National Center for Scientific Research Demokritos

# A pan - European framework for strengthening Critical Infrastructure resilience to climate change EU-CIRCLE

ATHANASIOS SFETSOS
on behalf of the EU-CIRCLE consortium

# EU-CIRCLE Data

- Call: H2020-drs-2014: “Disaster-resilience: Safeguarding And Securing Society, Including Adapting To Climate Change”

- **Topic: Disaster Resilience & Climate Change topic 1**:

Science and innovation for adaptation to climate change: from assessing costs, risks and opportunities to demonstration of options and practices

- Grant Agreement: 653824

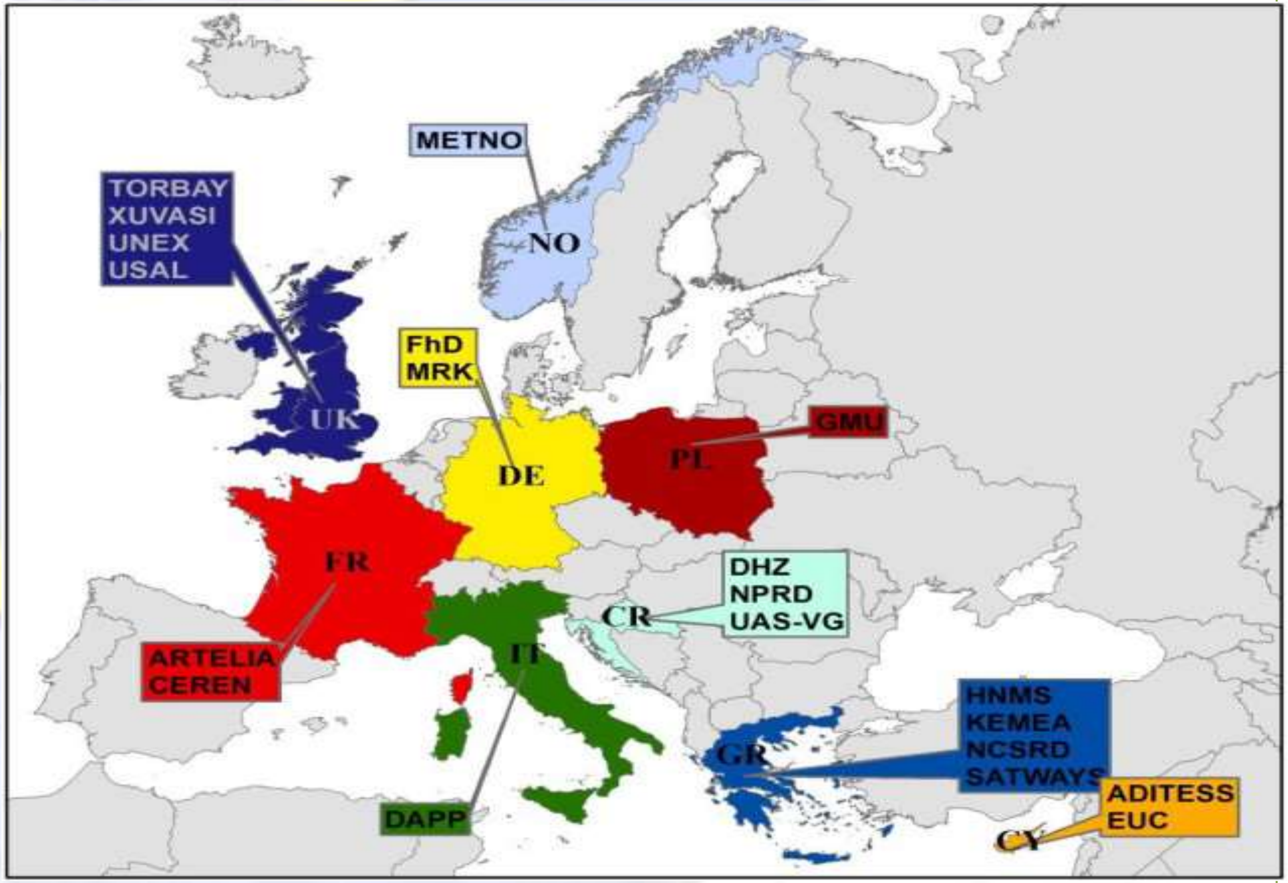
- Total Budget: 7,283,525.00 €

# EU-CIRCLE Consortium

20 partners

9 EU countries

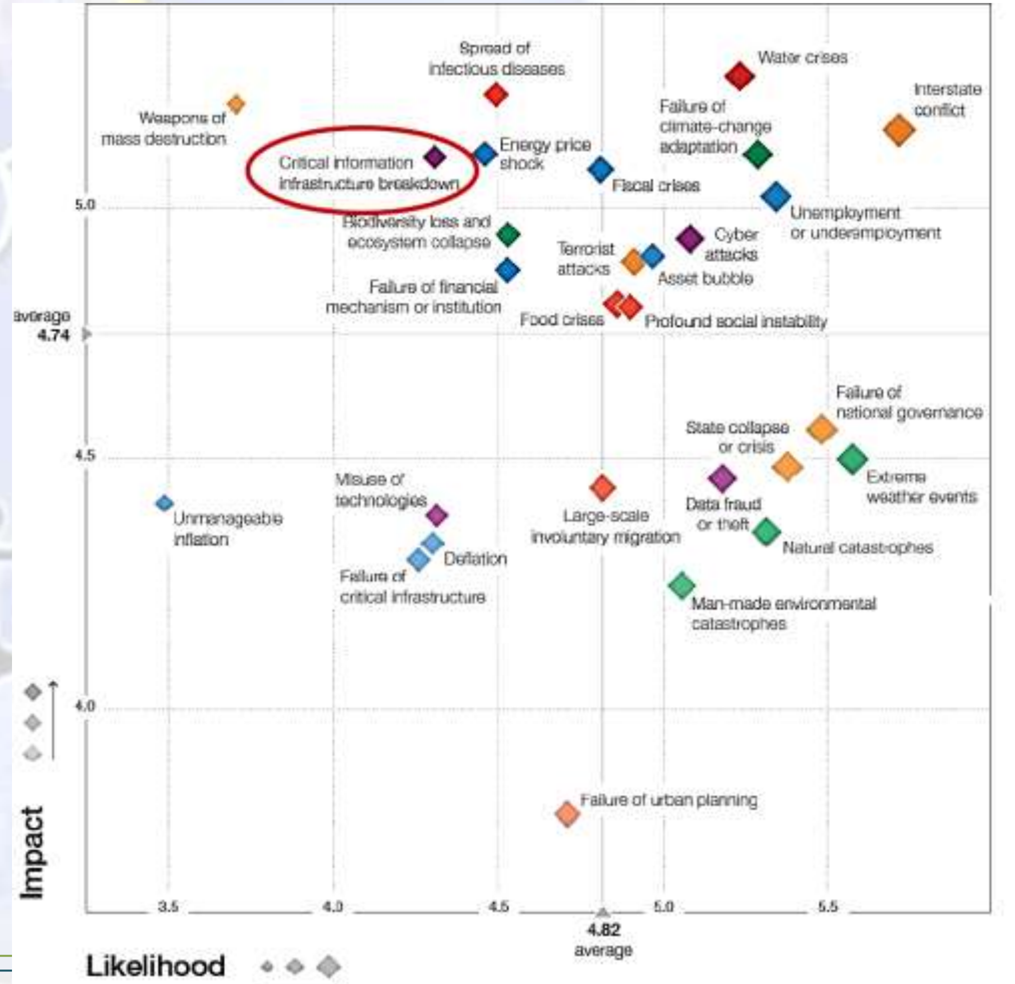
13 International members of Stakeholder's Advisory Group



# World Economic Forum – Global risks 2015

Top 10 risks in terms of
**Impact**

1. Water crises
2. Spread of infectious diseases
3. Weapons of mass destruction
4. Interstate conflict
5. Failure of climate-change adaptation
6. Energy price shock
7. Critical information infrastructure breakdown
8. Fiscal crises
9. Unemployment or underemployment
10. Biodiversity loss and ecosystem collapse



# Related Policies

- **The EU Strategy on Climate adaptation, as identified in *COM (2013) 216 - An EU Strategy on adaptation to climate change*,**

- **National Risk Assessment Plans – DG-ECHO**

- **European Programme for Critical Infrastructure Protection – DG HOME**

# CI loss in the 2014 - NRA

**Natural Hazards**

- Floods
- Severe weather
- Wild/Forest fires
- Earthquakes
- Pandemics/epidemics
- Livestock epidemics

**Man-made Hazards (Non Malicious)**

- Industrial accidents
- Nuclear/radiological accidents
- Transport accidents
- **Loss of critical infrastructure**

**Man-made Hazards (Malicious)**

- Cyber attacks
- Terrorist attacks

| Country | Risk Level | Term used |
|---|---|---|
| CZ | High | Critical infrastructure disruption |
| DE | - | Outage of critical infrastructure |
| IE | High | Loss Critical Infrastructure |
| PL | Medium | Disruption of electricity supplies, of fuel supplies, of natural gas supplies |
| SE | Very High | Disruption in food supply die to fuel shortages |
| UK | High | Attacks on Infrastructure |
| NL | Very High | IP Network failure/ Malicious prolonged electricity failure |
| | High | National power failure/ malicious power supply failure |
| | Medium | Malicious gas supply failure |

COMMISSION STAFF WORKING DOCUMENT, Overview of natural and man-made disaster risks in the EU, SWD(2014) 134 final, Brussels, 8.4.2014

# CI loss in the 2014 – NRA (2)

| Hazard | Cascade or correlated hazard | Country |
|---|---|---|
| Severe weather phenomena | Flood | DK, NO, RO, HU |
| | Landslides | IT |
| | Forest Fires | HU, IE, LT |
| | Pollution, **CI loss**, Transport accidents | DK, LT, SE, NO |
| Earthquakes | Landslides | HU, IT |
| | Tsunamis | EL |
| Landslides, Earthquakes or Volcanos | Transport Accidents | NO, IT, EL, UK |
| Nuclear chemical and transport accidents, **CI loss** | Contamination, Pollution | DK, LT, UK, NO |
| | Terrorist & Cyber attacks | NO, UK |
| **CI loss** | Flood, Pollution, **CI loss** or | UK, IE |
| | Pandemics | DK |

## Impact of CI loss

- In essence, the loss of CI directly translates to loss of vital services and affects the citizens.
- Only a few MS (EE, EL, LT, IE) attempt to capture the effect of CI loss, in two main ways:
  - to measure political or social impacts (e.g. loss of "vital services"):
    - for different levels of operation (partial or total disruption),
    - for varying time frames,
    - for varying geographical ranges,
  - to measure economic losses (e.g. IE uses the criterion "infrastructure").

