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JRC SCIENCE FOR POLICY REPORT

Recommendations for National Risk Assessment for Disaster Risk Management in EU

Approaches for identifying, analysing and evaluating risks

Version 0

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Abstract

Decision No 1313/2013/EU on a Union Civil Protection Mechanism (UCPM) calls Participating States to develop risk assessments periodically and make the summary of their National Risk Assessment (NRA) available to the European Commission as a way to prevent disaster risk in Europe. In order to facilitate countries on this task, the European Commission developed the Guidelines on risk assessment and mapping. In spite of these, the summaries received have revealed several challenges related to the process and the content of the assessments.

The current report aims to provide scientific support to the UCPM participant countries in their development of NRA, explaining why and how a risk assessment could be carried out, how the results of this could be used for Disaster Risk Management planning and in general, how science can help civil protection authorities and staff from ministries and agencies engaged in NRA activities. The report is the result of the collaborative effort of the Disaster Risk Management Knowledge Centre team and nine Joint Research Centre expert groups which provided their insight on tools and methods for specific risk assessment related to certain hazards and assets: drought, earthquakes, floods, terrorist attacks, biological disasters, critical infrastructures, chemical accidents, nuclear accidents and Natech accidents.

The current document would be improved by a next version that would include scientific guidance on other risks and the collaboration of potential users.

Executive summary

The purpose of this report is to provide a scientific support to Union Civil Protection Mechanism participating states and national authorities in charge of the preparation of National Risk Assessment process as well as disaster risk management planning in general. The scope of the report is to collect scientific contributions to the potential update of the guidelines "EU Risk Assessment and mapping guidelines for disaster risk management" (Commission Staff Working Paper, 2010). The focus of the report narrows down into recommendations in terms of instructions for robust and usable approaches for the risk assessment process in the context of National Risk Assessment to inform disaster risk management planning. Potential users of the document are civil protection authorities and ministries at European countries engaged in the National Risk Assessment process, and indirectly also technical staff and policymakers from agencies as well as research groups dealing with disaster risk reduction issues. The overall aim is to maximize the national capacity of a country in achieving the objectives National Risk Assessment process with the current knowledge, best available data, and already existing risk information.

Policy context

Decision No 1313/2013/EU on a Union Civil Protection Mechanism[1] (UCPM) calls participating states to **develop risk assessments periodically** (by 22 December 2015 and every three years afterwards) and make the summary of their National Risk Assessment (NRA) available to the European Commission every three years.

National risk assessment processes should be fully embedded in the national sustainable development strategies, and they should address all relevant issues and EU directives/policies, such as:

- The EU Flood directive (Directive 2007/60/EC)
- The Seveso III directive (Directive 2012/18/EU)
- The European programme for Critical Infrastructure (Council Directive 2008/114/EC)
- EU Solidarity Fund (Council Regulation (EC) No 2012/2002)
- EU strategy on adaptation to climate change (COM(2013)216)
- Directive on serious cross-border threats to health (Decision No 1082/2013/EU)
- The European programme for Critical Infrastructure (Council Directive 2008/114/EC)
- Council Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation
- Council Directive 2014/87/EURATOM amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations.

At a global level, by reinforcing a risk-informed approach to policy-making, the EU is contributing to the implementation of the UN Sendai Framework for Disaster Risk Reduction, the Paris Agreement on climate change, the New Urban Agenda, and the overarching UN 2030 Agenda for Sustainable Development.

[1] UCPM legislation is undergoing the revision process to strengthen EU civil protection response capacities to disasters with rescEU and stepping up disaster prevention and preparedness.

Main findings

National Risk Assessment (NRA) is a **demanding process** and presents a challenge for each and every Member State in terms of resources, time and complexity. The complexity is introduced through the **multi-disciplinary** nature of the disaster risk assessment that requires the involvement of many affected sectors and parties from different communities to consider their perspective, information, experiences and knowledge. The NRA process aims to **find a common understanding** with all relevant stakeholders of the risks faced and their relative priority in a transparent way to make disaster risk management (DRM) planning efficient and to **increase the country's resilience** in a steady but timely manner.

