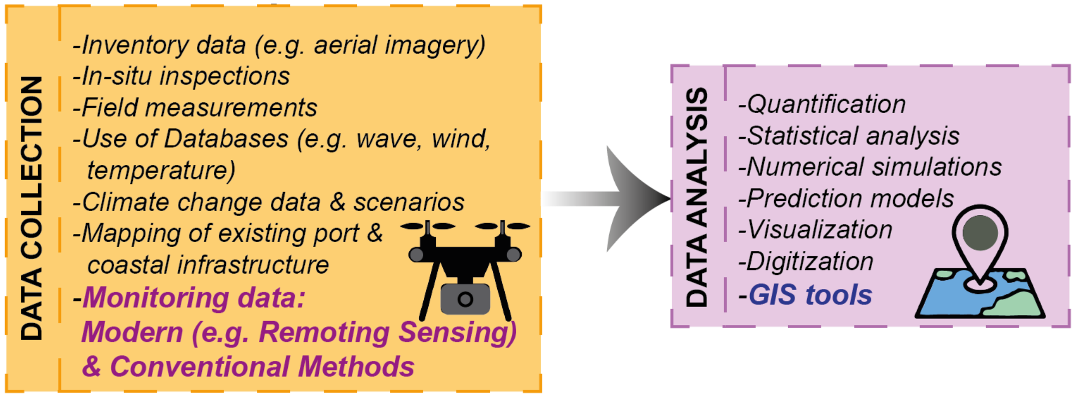
## Coastal vulnerability assessment



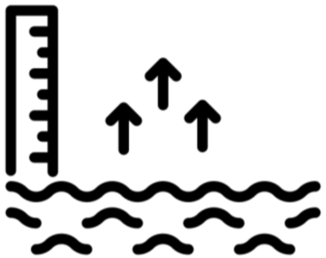

(Tsaimou et al, 2022)

## Coastal vulnerability components

- **Present vulnerability**, pressures by hazards regarding existing condition of coastal areas




- **Future vulnerability**, pressures by hazards regarding future threats and future condition of coastal areas due to climate change impacts (e.g. sea level rise, extreme storm events etc)



## Coastal Vulnerability Index

$$VI = E * S * AC$$

Where:

VI: Coastal Vulnerability (sub-)Index
E: Exposure
S: Susceptibility
AC: Adaptive Capacity

- **Physical sub-index PhCVI**
- **Technical sub-index TCVI**
- **Environmental sub-index ECVI**
- **Socio-economic sub-index SOCVI**

PhCVI or TCVI or ECVI or SOCVI=E∗S∗AC

## Physical Parameters

| No. | Parameters |
|---|---|
| 1 | Wave characteristics (e.g. significant wave height, period etc) |
| 2 | Geomorphology (e.g. type of beach sediment, thickness of layer sediment etc) |
| 3 | Coastal evolution (erosion or deposition) |
| 4 | Tide (meteorological or astrological) |
| 5 | Coastal slope (land or sea-bottom) |
| 6 | Beach width |
| 7 | Distance from vegetation |
| 8 | Number of extreme events |
| 9 | Number of disasters |
| 10 | Temperature |
| 11 | Precipitation |

## Technical Parameters

| No. | Parameters |
| --- | --- |
| 1 | Distance from back-beach structures |
| 2 | Distance from coastal road |
| 3 | Percentage of beach coverage by permanent structures |
| 4 | Coastal structures (e.g. breakwaters) |
| 5 | Port infrastructure |

## Environmental Parameters

| No. | Parameters |
|---|---|
| 1 | NATURA 2000 |
| 2 | Atmosphere indicators (air pollutants) |
| 3 | Number of critical habitats |
| 4 | Distance from aquaculture |

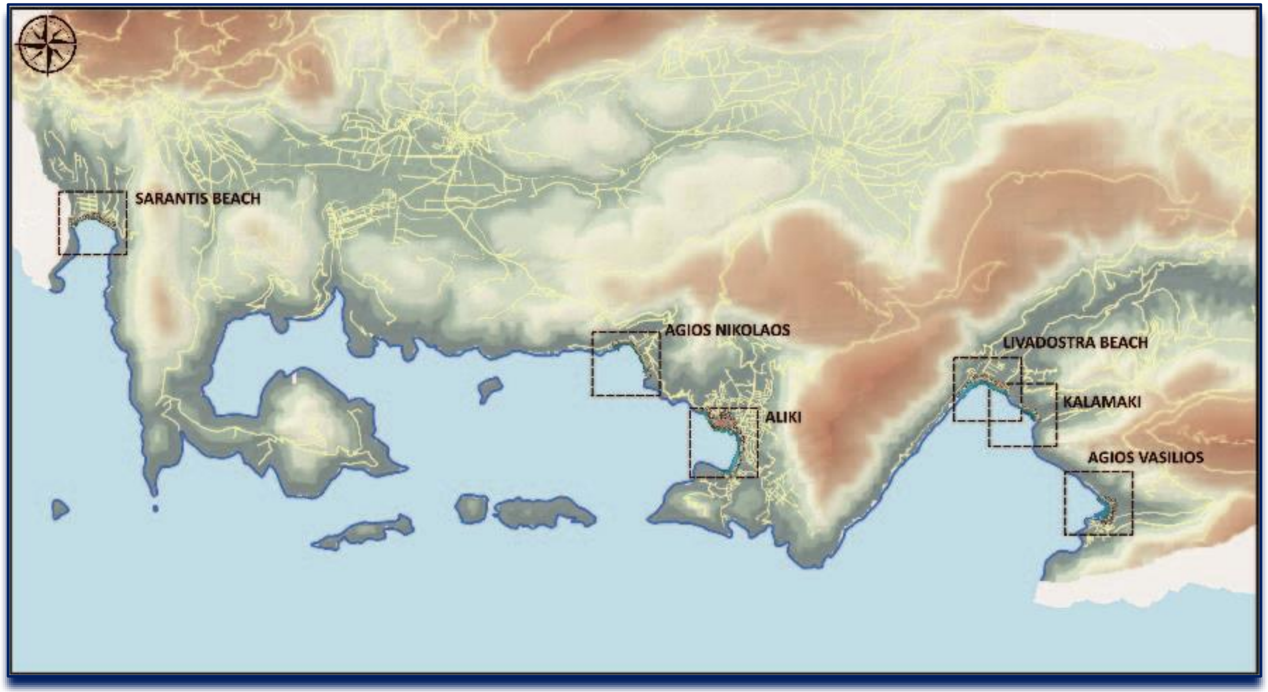
## Socio-economic Parameters

| No. | Parameters |
|---|---|
| 1 | Population characteristics (e.g. age, percentage of unemployment, type of employment, housing characteristics etc) |
| 2 | Distance from archeological monuments |
| 3 | Land use |
| 4 | Distance from capital / settlements |
| 5 | Cost by disasters / extreme events |

## Parameter estimation

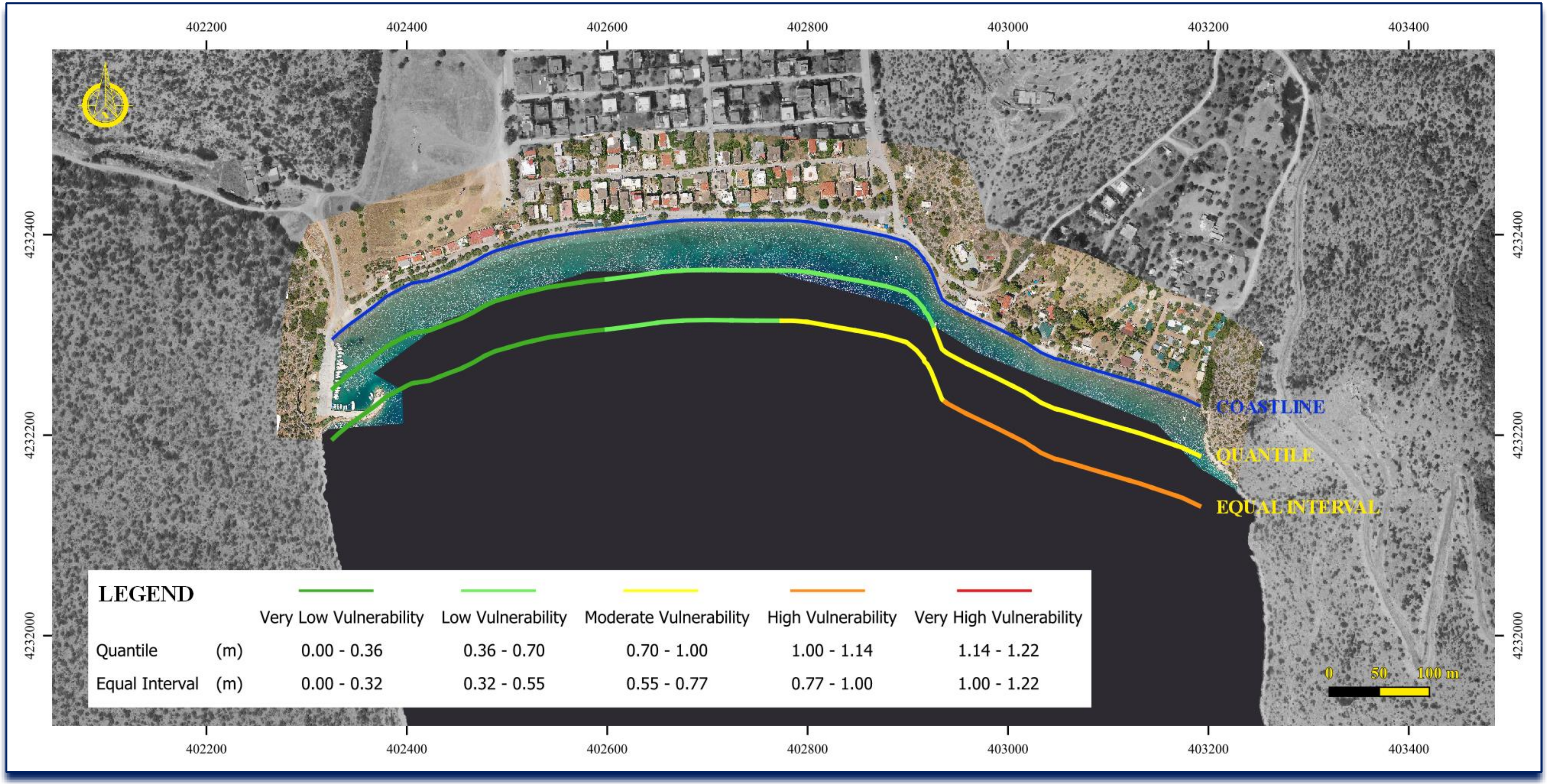
1. Segregation of each area is required for a detailed analysis to address the physical (e.g. hydrological and geomorphological features, wave climate and sediment transport), environmental (e.g. distances from critical habitats) and socio-economic (e.g. land use) discrepancies identified along the areas under investigation
2. Calculation of parameters' values (numerical models, open-source data etc)
3. Classification approaches for parameters' values (type of classification, number of classes, spatial scale etc)
4. Mapping parameters' values (GIS)