# How far into the future would you consider climate change analysis

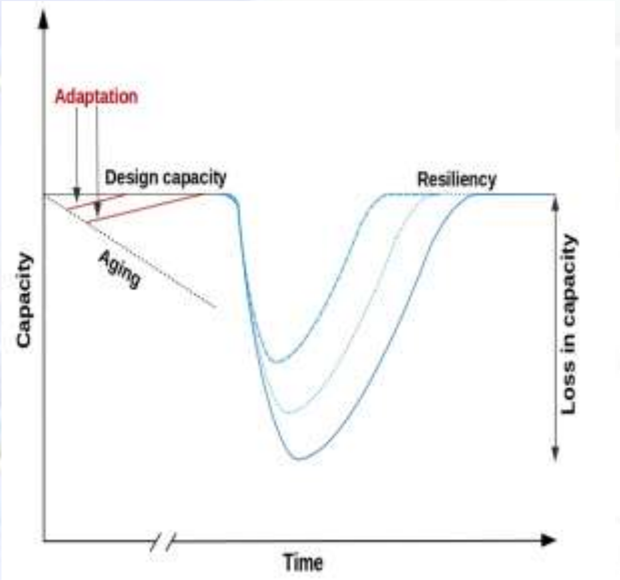
- CS1: heatwaves and dryness on electricity networks
- CS2: maritime scenario
- CS3: coastal flooding
- CS4: urban flooding

| | |
|---|---|
| Case Study 1 | 20 years |
| Case Study 2 | 100 years |
| Case Study 3 | 20/50/100 years |
| Case Study 4 | It depends on the lifecycle of the specific CI |

# The Time Scales Involved

CI are large scale projects,
that will service the
community for very long time frames.

- Climate change is expected to impact the security / safety critical levels of the infrastructure
- Expose new vulnerabilities due to ageing, changes in the climate patterns, land use…
- Impact the type and characteristics of the interconnections between infrastructures



# Context

# CI sectors of EU-CIRCLE

- Energy
  - Electricity
  - Oil
  - Gas
  - renewables
- Transport
  - Road
  - Rail
  - Ports
  - Airports
- Chemical industry
- Water
  - Water
  - Sewage
- ICT
- Health Sector
- Governmental services

# Climate hazards

- Drivers (direct output from GCM/RCM/…)

- Temperature
- Precipitation
- Snowfall
- Winds
- Clouds / Fog
- Solar radiation
- Humidity
- Sea level rise
- Ice, frost
- waves

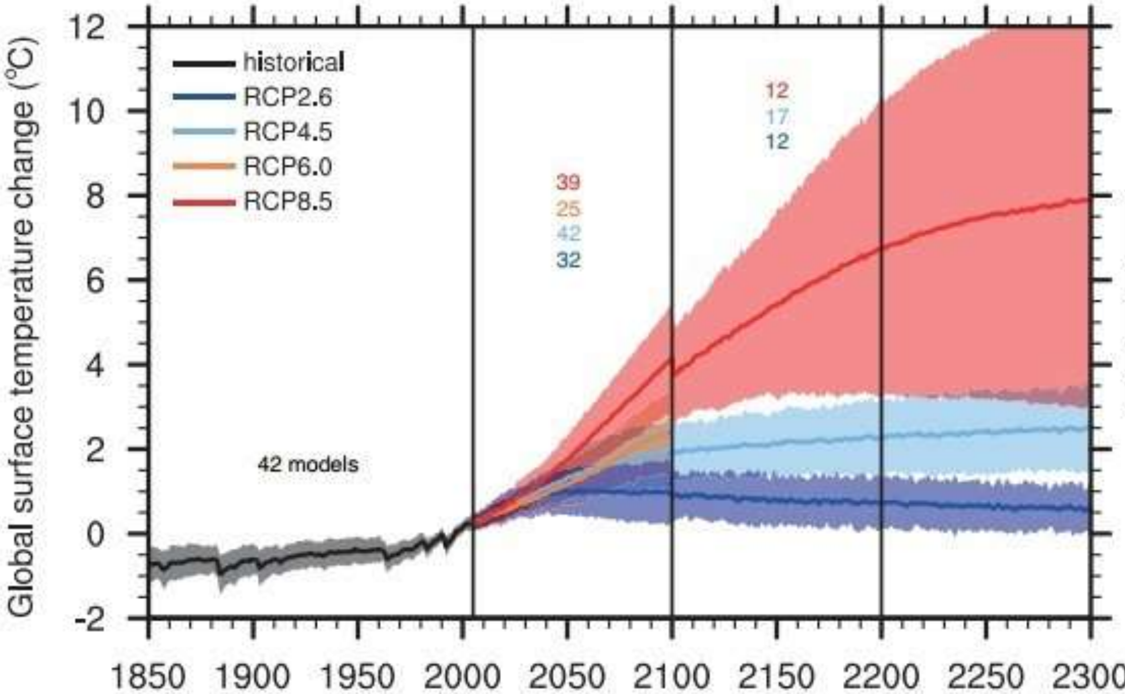
- Hazards (needs processing of drivers)

- Floods
- Forest fires
- Erosion / Landslides / avalanches
- Droughts
- Heat waves, cold snaps

# Operational objectives

- How will a {transportation network, regional CI network, … } will respond to extreme events,
- What is the risk of an extreme climate event to the rail sector or network / region
  - How resilient is the rail networks to a specific climate hazard,
  - Can we prevent future similar events?
- Which is the optimal adaptation measure for CI, and is this also beneficial for other CH
- How to reduce the domino effects to transportation from electricity network
- Cost benefit analysis (comparison) of different adaptation alternatives
- What is the economic / societal impacts of resilience

# Climate Change

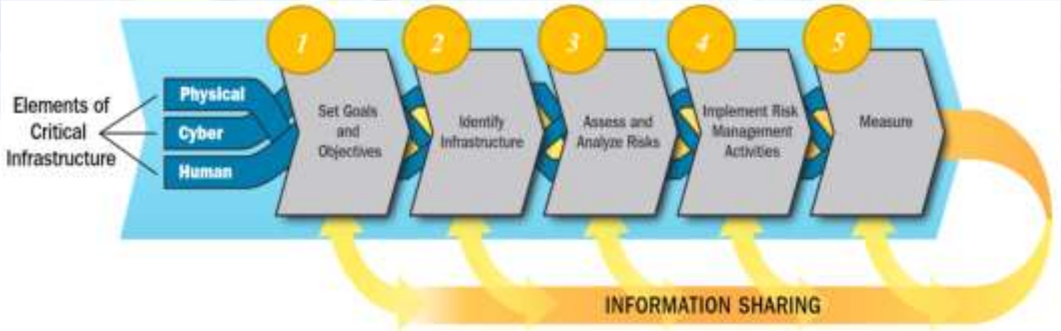



| Scenario | Warming in 2081–2100 (°C) |
|---|---|
| RCP2.6 | 1.6 ± 0.4 |
| RCP4.5 | 2.4 ± 0.5 |
| RCP6.0 | 2.8 ± 0.5 |
| RCP8.5 | 4.3 ± 0.7 |

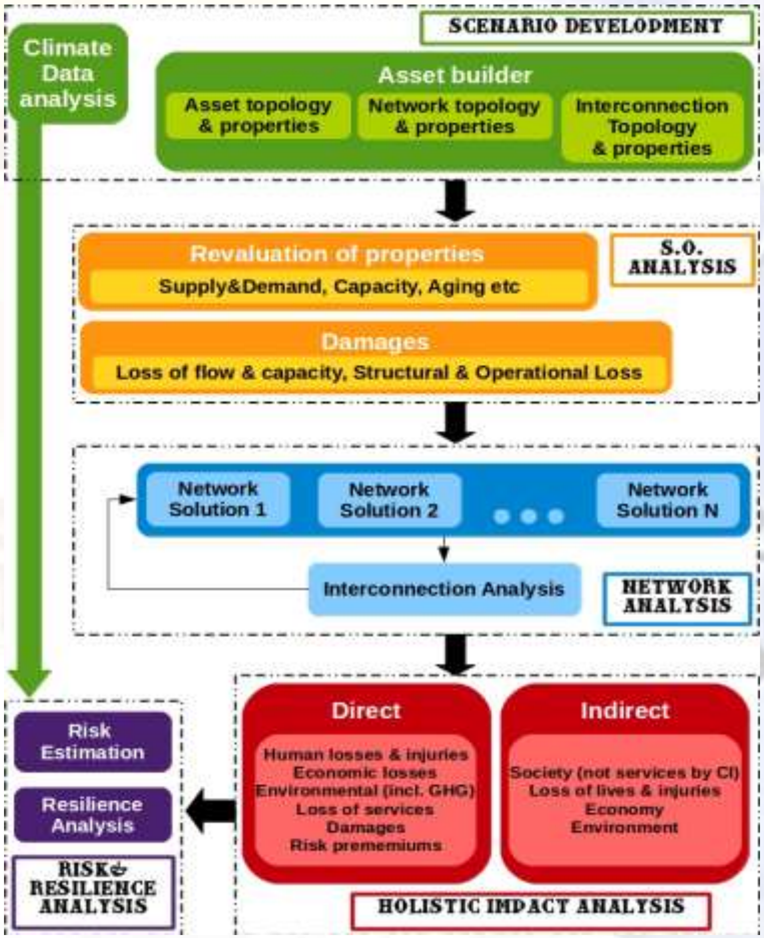
- IPCC: impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways.

