EU-CIRCLE

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

Final Report

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List of partners

No.	Participant organisation name	Acronym	Country	Type
1	National Center for Scientific Research “Demokritos”	NCSRD	Greece	RTO
2	Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V	Fraunhofer	Germany	RTO
3	Meteorologisk Institutt	METNO	Norway	End-User
4	University of Exeter	UNEXE	UK	RTO
5	Akademia Morska W Gdyni*	GMU	POL	RTO
6	ARTELIA Eau et Environnement SAS	ARTELIA	France	Industry
7	SATWAYS Ltd	STWS	Greece	SME
8	Entente pour la forêt Méditerranéenne | Valabre	EPFLM	France	End User
9	D’Appolonia S.P.A.	DAPP	Italy	Industry
10	Državni Hidrometeorološki Zavod – Meteorological And Hydrological Service	DHMZ	Croatia	End User
11	XUVASI Ltd	XUV	UK	SME
12	MRK Management Consultants GmbH	MRK	Germany	SME
13	European University of Cyprus / Center for Risk and Safety in the Environment	EUC	Cyprus	RTO
14	Center for Security Studies	KEMEA	Greece	End User
15	University of Salford	USAL	UK	RTO
16	National Protection and Rescue Directorate of the Republic of Croatia	DUZS	Croatia	End User
17	ADITESS Ltd	ADIT	Cyprus	SME
18	Torbay Council	TORBAY	UK	End User
19	Hellenic National Meteorological Service	HNMS	Greece	End User
20	University of Applied Sciences Velika Gorica	UVG	Croatia	RTO
21	University of Huddersfield	HUD	UK	RTO

* the participation of GMU was terminated on 31st January 2018

Useful information

Project 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

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1 Setting the scene

It is presently acknowledged and scientifically proven that climate related hazards have the potential to substantially affect the lifespan, serviceability or even destroy Critical Infrastructures (CI), such as the energy, transportation, telecommunications, buildings, marine and water management facilities. CI constitute the backbone for the smooth operation of modern societies; their partial unavailability or complete destruction may result in significant impacts to people, environment and society as well as devastating economic losses. In addition, CIs are inherently interconnected and interdependent systems, and thus their failure frequently leads to domino effects.

As CIs have lifetimes that span several decades, their design, build and operation is a multi-million euro decision making process, and so it is imperative to generate scientifically validated knowledge on the potential risks of climate change and future extreme weather events. Such knowledge can act as a viable pathway for making resilient infrastructures. Risks can be assessed on how patterns of frequency, intensity and magnitude of climate hazardous events may change. EU-CIRCLE has identified how anticipated changes in the future climate and an increased probability of occurrence of disastrous events may impact the operation of key assets and essential services that interconnected CI deliver. The impacts of extreme events on CI include direct damage to the infrastructure leading to multi-scale and multi-level effects which not only affect the capability of the CI to operate but also result in secondary effects that could severely disrupt normal societal operations.

CI have a critical role in maintaining smooth societal functioning and contributing to healthy cities, combating energy poverty and increasing the wellbeing of the European citizens. Furthermore, resilient CI that are able to resist and/or quickly recover from climate hazards are critical components of emergency management and thus their availability is central for societal response to disasters. The converging point of EU-CIRCLE, is to put the “service continuum” of the CI as the high-level concept, and building the CI climate change resilience framework around it. Owing to changing climate conditions on a local scale, CI are exposed to adverse climate conditions and extreme events; these could be intensified or even witness the appearance of new climate hazards in areas never seen before. During the project duration, Europe faced significant hazards, directly relevant with the project’s objectives, such as intensifying forest fires in the South (66 dead in Portugal 2017, 99 dead in Greece 2018) and in North Europe (Germany 2018, Sweden 2018), storms in the UK (Emma in March 2018), drought in Central Europe (summer 2018).

For any given extreme event scenario (e.g. flooding), in addition to CI assets and networks being affected directly by the event, CI assets and networks outside of the impacted hazard area can also be affected indirectly e.g. as a result of flooding an electricity sub-station fails and causes properties served by the sub-station, both inside and outside of the flood risk area to lose power. In other words, due to interdependencies between CI there can be many cascading effects which can be identified by undertaking a flood analysis. For example, if an electricity sub-station fails due to flooding then the polygon representing the area served by the sub-station is identified. This area may include other CI that are reliant on power and this cascading effect is also identified. A simplified example of how flooding can affect other CI, outside of the flood risk area, due to their interdependencies is shown in Figure 1 below. As can be seen properties and CI assets highlighted in blue are directly affected by the flooding. Due to interdependencies (Table 1), those CI assets and properties outside of the flood risk area, highlighted in red, are indirectly affected by the flooding

Table 1 Effects of flooding on CI

Critical Infrastructure	Effects of flooding
Electricity	Service disruption, Infrastructure damage
Gas	Service disruption, Infrastructure damage
Telecommunications	Service disruption, Infrastructure damage
Sea Defence	Overtopping, Infrastructure damage
Water	Service disruption, Infrastructure damage
Sewer	Service disruption, Infrastructure damage
Highways	Road network disruption, Road damage, diversions, Pressure on other routes, manpower issues
Rail	Rail network disruption, damage, diversions, pressure on other routes, manpower issues
Emergency Services	
Fire Service	Ability to attend flooding incidents and other emergency incidents
Police	Ability to attend flooding incidents and other emergency incidents
Ambulance	Ability to attend flooding incidents and other emergency incidents
Local Community	
Residents	Safety, damage to property/possessions, evacuation
Tourism	Depends on time of year, events, safety, evacuation
Businesses	Damage, disruption, evacuation
Hospital/Care homes	Service disruption, Infrastructure damage, evacuation
Schools	Service disruption, Infrastructure damage, evacuation
Environment	Damage, pollution

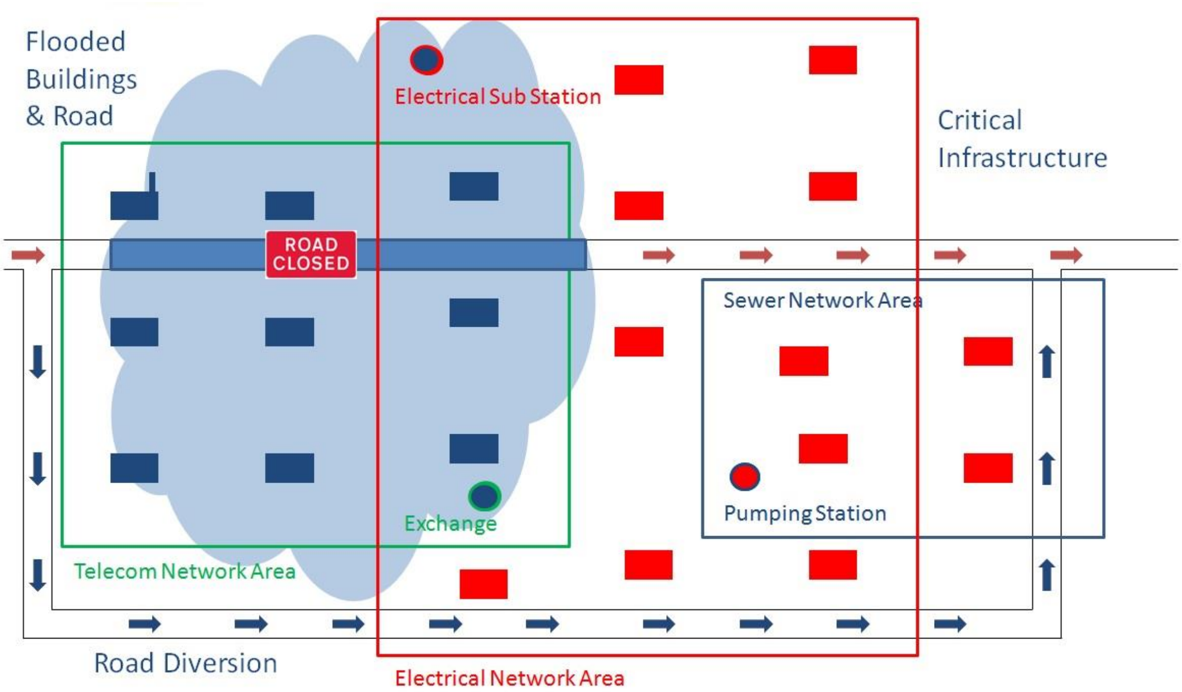


Figure 1 CI Assets and properties directly and indirectly affected by flooding

Linking policies

There are many different policies that are of relevance to Critical infrastructures for different initiatives such as CI protection (CIP), Sustainable Development (SD), Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR), at the European and International Level. Table 2 presents a summary of the main ones

Table 2. Link of policies to major initiatives

Policy	Comments	CIP	CCA	DRR	SD
UN SDG	UN Sustainable Development Goal: SDG9 Infrastructures and Industry				x
	UN Sustainable Development Goal: SDG13 Climate Action		x		x
	UN Sustainable Development Goal: SDG11 Sustainable Cities and Communities			x	x
EU-ISS	EU Internal Security Strategy, *COM(2010) 673 - The EU Internal Security Strategy in Action*, and in particular Objective 5: Increase Europe's resilience to crises and disasters	x		x	
EPCIP	Dir 114/2008, calling for all hazards approach for protection of CI, interconnections	x		x	
EU CC	EU Strategy on Climate adaptation, COM (2013) 216 - An EU Strategy on adaptation to climate change, and detailed in SWD (2013) 137 - Adapting infrastructure to climate change		x		
Sendai	Sendai Framework for DRR goal -d- : Substantially reduce disaster damage to critical infrastructure and disruption of basic services			x	
NRA	DGECHO - Overview of natural and man-made disaster risks in the EU, SWD(2014). CI have been identified as key national risks in 8 EU countries.			x	

It can be observed that all the above mentioned policies are implemented in silos and in many cases contradict each other, and/or work complementary. EU-CIRCLE proposes that all these policies can be bridged under the resilience concept (Figure 2), where project technical documents[1] provide a detailed assessment of how the specific policy targets and indicators have been mapped to EU-CIRCLE impact criteria. In full compliance to the 2015 Paris Agreement Art.7, EU-CIRCLE produced validated scientific knowledge on the resilience of CI to climate change, that was built on the systematic observation of the climate system and future projections, and emphasizing the role of early warning systems, in a manner that informs climate services and supports decision-making.