## Case study: Coastal Zone of Municipality of Thivaion




## Case study: Coastal Zone of Municipality of Thivaion

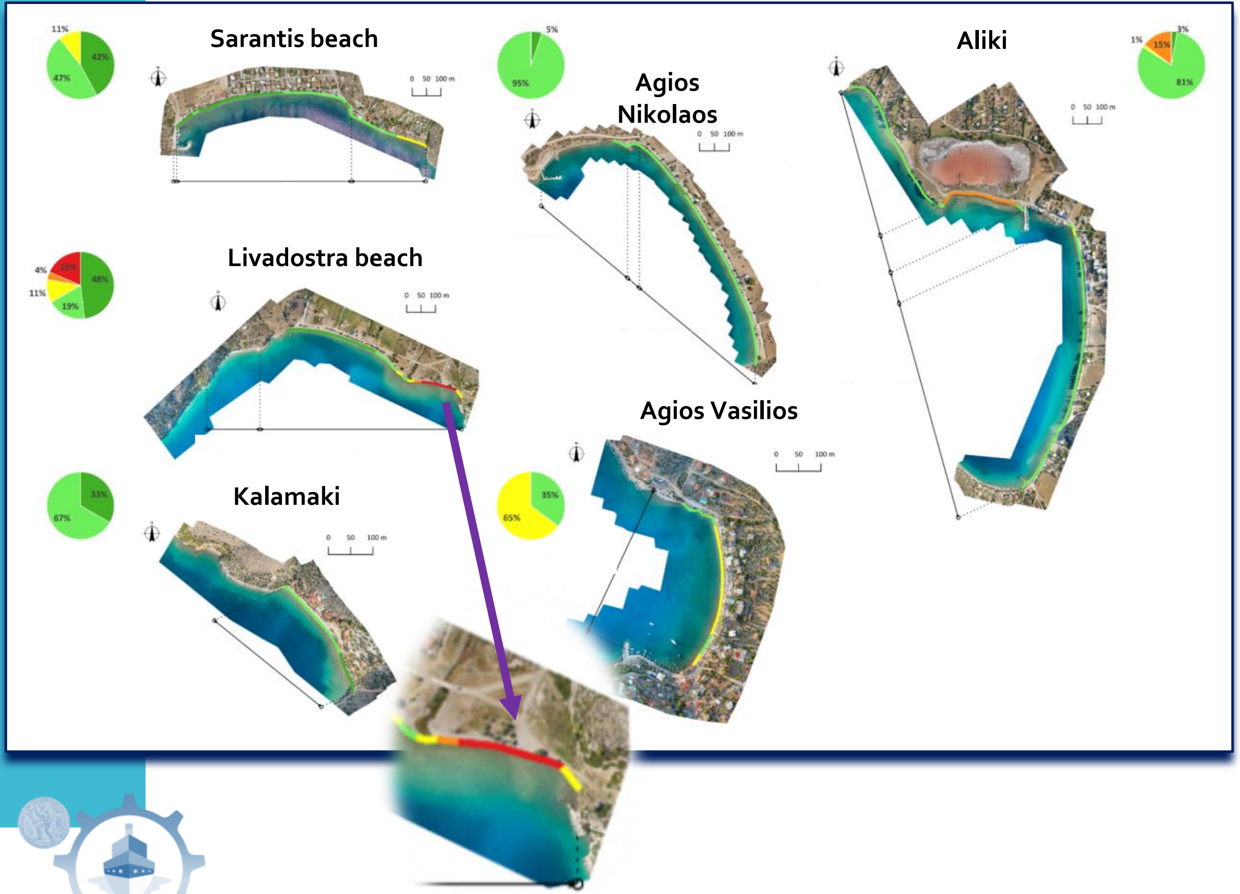

## Physical parameter: Significant wave height



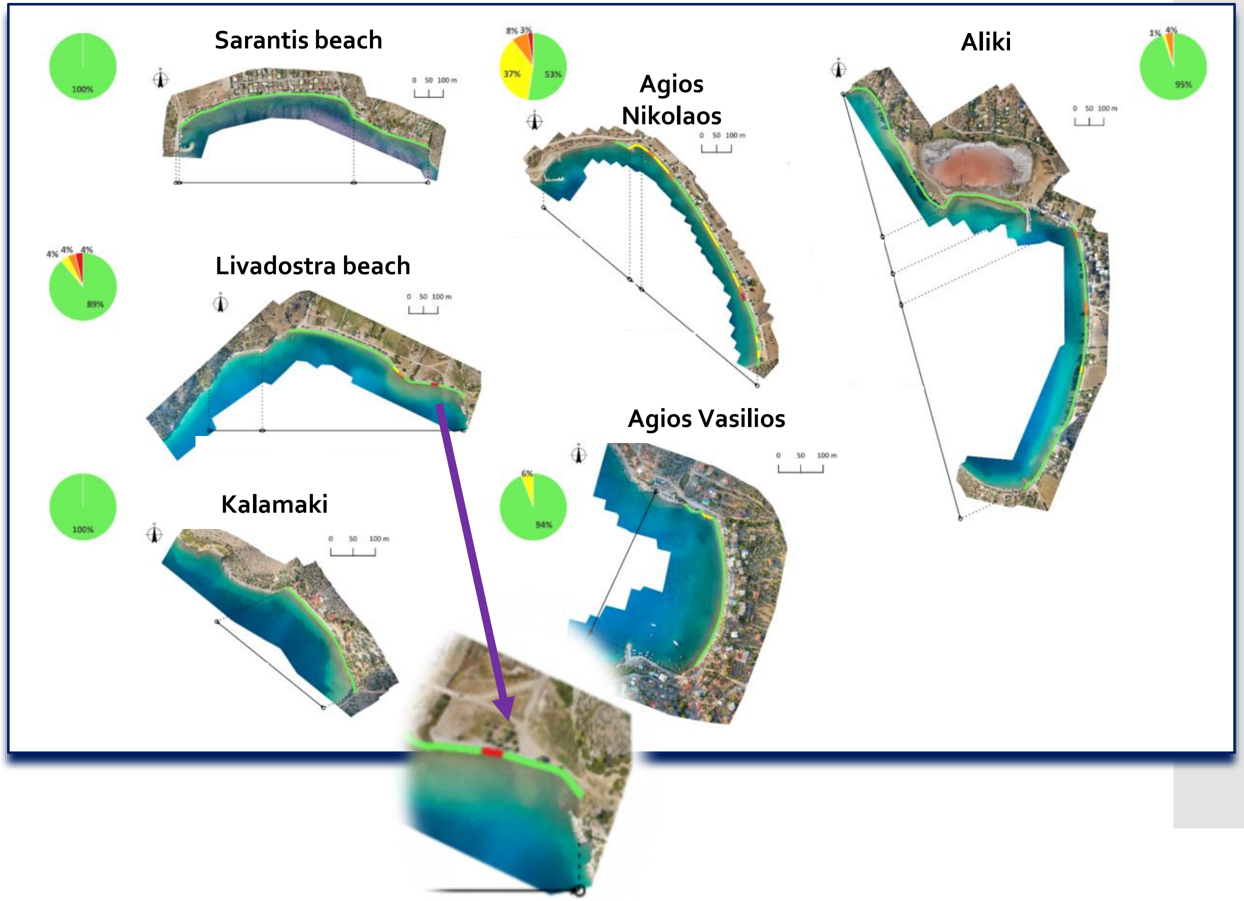

(Tsaimou et al, 2022)

## Coastline erosion-deposition

### Current vulnerability




### Future vulnerability



# Port vulnerability

"A port is a location on a coast or shore containing one or more **harbors** where ships can dock and transfer people or cargo to or from land".

*(Dwarakish and Salim, 2015)*

natural ↓ artificial

A part of the ocean, a lake, etc., that is next to land and that is protected and deep enough to provide safety for ships

Ports:

- Play an important role in the worldwide economy as essential nodes in the global trading network.
- Represent long-lasting and critical infrastructure that is sensitive to climate change.
- Provide jobs to millions of people worldwide.
- Differ in size and type.

Fishing shelter in Ormideia, Cyprus
Capacity: 35 fishing vessels
*(https://www.checkincyprus.com/)*

The port of Heraklion, Greece
Annual passenger capacity of up to 0.5 million for cruise tourism
~2 million passengers per year
*(https://www.cretapost.gr/)*

Rotterdam port, The Netherlands
10th globally
14.35 million TEUs in 2020
*(https://www.holland.com/) ©Guido Pijper*

**1.100 port facilities**

| | |
|---|---|
| Ports of international interest: 16 | Ports of greater interest: 25 |
| Ports of national interest: 16 | Ports of local interest: Rest |