# Risk management - procedure

- Typical 5-step procedure comprises the following stages (sometimes also 6-steps):
  1. Establishment of operational objectives/imperatives
  2. Identify assets, systems, networks, and functions
  3. Assess and evaluate risks
  4. Select and implement protective programs
  5. Measure effectiveness (monitoring of implemented measures)
- Feedback loops/ iterations always possible

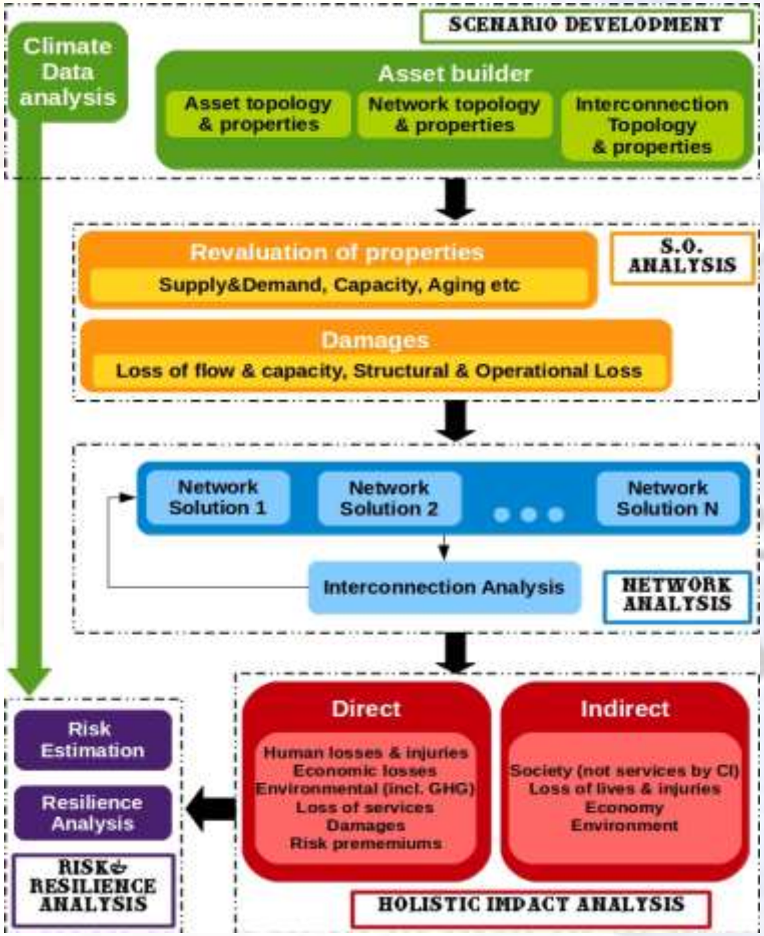


# Risk estimation approach




- Step1: Scenario Development
  - initial phase
  - the scientific question, that will be replied
  - the climate data ingest
  - the topology, properties and interconnections of assets
- Step2: Structural & Operational analysis
  - as input the constructed network, climate data
  - returns as output a quantifiable information on how different assets react
  - changes of network properties
  - changes due to damage

# Risk estimation approach




- Step3: The Network analysis
  - calculates for each network the simulated flow
  - estimates how each network affect the interconnected ones
- Step4: Holistic impact analysis
  - direct and indirect consequences
- Step5: Risk&Resilience
  - estimated likelihood of the event (step1)
  - the results from the impact analysis (step4)
  - risk&resilience of the network

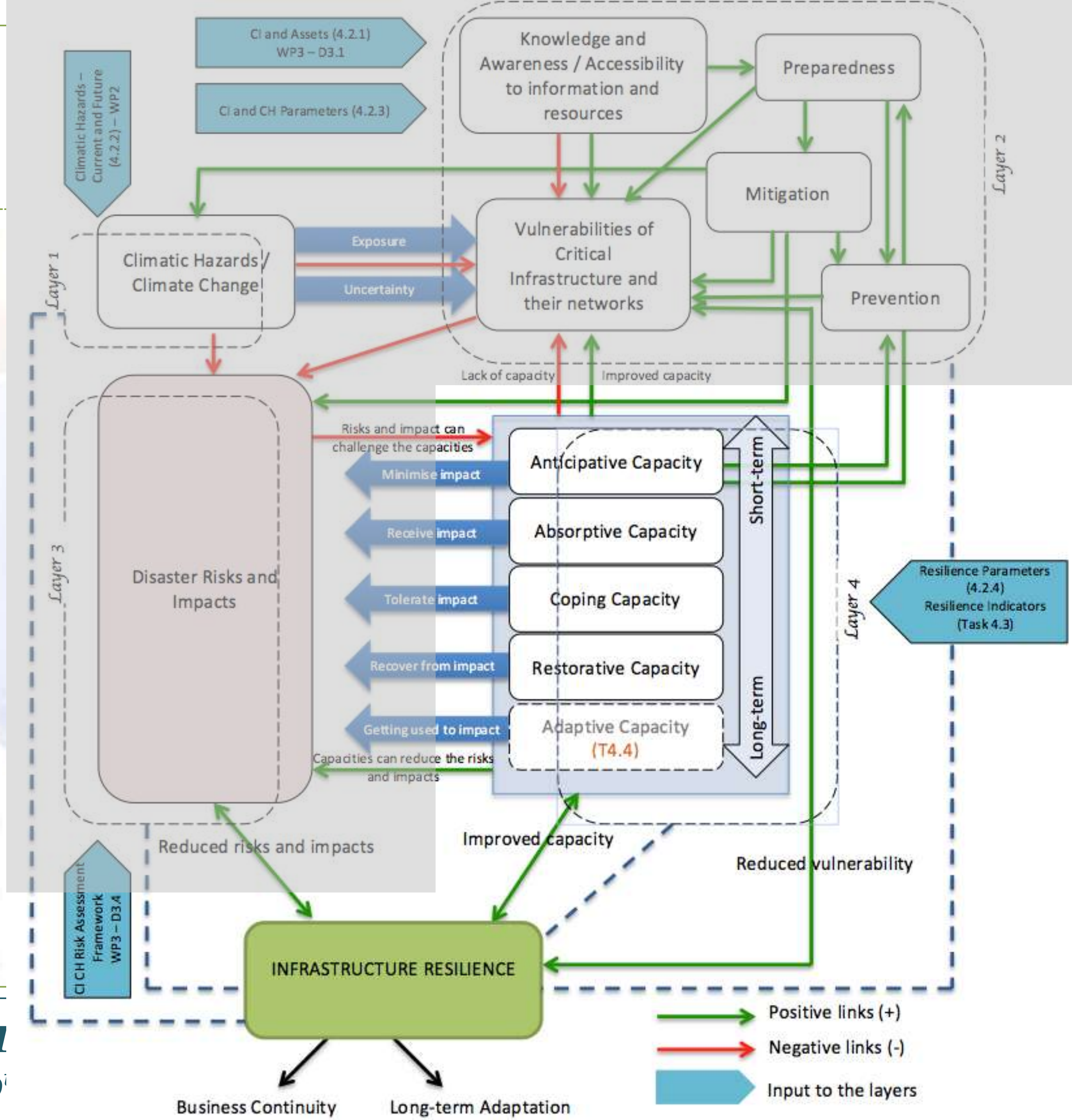
# 3 keyphrases of resilience

## Consolidation Workshop
*Main Outcomes from Roundtables*

### KEYWORDS FOR RESILIENCE

| | |
|---|---|
| Case Study 1 | Safe life, safe valuables, return to service |
| Case Study 2 | Strength, elasticity, insight (awareness) |
| Case Study 3 | Interruption of all sources of flooding, risk acceptance, capacity building |
| Case Study 4 | Adaptation, how to absorb the impact, recover |

May 18th , 2016
Milan, Italy
1 st CONSOLIDATION WORKSHOP


CI and Assets (4.2.1)
WP3 – D3.1
CI and CH Parameters (4.2.3)
Climatic Hazards – Current and Future (4.2.2) – WP2
Knowledge and Awareness / Accessibility to information and resources
Preparedness
Mitigation
Prevention
Layer 2
Vulnerabilities of Critical Infrastructure and their networks
Climatic Hazards / Climate Change
Layer 1
Exposure
Uncertainty
Lack of capacity
Improved capacity
Disaster Risks and Impacts
Layer 3
Risks and impact can challenge the capacities
Minimise impact
Receive impact
Tolerate impact
Recover from impact
Getting used to impact
Capacities can reduce the risks and impacts
Anticipative Capacity
Absorptive Capacity
Coping Capacity
Restorative Capacity
Adaptive Capacity
(T4.4)
Short-term
Long-term
Layer 4
Resilience Parameters (4.2.4)
Resilience Indicators (Task 4.3)
Reduced risks and impacts
Improved capacity
Reduced vulnerability
CI CH Risk Assessment Framework WP3 – D3.4
INFRASTRUCTURE RESILIENCE
Business Continuity
Long-term Adaptation
Positive links (+)
Negative links (-)
Input to the layers

’Pl

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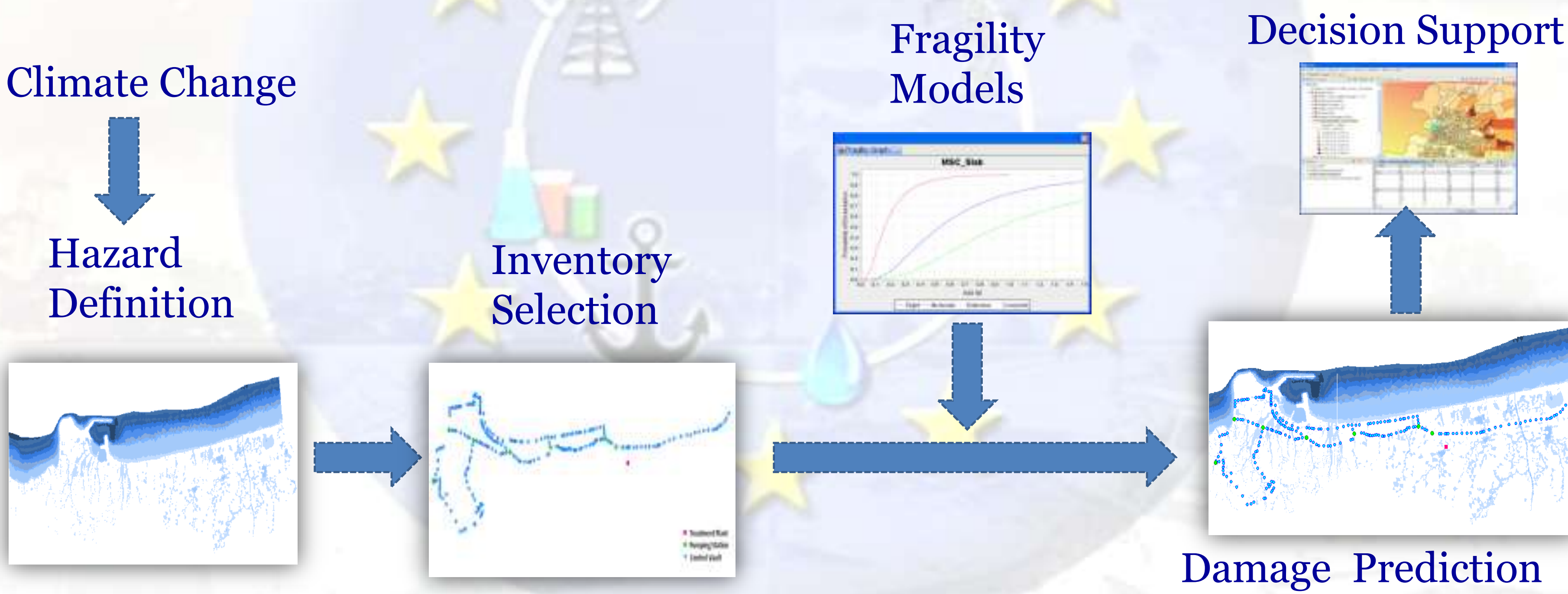
# CIRP – in a nutshell

