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EU-INTACT-case studies: Impact of extreme weather on critical Infrastructure

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Abstract. The resilience of critical infrastructures (CI) to Extreme Weather Events (EWE) is one of the most salient and demanding challenges facing society. Growing scientific evidence suggests that more frequent and severe weather extremes such as heat waves, hurricanes and droughts and their effects such as flooding are having an ever increasing impact, with the range and effects on society exacerbated when CI is disrupted or destroyed. Disruptions of CI systems frequently cause major social and economic losses, both directly and through failures in one system leading to disruptions in another (cascading effects). The ability to ensure continuity in services provided by CI directly relates to the resilience of communities to withstand and recover from disasters. The approach adopted by the INTACT-project recognizes that a European-wide coordinated and cooperative effort is required because of cross border CI-activities and impacts as well as an integrated EU-policy.

The INTACT-case studies and their expected outcomes are designed to bring added value for the concerned stakeholders locally and demonstrate the validity and applicability of the INTACT approach at the broader (European) scale. To achieve this, the selected case studies are geographically spread across Europe encompassing different climate, landscape and environmental zones, as to provide coverage of a representative range of CI types and also including different levels of governance.

One of the case studies is located in the Netherlands and deals with the port of Rotterdam. The situation in Rotterdam is representative for many other main ports in Europe. These ports are all situated in a delta area, near the sea and rivers or canals. Also, these ports are close to urban areas and industrial complexes. Finally, these ports have a multimodal transport infrastructure to and from its hinterland, which is also vulnerable for extreme weather events. The case study is not only significant for the development of methods and tools, but also of direct interest for the region itself. The combination of the National Water safety policy and the best practices from the INTACT cases offer challenges to create better adaptation options and coping capacity to these relatively unforeseen and unexpected impacts based on climate change scenario's and socio-economic megatrends.

1. Introduction and definitions to CI-vulnerability under natural disasters

The summer floods of 2007 in the UK (Pitt [1]) had a dramatic effect on electricity power substations, water and sewage treatment works, and the road and rail network. As a consequence of the events there was a strong possibility of the loss of power to 750,000 people leading to discussions about evacuation. Drinking water was lost to 350,000 people for up to 17 days. Tens of thousands of people lost power; some for more than two days, and tens of thousands of people were stranded as the road and rail networks ground to a halt.

From these lessons learned it is obvious that vulnerability of critical infrastructure due to flood hazards has a dramatic impact on the response and recovery processes of extreme events by non-functioning of CI.

This paper, as a result of the EU-FP7-Project INTACT, starts with a broader scope of multi hazard impacting Critical Infrastructure (CI). The project started with the development of a database on past EW-related events causing damage to CI in Europe. It encompasses 27 Extreme Weather Events (EWE) and more than 200 impacts on CI. The events cover data from Norway, Finland, Sweden, Germany, Spain and the USA with

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main effects on transportation (rail and road) as well as electricity (transmission). Respective key EW types are storms with extreme precipitation, extreme wind speeds, extreme temperatures as well as droughts causing floods, landslides and wildfires.

The definition of CI brings focus: Tightly coupled asset, network, system or part thereof located in Member states and subject to multiple hazards which is (perceived as) essential and provides non-substitutable services to maintain vital societal functions, health, safety, security, economic or social well-being of people. The disruption or destruction of these infrastructures for an extended period of time may have cascading effects across scales.

Vulnerability is the predisposition of exposed elements (e.g. infrastructures), as well as human beings and their livelihoods, to be negatively impacted by a hazard event. In most literature the vulnerability is more oriented to communities and individual citizen in less develop countries [2]).

Risk governance in the context of critical infrastructures embraces stakeholders, rules, conventions, processes, and mechanisms concerned with and governing risk. It is concerned with assessing, communicating and managing risks.

Finally building resilience of CI within the framework of the project is a logical step to get effective risk reduction. I.e. resilience for energy infrastructure refers to robustness and ability to recover operations to minimise interruptions to services. Resilience also implies the ability to withstand extraordinary events, secure the safety of equipment and people, and ensure the reliability of energy system as a whole.