[1] Deliverables D3.4 "D3.5 Holistic CI Climate Hazard Risk Assessment Framework" and D3.5 "Holistic CI Climate Hazard Risk Assessment Framework V2.0" available through the project website

Decisions concerning adaptation measures are commonly based on past events in CI management. A change of mind needs to be achieved to take prospective climate change into consideration as well. Especially in short – term, such as disaster risk reduction, applications related to life critical conditions all uncertain outputs should be presented. Decisions on climate change adaptation based on economic impacts have many quantitative measures and considerations. It is recommended to perform a sensitivity analysis to gain trust in the results. More importantly, transparency and clarity of the process of the simulations and model presentation is key in gaining acceptance of the generated results.

Furthermore, EU-CIRCLE set the basis for providing climate services directed towards the CI stakeholder community. For instance specific analyses and thresholds, even on CI asset and network level, could be a giant leap forward for the climate services in the national and EU environment.

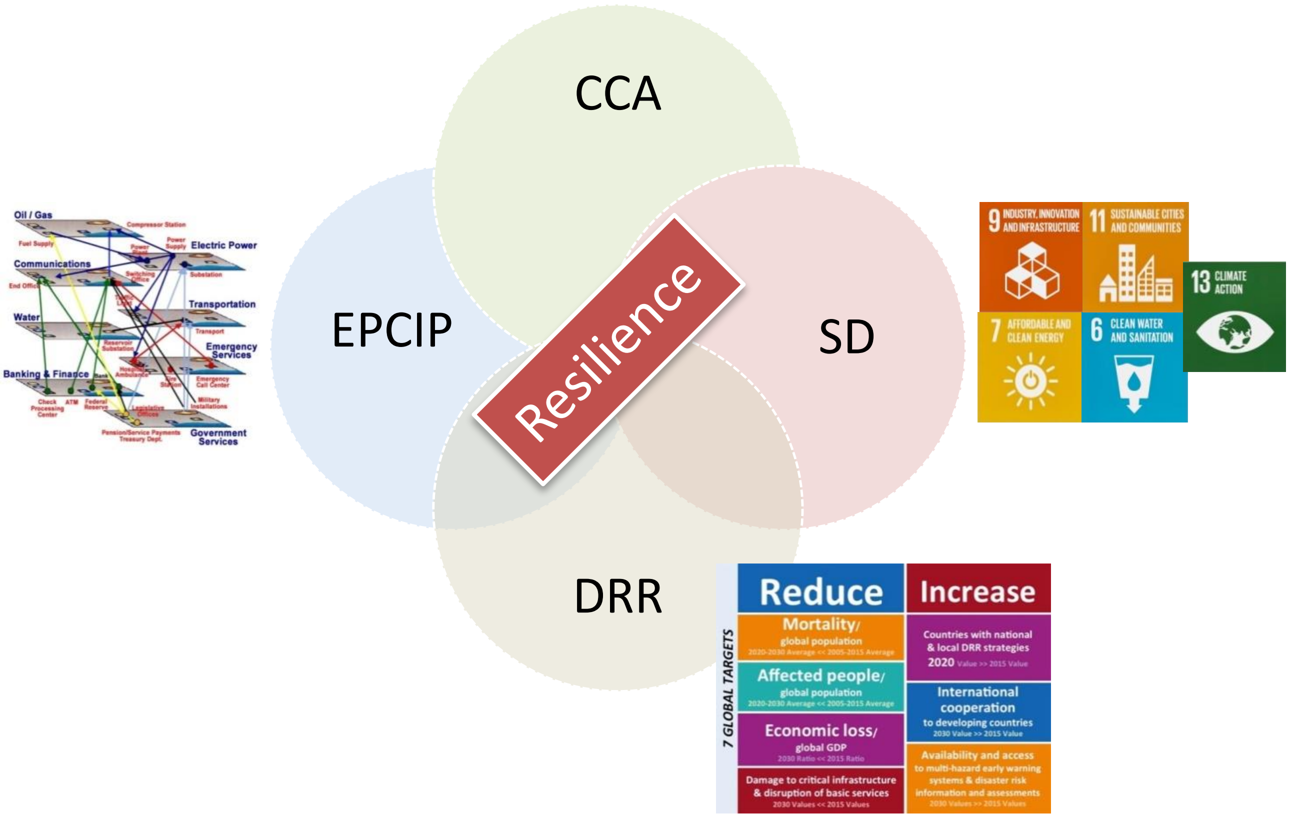


Figure 2. EU-CIRCLE's resilience concept as a bridge of different policies

From assessing impacts (risks) to business continuity (resilience)

EU-CIRCLE has built a comprehensive, interdisciplinary risk and resilience management framework. Methodologically, it is based on the identification of climate risks (stressors) on individual key assets, assessment of their impacts to the operability and organizational integrity of the services provided by the

CIs, and enhancement of resilience through the development of resilience indicators and the identification of adequate and efficient adaptation options.

At the center of the EU-CIRCLE approach is the concept ***of "service flow continuum"*** , where the resilience of CI is linked to how they can better understand the evolving nature of hazards due to climate change and implement early warning systems (anticipatory capacity), be exposed to lower levels of risk or reduce their climate vulnerabilities (absorbing capacity), be able to respond faster and collaborate more efficiently with other CI and emergency responders (coping capacity) and return to normality and full operational levels (restoration capacity). Finally, the adaptation capacity of CI is equally important and thus a policy shift towards resilience based adaptation is proposed. The resilience framework in this report also provides an outline of how ***business continuity*** can be considered especially through the preventative measures and adaptation options being considered in the model.

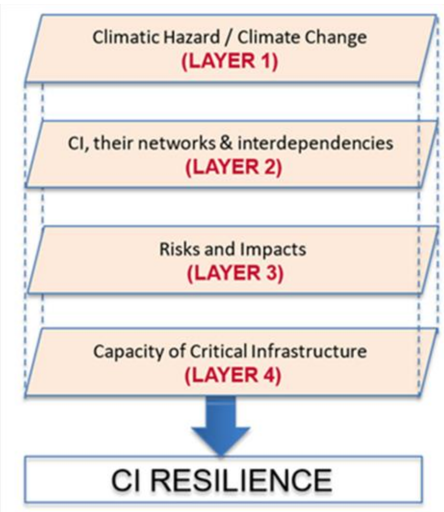


Figure 3. EU-CIRCLE resilience

EU CIRCLE introduces a novel 4 layered approach to critical infrastructure (CI) resilience which determine what constitutes CI resilience with their key components briefly summarised below:

1. Resilience for what – the disturbances which are caused by natural hazards which may be exacerbated due to climate change represented in Layer 1
2. Resilience of what – the context which is CI, their networks and interdependencies as incorporated in Layer 2.
3. Risks and Impacts - which includes the consequences of a hazard and the likelihood of the occurrence, detailed in Layer 3
4. Capacities of CI such as the ability to anticipate and reduce the impact; ability to buffer and bear; ability to be repaired easily and efficiently included in the final Layer 4
5. Resilience parameters i.e. properties that indicate different capacities, also included in Layer 4, and introduced in the previous paragraph.

The application of the EU-CIRCLE framework allows for:

i. Assessment of the current risks of a specific climate hazard to a single CI or a CI network or even an area of interest with interconnected and interdependent CI.

ii. Examination of how climate change may alter risk in the future (Figure 4), or expose new risks (Figure 5). This analysis includes a baseline assessment of the risks to CI assuming no additional adaptation actions under various climate change scenarios, as well as a second assessment which considers how current or future potential adaptation actions will affect the overall scale of risk to CIs in the future under the same climate change scenarios.

iii. Identification of climate change adaptation or risk mitigation options and definition of priorities (Figure 6). This step examines alternative strategies for mitigating risks to CI and strengthening their resilience such as: enhancing the defences of interconnected infrastructures and implementation of long term adaptation options.

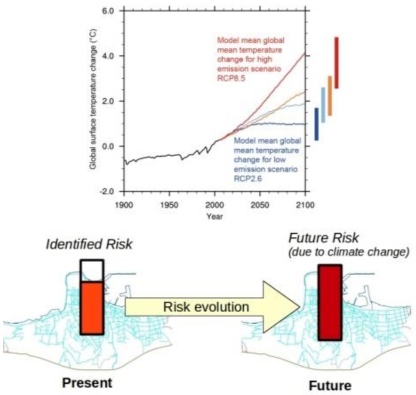


Figure 4. CI risk evolution due to climate change under no adaptation

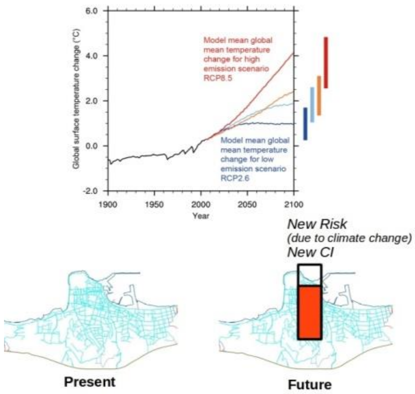


Figure 5. Identify new risks under future climate conditions, or due to new CI being planned (or expanded) in the future

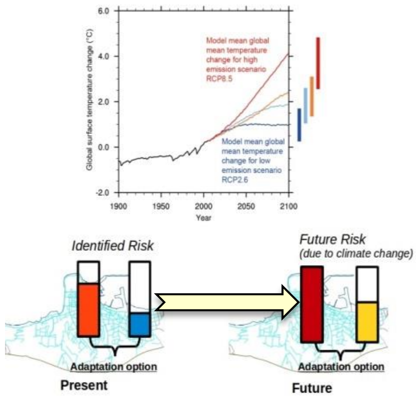


Figure 6. Assessing risks in the future under the application of different adaptation options policies and measures.