- **Inputs** - Hazards, Inventory, Fragility Models
- **Output** - Damage Prediction, Reporting, Decision Support



# EU-CIRCLE Validation

**Case Study 1**: Extreme Dryness and forest fires on electricity and transport networks
**Lead Partner**: ENTENTE POUR LA FORÊT MÉDITERRANÉENNE

**Case Study 2:** Storm and Sea Surge at a Baltic Sea Port , Gdynia Poland
**Lead Partner:** AKADEMIA MORSKA W GDYNI

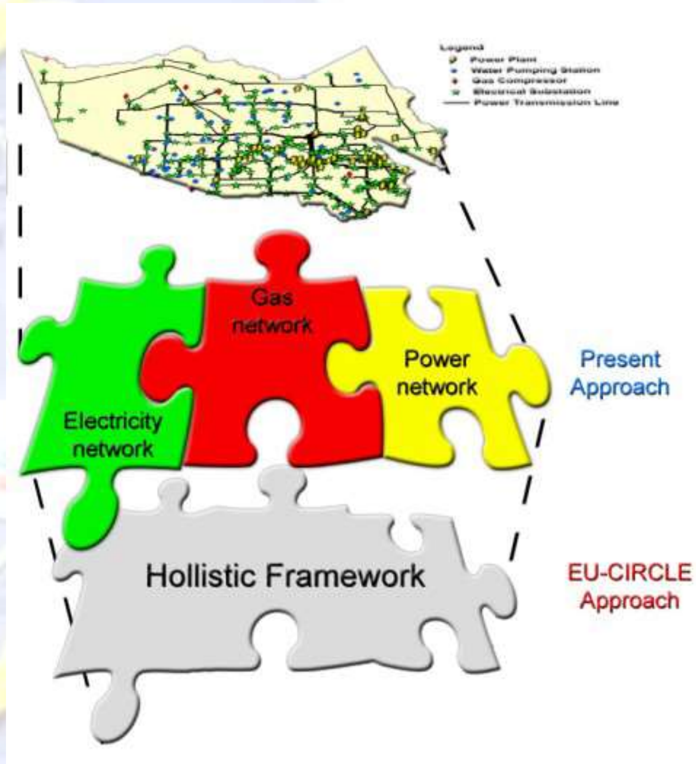
**Case Study 3**: Coastal Flooding (surface water, highway, sewer and watercourse flooding) across Torbay, UK
**Lead Partner:** UNEXE and Torbay Council

**Case Study 4**: International Event
**Lead Partner:** USAL and NCSRD

**Case Study 5:** Rapid Winter Flooding (melting ice, narrow mountain streams, flooding) around Dresden, Germany
**Lead Partner:** Fraunhofer IVI

# EU-CIRCLE Impact

✓Support the establishment of climate resilient infrastructure by ensuring that an asset is located, designed, built and operated with both the current and future climate in mind and incorporates resilience to the impacts of climate change over the lifetime of that asset.



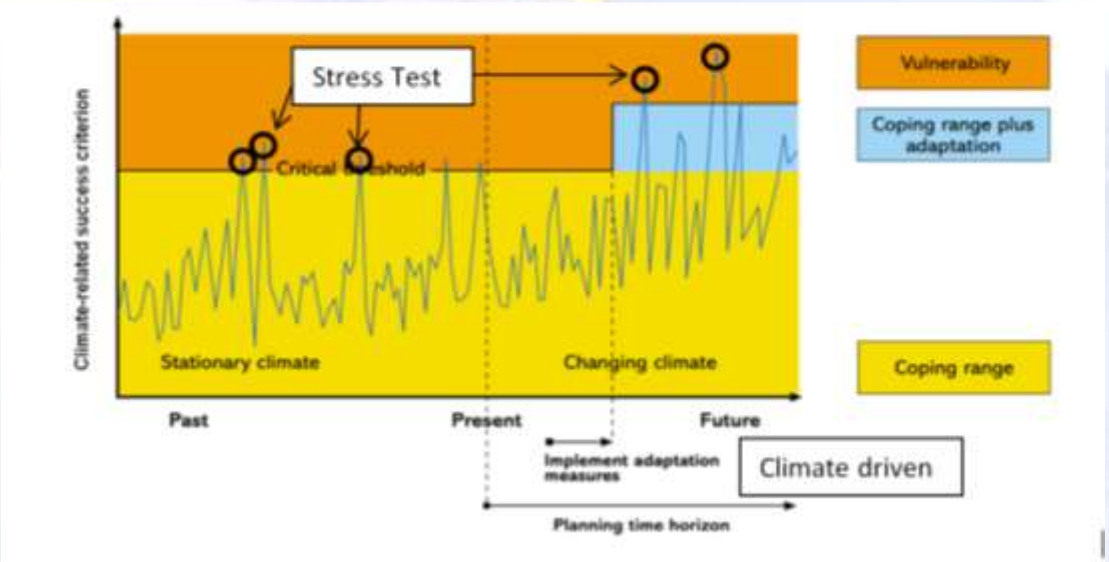

✓ Provide a coherent baseline for moving from sector-based climate resilience infrastructure frameworks, into holistic resilience plans for entire regions, introducing the interdependencies of heterogeneous infrastructures in the implementation process.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653824

Thank You For Your Attention

http://www.eu-circle.eu

# The link: climate related critical thresholds




- Two pathways
  - "Stress – test" as the driver. Use CIRP to determine the impacts to the CI Networks (based on critical thresholds) , and link them to climate data – return periods
  - "using climate" as the driver. From climate data obtain the thresholds for a specific analysis / assessment and then feed them to CIRP and obtain output.

# Resilience : Capacities

the ability of the CI system to anticipate and reduce the impact


- Anticipative
- Absorptive
- Coping
- Adaptive

# Resilience : Capacities

the ability of CI system to buffer, bear and endure the impacts

- Anticipative
- Absorptive
- Coping
- Adaptive

# Resilience : Capacities

ability of CI system to face and manage adverse conditions using available skills and resources,

Anticipative

Absorptive

Coping

Adaptive

# Resilience : Capacities

ability of CI system to face and manage adverse conditions using available skills and resources,

- Anticipative
- Absorptive
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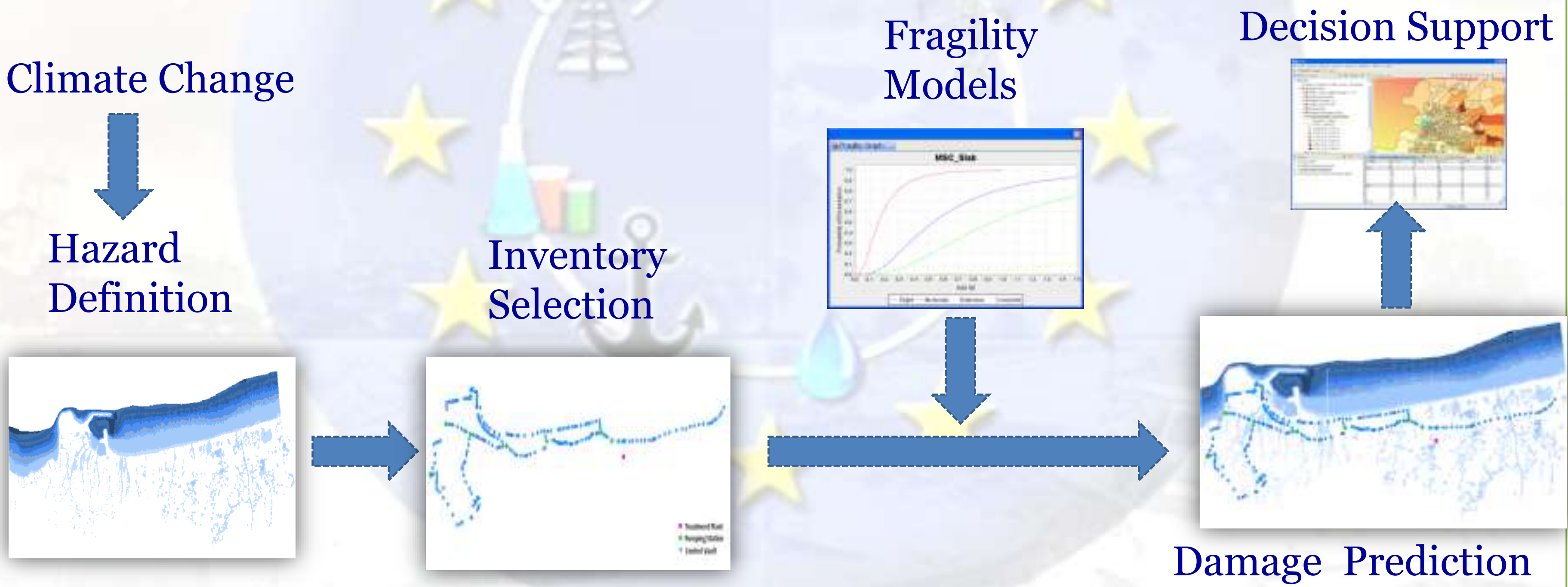
# The CIRP Objectives (1)

- EU-Circle will design and develop an innovative prototype solution for **detailed modeling of large scale interconnected CI** supported by modules **to assess cost – efficient adaptation of solutions in different types of scenarios**.

- EU-CIRCLE will provide the **generic plug-and-play environment** for **different and diverse types of simulation models** and climate information to be introduced and ***will apply partners' capabilities (models, climate data, risk – resilience assessment, adaptation scenarios) in the suggested test cases***.