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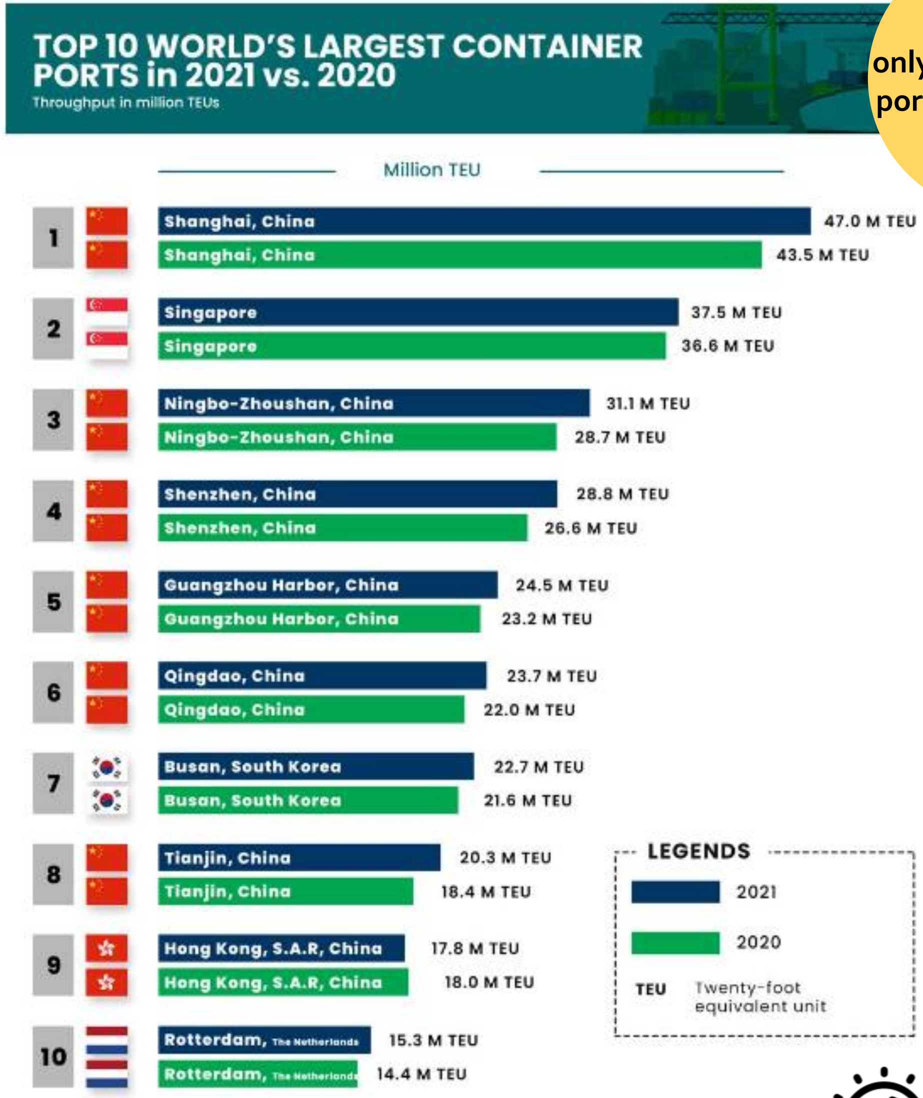
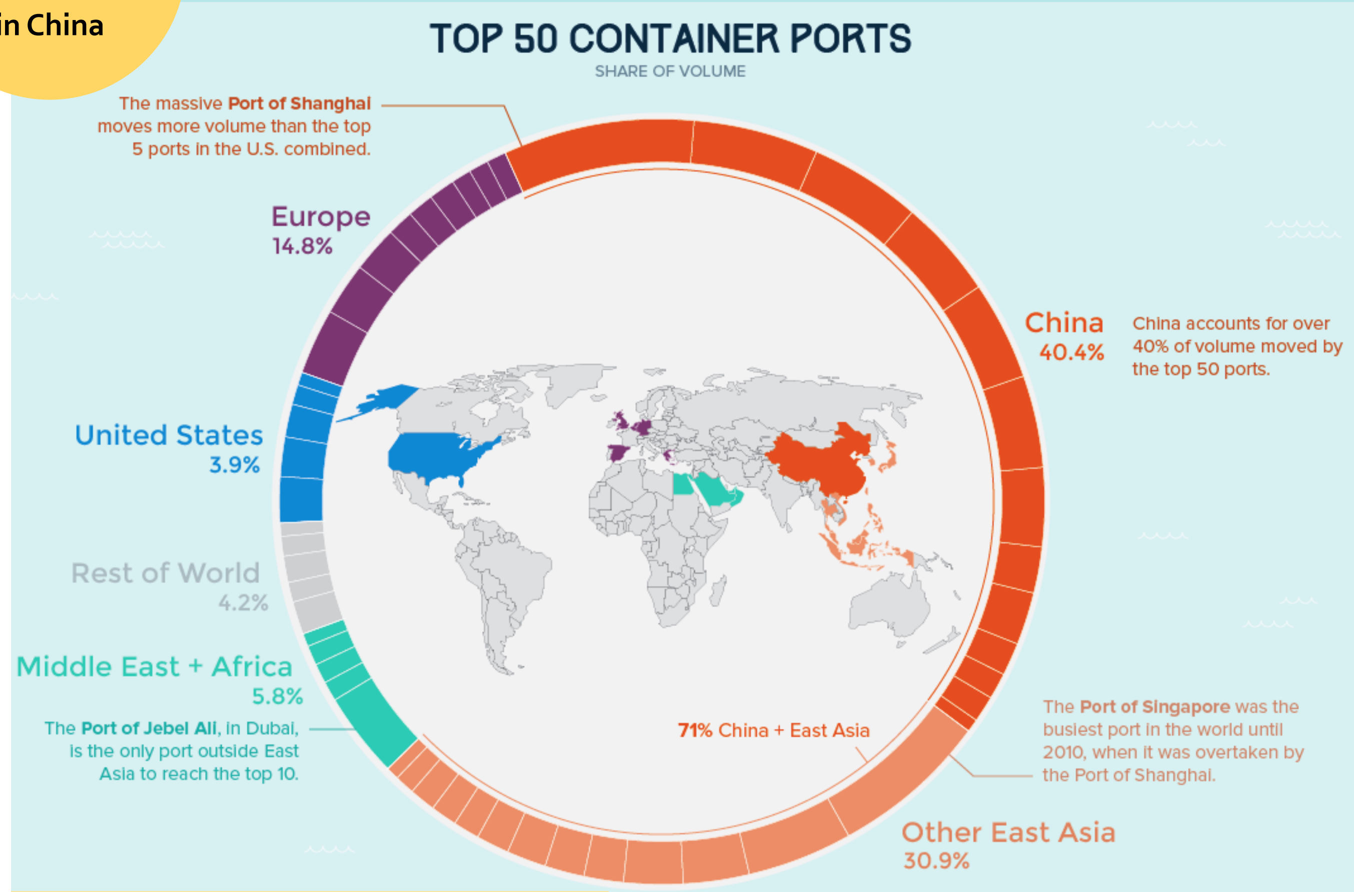
# Port vulnerability




(https://www.alcottglobal.com)

**In 2016**
**only 3 of the top 10 ports were located in China**




A TEU is an exact unit of measurement used to determine cargo capacity for container ships and terminals. This measurement is derived from the dimensions of a 20ft standardized shipping container. Because standard containers can be 20 or 40ft in length the capacity of a container ship can depend on the ratio of the two sizes. (40ft ship = 2 TEUs)

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# Port vulnerability

"Their location along coasts, rivers or lakes involves high exposure to a wide variety of hazards that include sea level rise, changes in extreme sea levels (such as wave set-up or storm surge) and flooding; these hazards may impact the port itself, the regional economy, the operation of supply chains and coastal populations". *(Ng et al., 2018)*

<u>Impacts in port infrastructure and operations:</u>

- SLR may lead to overtopping
- Increase in frequency of extreme events affects ports' susceptibility
- pH alteration may lead to eroded structures
- Ice melting creates different transportation routes in the Northern Hemisphere, affecting maritime transportation

➢ The floods of 2015 damaged the Port of Chennai, India *(Becker et al., 2018)*

*(https://www.thehindubusinessline.com/)*

➢ Hurricane Maria in 2017, caused infrastructure damage and port shutdown in the Caribbean *(Caribbean Development and Cooperation Committee, 2018)*

*(https://www.spokesman.com/)*

➢ Superstorm Sandy in 2012, which shut down the Port of New York and New Jersey for more than 8 days *(Smythe, 2013)*

Aerial photo shows the damage to an amusement park left in the wake of Superstorm Sandy, in Seaside Heights, N.J. *(AP Photo/Mike Groll)*

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# Port vulnerability

Goal: To enhance mitigation of and adaptation to climate change

## Port sector

- World Ports Climate Declaration

Commitment to reduce $CO_2$ emissions and improve air quality of ports
Target areas:
$CO_2$ emissions from ocean emissions from ocean-going vessels
$CO_2$ emissions from port operations and development
$CO_2$ emissions from hinterland transport
Use of renewable energy
Carbon footprint
Implementation strategies

- World Ports Climate Initiative

A global program to provide ports worldwide with a framework to mitigate their impact on climate change.
The WPCI was launched in 2008 by the International Association of Ports and Harbours (IAPH) and regional Port Organizations.

Enhanced climate resilience is needed through adaptation strategies

They are still at the planning stage for most seaports

*(Becker et al., 2012)*

## Example

The stakeholders of the port of Rotterdam developed and adaptation plan to secure the city and the port operations up to 2025 regarding climate change impacts. The port of Rotterdam is one of the safest ports in the world.

*(Rotterdam Climate Proof, 2013)*

[Rotterdam: Adapting to climate change | Institution of Civil ...](https://myice.ice.org.uk/.../case-studies/rotterdam-adapting-to-climate-change)
https://myice.ice.org.uk/.../case-studies/rotterdam-adapting-to-climate-change ▾

As part of RCP in 2013, RCI published its Climate Change Adaptation Strategy. It details the main methods Rotterdam intends to utilise to achieve a **climate-proof** city. The priority for outer-dike areas of the city is to 'build with nature', providing flood protection including 'flood-proof' buildings and public areas, and ... Δείτε περισσότερα

**Rotterdam**

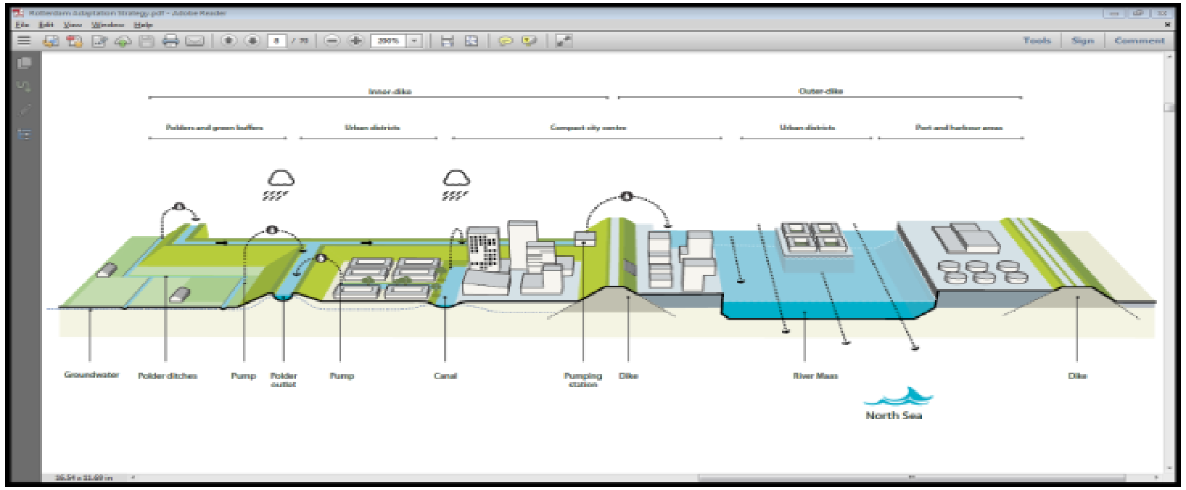
Rotterdam, the Netherlands' second city with a population 619,000, is one of the most urbanised parts of the country. It also contains the Port of Rotterdam, which extends over 40k... Δείτε περισσότερα

**Vulnerabilities**

Much of Rotterdam's economic success and development is linked to its location on the agriculturally rich Rhine–Meuse Delta, where the River Maas meets the North Sea, offering shipping links to the Atlantic and inlan... Δείτε περισσότερα

- Storm surge barriers are being optimised, rainwater storage to delay drainage is being created (including green roofs and facades, less paving and more flora in public streets and neighbourhoods, water squares and infiltration zones integrated into the infrastructure).