1.1 Engaging stakeholders in understanding the future climate

EU-CIRCLE was a multidimensional project focusing on how to enhance resilience of critical infrastructures from climate change induced risks. The key conclusion of the project is that resilience enhancement can be achieved through the interdisciplinary co-operation of involved stakeholders: CI operators and national / local authorities, academia and the innovation producing private sector. The project successfully managed to increase the awareness of CI operators to the benefits of enhancing their resilience to more efficiently adapt to climate change.

EU-CIRCLE effectively engaged the CI community in the different case studies. The case studies were implemented in a participatory approach, where CI operators, national / regional and local authorities and emergency responders were engaged in designing the specific scenarios, providing accurate data, assessing the potential impacts and generating damage assessments due to climate change, proposing and contributing to adaptation options customised to their needs, and then discussing results and participating in project events. The involvement made CI stakeholders more conscious about the potential impacts of climate change on CI and thus many of them were willing to use the project’s results and methodology to manage their exposure to hazards.

There was considerable interaction with CI stakeholders throughout the 2nd reporting period of the project. Interaction with the CI and climatology stakeholders was an important element in producing meaningful and usable results that could be further exploited by the consortium. There was exchange of opinion on numerous events on climate change impacts to CIs, the methodological framework of the project and to familiarize end users with the approach adopted by the consortium for assessing climate change related risks to essential services as well as for considering resilience concepts and indicators within the operators planning process.

Table 3. Involved CI stakeholders per EU-CIRCLE case studies

Case Study	Involved CI operators, Local/Regional/National Authorities Non-project partners
CS1	RTE, ENEDIS, ESCOTA, Forestry National Organization, EMIZ, SDIS83
CS2	Electricity Authority Cyprus, VTT Vasilikos, Petrolina, Vasilikos Cement Plant, Cyprus Civil Defence, Department of Meteorology, Fire Department
CS3	South West Water, Western Power Distribution, British Telecommunication, Torbay Council (Highways, Emergency Planning, Engineering), Wales and West, Environment Agency, Network Rail
CS4	Khulna Power Company, Centre for Environment and Geographic Information Sciences (CEGIS), Khulna City Corporation, Khulna University, Khulna University of Engineering and Technology, Khulna Water and Sewerage Authority, Khulna Development Authority, West Zone Power Distribution Company Limited, Bangladesh Meteorological Department
CS5	City of Dresden - Department of environment, City Sewage system operator, DREWAG, Dresdner Verkehrsbetriebe

Stakeholders need a strong motivation to join research projects. This could be best achieved by providing tangible benefits. These may vary between different stakeholders (e.g. safety and security improvement or economic aspects). Researchers should ask openly for the needs and expectations of stakeholders and must clearly name the benefits for them in participating in the project. The involvement of associations that open doors to stakeholders can be supportive. Contacts should be made even before the project itself starts and should be maintained permanently by means of established mechanisms. Data demands should be reduced to a minimum. The project data provided to the stakeholders need to be well organised.

2 Case studies description

Five different real world Case Studies have been conducted during the project. The selected case studies have been designed to address climate hazards that are considered to be of high importance to the EU and cover all types of CI.

2.1 South France

The first case study proposed an application of the EU-CIRCLE approach on heat wave and forest fire impacts on electric and road transport networks, in the Provence-Alpes-Côte d'Azur Region (southern of France). This case study presented the unique concept of organizing a Table Top Exercise and a real crisis event, with the involved CI operators and the Provence Alpes Cote d'Azur (PACA) area emergency responders.

Due to specific topographic relief of the PACA region there are significant consequences on the organization of the electricity and transport networks. Indeed, in terms of transportation, the main axis is east-west oriented. This is the only one besides secondary road networks serving the eastern part of the region. Regarding the electricity network, the imbalance is even more obvious. In 2015, PACA region produced 41% of the electricity that was consumed in the region. It therefore had to import almost 25GWh that same year, mainly from the nuclear power plants located in the Rhone Valley. 64% of the electricity production in the region comes from renewable sources, mainly hydropower (Durance and Verdon valleys mainly, Nice hinterland to a lesser extent). It creates a situation of electricity peninsula were the eastern part of the region is heavily reliant on one main transmission line.

The case study occurs during the summer, when the population highly increases due to an increase in the number of tourists , resulting in an overloaded flux of people on the highway networks and increasing the consumption of electricity. Moreover, with the presence of tourists during this high risk period, the fire ignition probability increases too. In recent years, there have been repeated wildfire incidents where many dwellings lost electricity, e.g.: May 2005: 1 500 000 , July 2009: 1 200 000 December 2009: 2 100 000

The EU-CIRCLE approach application to the French case study was conducted following three steps:

- The resilience assessment of each infrastructure.
- The risk analysis, to identify the critical points of the interconnected infrastructures regarding heatwaves and forest fires (in the climate change context).
- The identification of relevant adaptation options (according to the possible resilience improvement) and its prioritization, to first improve the resilience of the most critical assets.

Some specific details of the examined scenario are included below:

a. A heat wave has been striking the south-east of France for a couple of days, causing incidents on the electricity network (temperature alerts reached in some substations) and on the roadway (behaviour changes caused by stress). The forest fire risk index is extremely high, especially in the Var department.

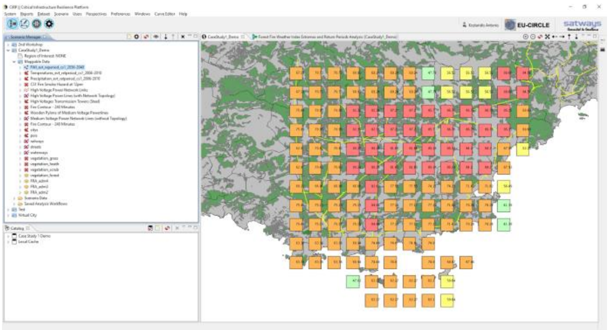
b. A forest fire ignites north of the city of Brignoles and is pushed south-west by the wind. Soon, the fire reaches both the highway (A8) used by thousands of tourists in summer time. Due to the important smoke production, visibility is significantly reduced so that the highway has to be closed, resulting in an important traffic increase on the secondary road networks. Tourists are confined to highway rest and service areas, while basic services delivery (Drinking water, road signalling, radio emission, etc) is threatened. Additional accidents are caused because of panic by people.

c. Because of the risk of electrical priming caused by smoke, as well as to facilitate aerial firefighting operations, electricity lines are cut off, and in particular extra high aerial lines serving the eastern part of the region (400kV and 2325kV). Load-shedding plans have to be applied.

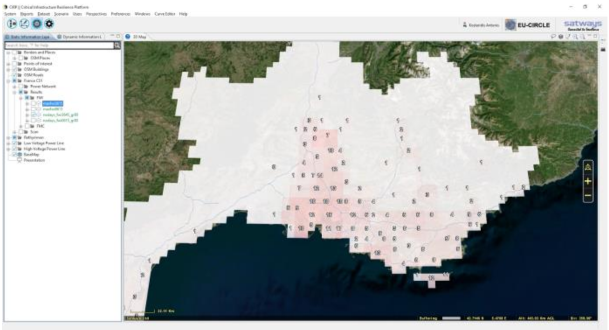
d. Because of the high soil and ground temperature, a junction box of the buried extra high tension line crossing the north of the Var department stops functioning, cutting this line as well.

e. The risk of a black out in the eastern part of the region is extremely high, given that the two main power transmission lines are cut. The impact on the general public and on the other CIs (in particular the highway network) may be very severe.

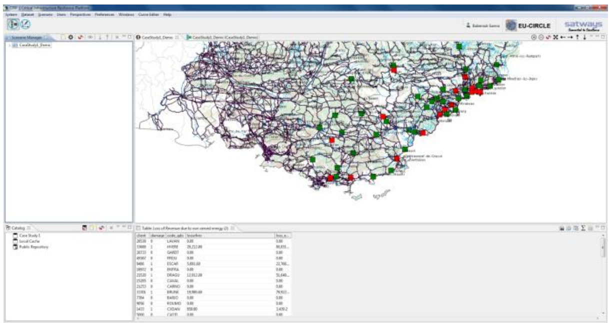
f. Other emergency operations are disturbed because of the large delay of alert, decrease of available means and major dispersion of such means.



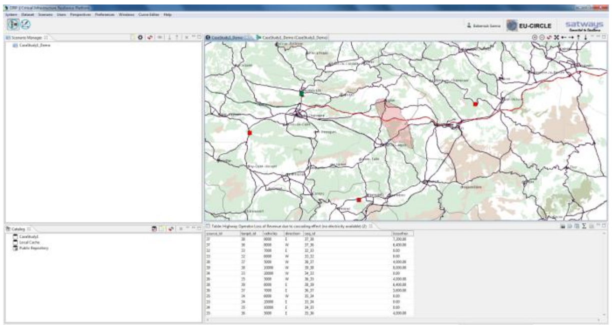
RCP4.5 Return period 100y



RCP8.5 Number of days > 80



Clients Not Served with electricity



Highway loss of income due to cascading effects

Figure 7. Some Results from French Case Study as an example

EU-CIRCLE proposed a set of different analyses that included the number of electricity wooden pylon burned, impact on high voltage transmission lines, number of people without electricity, highway halting of services and related income loss. It is obvious that the combined results of the various tools proposed in EU-CIRCLE will help managers to refine their various prevention planning and guide them for taking decisions about future investments. In addition, the Climate Change part of the CIRP could be used by territorial managers or private companies involved in the elaboration of the prevention plans such as PPRIF (Forest Fire Risk Prevention Plan).

The conduction of the French Case Study Workshop on 7th of December 2017 was the single most important milestone in the project. The theoretical framework and software CIRP / RAT were demonstrated to the stakeholders for the first time, demonstrating the capabilities of EU-CIRCLE tools.