# CIRP – Input & Outputs

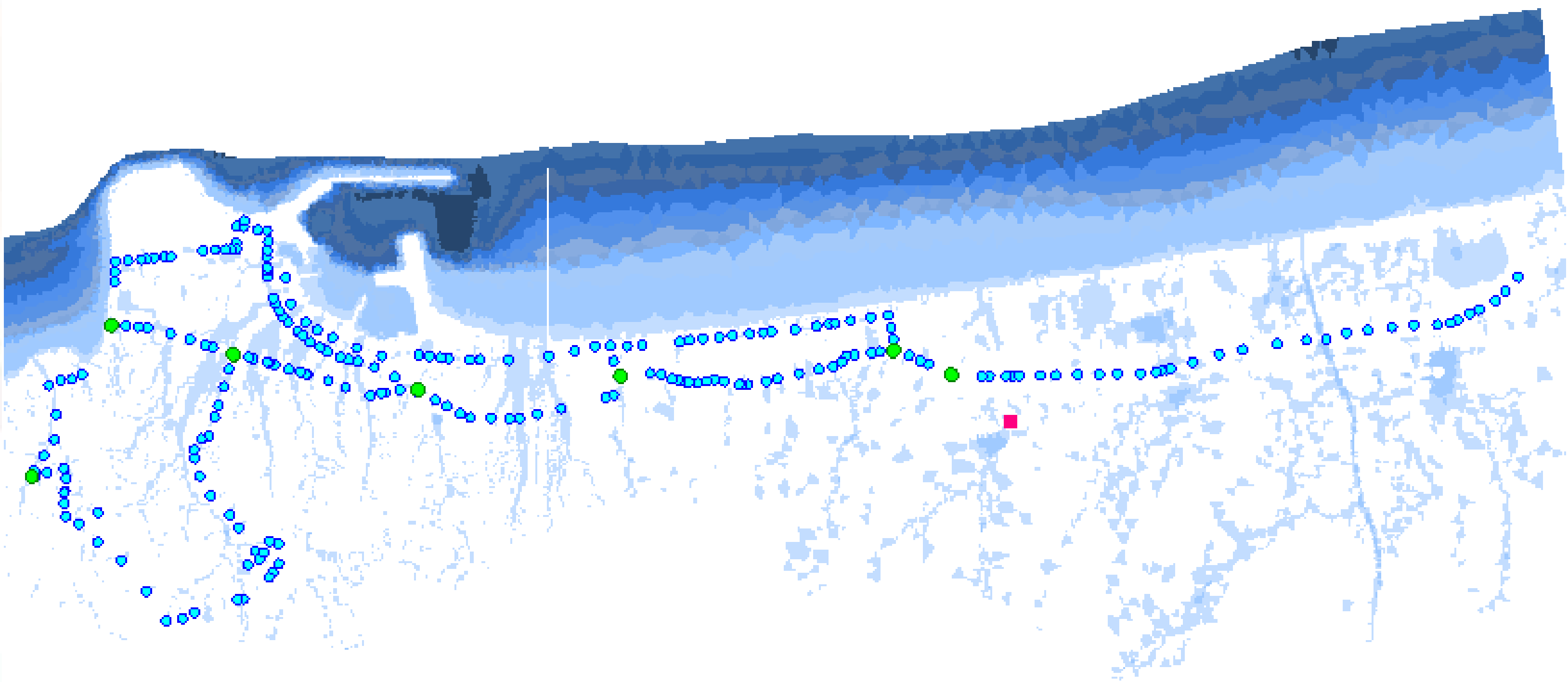
- **Inputs** - Hazards, Inventory, Fragility Models
- **Output** - Damage Prediction, Reporting, Decision Support



# CIRP –Example Analysis-Flood Structural Damage

**Create and Load Input Datasets**

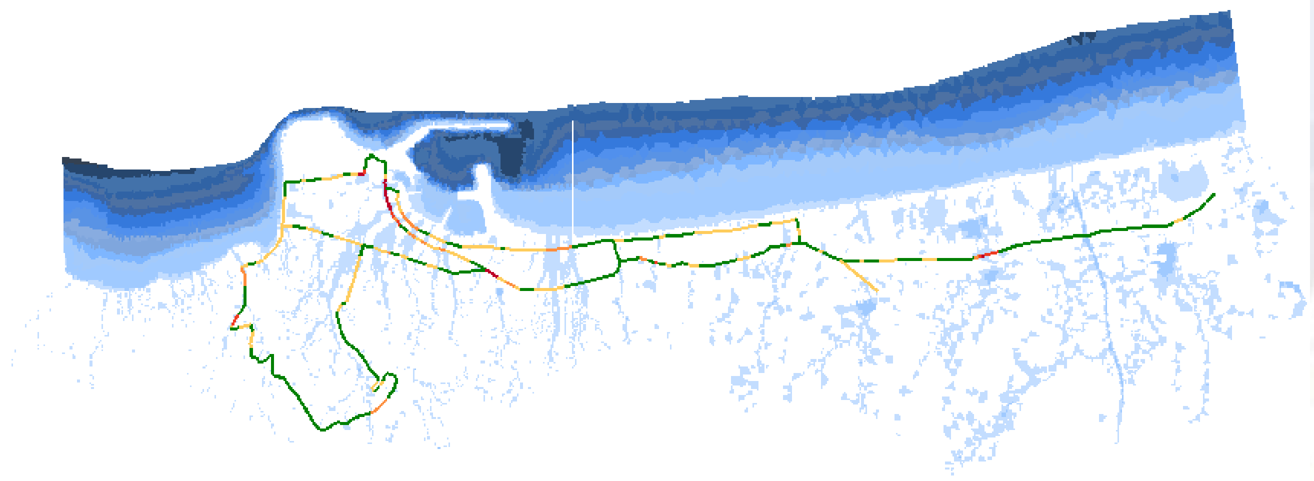
- **Input Visualization**



# CIRP –Example Analysis-Flood Network Damage

**Network Damage Analysis**

- **Results Visualization**



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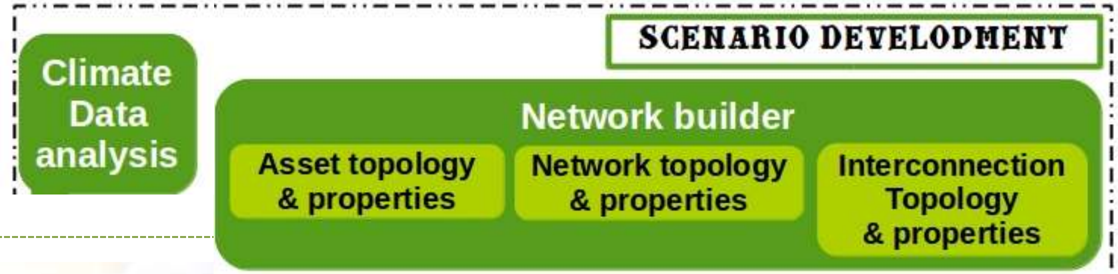
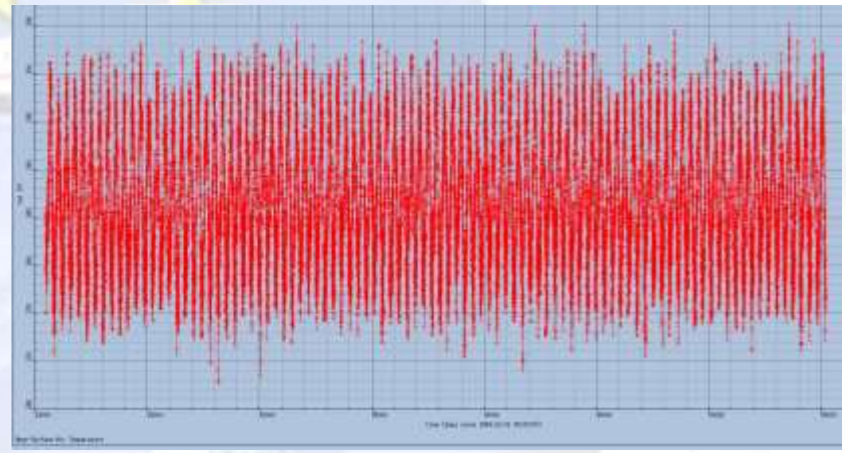
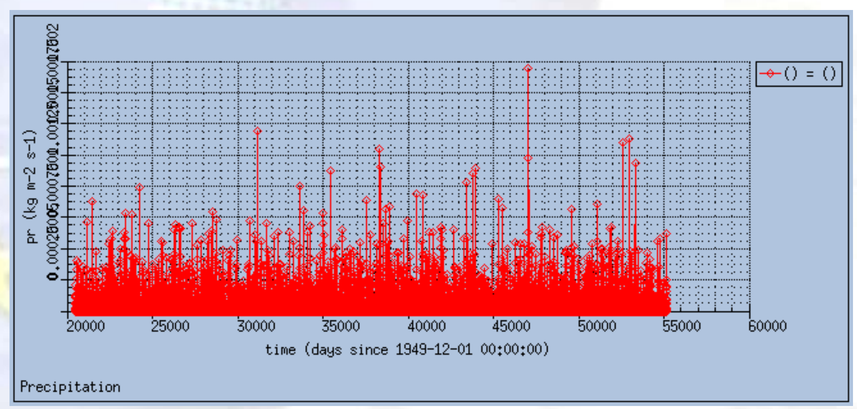



- Problem definitions
- Climate data processing
- Asset description
- Network topology

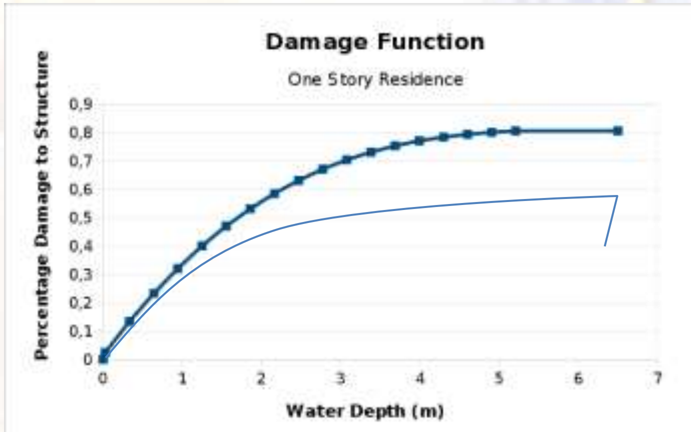


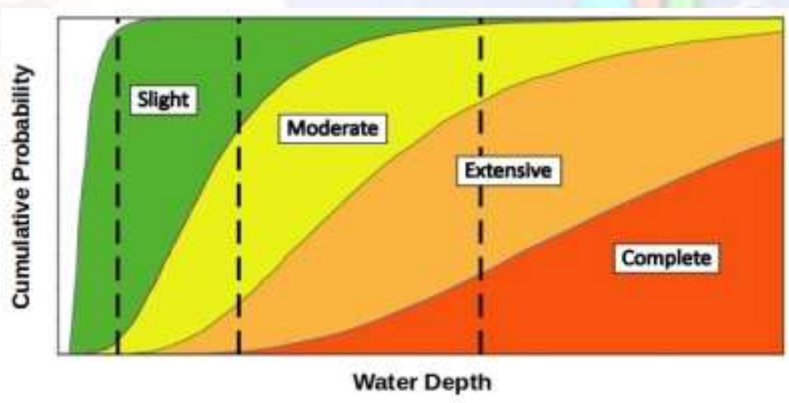


**Revaluation of properties**
Supply&Demand, Capacity, Aging etc

**S.O. ANALYSIS**

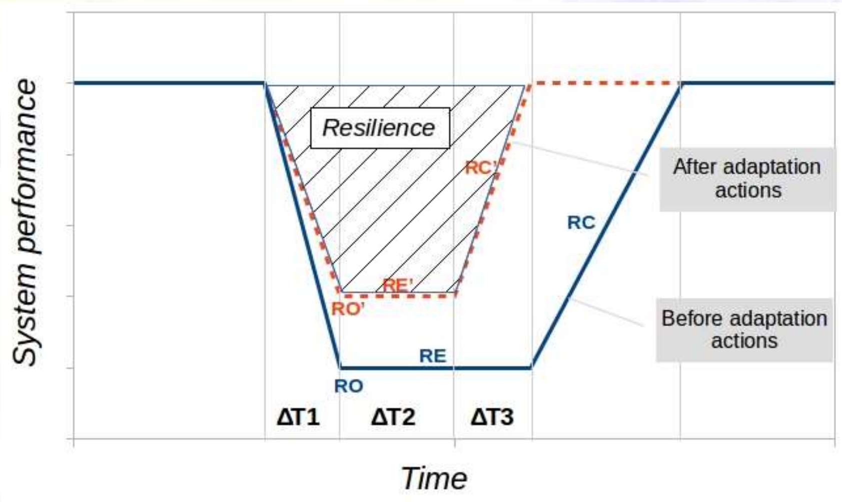
**Damages**
Loss of flow & capacity, Structural & Operational Loss