Diagram of Rotterdam's green and blue adaptation infrastructure *(Rotterdam Climate Initiative, 2013)*




These green and blue adaptation measures demonstrate best practice in the use of hard and soft infrastructure maximising natural flood attenuation mechanisms.

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In the adaptation framework, a necessary step is **risk analysis** that addresses the issue of "adapting to what".
*(IPCC, 2014)*

Such an assessment will provide information on the resilience of an existing port or a new investment in the upcoming decades, focusing on the major impacts of climate change that contribute to increased risk in terms of economic, social and environmental consequences.

nature climate change
ARTICLES
https://doi.org/10.1038/s41558-020-00937-z
Check for updates

## Climate change risk to global port operations

C. Izaguirre[1], I. J. Losada[1]✉, P. Camus[1], J. L. Vigh[2] and V. Stenek[3]

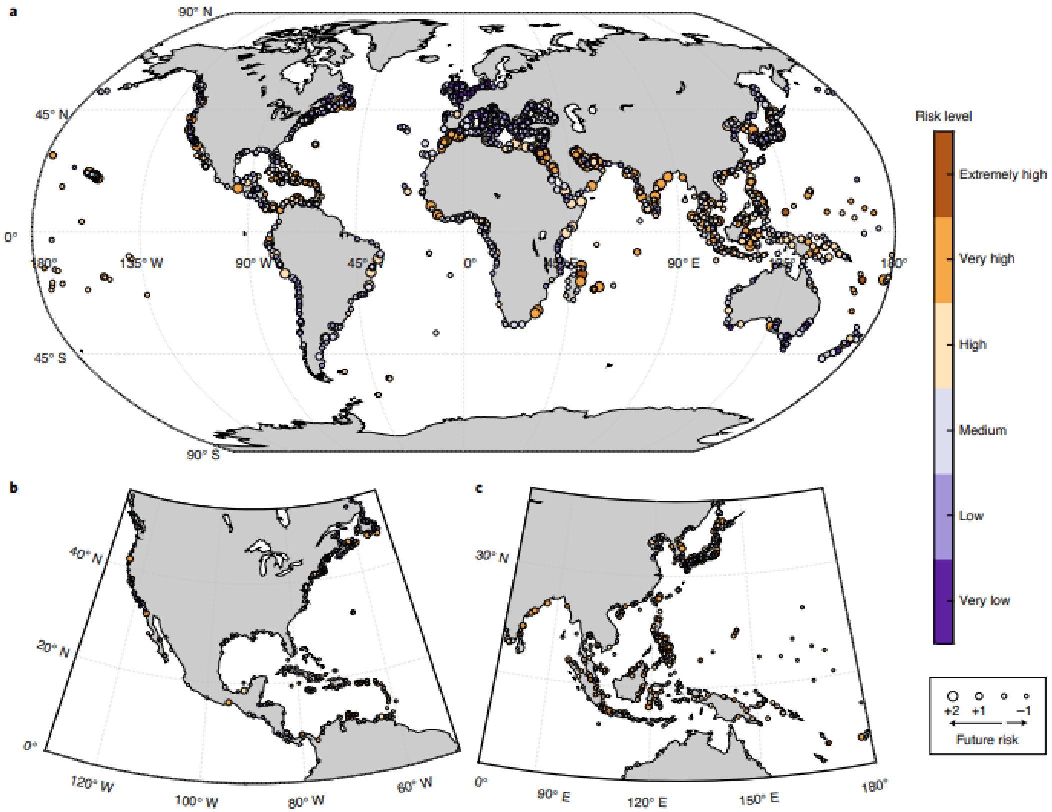


**Fig. 3 | Climate risk for the world port sector in the year 2100 under RCP8.5. a–c**, Details of future climate risk for ports worldwide (**a**), for Caribbean and North American ports (**b**) and for Asia-Pacific ports (**c**). The marker size reflects the change in risk level.

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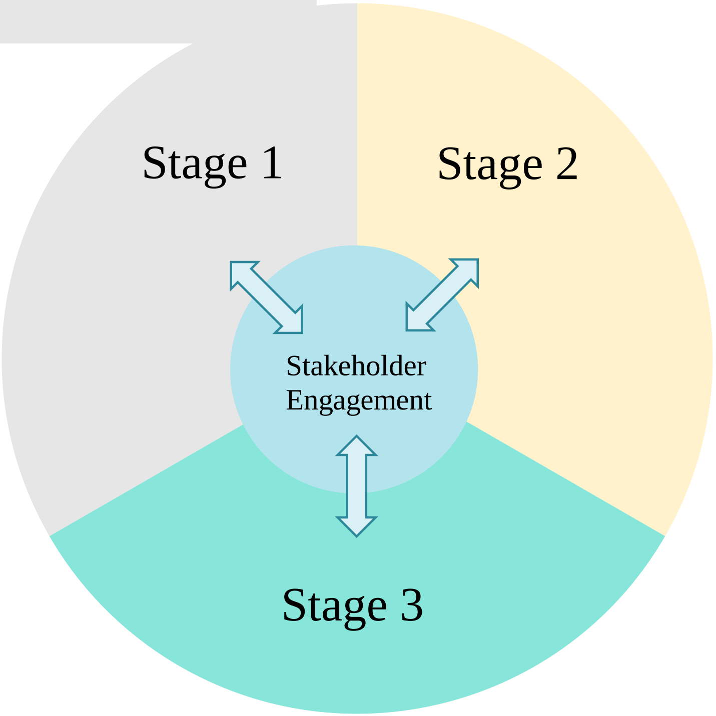
Prior to the detailed risk analysis, understanding of climate drivers, susceptibility and vulnerability of port infrastructure and operations are needed.

- Set goals
- Identify critical assets, operations and systems
- Indicate the susceptibility of the assets, operations and systems
- Determine adaptation objectives
- Consider data needs




- Define the climate variables causing impacts to measure susceptibility
- Understand baseline conditions
- Explore possible future climate conditions
- Analyze data to understand the climate change hazard

***Susceptibility*** *indicates whether an asset, operation or system is prone to harm, disruption or other adverse effects as a result of changes in meteorological, oceanographic or hydrological characteristics.*

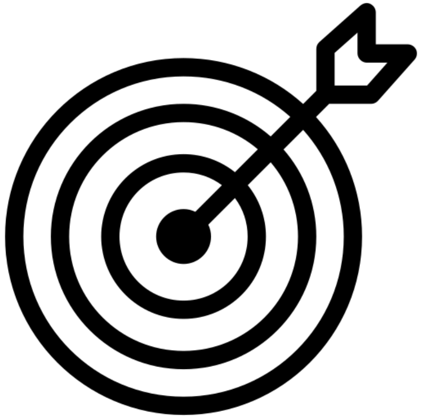
***Vulnerability*** *indicates the degree to which a system is susceptible to, and unable to cope with, adverse climate change effects, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which an asset, operation or system is exposed, its sensitivity (see criticality) and its adaptive capacity.*

- Agree approach to vulnerability assessment
- Establish changes in susceptibility
- Agree on indicators
- Define the scale of vulnerability for each indicator
- Measure vulnerability

**After** all 3 Stages: Design adaptation pathways

## Stage 1: Identify objectives

- **High level objectives**
- **Medium to long-term**



Example:

Make the port fully resilient to the impacts of climate change by 2025 and ensure that it remains one of the safest port cities in the world.

## Stage 1: Identify critical assets


*(PIANC, 2020)*

## Stage 1: Identify critical assets

| Maritime and inland port and navigation infrastructure | | | | Key facts | | | | | Criticality | | | | Susceptibility to hazards causing impacts | | | | | | | | | | | Key facts | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Geometrical data | | | Responsible department or organisation | | | | | | | | | | | | | | | | | Design data | | | Asset condition | | | Performance | | |
| | | | | Location | Depth (m relative to OD) | Elevation (m relative to OD) | Management | Operation and maintenance | Not critical | Unlikely | Probably | Yes | Flooding | Overtopping | Flow velocities/extreme waves | Low river flow | Changes in bathymetry | Bed or bank erosion | Fog or reduced visibility | Changes in wind | Extreme cold, ice or icing | Extreme heat, also humidity | Changes in water chemistry | Changes in biology | Design life (years) | Date of construction | Residual life | Good | Moderate | Poor | Maintencance cost | Performance against target | Available adaptive capacity |
| MARINE / OFFSHORE / IN RIVER | Operational use or modification of water area | | Channel / fairway / waterway (natural) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Channel / fairway / waterway (maintained; dredged) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Dredged material aquatic disposal or placement site | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Mooring areas (outside the harbour) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Anchorage | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Assets | Structures | Breakwater, wave chambers | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Dolphins | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Current deflector | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Storm surge barrier | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Aids to Navigation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Fuelling; re-fuelling; bunkering barge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | ical systems and util | Monitoring equipment, telemetry, MET | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Scour protection | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Plant and equipment | Dredging plant | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Resources | Natural habitat features | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Created or enhanced habitat features | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Archaeological or heritage resources | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Operations | | Pilotage | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Marker buoys navigation aids | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Dredging / disposal | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Maintenance of infrastructure | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Recreational use | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Sailing / water sports events | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Marker buoys navigation aids water sports events | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