As guidance to cover the whole range of measures the various elements of CI-resilience have been gathered in Table 1. They will become integral parts of the technical literature and will be easily found online [4, 9].

Characteristic	the ability to
Robustness	Absorb shocks and continue operating
Resourcefulness	Skilfully manage a crisis as it unfolds
Rapid Recovery	Get services back as quick as possible; and
Adaptability	Incorporate lessons learned from past events to improve resilience

Table 1. Overview and definitions of Characteristics within CI-resilience.

2. Project Approach

2.1 INTACT-project

INTACT is an EU funded project which aims to offer Decision Support to CI operators and policy makers regarding Critical Infrastructure Protection (CIP) against changing Extreme Weather Event (EWE) risks caused by climate change. The objectives for the INTACT-project are:

- Assess regionally differentiated risks throughout Europe associated with extreme weather;
- Identify and classify, on a Europe wide basis, CI and to assess the resilience of such CI to the impact of EWE;
- Raise awareness of decision-makers and CI operators about the challenges that current and future EW conditions may pose to their CI; and,
- Indicate a set of potential measures and technologies to consider and implement, for planning, designing and protecting CI or for effectively preparing for crisis response and recovery.

The expected impact of INTACT on an EU-scale is:

- bringing together climate researchers, meteorologists, first responders, with critical infrastructure owners, operators and planners;
- Measures should be suggested, in order to prevent major catastrophes and/or cascading effects;
- Simulations are to be performed and the effectiveness of the measures needs to be quantified to inform decision makers

The INTACT project will realise this through providing guidance how to determine future risks due to climate change, and best practices on protective measures as well as crisis response and recovery capabilities. The INTACT Wiki serves as the portal to this information.

Workpackage	Activities
Framing and Perspectives	Establishes an in-depth appreciation of the interface between Critical Infrastructure and Extreme Weather Events and develop a comprehensive understanding of the current state of the art, and provide contextual guidance and theoretical underpinning to other WPs
Climate and Extreme Weather	Collects and analyses trends up to 2100, patterns and tendencies in extreme weather and demonstrated in 5 selected case study regions.
Vulnerability and Resilience of European Critical Infrastructures	Develops a methodological framework for CI vulnerability assessment and an analysis of CI protection measures.
Risk and Risk Analysis	Develops methodologies and tools for risk management, highlights gaps in risk modelling and data availability and seeks for approaches and alternatives to close respective gaps.
Stakeholder Engagement and Dissemination	Collects and disseminates best practice approaches and brings together stakeholders.
Case Studies	Performs five case studies to gather their needs and test the developed methods.
INTACT Wiki	Composes all information and knowledge gained within the project into a comprehensive and yet practical guide for CI operators and associated policy makers.

Table 2: Summary of activities in various INTACT-work packages

2.2 Introduction to INTACT cases

The INTACT project incorporates five case studies, each based in different European countries in order to attain different regional settings and extreme weather conditions. The INTACT team prepares and organises workshops with stakeholders and organisations in different regions and with different responsibilities for CI (see for example [6]).

The cases provide requirements, to develop a chain of tools and test a Wiki-based support method for decision making. The stakeholders are engaged in the project to give information on EWE-indicators, Vulnerability factors and existing measures to reduce the impact of EWE (early warnings, Exceeding thresholds for various threats (like water depth, wind speed) and trigger levels for measures to keep up the level of services provision). By using questionnaires information has been collected and used to fill the risk framework and perform gap analyses with respect to simulation methods or Cost Benefit Analysis-tools.

2.3 Stakeholders

Stakeholder engagement during local workshops was supported by methods to reach interaction between stakeholders (CI-owner, CI-operator, and CI-user) on all levels from local to National and EU-sectorial organisations. This has resulted in knowing the system (i.e. CI- chain from production, distribution to users) and responsibilities of CI-owners and operators, systems vulnerability for multi-hazard. Special attention was paid to contingency plans and sharing of responsibility for cascading effects.