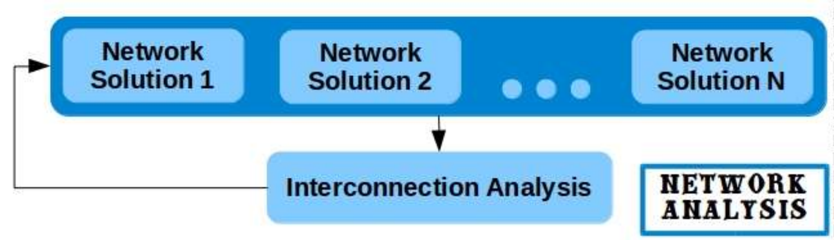

- Change of properties
  - Generation/Distribution values
  - Capacity of network
- Change due to damage
- Introduction of Resilience as a damage reduction function

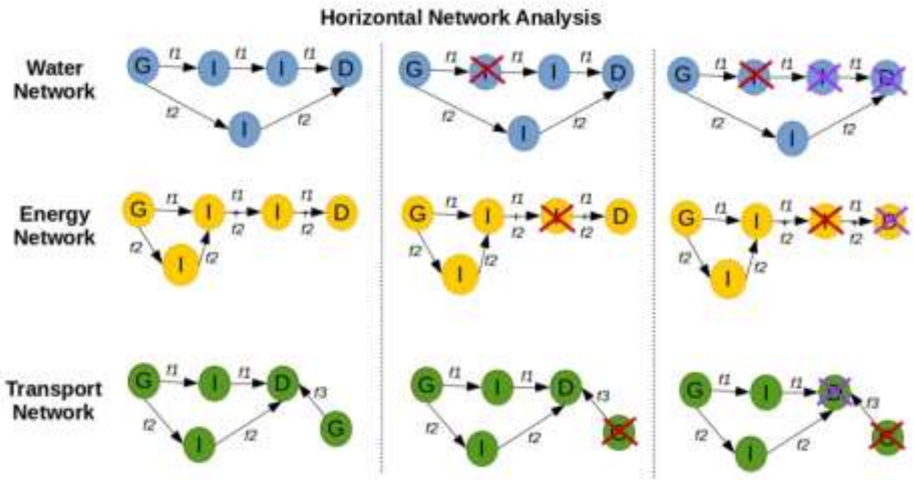
# Resilience




- Resilience is quantified as the area of the inverse trapezoid

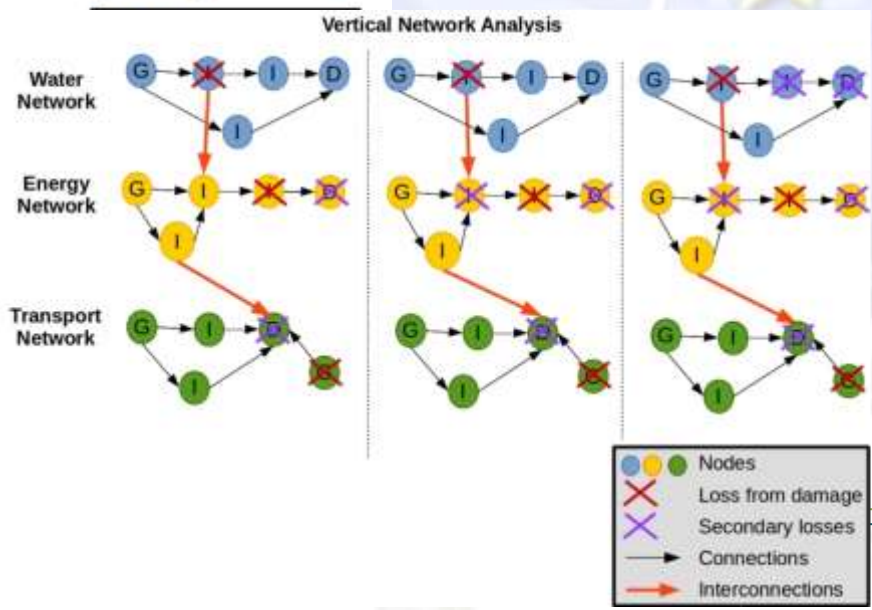
- Behavior of the CI
  - curve evolving through time
  - impact on system performance
- Improve the CI functionality and performance level




*Minimum cost/Maximum flow optimization*

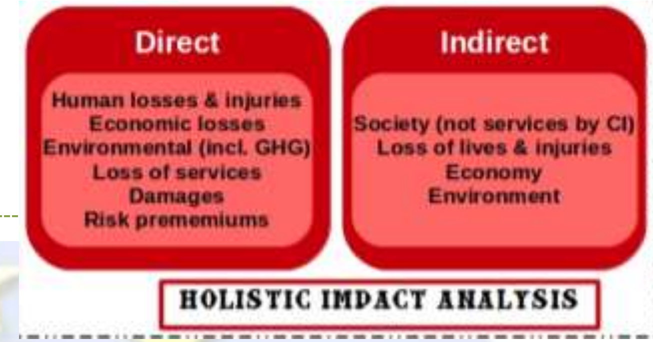
$$\min\left(\sum_{j=1}^{N}\sum_{i=1}^{N} flow_{ij}cost_{ij}\right)$$




*Interdependency Network Analysis*

$$C(i,j) = (previous\ state, \text{interconnections}, \text{type of interconnections})$$

- Generation nodes G
- Produced flow PR
- Distribution nodes D
- Consumed flow CS
- Intermediate nodes I


- Economy
- Society
- Loss of lives
- Reputation
- ...

**Service Flow reduction**

$$SFR = 1 - \sum_{i=1}^{N} \frac{PR_i}{CS_i}$$

**Connectivity Loss**

$$CL = 1 - \sum_{i=1}^{N} \frac{G^{ap}{}_i}{G^{af}{}_i}$$

All these are a combination of:

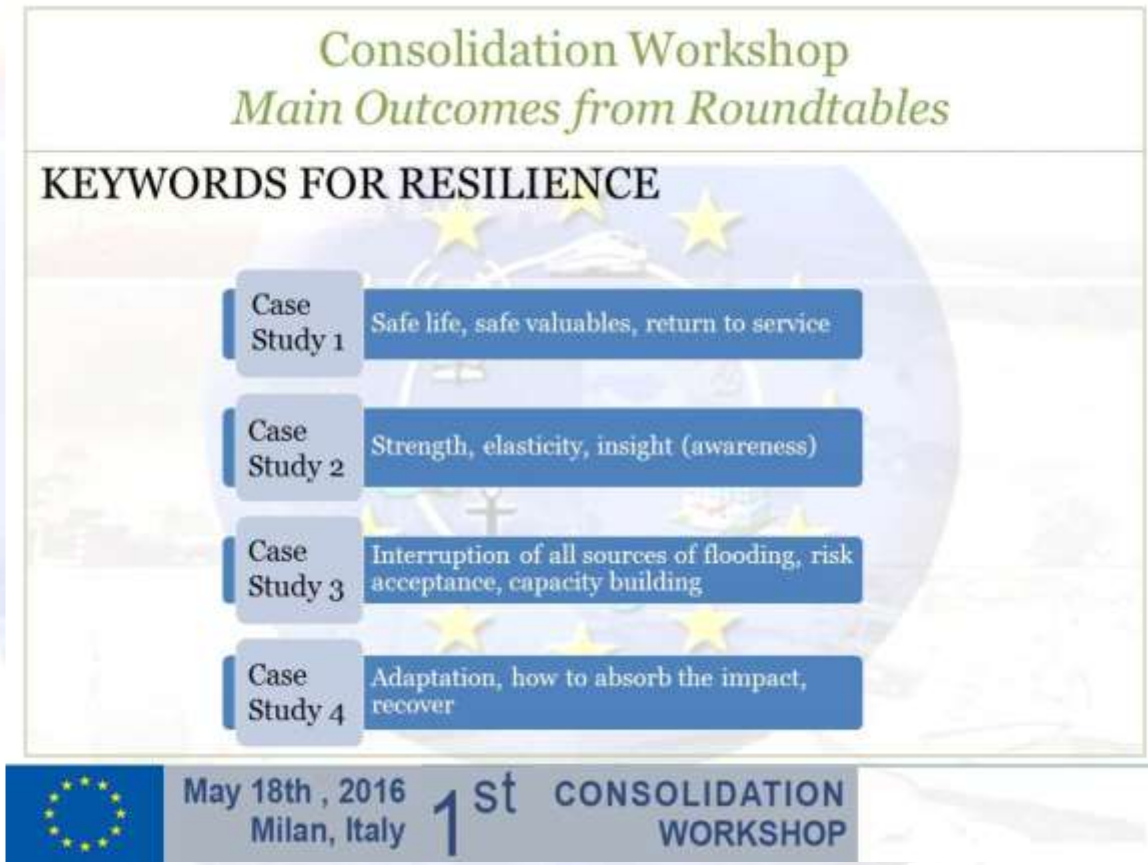
- damage function
- network solution flows f


- Direct to the Network
  - Loss of lives
  - Economics-Financial
  - Services
  - Safety – Reliability Levels
  - Reputation
- Societal
  - Loss of lives
  - Economy – sectoral IO
  - Provision of services
    - Also to specific society groups
  - Environmental