*(PIANC, 2020)*

## Stage 1: Determine criticality of assets

| Implications for: / Scale of impact: | Safety | Economic effects; business continuity | Public effects and local community | Environment sustainability and compliance | Critical? |
|---|---|---|---|---|---|
| **Catastrophic** | Risk of large numbers of serious injuries or loss of life | Loss or degradation would risk long-term viability of business including supply chains | Essential services lost, daily life becomes intolerable, unacceptable physical suffering | Irrecoverable damage, proven breach, prospect of corporate penalty | Yes |
| **Major** | Risk of isolated instances of serious injuries or loss of life | Loss or degradation would have serious effects on business requiring significant remedial action | Severe disruption of essential services and hence daily life, high levels of physical suffering | Severe and continuing loss, significant management effort needed to deal with compliance failure | Probably |
| **Moderate** | Risk of small numbers of injuries | Intervention needed to protect business continuity | Frequent disruption of essential services; daily life difficult, moderate levels of physical suffering | Minor, reversible damage, action needed on issues of compliance | Unlikely |
| **Minor or insignificant** | Risk of near misses or minor injuries | Isolated difficulties (e.g. in supply chain, replacements or alternatives exist) | Intermittent disruption of essential services and daily life, low levels of physical suffering | Negligible damage, minor breaches, easily resolved | Not critical |

*(PIANC, 2020)*

| Maritime and inland port and navigation infrastructure | | | | Location | Depth (m relative to OD) | Elevation (m relative to OD) | Management | Operation and maintenance | Not critical | Unlikely | Probably | Yes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MARINE / OFFSHORE / IN RIVER | Operational use or modification of water area | | Channel / fairway / waterway (natural) | | | | | | | | | |
| | | | Channel / fairway / waterway (maintained; dredged) | | | | | | | | | |
| | | | Dredged material aquatic disposal or placement site | | | | | | | | | |
| | | | Mooring areas (outside the harbour) | | | | | | | | | |
| | | | Anchorage | | | | | | | | | |
| | Assets | Structures | Breakwater, wave chambers | | | | | | | | | |
| | | | Dolphins | | | | | | | | | |
| | | | Current deflector | | | | | | | | | |
| | | | Storm surge barrier | | | | | | | | | |
| | | | Aids to Navigation | | | | | | | | | |
| | | | Fuelling; re-fuelling; bunkering barge | | | | | | | | | |
| | | ical systems and util | Monitoring equipment, telemetry, MET | | | | | | | | | |
| | | | Scour protection | | | | | | | | | |
| | | Plant and equipment | Dredging plant | | | | | | | | | |
| | | Resources | Natural habitat features | | | | | | | | | |
| | | | Created or enhanced habitat features | | | | | | | | | |
| | | | Archaeological or heritage resources | | | | | | | | | |
| | Operations | | Pilotage | | | | | | | | | |
| | | | Marker buoys navigation aids | | | | | | | | | |
| | | | Dredging / disposal | | | | | | | | | |
| | | | Maintenance of infrastructure | | | | | | | | | |
| | | | Recreational use | | | | | | | | | |
| | | | Sailing / water sports events | | | | | | | | | |
| | | | Marker buoys navigation aids water sports events | | | | | | | | | |

## Stage 1:Identify hazards

| Susceptibility to hazards causing impacts | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flooding | Overtopping | Flow velocities/extreme waves | Low river flow | Changes in bathymetry | Bed or bank erosion | Fog or reduced visibility | Changes in wind | Extreme cold, ice or icing | Extreme heat, also humidity | Changes in water chemistry | Changes in biology |

**Hazards**

- Flooding
- Overtopping
- Flow velocities
- Extreme waves
- Low river flow
- Changes in bathymetry
- Bed or bank erosion
- Fog/reduced visibility
- Changes in wind
- Extreme cold, ice or icing
- Extreme heat, also humidity (magnitude, duration, frequency)
- Changes in water chemistry (acidity, salinity)
- Changes in biological character (vegetation growth rates, species migration, invasive species)

+ Any other such as Heavy rainfall, Electric storms

**Specification of hazards**

•Flooding due to overwhelmed drainage systems or high groundwater levels
•Overtopping and flooding due to high river flow levels, high tide or storm surge
•High in-channel river flow velocities or changes in sea state (extreme waves, agitation)
•Fog or other reduced visibility, for example due to blizzard conditions or sandstorms

## Stage 1:Indicate susceptibility

| Maritime and inland port and navigation infrastructure | | | | Criticality | | | | Susceptibility to hazards causing impacts | | | | | | | | | | | | Key facts | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | Design data | | | Asset condition | | | Performance | | |
| | | | | Not cirtical | Unlikely | Probably | Yes | Flooding | Overtopping | Flow velocities/extreme waves | Low river flow | Changes in bathymetry | Bed or bank erosion | Fog or reduced visibility | Changes in wind | Extreme cold, ice or icing | Extreme heat, also humidity | Changes in water chemistry | Changes in biology | Design life (years) | Date of construction | Residual life | Good | Moderate | Poor | Maintenance cost | Performance against target | Available adaptive capacity |
| LAND-WATER INTERFACE; INTERTIDAL; RIPARIAN ZONE | Assets | Structures | Quay wall (i) | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | 50 | 1994 | 25 | | ✓ | | ↔ | ✗ | ✗✗ |
| | | | Quay wall (ii) | | | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | 50 | 2014 | 45 | ✓ | | | ↔ | ✓ | ✓ |
| | | | Fenders | | | ✓ | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | 15 | 2014 | 10 | ✓ | | | ↔ | ✓ | ✓ |
| | | | Ladders | | | ✓ | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | 15 | 2014 | 10 | ✓ | | | ↔ | ✓ | ✓ |
| | | | Slipway | ✓ | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Physical systems | Cathodic protection | | | | ✓ | | | | | | ✓ | | | ✓ | | ✓ | | 10 | 2014 | 5 | ✓ | | | ↔ | ✓ | ✓ |
| | | Resources | Heritage resource (Lighthouse) | | | | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | | | N/A | 1950 | N/A | | ✓ | | ↑ | ✓ | ✗ |
| | | | Beach nourishment | | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ | 15 | 2018 | 14 | ✓ | | | ↔ | – | – |
| | Operations | | Pilotage | | | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | | | N/A | N/A | N/A | N/A | N/A | N/A | ↔ | ✓ | ✓ |
| | | | Dredging / disposal | | | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | | N/A | N/A | N/A | N/A | N/A | N/A | ↑ | ✗ | ✗✗ |
| | | | Sailing / water sports events | | ✓ | | | | | | | | | | | | | | | | | | | | | | | |
| | | | Marker buoys navigation aids water sports events | | ✓ | | | | | | | | | | | | | | | | | | | | | | | |

| Legend | High | Moderate | Low |
|---|---|---|---|
| Increasing | ↑ | ↑ | ↑ |
| Stable | ↔ | ↔ | ↔ |
| Reducing | ↓ | ↓ | ↓ |

*(PIANC, 2020)*

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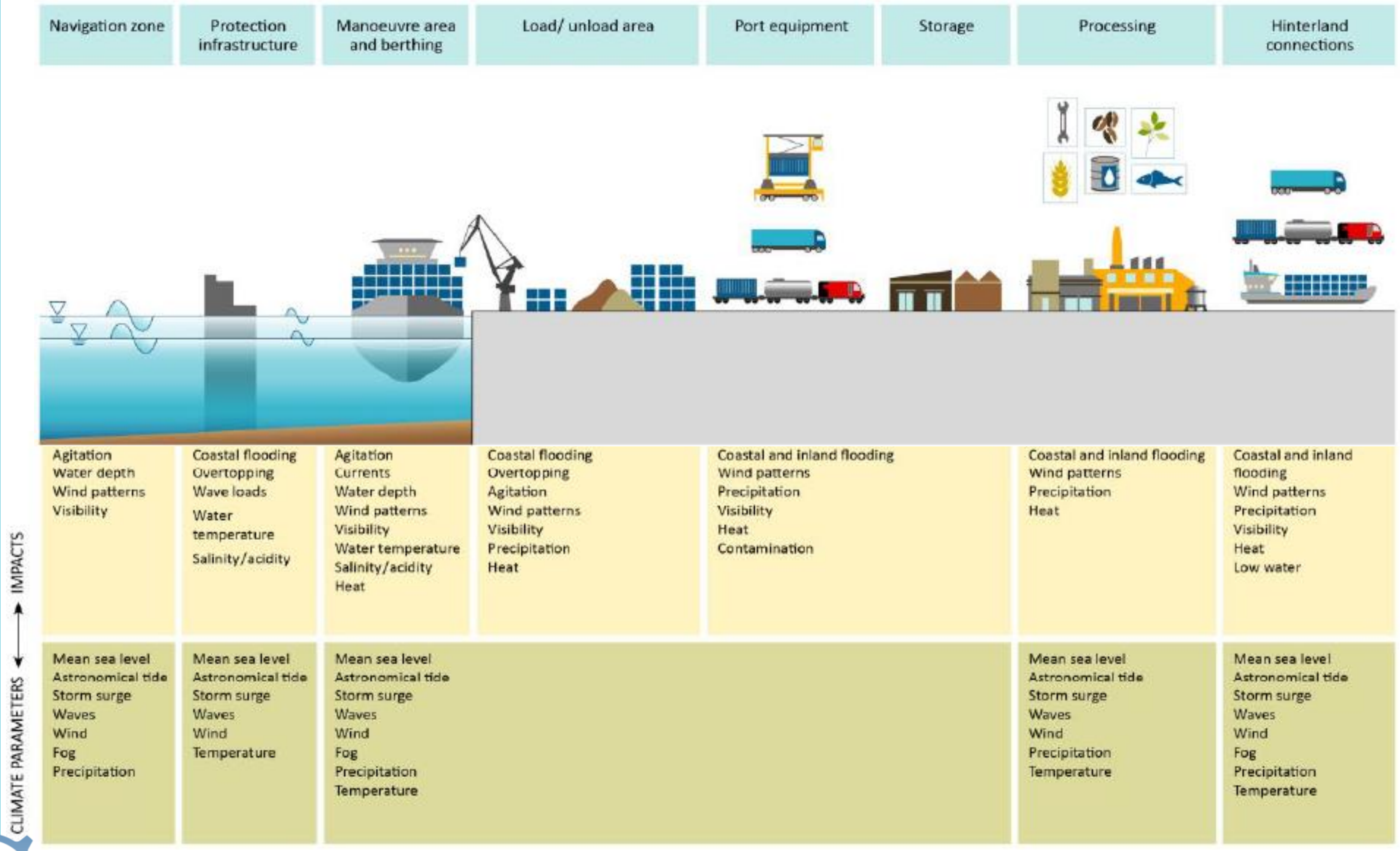
## Stage 2:Measure susceptibility