Methods used are:

- a quick scan for risk assessment, based on the ROADAPT Quick Scan methodology [10], that is used to gain insight in the top risks,
- the CIrcle tool [8] in order to gain insight in cascading effects,
- a storyline approach in order to gain understanding of best practices and requirements for risk reduction.

Important for interaction is the geographical information like hazard maps, vulnerable CI and social exposure. Questionnaires were used to gather detailed information on CI and risk methods.

The expected responsibilities and the areas where INTACT will offer support is well expressed in figure 1. The support accessible through the INTACT-Wiki will be scaled to an EU-level.

Figure 1. Basic elements of responsibilities of CI-owners, operators and authorities for reduce risks in multi-hazards situations.

3. Risk framework

The INTACT project has adopted the IEC-standard for the risk framework (see figure 2). It covers the complete range of activities in the case study to gather relevant information and it is also the guidance framework in the INTACT Wiki tool for decision support. This includes modelling and risk structure for simulation of hazards on infrastructure operations and testing mitigation to support decision making by CI owners and operators.

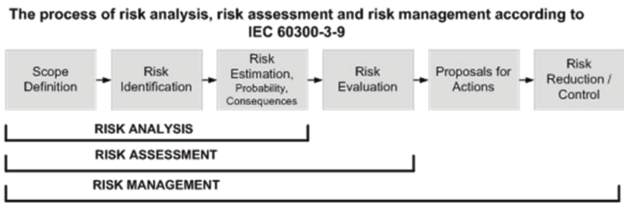

Figure 2. Intact RISK-Framework

The activities related to the INTACT Risk Framework show the following elements:

<u>Risk analysis and assessment</u>

- Climate and extreme weather: EW-data and indicators, historical trends and Regional climate model performance, future scenario's for EW-indicators
- CI/EWE assessment: Risk Process, Hazard and hazard exposure models, Vulnerability analysis and methods, Risk evaluation and impact assessment, Assessment of present and future measures and methods

<u>Risk management</u>

- Guidance and best practices: Guidance on EWE and CI, Gap analysis, Best practices from INTACT Case studies, Data requirements, Intact database

on historical disasters with CI, CI-vulnerability and resilience factors and future changes.
- Governance, Legislations and Regulations, Standards on National and EU-levels

The definitions and taxonomy of various terms concerning risk in the project are based on figure 3. CI-related impact of EWE has social consequences in terms of expected annual damage.

For EWE/Hazards input from meteorological and climatological models with expected precipitation of wind speed hydrological and hydrodynamic models is used. Water depth for specific return periods resulting in pluvial, fluvial or coastal flooding, flash floods or landslides are dealt with in the INTACT case studies. These hazards with direct consequences: loss of human life, damage to property, destruction of crops, loss of livestock, and deterioration of health conditions owing to waterborne diseases. Indirectly, a hazard can affect the function of a wide range of critical infrastructure. Indirect effects are characterized by the event affecting the performance of critical infrastructure, which in its turn affect the health, safety, security or economic or social well-being of people.

The exposure is explained as “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.

For INTACT, it is important to include vulnerability as part of the risk and define it as a function of susceptibility and capacities of response (see figure 3).