2.2 Cyprus – Vasiliko Energy Center

The 2nd Case Study was focused on the implementation of the EU-CIRCLE risk assessment methodology to the CIs of the Vasilikos area in Cyprus. The area has two oil terminals and an industrial port which are ideal for testing of the EU-CIRCLE risk methodology on energy and transport infrastructure. Importantly the area will be further developed into the Vasilikos Energy Centre (VEC) which will include a Liquid Natural Gas floating storage and regasification facility with a jetty intended for the Unit's safe mooring and the required pipelines; a 210,000-tonne storage facility for the Cyprus Organisation for Storage and Management of Oil Stocks that will include the strategic fuel stocks for the Republic, and truck loading facilities for the local market. The VEC is also the designated area for the relocation of petroleum storage facilities currently operating at Larnaca bay by 2019 and for gas storage facilities by 2020. Thus Vasilikos is currently of strategic importance to Cyprus, an importance that will only increase with the development of the VEC.

Cyprus is located in the Eastern Mediterranean, an area identified by scientists as a climate hotspot expected to experience significant warming and drying in the next decades. Observations from the 1960s onwards show that the temperature of hot summer days and nights and the number, length and intensity of heat waves have increased significantly in the Mediterranean region.

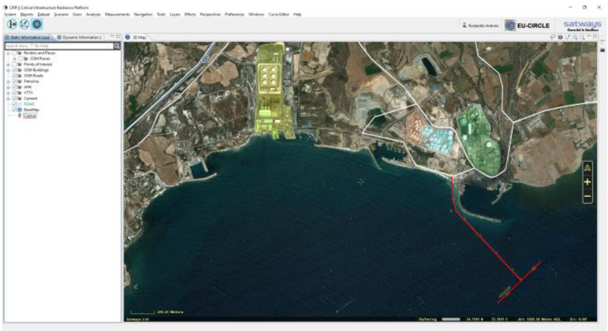
In discussions with the national authorities, including the Cyprus Civil Defence, the Department of Meteorology and the Fire Service, it was decided that a multi-hazard risk assessment would be carried out for the hazards of extreme temperature, precipitation, lightning and wind. The hazards were chosen based on the historical incidence of such hazards. These hazards were then discussed with the CI operators and were finalised based on a discussion of observed historic events at CI operators' sites as well as the potential impacts that may occur if the climate hazards were to increase in magnitude, frequency and intensity.

Due to an increase in the incidence of Medicanes in the Mediterranean basin, the impacts of such an event were also be investigated, through a Table Top Exercise (TTX) during the case study workshop. Medicanes (Mediterranean hurricanes) are rare events of cyclones that exhibit visual characteristics similar to tropical cyclones, such as an eye and a spiral of dense cloud coverage. The Mediterranean basin is a well-known European area for cyclone formation and is a region with a high density of cyclones, which are responsible for heavy precipitation and strong wind events. Mediterranean cyclones are often responsible for considerable damage mainly in the Mediterranean islands and coastal zones.

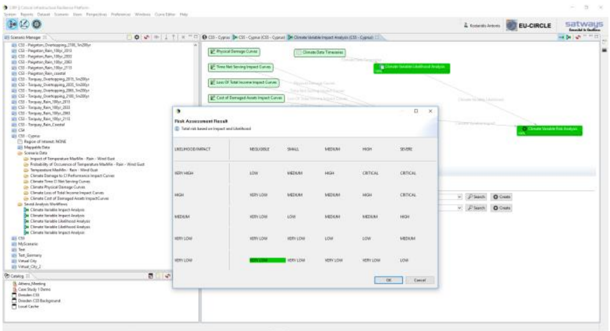
The climate change risk assessment included: a) Conduction of climate analysis and estimation of return periods, 2) Exposure analysis, 3) Estimation of likelihood, 4) Estimation of consequences through impact indicator tables and 5) Estimation of multi-hazard risk. The examined climate threats, as jointly decided with the Cyprus Department of Meteorology, include: Max / Min T, Rain, Wind Gust and Lightning. All participants agreed that the Vasiliko CI are climate-proof when consider the climate projections from present-day simulation models.

At the final workshop, a Medicane (i.e., a Mediterranean hurricane) was simulated over the Vasilikos area and a table-top exercise was discussed with the CI operators. In discussion with the CI operators, it became clear that indirect impacts related to staff, logistics and production were more important and more likely than structural damage to the CI assets directly. The CI operators believed that structural damage to their CI assets would be unlikely, even in the event of exceedance of thresholds, as the thresholds would need to be breached for a sustained period of time, which is unlikely based on the climate analyses.

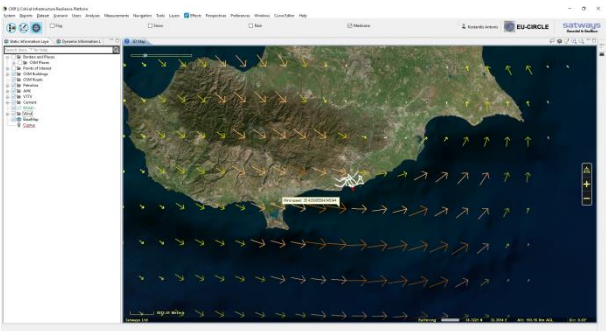
The CI operators considered that the risk analysis is useful for discussing climate change impacts and what type of response is necessary and how long it could take. It is important to know what climate hazards are likely to affect CI operations, and it is important for CI operators to have scientific input to understand the hazards and risks. Understanding the interconnections between CIs is vital, as a CI's assets may not be impacted under a given hazard, but if it impacts electricity production and there is no electricity then operations will still be affected. Both the CI operators and national authorities recommended that joint climate change risk assessment of the entire area should be conducted, particularly in light of the future development of the VEC.



Map of Vasilikos Area



Risk Matrix Example



Medicane visualization over Cyprus

CY Case Study Workshop

Figure 8. Examples from CY case study implementation

The case study included the Vasilikos Cement Plant, which is also located in the area, and is interconnected with the other energy infrastructures. The climate change risk methodology was also implemented at this facility further supporting the versatility and expandability of the proposed framework.

2.3 Torbay – South West UK

CS3 focused on the effects of coastal flooding on CI within Torbay. Torbay covers an area of approximately 62 km2 and is a popular tourist destination in the UK. The region includes three urban towns (Torquay, Paignton and Brixham) and hosts more than 3 million tourists every year that contribute over £450 million to the local economy. This CS verified the EU-CIRCLE framework for assessing the impacts on the CI around Torbay as a result of coastal flooding under present and future climate change scenarios. The assessment included the damage to residential and commercial properties, together with the impact of flooding to highways, transportation, tourism, local economy, infrastructure (sewers, gas, electricity, water, telephones, etc.), health and the local environment.

The area has suffered from flooding, during intense rainfall events, over many years from a number of different sources, including surface water run-off, highway flooding, sewer flooding, main river and ordinary watercourse. Historically, the consequences of these flooding events has resulted in many residential and commercial buildings in the town centres of Torquay, Paignton and Brixham being flooded together with roads being closed. As Torbay relies on tourism for its economy, flooding of this nature has a very significant economic impact on the area. In addition the coastal areas of Torbay suffer coastal flooding due to overtopping of the sea defences during high tides that coincide with easterly winds. Figure 9, shows the effects of Storm Emma (March 2018) on the Torquay sea front. (Further evidence of flooding to the Torquay sea front can be seen using the following link: https://youtu.be/Oc2Imxkp9iY).

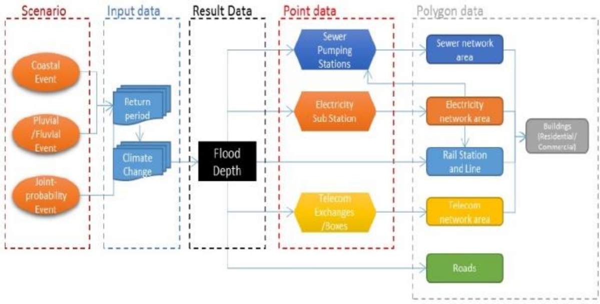
Rising sea levels, as a result of climate change, will increase local flood risk both in coastal regions from increased risk of overtopping of the sea wall and inland from main rivers and watercourses due to the interaction with drains, sewers and watercourses. As sea level is predicted to rise by over 1m in Torbay over the next 100 years the frequency and impact of overtopping of the sea defences will increase resulting in more infrastructure and properties being affected by flooding.

During the stakeholder workshop it was agreed that in order to demonstrate the application of the CIRP tool, the following questions should be answered within the CS: 1) Which roads are closed due to 0.15m depth of flooding? 2) How many residential and commercial properties would be flooded? 3) Which CI (assets) affected directly or indirectly by flooding (identifying all of them)? 4) How many residents are affected by the storm event in question?, and 5) What is the cost of a particular storm event?

The scenarios chosen by the stakeholders to be assessed during the CS were as follows: 1) Flooding scenarios to be tested included coastal flooding, pluvial/fluvial flooding, breach failure and a joint coastal/pluvial/fluvial flooding event; 2) Climate change scenarios used were the present day, 20, 50, 100 years of climate change and 3) Storm events used were 100 year return period for pluvial/fluvial, 200 year return period for coastal and a joint probability for the combination of coastal/pluvial/fluvial event with 50 year return period.

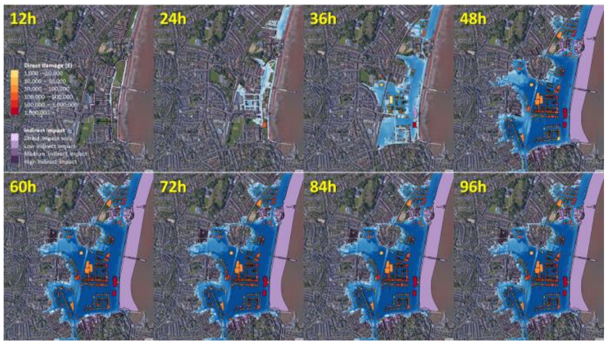
As sea level is predicted to rise in the Torbay area by over 1 m in the next 100 years, both frequency and impact of overtopping will increase, resulting in more infrastructure and properties being affected by flooding. Also, intensified rainfall, due to climate change, may cause additional surface runoff exacerbating localised flooding due to pluvial/river and coastal flooding. Existing drainage systems already have capacity issues and therefore more intense rainfall will increase the flood risk from these systems. Figure 9 shows the predicted coastal flooding as a result of overtopping within Paignton for the 1 in 200 year storm event plus 50 years of climate change.