*(PIANC, 2020)*

•Link climate parameters to impacts to define susceptibility

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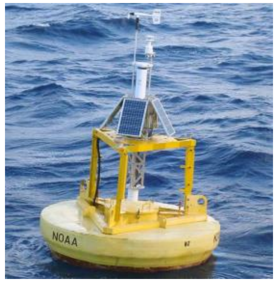
# Port vulnerability

## Stage 2: Find data

•Find sources of data

Copernicus GEODATA EMODnet European Marine Observation and Data Network

Masterplan




Information from buoys

ΕΦΗΜΕΡΙΔΑ ΤΗΣ ΚΥΒΕΡΝΗΣΕΩΣ

National legislation

•Gather data to measure current state

- Climate data
- Environmental data
- Infrastructural data
- Socioeconomic data

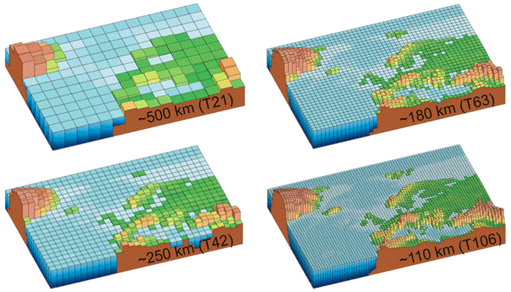
e.g.

| | Hs at 20m depth | |
|---|---|---|
| Port | Range | Direction |
| 1 | 4.25-4.75 | NE |
| 2 | 3.25-3.75 | NW |
| 3 | 6.75-7.75 | SW |
| 4 | 3.25-3.75 | S |

•Explore projections to estimate future state

Use of global climate models, hydrodynamic models, projections from literature or estimations

Global Regional



## Stage 3: Identify vulnerability

Stage 3 brings together the collated information on critical assets, operations and systems (from Stage 1) and the understanding about projected changes in the climate parameters and processes to which these assets, operations and systems are susceptible (from Stage 2), to identify and assess potential risks associated with climate change.

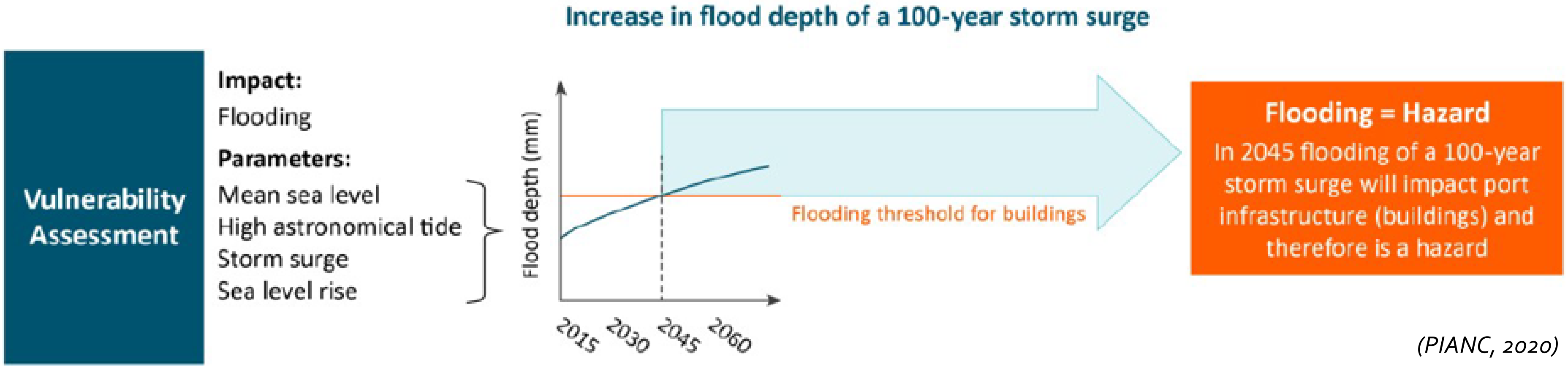
A vulnerability assessment involves, for each climate change scenario as appropriate:

•Determining whether the projected changes in relevant climate parameters and processes highlighted in Stage 2, will lead to a change in the susceptibility of any of the critical assets, operations or systems identified in Stage 1.

•Assessing whether vulnerability is likely to increase within the adaptation planning horizon when factors such as proximity to thresholds and the availability of adaptive capacity are taken into account.

## Stage 3: Identify vulnerability

Examples




*(PIANC, 2020)*

Climate parameter: T
Impacts: Workforce health and safety, Energy demand

Susceptibility → Changes in susceptibility

*T increase (change in parameter) and alteration of the impacts*

↓

Indicators to track vulnerability

- *Number of days during which staff working outdoors is at "high risk"*
- *Increase in energy requirements*

← Changes in indicators ← Assess the level of vulnerability

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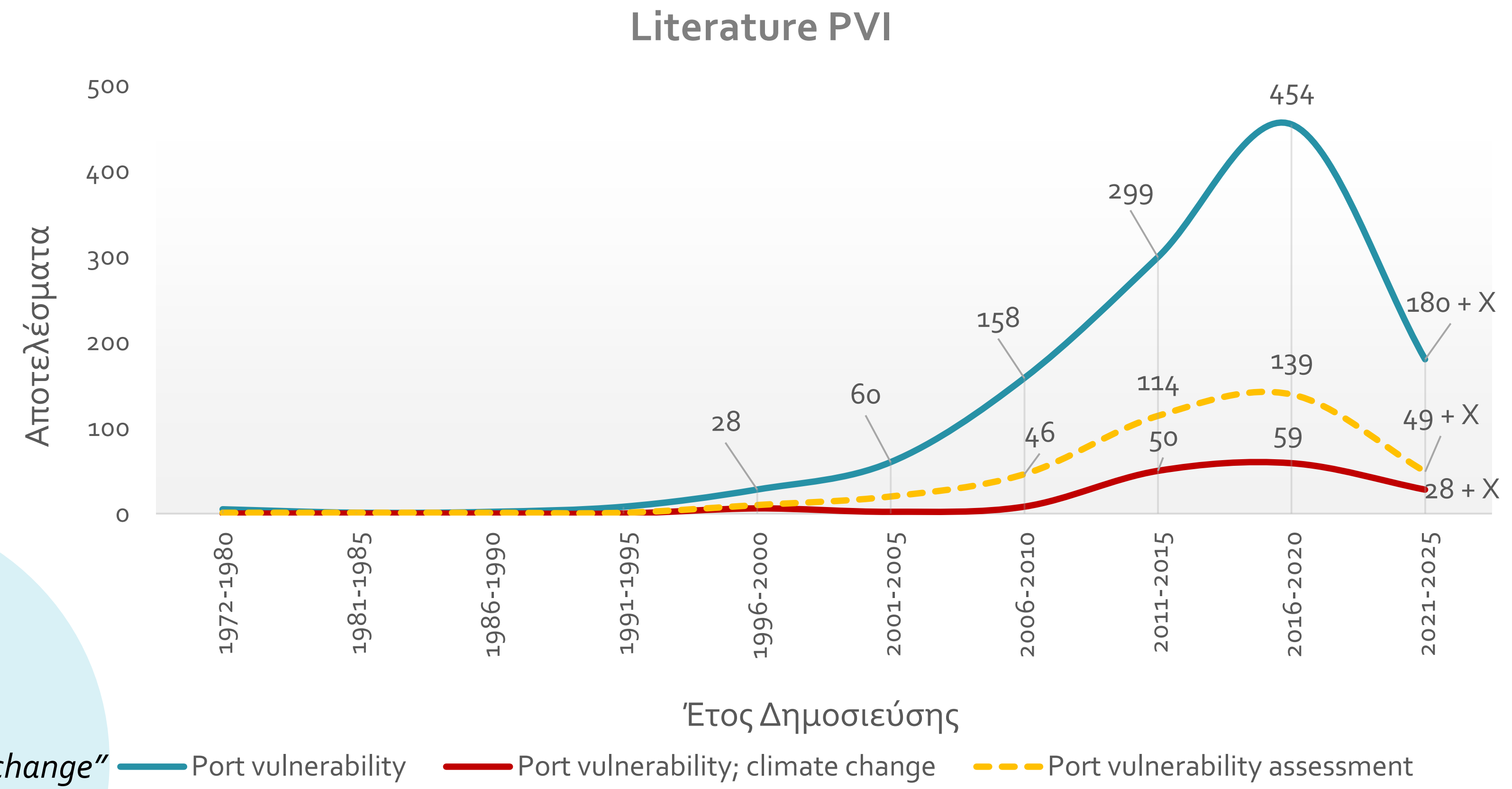
# Port Vulnerability Index

***1198***
*results*
*in Scopus*




*(Koulouri, 2022)*

*Search terms:*

*"port vulnerability"*
*"port vulnerability; climate change"*
*"port vulnerability assessment"*

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# Port Vulnerability Index

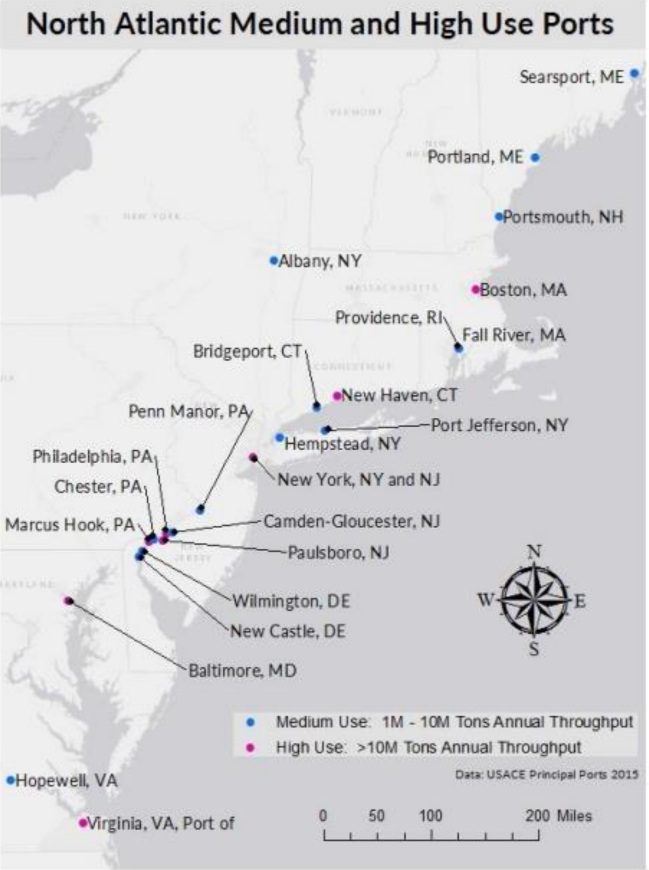
- Development of PVI has followed the CVI rationale.
- Paradigms for all over the world, mostly commercial ports of international importance.
- Expert judgement is used to evaluate vulnerability.
- Climate, socioeconomic and technical data are considered.
- The common goal is to assess vulnerability, thus improving ports' resilience and planning for the future.