# 2nd open question

- 3 keywords / key-phrases for resilience

# Responses from the users

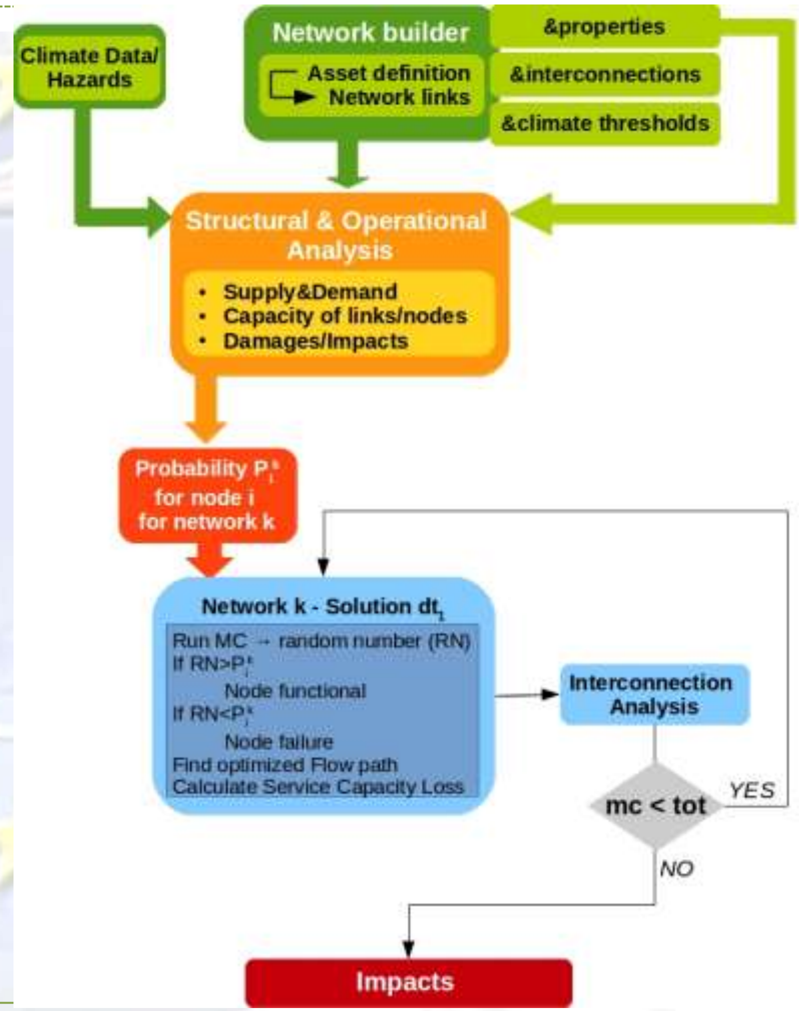


# Standard Probabilistic

- Network nodes are governed by a probability of failure (0-1) in terms of loss of service
- INA: Vertical link exists based on probability

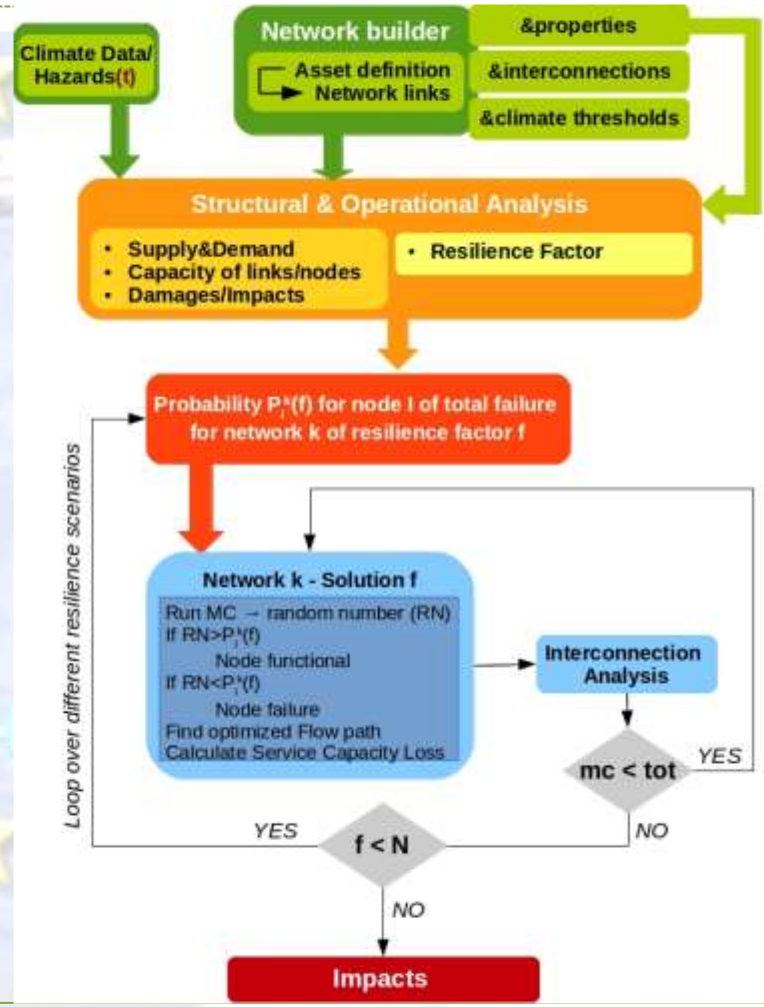
Proposal:

- Selection of damage state
- Loss of node capacity with hazard

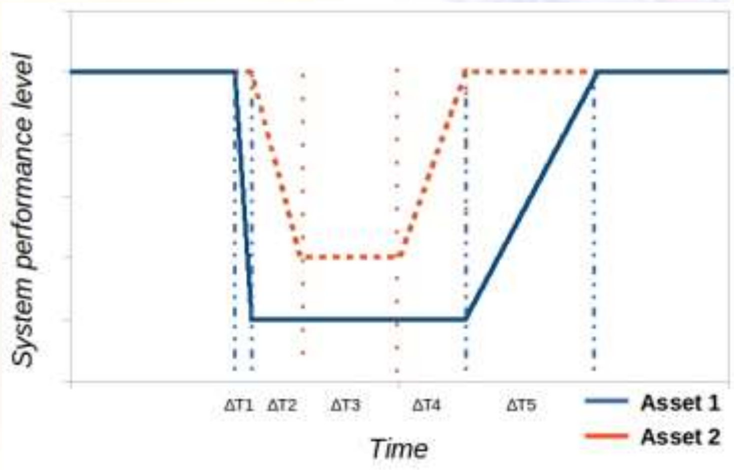


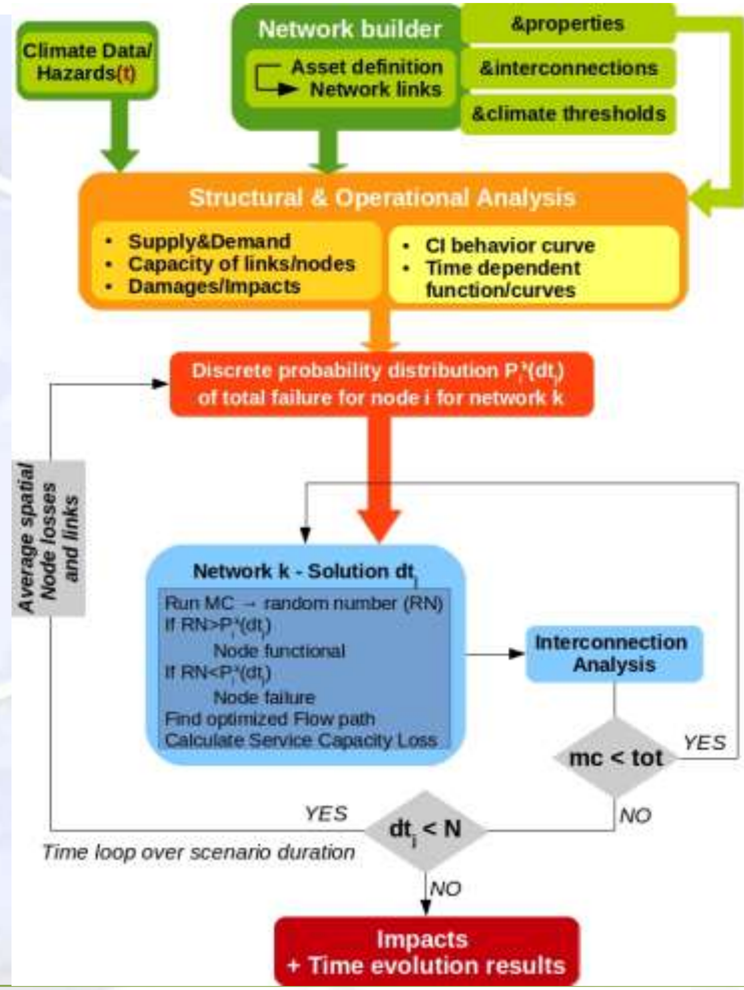
# Resilience Capacity Probabilistic

- As before but:
  - Probability (or damage) reduction based on resilience capacities
  - INA: Introduction of resilience in the interconnection function



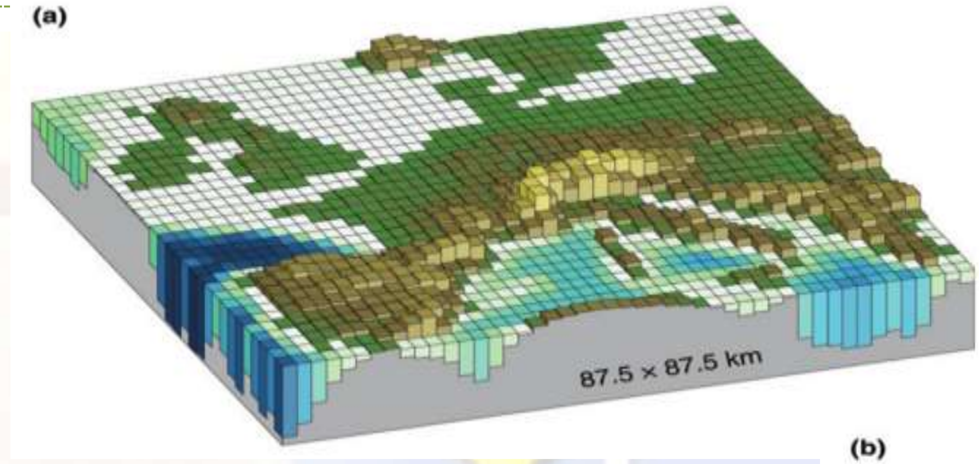
# Time interval probabilistic

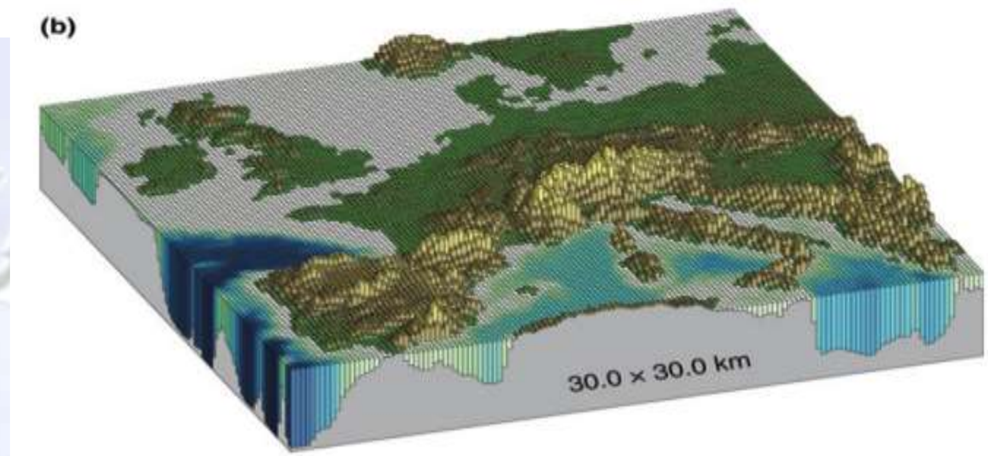



- Introduction of time
- Discrete time steps where each asset has a different behavior according to image above.
- Asset's capacity changes with time.
- Need to repeat NA each discrete time step.