Storm Emma (March 2018)



Impact Assessment chain

Flood simulations



Damage Assessment

Figure 9. Example results from Torbay Case Study

An adaptation scenario was assessed within the case study where a secondary coastal defence was included behind the existing coastal defence in Paignton. The benefits provided by this secondary defence were demonstrated within the CIRP tool and the visualisation for the 200 year event with 50 years of climate change as shown in Figure 10. At the end of the dissemination workshop a question and answer session was held where stakeholders and other partners were invited to provide feedback and discuss the CS. The consensus of opinion was that the CS had successfully demonstrated the tools that have been developed as part of the EU-CIRCLE Project. The stakeholders were impressed with the visualisation and CIRP tools that were presented and made available for further demonstration during the comfort breaks.

The practice also allowed EU-CIRCLE partners to better understand the main concerns of stakeholders regarding CI resilience to climate change and tailored the research outcome to address those key questions. The methodology and results were demonstrated via the engagement workshops that trigged more discussions among the involved parties. The study also showed the needs for further scientific research (e.g. the physical damage to underground infrastructure caused by erosion during flooding). The outcomes have attracted other local stakeholders who would like to implement EU-CIRCLE approach to other coastal protection planning in the Southwest England.

Combined coastal/pluvial flooding in Paignton for 2065

Coastal flooding in Paignton for 2065

Flooding in Paignton following adaptation scheme for 2065

Figure 10. Visualization of Adaptation measures

During the CS, Torbay suffered extensive coastal flooding due to Storm Emma (March 2018). A new scenario was included to demonstrate the performance of the model against the actual storm event. It gave strong evidence that extreme events associated with climate change may occur at any time, now or in the future.

2.4 Khulna City – Bangladesh

The Khulna area in Bangladesh is a significant interior coastal city situated roughly equidistant between the C40 megacities of Dhaka Bangladesh and Kolkata, India. The city of Khulna is the second port city of Bangladesh and the third largest in size. Approximately 100 km from the coast and just north of Mongla Export Processing Zone and port complex and the under construction Rampal coal power station and Khan Jahan Airport, Khulna is a growing regional hub with a dense historic experience of tropical cyclones, a persistent urban drainage problem and a projected storm surge risk. Khulna is currently receiving a significant infrastructural boost by significant central government investment, and include re-development of the port facilities and river navigability, construction of a local airport and the Rampal power plant, the reopening of the Khulna-Kolkata rail connection, and the opening up to tourism. All these suggest a positive economic, if not ecological and social, trajectory for the region and its Export Processing Zone.

Khulna City was selected for a number of research design, socio-technical and geo-economic reasons. Firstly as the out of Europe International case study for the EU-CIRCLE collaboration we would be able to strength test CIRP methods and RA frameworks to a tropical operational environment in the Global South with data resources and projected climate change impacts that reflected the inequalities and inequities of the Climate challenge. As it is the third city of Bangladesh, situated in the interior coast, currently receiving a significant infrastructural boost and likely to play an important role in the lives of future climate displacees, The critical infrastructure assemblage of organisations, relationships and built assets of Khulna therefore presents a big opportunity for research interventions like EU-CIRCLE to demonstrate their relevance, highlight limitations and mature for a wider participation.

Visiting Khulna for data collection in Autumn 2017, the practical realities of several interacting hazards, climatic and non-climatic became clear. From salinity in the ground water which degraded buildings in the city, to urban waterlogging and looming though relatively underdetermined threat of storm surge, cyclonic storms were chosen as they presented devastating, and readily quantifiable discrete phenomena with baselines studies that the team could connect with. Second to famines, cyclones have historically exacted the greatest human toll on Bangladesh. Given the drastic reduction in human life losses in recent decades due to early warning and cyclone shelters, and higher projected sea surface temperatures in the Indian Ocean (the nursery for cyclones), the development of tools to quantify potential losses and model resilience measures to cyclones is attractive policy-wise, especially given the growing role of Loss and Damage and Adaptation financing policy at the global level.

Storm surges have been projected to approach Khulna City within decades by the Institute of Water Modelling. However, they were felt to be too extreme a case to credibly demonstrate with the CIRP given available data, resources and stakeholder dismissal thresholds. The Khulna case study characterised weather conditions by foregrounding the known and named on the basis that stakeholders would engage more readily. Rather than projections of arbitrary time points situated in climatic futures modified by a simulated emissions trajectory, the team, following extensive debate, decided to use historic storm data to test the performance and cascading failure of the Critical Infrastructure in question. The concept of the Synthetic Storm was developed with MetNor to sample the wind velocity and precipitation characteristics of historically known storms, and reroute them through the city.

Early sounding with stakeholders showed that institutional memories do not extend far back into the past, so the near past was prioritized. In the end Cyclone Mora (2017), Cyclone Nargis (2008) were made available from the Indian Ocean Archive, with Hurricane Matthew (2016) additionally imported from the Atlantic as an example of a particularly high wind speed case (Table 4).

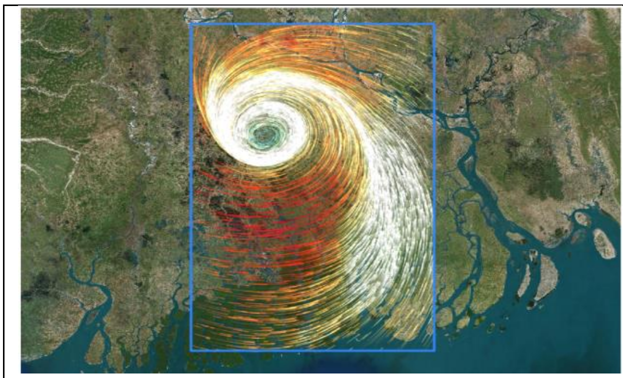
Table 4. Historic Cyclones of relevance to Khulna

Name	Cyclone Nargis	Hurricane Matthew	Cyclone Mora
Dates	27th April-3rd May 2008	28th Sept -10th Oct 2016	28th-31st May 2017
Highest sustained wind speed (1 minute)	215 km/h	270 km/h	120 km/h
Model wind max	49.7 m/s	56.1 m/s	38.3 m/s
Model total rain max	1071 mm	471 mm	462 mm
Est. Lives lost	>140 000	603	135
Est. Dollar Damage ($)	12.9 billion	15.1 billion	1.37 billion
Areas impacted	Myanmar, Bangladesh, India, Sri Lanka, Thailand, Laos, China	Caribbean, N America	Sri Lanka, Bangladesh, Myanmar, E&NE India, Bhutan, Tibet

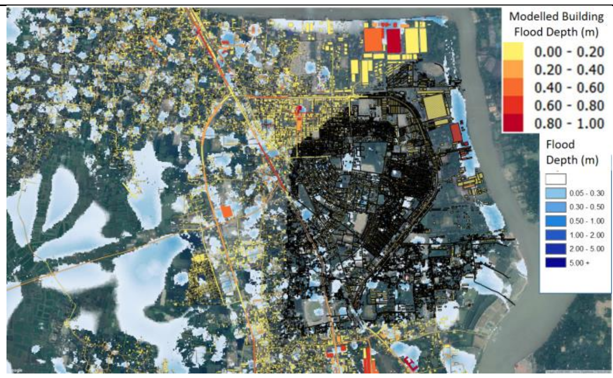
After discussions with the local stakeholders, the following policy questions were formulated: i) What extent of the road network would be impassable after each cyclone? ii) What would be the cost of restoring road infrastructure after each cyclones? iii) What proportion of the electricity distribution network would be disrupted by each cyclone and for how long? iv) What further damage can cause, the disruption of electrical poles? v) How long and how much would the power distribution recovery cost be? vi) How many buildings would be disconnected from piped water supply by each cyclone? vii) How many schools, hospitals would be inundated and damaged by each cyclone?

The demonstration event showed i) how, due to regulation, spatially focussed private sector operators, such as the power company, could be in a much better technical resilience position than spatially distributed state operators, and ii) that a platform for growing and sharing processes, data and expertise, including the higher educational sector is necessary.

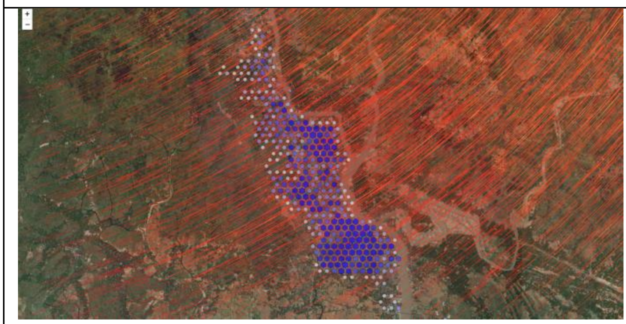
The main work performed included the assessment of extreme wind and flooding to CI. These included : - The felling of electric poles by wind, and the subsequent blockage of roads by poles, - CADDIES modelling of the behavior of heavy precipitation across the city scape as the storms progressed and surface water pooled, - building inundation and electricity distribution impacts (area in black) caused by flooding at an electricity substation, - visualization to depict the progressing wind field and the likelihood of electric pole damage (Figure 11).