| Year | Study area | Researchers |
|---|---|---|
| **2011** | 136 ports globally | Hanson S. et al. |
| **2011** | 2 ports, New York & New Jersey | McLaughlin B. et al. |
| **2013** | Ports in Australia | Nursey-Bray M. et al. |
| **2014** | 4 international ports | Hsieh C. H. et al. |
| **2015** | Port Kembla and adjacent area, Australia | Chhetri P. et al. |
| **2016** | 3 ports, East Asia | Dong-Taur Su et al. |
| **2017** | Methods | McIntosh R. D. & Becker A. |
| **2018** | Fishing shelters, Lesvos, Greece | Kontogianni A. et al. |
| **2019** | 22 ports in North Atlantic, USA | McIntosh R. D. & Becker A. |
| **2020** | 22 ports in North Atlantic, USA | McIntosh R. D. & Becker A. |
| **2021** | Port Mobile, Alabama, USA. | Abdelhafez M., et al. |

# Port Vulnerability Index

## Examples of indicators

| Indicator | Description | Units | Data Source |
|---|---|---|---|
| Average.Cost.of.Storm.Events | Average cost of property damage from storm events in the port county since 1950 with property damage > $1 Million | $ | NOAA Storm Events Database |
| **Channel.Depth** | The controlling depth of the principal or deepest channel at chart datum | A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments | World Port Index (Pub 150) |
| **Containership.Capacity** | Container Vessel Capacity | calls x DWT | MARAD: Vessel Calls at U.S. Ports by Vessel Type |
| Disaster.Housing.Assistance | The total disaster housing assistance of Presidential Disaster Declarations for the port county since 1953 | Declarations | FEMA: Disaster Declarations |
| **Entrance.Restrictions** | Presence or absence of entrance restrictions | Tide, Swell, Ice, Other | World Port Index (Pub 150) |
| Environmental.Index..ESI. | Environmental Sensitivity Index (ESI) shoreline sensitivity to an oil spill for the most sensitive shoreline within the port | ESI Rank (1.00 - 10.83) | NOAA Office of Response and Restoration |
| **Gas.Carrier.Capacity** | Gas Carrier Capacity | calls x DWT | MARAD: Vessel Calls at U.S. Ports by Vessel Type |
| **Harbor.Size** | Harbor Size | Large, Medium, Small, Very-Small | World Port Index (Pub 150) |
| Hundred.Year.High.Water | 1% annual exceedance probability high water level which corresponds to the level that would be exceeded one time per century, for the nearest NOAA tide station to the port | m above MHHW | NOAA Tides and Currents: Extreme Water Levels |
| Hundred.Year.Low.Water | 1% annual exceedance probability low water level for the nearest NOAA tide station to the port, which corresponds to the level that would be exceeded one time per century | m below MLLW | NOAA Extreme Water Levels |
| **Marine.Transportation.GDP** | County Marine Transportation GDP | $ | NOAA Office for Coastal Management |
| **Marine.Transportation.Jobs** | Number of Marine Transportation Jobs in the port county | number of jobs | NOAA Office for Coastal Management |
| Number.of.Critical.Habitat.Areas | Number of Critical Habitat Areas within 50 miles of the port | Areas | U.S. Fish & Wildlife Service |
| Number.of.Cyclones | Number of cyclones that have passed within 100 nm of the port since 1842 | Number of cyclones | NOAA Historical Hurricane Tracks Tool |
| Number.of.Disasters | Number of Presidential Disaster Declarations for the port county since 1953 | Disaster Type | FEMA: Disaster Declarations |
| Number.of.Endangered.Species | Number of Threatened or Endangered Species found in port county | Species | U.S. Fish & Wildlife Service |
| Number.of.Hazmat.Incidents | Number of Hazardous Materials Incidents in port city since 2007 | Number of Incidents | U.S. DOT Pipeline and Hazardous Materials Safety Administration |
| Number.of.Storm.Events | Number of storm events in port county w/ property damage > $1M | events | NOAA Storm Events Database |
| **Overhead.Limits** | Presence or absence of overhead limitations | Y/N | World Port Index (Pub 150) |
| Percent.of.Bridges.Deficient | Percent of bridges in the port county that are structurally deficient or functionally obsolete | % | US DOT FHA National Bridge Inventory |
| **Pier.Depth** | The greatest depth at chart datum alongside the respective wharf/pier. If there is more than one wharf/pier, then the one which has greatest usable depth is shown. | A (over 76 ft) to Q (0 – 5 ft) in 5-foot increments | World Port Index (Pub 150) |
| Population.Change | Rate of population change (from 2000-2010) in the port county, expressed as a percent change | % | NOAA Office for Coastal Management |
| Population.Inside.Floodplain | Percent of the port county population living inside the FEMA Floodplain | % | NOAA Coastal County Snapshots |
| Projected.Change.in.Days.Above.Baseline.Extremely.Hot.Temperature | The percent change from observed baseline of the average number of days per year above baseline "Extremely Hot" temperature projected for the end-of-century, downscaled to 12km resolution for the port location | % | US DOT CMIP Climate Data Processing Tool |
| Projected.Change.in.Number.of.Extremely.Heavy.Precipitation.Events | The percent change from observed baseline of the average number of "Extremely Heavy" Precipitation Events projected for the end-of-century, downscaled to 12km resolution for the port location | % | US DOT CMIP Climate Data Processing Tool |
| Sea.Level.Trend | Local Mean Sea Level Trend | mm / yr | NOAA Tides and Currents: Sea Level Trends |
| **Shelter.Afforded** | The shelter afforded from wind, sea, and swell, refers to the area where normal port operations are conducted, usually the wharf area. | Excellent (5), Good (4), Fair (3), Poor (2), None (1) | World Port Index (Pub 150) |




*(McIntosh & Becker, 2019)*

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## Examples of indicators

| Sub-index | Variable | Relation with vulnerability |
|---|---|---|
| Physical | P1. Jetty crest freeboard (difference between crest elevation and water surface elevation) | Higher elevation from the sea surface indicates lower degree of vulnerability. |
| | P2. Frequency of extreme weather events | More frequent extreme weather events imply higher degree of vulnerability. |
| | P3. Important wave height | The appearance of higher waves increases the vulnerability. |
| | P4. Important wave length | The appearance of longer waves increases the vulnerability. |
| Social | S1. Professional usage | The professional usage of each harbour increases the vulnerability. |
| | S2. Occupancy rate | The higher existing occupancy rate of each harbour indicates higher degree of vulnerability. |
| | S3. Capacity | The higher capacity of the ports in terms of boats increases the vulnerability. |
| | S4. Distance from the urban area | Longer distance of each harbour from the urban centres implies higher vulnerability. |
| | S5. Number of inhabitants | A community with small number of inhabitants indicates higher vulnerability. |
| Economic | E1. Construction materials | The higher the structural integrity of the harbour the lower its vulnerability. |
| | E2. Dredging volume | The higher dredging volume implies higher degree of vulnerability. |
| | E3. Stone volume | The higher stone volume implies higher degree of vulnerability. |
| | E4. Concrete volume | The higher concrete volume implies higher degree of vulnerability. |

| Indices | Parameters | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Physical | P1. Distance from the sea surface (m) | >0.75 | 0.51–0.75 | 0.26–0.50 | 0.01–0.25 | 0 |
| | P2. Frequency of extreme weather events (%) | <30% | 30–49% | 50–69% | 70–89% | ≥90% |
| | P3. Important wave high (m) | <0.3 | 0.3–0.6 | 0.7–1.0 | 1.1–1.4 | ≥1.5 |
| | P4. Important wave length (m) | <5 | 5–9 | 10–14 | 15–19 | ≥20 |
| Social | S1. Professional usage (%) | <30% | 30–49% | 50–69% | 70–89% | ≥90% |
| | S2. Current usage (%) | <30% | 30–49% | 50–69% | 70–89% | ≥90% |
| | S3. Capacity (boats) | <25 | 25–49 | 50–74 | 75–99 | ≥100 |
| | S4. Distance from the urban area (km) | <5 | 5–9 | 10–14 | 15–19 | ≥20 |
| | S5. Number of inhabitants | >10000 | 7501–10000 | 5001–7500 | 2501–5000 | ≤2500 |
| Economic | E1. Construction materials | Mainly concrete | Partly concrete | Mainly cement | Partly cement | No cement |
| | E2. Dredging volume ($m^3$) | <500 | 500–999 | 1000–1499 | 1500–2999 | ≥3000 |
| | E3. Boulders volume ($m^3$) | <500 | 500–1499 | 1500–3499 | 3500–4999 | ≥5000 |
| | E4. Concrete volume ($m^3$) | <100 | 100–199 | 200–349 | 350–499 | ≥500 |

*(Kontogianni et al., 2018)*

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- Η μελέτη μίας παράκτιας περιοχής, στην οποία λειτουργεί ένας λιμένας, δε μπορεί να μη λάβει υπόψιν τις πιέσεις της τεχνικής υποδομής. Αντίστοιχα, οι λειτουργίες ενός λιμένα εξαρτώνται άμεσα από τα κοινωνικά και οικονομικά χαρακτηριστικά της περιοχής στην οποία ανήκει και παράλληλα επηρεάζει τους παράκτιους βιοτόπους και το οικοσύστημα.

- Κατά πόσο τελικά, η αποσπασματική μελέτη της τρωτότητας μίας παράκτιας περιοχής, μέσω του CVI και ενός λιμένα, μέσω του PVI, μπορεί να καταλήξει σε ορθό σχεδιασμό και σωστά αποτελέσματα;

- Για τη βέλτιστη κατηγοριοποίηση των παραμέτρων χρησιμοποιούνται κατηγορίες σε 4 βασικούς υποδείκτες.