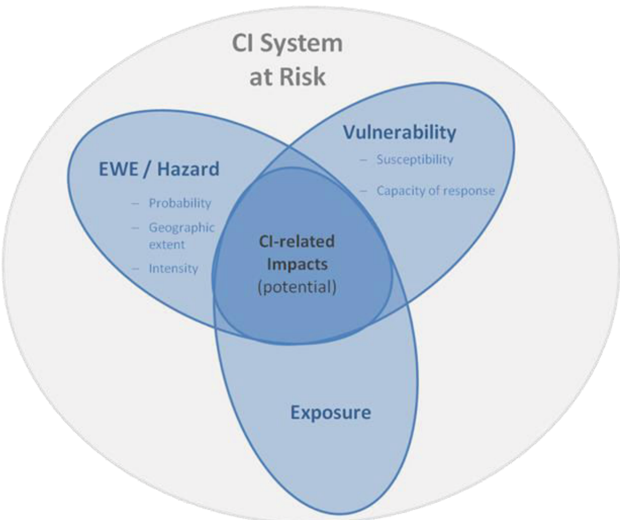

Figure 3. Schematic explanation of CI-Risk elements

Impact/consequences: Electricity generation, transport and distribution can be hampered or deliberately shut down to avoid electrocution. Transport modes (road, rail, pipelines for oil and gas) can be damaged or rendered inoperative, with ICT and telecom infrastructures extremely susceptible and vulnerable to flooding. Production and distribution of drinking water can be affected and crops and livestock are lost in food production. Water management infrastructures can be damaged by water levels beyond their design, access and availability of health care can be compromised, electronic payment systems can fail and transport nodes (such as airports and stations) and connections (such as roads and rails) lose their function if flooded. The loss of many infrastructures can in their turn hamper the crisis response of Public and legal order and safety sector.

4. Case study Port of Rotterdam (NL)

4.1 Scope definition

The Rotterdam Port area forms a good case study location. It is located in a delta area, near the sea and major rivers. Like other European ports (including Antwerp, Hamburg, Valencia and Le Havre) it is understandably vulnerable to EWE. As such there is good reason for looking at a representative port such as the one at Rotterdam to analyse various CI impact scenarios. In this regard, the project examines the current status of the EWE and CI hazards in detail, the risk analysis performed for the current climate situation and mitigation scenarios, analysis of future risks, and finally an assessment of measures and strategies to alleviate these risks. There are several Dutch authorities involved in the region and the transport activities, the Port of Rotterdam Authority, ProRail (rail owner), Rijkswaterstaat (road and waterway owner), LSNed (pipelines owner), EVO (branch organisation of transport operators) and the safety region S-Holland-S (first responder). Each of these organisations fully supports the case study. Detailed information and experiences gained in the case study can be found here.

In the comparison to other case studies the situation in the Netherlands with the high protection level against flooding has more focus on economic losses. The extreme weather events which affect the port of Rotterdam in the Netherlands can be relatively diverse. Indeed, several types of impacts of hazards on critical infrastructure can be identified, both culminating in long and short term effects. This is not surprising given that the Rotterdam area has a multi-modal transport network connected with the port hinterland as well as urban areas and industrial complexes close by. Given the range in types of CI in place, there is more room for different types of EWE to make an impact (power supply and telecommunication network, Emergency coordination centres, Industry and hospitals).

4.2 Problem exploration and risk analysis

During a stakeholder workshop various tools were used to get access to or information during the discussion on cascading effects (CIrcle-tool [8]) and ranking risk semi quantitative. Based on identification of direct impacts, Cascading impacts, Disruption/Damage – indicators, Response actions, ranking high, medium and low impacts, definition of consequences the top three CI/EWE combinations with high risk has been selected for more detailed quantitative analysis (see figure 4 for ranked risk).

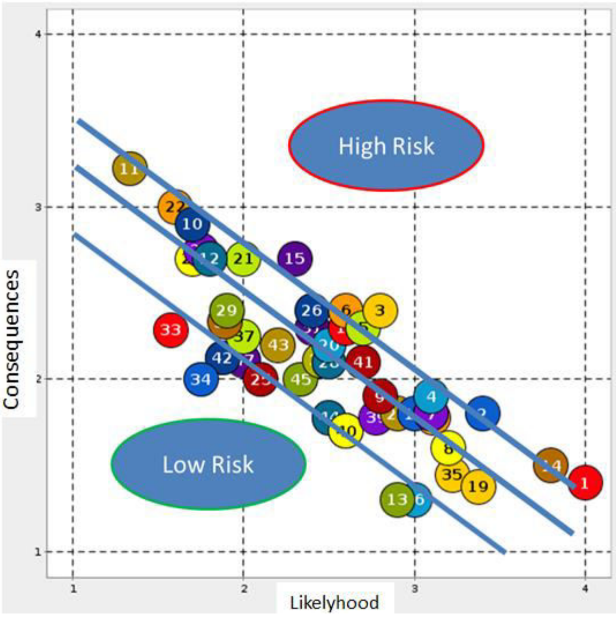

Figure 4. Ordering of risk EWE/CI combination. Numbers represent specific identified unwanted events specified by stakeholders during a workshop for the port of Rotterdam (#1 frequent storm and precipitation resulting in traffic jams; #11 severe flooding with long term failures in power supply)