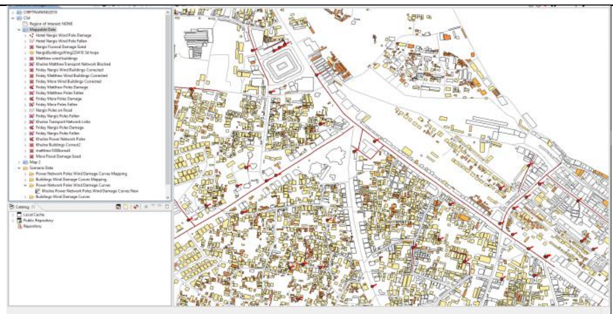
Simulated typhoon over Khulna



Max. flood depth, virtual hurricane Matthew



Wind fields and fallen electricity poles density



Damages due to winds

Figure 11. Example screen shots from International Case Study

Critical Infrastructure operators that were invited and attended the demonstration event, were broadly positive about the value of the project and the institutional value of being able to estimate expected costs of damage in advance of events, for national resource making claims and internal performance issues. Each operator was on a distinct journey of regionalization, technical growth and resilience.

As the out of Europe, International EU-CIRCLE case study we were able to test EU-CIRCLE in a tropical operational environment in the Global South with data resources and projected climate change impacts that reflected the inequalities and inequities of the Climate change challenge. The results showed that "synthetic storms" are viable tools to estimate risk from extreme events. CIRP exhibited great potential to work in conjunction with Building research and organisational capacity building in locations like Bangladesh.

2.5 Dresden – Germany

The final case study to validate the EU-CIRCLE methodology involved the interconnected critical infrastructures of the city of Dresden in Germany. The city of Dresden suffered flood events in the years 2002 (HQ 100), 2006 (HQ 10) and 2013 (HQ 50 – HQ 100). Following the first severe event, various studies were conducted in order to assess the flood damages and the vulnerability of important CI assets, with the aim to enhance the infrastructure resilience to fluvial flooding. During the meetings and discussions with stakeholders, all flooding scenarios related to flash floods were excluded due to the moderate consequences. Therefore, river flooding, especially of the river Elbe, was selected as the climate hazard of interest.

In recent years, the city of Dresden has been affected by several fluvial flood events with different severities. The factors temperature and circulation patterns and precipitation constitute the most important factors that influence the development of fluvial flooding by the water bodies in the area of Dresden. The analysis of the historic development showed an increase of both mean temperature and precipitation, which is considered to proceed or even accelerate prospectively due to climate change. Following the severe flood in the year 2002, the city of Dresden implemented adaptation measures along several water bodies in the city. However, specific assets of different CI sectors still remain highly vulnerable to flooding.

Fraunhofer IVI conducted multiple meetings with representatives of CI operators and the city administration to discuss, prioritise and select a specific case study location. The City of Dresden provided geo data containing risk points, water bodies, historic flood surfaces etc.It was decided to test the modelling platform for a large test area - the east part of the City of Dresden, focusing on the "behaviour" of the electrical grid and the sewage grid under extreme climate hazard situations. Summarizing, the following criteria were considered in defining of the case study

- ✓ The location and whether it has actually been affected by recent natural hazards, it is included in officially designated inundation areas, it is declared as an area with flood protection deficits (protection from flooding < HQ 100), or it is located in proximity to locations at risk along 2nd order water bodies.
- ✓ There is a high probability of damage to infrastructure, either structural or operational with substantial magnitude. Thereby, it needs to be classified how to distinguish "considerable" from "negligible" damage. Few days of detour of bus routes, cleaning costs etc. are considered negligible, but impacts become severe, if for example electrical components have to be replaced.

- ✓ Substantial cascading effects (functional or structural) to connected and interdependent infrastructure are expected but have yet to be studied in detail, and thus the city is not prepared for them.
- ✓ Extensive societal, environmental and economic impacts occur, such as evacuations, e.g. due to malfunctioning of electricity provision, water supply, sewage etc.

The city administration itself had already conducted detailed simulations on flood hazards and was able to provide water depths estimations for specific flood scenarios and used this hazard scenario in current discussions related to flood protection (Table 5). The first alert level is issued at a level of 400 cm. When the highest level (700 cm) is reached, protection measures must be implemented. Therefore, this alert level was considered as very important for the analysis. The city of Dresden aims to protect the entire city area against a HQ 100 flood. This is in general already achieved in the city center area, apart from few neighbouring city districts.

The area of EU - CIRCLE case study 5 was determined in consultation with the city administration and CI operators in the city of Dresden. It is located in the eastern part of the city between the bridge „Blaues Wunder“ and the district Pillnitz. In the case study area, the CI affected by flooding of the Elbe river is the electrical grid, whose disruption leads to failure of sewage assets and therewith the incapability to serve several households. Further, important parts of the road network are located in the flood prone area. If these are inaccessible due to inundation, traffic will need to make long detours. The closure of roads affects emergency and evacuation operations and public transport.

The case study scenario was defined as a fluvial flood event, with the Elbe river reaching a water gauge of 10.5 m. The data required for the modelling was provided by the stakeholders and administrative bodies of the city of Dresden. For the modelling in the CIRP, several plugins were developed by Fraunhofer IVI. The plugins compute the affected inhabitants, buildings and CI network entities, as well as revenue losses for electricity operators. The modelling considered interdependencies between electrical substations and sewage pumps and allowed to analyse cascading effects.

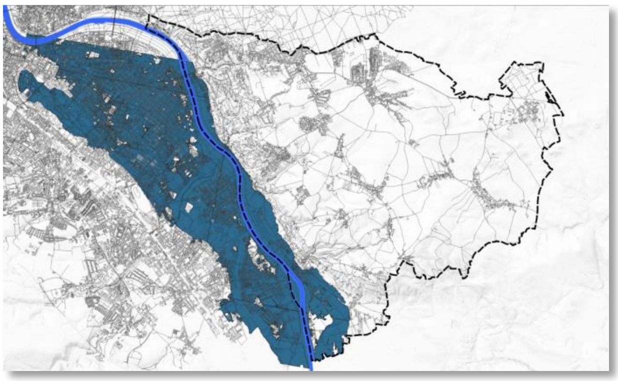
The city administration considers the maximum flood level of the river Elbe at 10.50 m. Until now, this flood level has never been reached, but it should be considered as an extreme possible flooding. Figure 12 shows a map of the city center in the maximum flood scenario. Obviously, large parts would be flooded if the Elbe river reached a level of 10.50 m. The city of Dresden provided the geo data (shape-files) for the project with the inundation areas and water depths for the different flood levels.

Table 5: Alert levels at water gauge Dresden

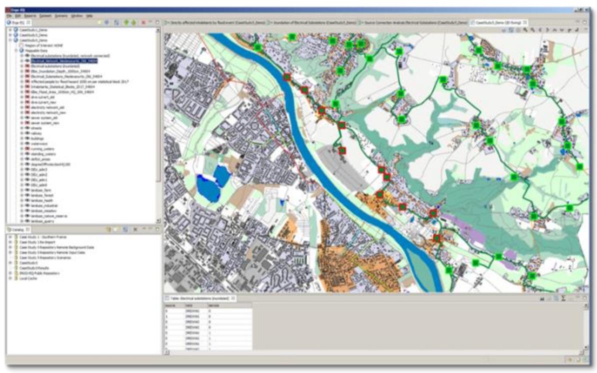
Official fixing	Level Dresden
HQ 500	10.50 m
HQ 100	9.24 m
Alert level 4 (<HQ10)	7.00 m
Alert level 3	6.00 m
Alert level 2	5.00 m
Alert level 1	4.00 m

Figure 12: Inundation of city center at water level of 10.50m (simulation). Source: Themenstadtplan Dresden (Landeshauptstadt Dresden, 2018a).

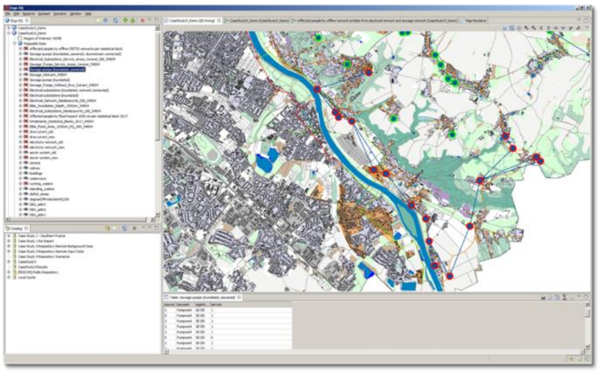
All results were calculated for different flooding scenarios (7.00, 9.24 and 10.50 m) pertaining to different assumptions: - with and without adaptation measures (construction of a new sewage culvert under the river Elbe, relocation of electric substation station to higher altitude position), - three different climate hazards (flood levels) as described above and - two demographic situations (2017 and 2025).



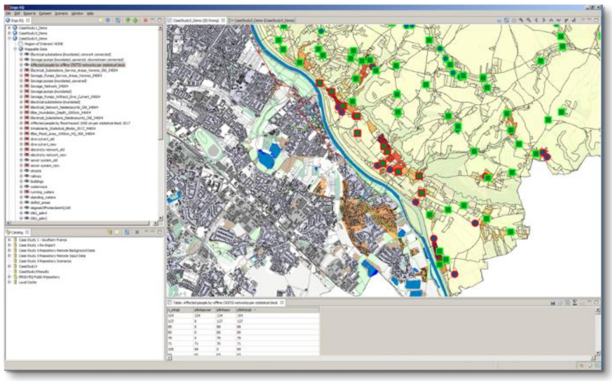
Inundation with flood level 1050 cm



Directly affected electricity substations



Out of service sewage pumps due to electricity failure



Affected population due to CI loss of service

Figure 13. Example results from Dresden case study

This case study workshop was an opportunity to invite local and international research community and stakeholders to discuss and exchange opinions on CCA and DRR and also future research priorities, demonstrate prototypes and collaborate. Some of the key findings include: For short - term applications related to life critical conditions all uncertain outputs should be presented. Decisions on climate change adaptation based on economic impacts have many quantitative measures and considerations. Sensitivity analysis is recommended to gain trust in the results. Transparency and clarity of the simulations process and model presentation is vital in gaining acceptance of the generated results.