**Αξιολόγηση Τρωτότητας Ενιαίου Συστήματος (Παράκτια Ζώνη - Λιμένας)**

- **Φυσικός Υποδείκτης**
  - Κλιματικά στοιχεία
  - Μορφολογία & γεωλογία περιοχής
  - Υδροδυναμικά χαρακτηριστικά
- **Τεχνικός Υποδείκτης**
  - Γενικά χαρακτηριστικά
  - Κατάσταση λιμενικών υποδομών
  - Προσβασιμότητα
  - Ικανότητα λιμένος
- **Περιβαλλοντικός Υποδείκτης**
  - Χλωρίδα & πανίδα περιοχής
  - Περιοχές περιβαλλοντικού ενδιαφέροντος
- **Κοινωνικό-Οικονομικός Υποδείκτης**
  - Χρήσεις γης
  - Οικονομικά στοιχεία
  - Δημογραφικά στοιχεία

# CVI & PVI

- **Φυσικός Υποδείκτης**
  - Κλιματικά Στοιχεία
    - Ταχύτητα Ανέμου (m/s)
    - Εύρος Θερμοκρασίας ($^oC$)
    - Συχνότητα Εμφάνισης Ακραίων Φαινομένων
    - Προβλεπόμενη Αλλαγή Ποσοστού Ημερών Πάνω Από Τη Μέση Μεγαλύτερη Τιμή Θερμοκρασίας (%)
  - Μορφολογία & Γεωλογία Περιοχής
    - Ιζήματα Πυθμένα
    - Βαθυμετρία Περιοχής
    - Διάβρωση Ακτής
    - Ιστορική Μετατόπιση Ακτογραμμής (m/έτος)
  - Υδροδυναμικά Χαρακτηριστικά
    - Σημαντικό Ύψος Κύματος (m)
    - Τάση Μέσης Στάθμης Της Θάλασσας (mm/year)
- **Περιβαλλοντικός Υποδείκτης**
  - Χλωρίδα & Πανίδα Περιοχής
    - Αριθμός Απειλούμενων Ειδών στην Περιοχή
    - Ύπαρξη Λιβαδιών Ποσειδωνίας
  - Περιοχές Περιβαλλοντικού Ενδιαφέροντος
    - Απόσταση από Ιχθυοκαλλιέργειες
    - Περιοχή Κρίσιμων Ενδιαιτημάτων
    - Ύπαρξη Περιοχών Δικτύου NATURA
    - Σύνδεση και Απορροή Υδάτινων Σωμάτων
- **Τεχνικός Υποδείκτης**
  - Γενικά Χαρακτηριστικά
    - Είδος Χρήσης
    - Μέγεθος Λιμένα
    - Ηλικία Λιμένος
    - Βάθος Λιμενολεκάνης (m)
    - Χωρητικότητα Πλοίων
    - Καταγραφή Σεισμικών Φαινομένων
  - Κατάσταση Λιμενικών Υποδομών
    - Γενική Κατάσταση
    - Αριθμός Κρηπιδωμάτων
    - Προστασία Κυματοθραύστη
    - Υλικά Κατασκευής
  - Προσβασιμότητα
    - Απόσταση από τον Αστικό Ιστό
    - Απόσταση από κοντινότερο Λιμάνι
  - Ικανότητα Λιμένα
    - Παραγωγικότητα Αποβάθρας
    - Βαθμός Κατάληψης Αποβάθρας
- **Κοινωνικο-Οικονομικός Υποδείκτης**
  - Χρήσεις Γης
    - Χρήσεις Γης & Κάλυψης
  - Οικονομικά Στοιχεία
    - Μέσο Κόστος Υλικών Ζημιών Στην Ενδοχώρα Από Έντονα Καιρικά Φαινόμενα
    - Ποσοστό Απασχόλησης Επί Του Λιμένα
    - Μέσο Κατά Κεφαλήν Εισόδημα
    - Μέσος Ετήσιος Αριθμός Διακίνησης TEUs
    - Μέσος Ετήσιος Αριθμός Επιβατών Κρουαζιέρας
  - Δημογραφικά Στοιχεία
    - Αριθμός Κατοίκων
    - Ρυθμός Πληθυσμιακής Μεταβολής
  - SoVI

LHW-NTUA

| Υποδείκτες | Α/Α.Α | Κατηγορία | Α/Α.Α.Α | Παράμετρος | Συμβολισμός | Μονάδες Μέτρησης | Κατηγοριοποίηση βάση McIntosh & Becker, 2020 | Ορισμός/Σημασία παραμέτρου Very Low (1) | Τιμές Βαθμολόγησης έναντι Τρωτότητας | | | | | ΣΚΟΡ | Ορισμός/Σημασία παραμέτρου Very High (5) | Περιγραφή Παραμέτρου (Description) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Very Low (1) | Low (2) | Moderate (3) | High (4) | Very High (5) | | | |
| Φυσικός Υποδείκτης (Physical) | 1,1 | Κλιματολογικά στοιχεία (Climate) | 1.1.1 | Ταχύτητα Ανέμου / Speed Wind | U | m/s | exposure | Νηνεμία. Δεν προκαλούνται προβλήματα στη λειτουργία του λιμένος. | <1.5 | 1.6-5.5 | 5.6-10.9 | 11.0-16.9 | >17.0 | | Παύση εργασιών. Ο λιμένας δε μπορεί να δεχτεί και να εξυπηρετήσει κανένα είδους πλοίου. | Container terminals will significantly reduce their operability for wind speeds higher than the Beaufort scale 6 (13.8m/s). Υψηλότερες τιμές ταχύτητας ανέμου αυξάνουν την τρωτότητα και προκαλούν δεσλειτουργίες στο λιμένα. |
| | | | 1.1.2 | Εύρος Θερμοκρασίας / Temperature Range | TmR | °C | exposure | Μικρό εύρος μεταξύ των θερμοκρασιών στο ίδιο έτος. | <6.9 | 7-10.4 | 10.5-13.9 | 14-17.4 | >17.5 | 2 | Το εύρος των τιμών μεταξύ του θερμότερου καλοκαιριού και του ψυχρότερου χειμώνα. | Εύρος μεταβολής τιμών θερμοκασίας εντός έτους. Οι μεγαλύτερες διακυμάνσεις και αλλαγές στη θερμοκρασία αυξάνουν την τρωτότητα. |
| | | | 1.1.3 | Συχνότητα εμφάνισης ακραίων φαινομένων / Frequency of extreme weather events | Fr.Ex.Ev. | % | exposure | Καιρικά φαινόμενα βάση εποχής, χωρίς αύξηση στην έντασή τους. | Χωρίς μεταβολή | | | | | | Σενάριο μέγιστης αύξησης καιρικών φαινομένων. | More frequent extreme weather events imply higher degree of vulnerability. Η αύξηση των έντονων καιρικών φαινομένων εντείνουν την τρωτότητα του λιμένα. |
| | | | | | | | | | <30 | 30-49 | 50-69 | 70-89 | >90 | | | |
| | | | 1.1.4 | Πρόβλεπόμενη αλλαγή ποσοστού ημερών πάνω από τη μέση μεγαλύτερη τιμή θερμοκρασίας / Projected change in days above baseline extremely hot temperature | Pr.Ch.Hot | % | exposure | Καμία αλλαγή στην αύξηση των θερμών ημερών. | | | | | | | Σενάριο μέγιστης αλλαγής και αύξησης θερμών ημερών. | The percent change from observed baseline of the average number of days per year above baseline "Extremely Hot" temperature projected for the end-of-century, downscaled to 12 km resolution for the port location. Όσο μεγαλύτερη η αλλαγή και η αύξηση των θερμών ημερών τόσο αυξάνεται η τρωτότητα του λιμένα. |
| | 1,2 | Μορφολογία / Γεωλογία (Morphology / Geology) | 1.2.1 | Ιζήματα πυθμένα / Buttom's sediment | But.Sed. | - | sensitivity | Εδάφη υψηλής αντοχής & πυκνότητας παρουσιάζουν χαμηλή τρωτότητα έναντι αλλαγών σε καιρικά φαινόμενα και έντονη κυματική φόρτιση. | Βράχος | Σκληρή άργιλος-Συνεκτική άργιλος | Αμμώδης άργιλος-Χονδρόκοκκη άμμος | Μεσόκοκκη άμμος-Λεπτόκοκκη άμμος | Λάσπη-Ιλύς | | Εδάφη χαμηλής αντοχής, έντονης διαπερατότητας θα παρουσιάσουν υψηλότερη τρωτότητα έναντι κλιματικών αλλαγών. Μετακινήσεις-καθιζήσεις-προσχώσεις που θα δημιουργήσουν τεχνικες δυσλειτουργίες στο λιμένα. | Το είδος των εδαφών του πυθμένα. |
| | | | | | | | | | Πολύ πυκνό | Πυκνό | Μέσης Πυκνότητας | Χαλαρό | Πολύ Χαλαρό | | | |
| | | | 1.2.2 | Βαθυμετρία περιοχής / Bathymetry - Slope | β | - | sensitivity | | | | | | | | | |
| | 1,3 | Υδροδυναμική (Hydrodynamic) | 1.3.1 | Σημαντικό ύψος κύματος / Important Wave Height | Hs | m | exposure | Μέσο ύψος κύματος περιοχής σε κατάσταση νηνεμίας. | <0.3 | 0.3-0.6 | 0.7-1.0 | 1.1-1.4 | >1.5 | | Ανώτατο επιτρεπόμενο όριο για την καλή λειτουργία των δραστηριοτήτων του λιμένα. | The appearance of higher waves increases the vulnerability. Όσο μεγαλύτερο είναι το ύψος των κυματισμών που προσβάλλουν το λιμένα τόσο αυξάνεται η τρωτότητα του. |
| | | | 1.3.2 | Τάση μέσης στάθμης της θάλασσας / Sea level trend | MSL | mm/year | exposure | Χωρίς μεταβολή στη μέση στάθμη της θάλασσας. | | | | | | | Σενάριο μέγιστης αύξησης της στάθμης της θάλασσας | Local Mean Sea Level Trend. Όσο αυξάνεται η στάθμη της θάλασσας, λόγω κλιματικής αλλαγής, τόσο αυξάνεται η τρωτότητα ενός λιμένος. |

*(Koulouri, 2022)*