Common problems to the port of Rotterdam can originate from storms and heavy rainfall, local flooding as induced hazards leading to disruptions in the port and transport operations, damages and power outages. Disruptions in the transport chains at the port can have costly ramifications locally, regionally and nationally. Extreme weather has also continuously impacted upon shipping commerce and has necessitated closing the port. On the long term more frequent disruptions lead to adverse market position of the port of Rotterdam. Extremes with long lasting disruption (more than one week) can lead to blockage of goods to the international hinterland (i.e. raw materials for German steel industry).

City of Rotterdam is also ambitious under the Rockefeller Initiative of 100 resilient cities [12] to be climate prove on all natural threads. This makes it easier to combine the ports commercial activities and urban community to build resilience and reduce impacts of potential change in risk reduction approach (adaptive Delta scenarios, Haasnoot [13]). It will result in measures where governance becomes more important by combining Flood mitigation (i.e. room for the river - focussing on robustness and reducing CI physical vulnerability) with building (community) resilience (i.e. operational response action and self-reliance for citizens)

4.3 Results and Lessons learned

Problem exploration and Risk identification was effectively arranged by a stakeholder workshop using quick assessment tools and maps with relevant geographical information on hazards and CI-networks.

Proposals for action/ Risk reduction control should be based on Multi-hazard and best practices in sectorial CI-business continuity and preferable embedded in a National risk assessment for CI. Governance on National level should bridge the gap in quantative assessment of risk and stimulate cross sectoral approaches at EU-level.

With focus on flooding affecting our critical infrastructure and considering ways in which the resilience of CI- systems can be enhanced:

- taking a systematic approach to reducing disruption to our essential services;
- understanding the level of risk that is tolerable;
- delivering greater resilience in critical infrastructure;
- minimizing the permanent loss of essential services;
- enabling better emergency planning through information sharing and engagement; and
- effective water management (droughts and extreme rainfall)

What is lacking for decisions on preventive and adaptive measures in risk management is: Cost-Benefit Analysis (CBA) and Cost-Effectiveness Analysis (CEA) of e.g. lower thresholds due to climate change; and with Multi-Criteria Decision Analysis (MCDA) including not only economic efficiency/effectiveness but also criteria like equity and institutional operating capacity, which might vary between countries.

5. INTACT Wiki

The INTACT project will result in a Wiki-tool which Composes all information and knowledge gained within the project into a comprehensive and yet practical guide for CI operators and associated policy makers.

The ultimate objective of the INTACT project is to create a set of best practice guidelines with accompanying supporting methods and tools to aid policy makers, decision makers and other stakeholders concerned with the operation and development of CI to establish and strengthen durable and lasting resilient infrastructure.

An overview of examples of adaptation or mitigation measures along the disaster cycle steps as part of a risk reduction strategy and to be used for building resilience consist of clusters:

- Mitigation: Minimizing the effects of disasters by Prevention, Protection
- Preparedness: Planning how to respond
- Response: Efforts to minimize the hazards created by a disaster and Damage Control
- Recovery: Returning the community/infrastructure to normal
- Reconstruction, Rebuild: Improve resilience for next EWE

6. From national to EU-scale

Five case studies have been conducted with varying CI-Hazard combinations. Regarding the risks due to failing CI during EWE, the cases show different levels of awareness and governance. As such risk reduction can be established at various levels of the physical, socio-economic and environmental assets.

The risk mitigation measures at the preparation, response or recovery phase need governance at local, regional and national level. The EU-level has shown good practices by the Flood directive. The experiences on national level should be linked to a sector approach for CI- continuity, robustness and resilience on EU-level.