3 EU-CIRCLE key take-away messages

The key points identified as take-away messages from the EU-CIRCLE project are:

1. Climate change will have significant effects on the nature and characteristics of hydrometeorological hazards. ***Changes in the hazards' frequency of appearance, magnitude, intensity, speed of event*** should be exhaustively estimated when assessing the impact of climate change. Hazards evolving at a faster pace will require new capabilities to anticipate, such as early warning systems, and efficient responders' placement and also faster deployment and establishing collaboration between stakeholders. More intense hazards could lead to higher vulnerabilities and potentially increased damages to the operational capacity of CI.
2. Think "out of the box" when considering which hazards could be of relevance to climate change risk assessment. The use of "***synthetic hazards***" to stress-test CI capacities is highly recommended, as global / regional climate models are not yet capable of capturing several high-end phenomena (e.g. tornadoes, waterspouts, lightning) which are considered outside of the capabilities of present Global and Regional Climate Models.
3. It is highly recommended that future climate-proofing of critical infrastructures, should be performed through the shifting from traditional prevention / protection concepts to resilience. The objective is to provide a suitable environment for science informed decision where optimal investment decisions are able to cope with present day extreme events as well as disruption to normality due to future anticipated climatic risks.
4. Climate change may induce the necessity to re-design or enhance defences of CI assets. It is recommended to perform assessment of CI assets based on micro-scale climate characteristics rather than relying on large scale global simulations. Work on ***identifying new relevant and reliable indicators*** related to the specific characteristics of CI, even on a local scale, should be actively pursued in the context of climate services. Also it is highly recommended to introduce the element of ***"resilience – by – design"*** when assessing the potential impacts of newly planned infrastructures to climate pressures and future time horizons
5. The ***vulnerability of CI to climate change is a multi-dimensional process*** and should account for (a) physical/structural damages due to extreme events, (b), the operational element of CI, including changes to supply and demand profiles, (c) the impact to society, which should not be neglected.
6. The element of ***dependencies and interdependencies between CIs*** becomes highly critical, also when assessing climate change risks. It is recommended to establish local/regional/thematic forums to expand knowledge base, focusing on the operational, regulatory and technology element in addition to the physical, geographical and cyber (inter-)dependencies.

Lastly,

7. It is worth remembering that ***climate change is*** not only about negative impacts, but rather ***one of the many challenges that CI owners/operators must address when preparing for a sustainable future***. EU-CIRCLE project's key recommendation is that Resilience based Adaptation could provide a sustainable modus operandi linking Climate Change Adaptation and Disaster Risk Reduction and this process should ***engage CI operators, national authorities and scientists***.

December 2018,

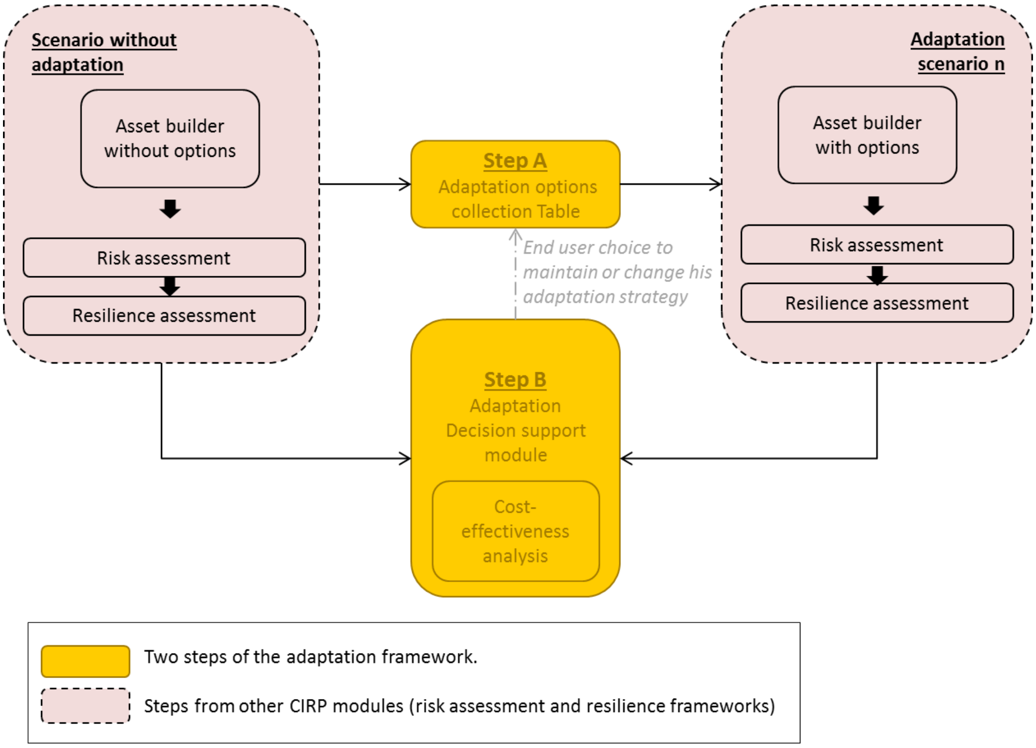
The EU-CIRCLE consortium

4 Annex I – Science briefs

4.1 EU-CIRCLE Resilience Based Adaptation Concept

Built on a review of existing new approaches for decision-making under deep uncertainty (especially robust decision-making and adaptation pathways), this methodology is based on two main steps:

1. Step A: selection of a range of adaptation options, according to the risk and resilience analysis (scenario without adaptation).
2. Step B: assessment of the selected options, according to their impact on the resilience and to their cost-effectiveness (comparing both scenarios without and with adaptation).



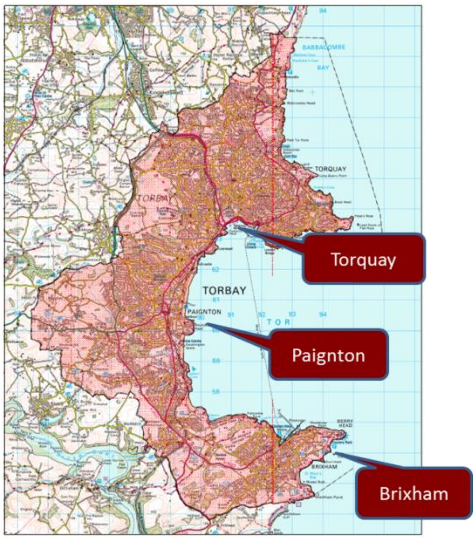
These two steps are divided into seven concrete stages, as follow:

Step	Stage	Description
A/ Identification of adaptation options	1. Establishment of the decision context	Definition of the acceptable resilience level (CI operator point of view) within climate change context; using the EU-CIRCLE Resilience Assessment Tool.
	2. Identification of options	Identification of adaptation options to reduce the damages (assessed using the risk assessment framework) and to improve resilience capacities (assessed using the Resilience Assessment Tool).
B/ Adaptation Decision Support	3. Identification of objectives and criteria	Regarding the decision context, determination of criteria to evaluate the adaptation options (including

Step	Stage	Description
Module		cost-effectiveness).
	4. Scoring of the expected performance in comparison to the defined criteria	Evaluation of the performance of each adaptation option against the selected criteria.
	5. Definition of weights for all criteria	Assignment of specific weight for each criterion with the decision makers.
	6. Computing the overall scoring/value for each adaptation option	Final analysis.
	7. Sensitivity analysis	Results analysis to assess their stability to changes in the input parameters (climate change scenarios, criteria weights, etc.).

4.1.1 Application within the Torquay case study (CS3)

The adaptation framework was applied within the Torbay case study, following the described two steps and seven stages:



A-1 Establishment of the decision context: resilience to the simultaneous occurrence of coastal (1 in 200 year event) and pluvial/fluvial (1 in 100 year event) flooding in Torbay.

A-2 Identification of options: the option of providing a secondary set back wall, in Paignton, was selected as the most effective intervention based on the initial simulations of flooding in the area.

B-3 Identification of objectives and criteria:

Objective: minimising the flood impact in the urban area.

Criteria: damage curves estimated based on local experience from stakeholders.

B-4 Scoring of the expected performance in comparison to the defined criteria: evaluation using the predicted flooding for each wall height.

B-5 Definition of weights for all criteria: the priority weighting was given to reducing the risk of flooding to properties (residential and commercial) followed by the associated damage costs.

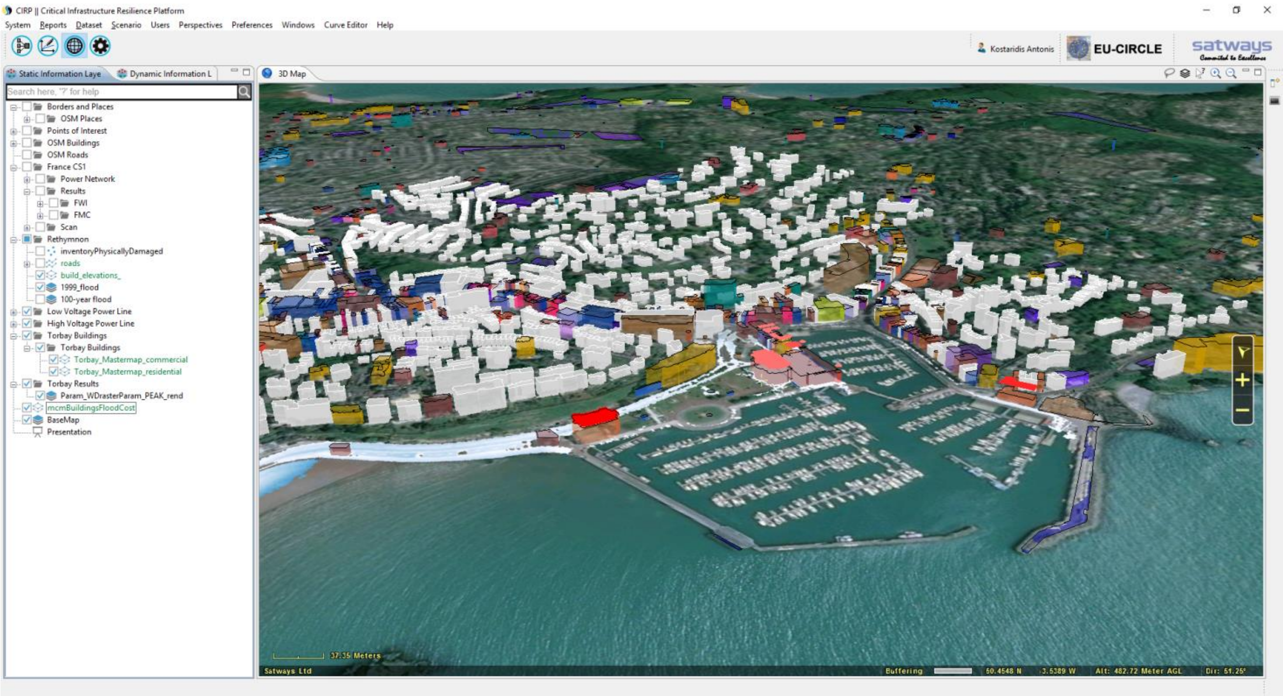
B-6 Computing the overall scoring/value for each adaptation option: the overall scoring and value for each adaptation option was carried out using damage curves and flooded areas.