# Spatial resolution of climate modes

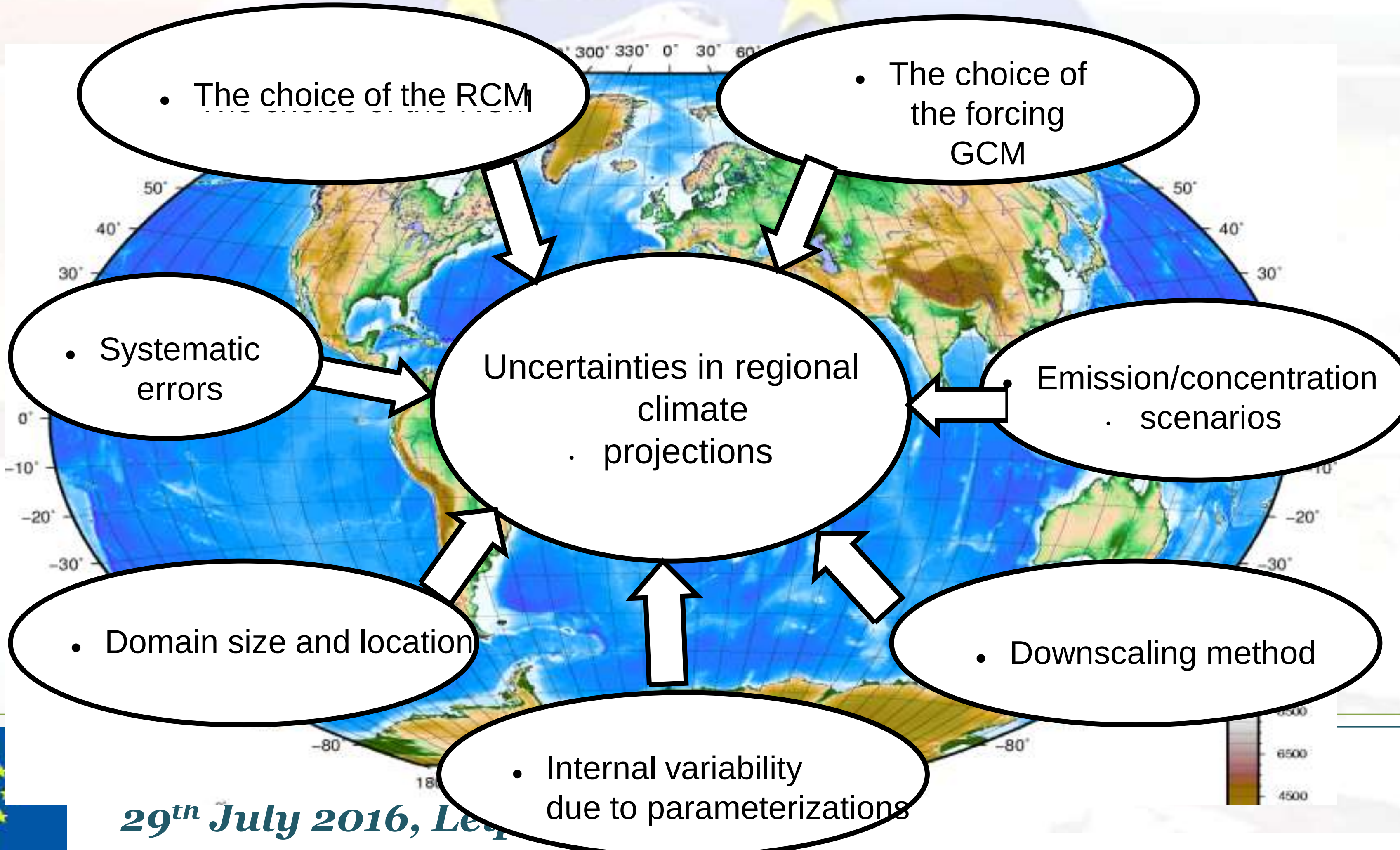



Rummukainen (2015; Figure 2)
(a) illustration of the European topography at the resolution 87.5 km
(b) same as (a) but for 30.0 km.

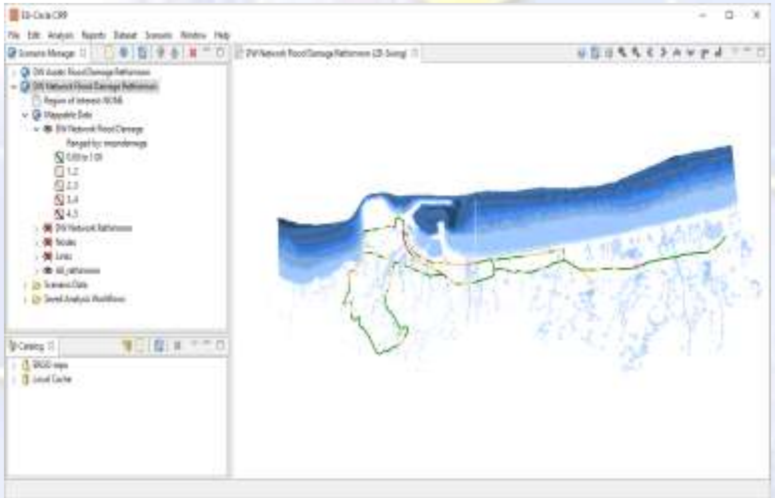
# Uncertainties in regional climate modelling

Range of possibilities, make the adaptation harder

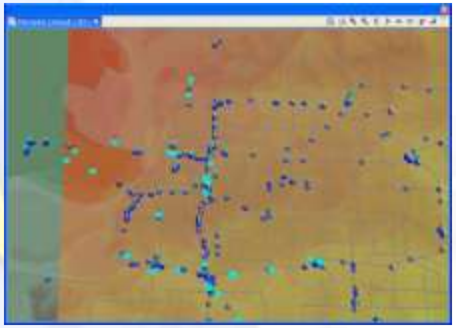


# The CIRP User Interface


Data Catalog



Main Window

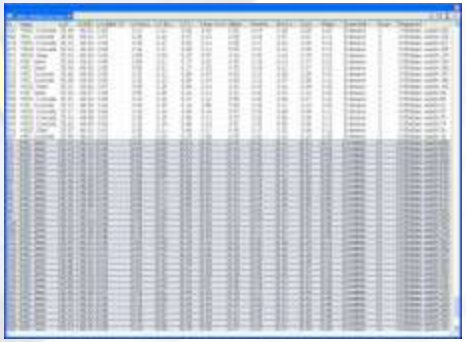


2D & 3D Views

Scenario Browser

Style Editor

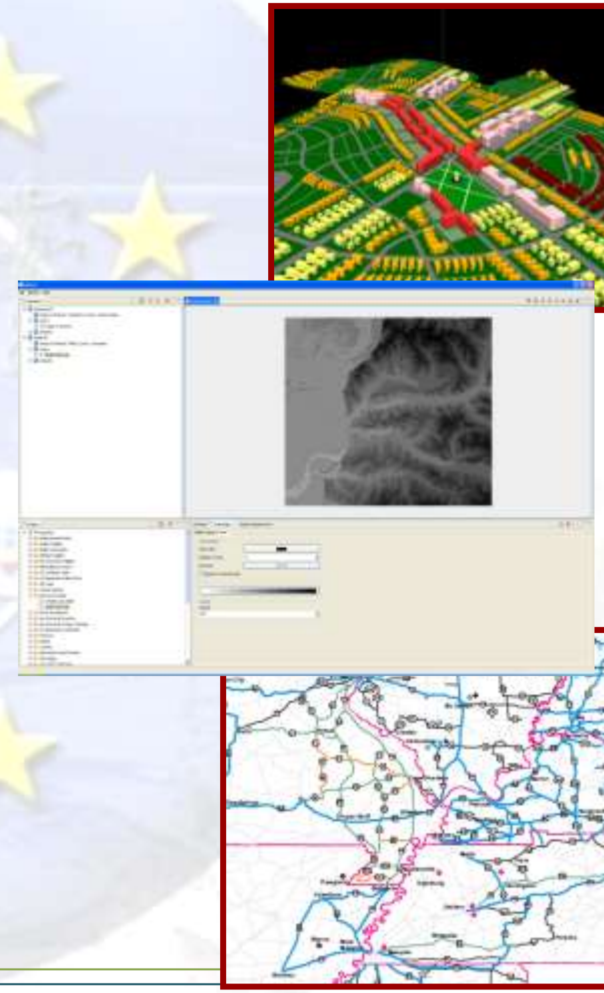
Result Charting



Synchronized Data Views

# CIRP Input: Inventory, Terrain, Networks

- **Source -** Public data, Tax assessor data or inferences from aerial photography
- **Inventory -** CI buildings, bridges, pipelines, dams, hospitals, power/water plants, etc
- **Terrain –** satellite digital terrain maps for any region anywhere
- **Network information -** transportation, gas, water, electricity, telecommunications, etc.



# CIRP Input: Fragilities

- **Engineering Models Fragility**
  - Dependent on the inventory content
  - evaluate probability of reaching limit states of damage
- **Social-Economic Models Fragility**
  - Uses relationships between physical and socio-economic losses to establish impact society
- **Source of fragilities**
  - scientific data, research papers, derived from observations, experiments or simulations