Such a sector approach on EU-level for CI-owners and operators has already taken place for roads regarding climate change adaptation (CEDR-ROADAPT [10]). It concerns assessments of vulnerability and impact, which together with the cause (climate change) results in a climate change risk profile for National Road Authorities. When the level of acceptable risk is exceeded, risk mitigation measures need to be taken. Guidance into these measures is provided in a guideline in which ten steps are used that a road authority can use to get to an appropriate adaptation strategy (ROADAPT [11]):

- Identify the road owners' needs
- Identify damage mechanisms, design models, climate parameters
- Assess the resilience of the asset in the current and in the future situation
- Identify adaptation measures and policies
- Assess consequences of measures
- Select adaptation strategies
- Identify stakeholders to be involved
- Identify knowledge gaps in climate change projections, adaptation technologies and essential data
- Develop technology roadmaps using the time to market of innovative adaptation technologies

Adaptation measures are structured according to their applicability in a phase in the disaster risk cycle (ranging from pro-active to reactive) and different categories (planning, robust construction, legislation/regulation, resilient construction, maintenance and management, traffic management, capacity building, monitoring and research). Different strategies are possible: the 'do minimum' and 'develop contingency plans' strategies, the 'future proof designs', 'retrofit solutions' and 'update operating procedures' strategies, the 'monitoring' strategy and finally the 'extra research' strategy.

Specific characters of CI financial arrangement on Public-Private partnership for design, construct, operate and maintain national road systems

7. Setting a framework for financing resilience (World Energy Council)

Adaptation measures often lack regulatory or legal guidance regarding the necessity to increase resilience. There is currently no agreed goal or metric for adaptation, or specific responses to extreme weather. Nor is there agreement on how much resilience is sufficient and how increased resilience can be related to an additional revenue stream and so become attractive for investors. Government and regulators should implement regulatory frameworks to clearly define the levels of resilience required for energy infrastructure. This could enable the finance sector to create suitable financial vehicles which would help the private sector to carry their responsibility in resilience. Currently institutional investors like pension and insurance companies cannot invest substantially in energy infrastructure because of solvency regulations. Introducing a new asset class that includes long-term investments in infrastructure can make large funds available for future energy supplies. With greater transparency, insurance companies and banks could take advantage of extreme weather risks to create unique financial vehicles that help fill project financing gaps. Long-term and institutional investors could use this approach to overcome regulatory restraints by incorporating extreme weather and climate in investment planning, by using responsible investment standards, to help de-risk energy investments, see [3].

8. Call to action

Increasing the resilience of energy infrastructure to extreme weather events is not an option – it is a must. While stakeholders are driven by diverse objectives, everyone has a role to play, and there are some common obstacles to be overcome together to ensure that energy supply is secure and reliable, now and in the future. The energy system will only be able to play its crucial role as the backbone of the global economy if all stakeholders work together. Continuity Plan for disturbance of power supply or ICT connections including the guaranty of safety for CI-users. Citizens during extreme events are vulnerable due to absence of live saving condition. Contingency planning during long lasting CI-disruptions, coping capacity and training/ exercising of 1st responders and disaster management experts are no-regret measures.

9. Discussion

High level of knowledge on climate change and real action to adapt to climate change happens at the national, regional, and local levels. Still, many member states and local governments which are proactive in identifying how extreme weather affects transportation, have not yet integrated climate change challenges into their planning and operations. Increase of societal resilience by offering better operational perspectives should not wait for the next disaster.

It is important to realise that national Infrastructure has an important role during evacuations related to natural disasters. Even a multi-hazard evacuation scenario is giving constrains to CI.

In relation to flooding evacuation by leaving the exposed area means explicit decisions on the measures to fulfil requirements for national roads under predicted thread of a flood scenario. In case of vertical evacuation (staying in the area under thread) the requirements for CI in safe heavens or private houses needs to be taken into account for procedures of rescuing citizens from their house. It means a good communication strategy for informing persons at risk on their possibilities for action and operation of first responders. It concerns the present of primary needs to survive a number of days (information provision, heating, drinking water, food supply, etc.)

These measures for an evacuation scenario can be incorporate as part of asset management for single transport mode or an optimized approach for combinations of modes of transport (rail, road, and shipping).

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