B-7 Sensitivity analysis: Torbay Council had carried out a sensitivity analysis using different storm return periods (50, 75, 100, 200 and 1,000 year storm events). The overtopping rate for each storm event based on various secondary defence wall heights was calculated. For the objectives set for the adaptation measures the sensitivity analysis has resulted in the wall height for the secondary defence being 1.6m as this will result in an acceptable level of flooding.

4.2 CIRP and state of the science software

EU-CIRCLE developed the Critical Infrastructure Resilience Platform (CIRP). CIRP offers an end-to-end collaborative modelling environment (Figure 14) where new analyses can be added anywhere along the analysis workflow and where multiple scientific disciplines can work together to understand interdependencies, validate results, and present findings in a unified manner providing an efficient solution that integrates existing modelling tools and data into a holistic resilience model in a standardised fashion.

The final release of CIRP provides advance capabilities to the users, like the ability to create custom damage curves and mapping datasets via a Graphical Editor and the ability to read and visualize grid climate data.



3D View of flood impact results – Torbay case study.

Figure 14: UML deployment diagram of the CIRP software system

The “CIRP as built” has been made available to model likelihood, impact and risk analyses as well as the data type schemas utilized by these analyses (input / outputs). Overall more than 70 different analyses and external software have been implemented in the platform in support of the 5 case studies (Figure 15).

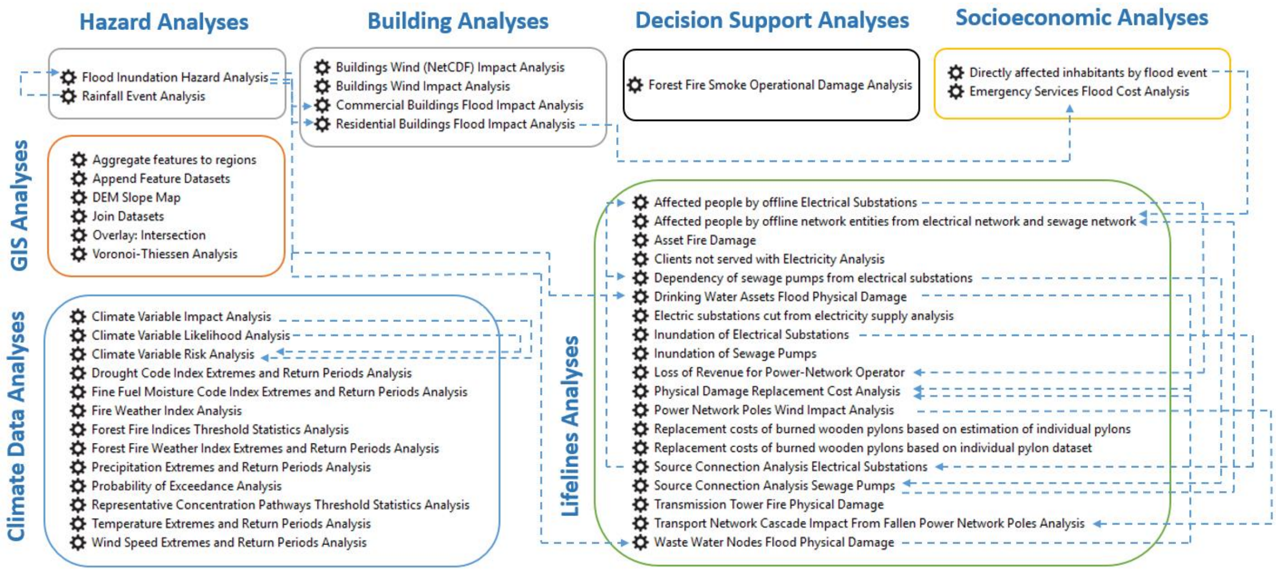


Figure 15: The CIRP analyses toolbox

Additionally, the consortium being fully aware of the difficulties that exist in obtaining accurate and reliable data for the scientific community, produced a unique reference test-bed with a fully functional set of CI and hazards. The **EU-CIRCLE Virtual city dataset** is a reference virtual environment that allows the research and scientific community to experiment in the area of assessing risk and resilience of infrastructures to climate pressures. It aims to serve as a testbed and provides a reference environment for future expansion. It has already been used effectively as a controlled environment for Simulating Interconnected (Critical) Infrastructures, Climate Hazards, Effects, and Risk/Impact Propagation through dynamic orchestration of models. It introduces a fully functional set of critical infrastructures in terms of assets and networks, geographically attributed and dimensioned taking into consideration the sizing, population, needs and demands of the virtual city. The data are contained in three main fields:

Main infrastructures (Figure 16): Drinking water network, Wastewater network, Electricity network, Oil network, Road network, Govermental buildings and Health Services

Auxilliary Data: Buildings, Topography, Vegetation and Fuel map

Hazard Data (Figure 17): Wildfire , Flood

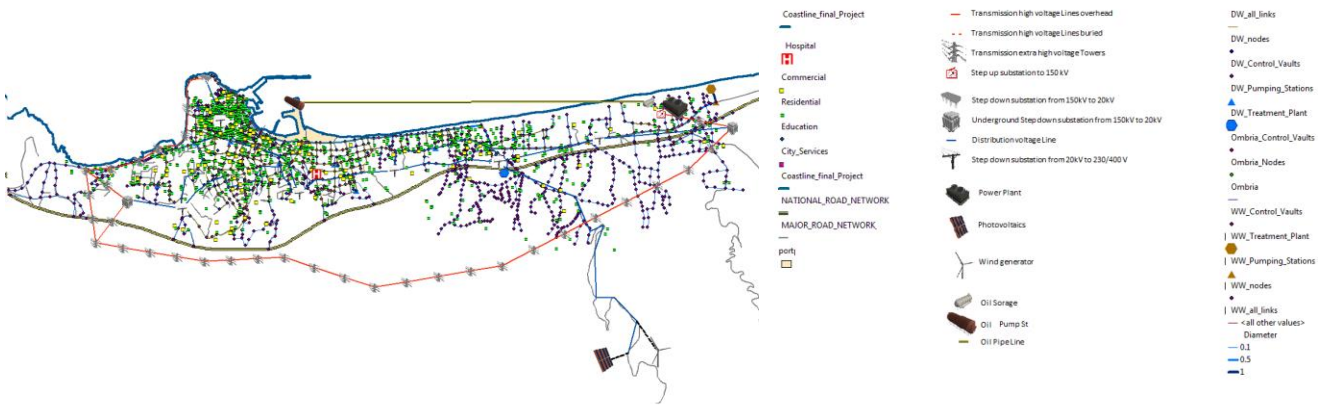
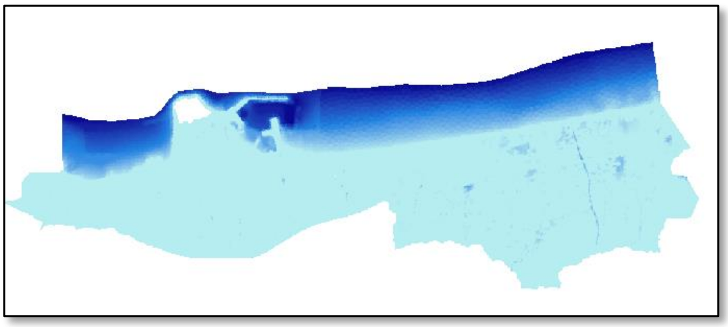


Figure 16. Virtual data set – networks georeference



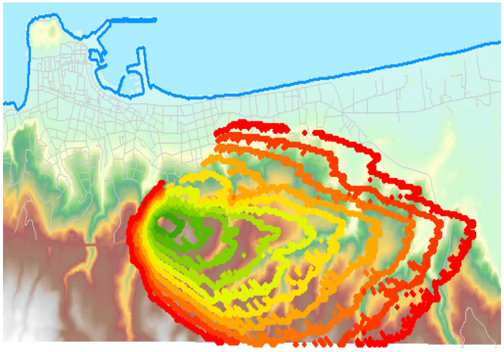


Figure 17. Flood (L)and wildfire (R) simulation in the virtual environment

The virtual environment data are publicly available through OPENAIRE: doi: 10.5281/zenodo.1408743

References:

Theodoros Katopodis, Athanasios Sfetsos, Vasiliki Varela, Stelios Karozis, Georgios Karavokyros, Georgios Eftychidis, Ilias Gkotsis, Georgios Leventakis, Ralf Hedel, Ifigenia Koutiva, Christos Makropoulos, EU-CIRCLE methodological approach for assessing the resilience of the interconnected critical infrastructures of the virtual city scenario to climate change, Energetika 64(1), pp 23–31, 2018

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