National Risk Assessment is a compound of many processes of risk assessment. Different hazards as well as different assets require very different analysis of their risk. In order to support the integrated DRM approach there is a need to compare risks across hazards and to understand the different drivers of risk. From a scientific point of view we are facing two main challenges:

1. having consistent disaster risk assessment processes where risks arising from different hazards as well as the consideration of different assets can be compared or aggregated;
2. having the understanding of how underlying risk drivers and capacities define the level of risk.

Key conclusions

Risk comparability should be treated in the context of risks in a multilayer single-hazard framework. Knowing the differences among risk assessment approaches related to different hazards/assets will eventually help us to find the most appropriate framework covering all hazards/assets in terms of terminology, set of methodologies, risk metrics, data needed and results required for further treatment of risk. Harmonising and standardising the assessment as well as the risk metrics among different hazards is the first step towards a multi hazard assessment. For multirisk assessment approach better understanding of the interactions between the hazard (cascading effects) and the different vulnerability levels is required.

The issues regarding **better understanding of underlying risk drivers and capacities** can be dealt with a better knowledge base of the risk, the availability of data to describe the hazard, the exposure and vulnerability as well as the development of the risk analysis methodologies that enables to model the links between underlying risk drivers and capacities, risk components and risk levels. The disaster loss databases are of major importance. For example, by using losses from past events it is possible to identify and quantify a wide range of socio-politic-economic as well as physical drivers associated with the vulnerability.

Related and future JRC work

The Disaster Risk Management Knowledge Centre (DRMKC) aims to provide Participant States in the UCPM support to carry out disaster risk management activities. This report starts the process of involving the scientific community to help overcome obstacles that national authorities in charge of the preparation of the NRA process are confronting. DRMKC is providing also a database of DRM research projects and results (Project Explorer), running a process of publishing periodic Science reports (Science for DRM 2020) to create a collective knowledge base in a format to be used by disaster risk management authorities, such as civil protection and policy-makers. DRMKC is developing a holistic repository of risk information (Risk Data Hub) to link research results with policies, disaster loss data (past) with risk assessment (future), and governance at European with local level as well as supporting the development and monitoring of disaster risk reduction (DRR) strategies.

This report is the result of the collaborative effort of the Disaster Risk Management Knowledge Centre team and 9 Joint Research Centre expert groups from 5 different units (E1, E2, E4, E7, G10) to cover drought, earthquakes, floods, terrorist attacks, biological disasters, critical infrastructures, chemical accidents, nuclear accidents, and Natech accidents risks. Expert groups provide structured advice for risk assessment in a single-hazard framework. In forthcoming versions (this is Version 0) the focus will be shifted to the assets to be protected. Potential impacts on specific assets arising from different hazards will be compared, calling for stronger collaboration among different expert groups. The aim is to find common risk metrics and making multihazard risk assessment feasible. Next version will expand in a number of disaster risk scientific communities involved to introduce risks herein not mentioned, such as **forest fires risk, extreme weather risk, cyber security risk or hybrid threat**, that are also identified among the most frequent disaster risks among Member States (MS) according to the last EU risk overview (Commission Staff Working Paper, 2017).

Quick guide

This report attempts to answer the question of why and how to do a risk assessment, how to use the results of risk assessment within the NRA context and how science can help. First, we discuss what the NRA is, the role of risk assessment processes therein, and how to tackle the whole process at the national level. Then we introduce the risk concept and risk metrics to establish the common understanding of risk and identify the most important scientific inputs for the disaster risk management planning. Afterwards, we describe the common steps in risk assessment process based on ISO 31010 (2018) to improve the coherence and consistency among the risk assessments and eventually assure that different risk assessment processes fit into NRA and as such, NRA could provide a useful output for decision makers in the process of disaster risk management planning. Then we summarize the challenges of different expert groups. Finally, the contributions of 9 expert groups explain the process of disaster risk assessment related to certain hazard or certain assets in the following order: drought, earthquakes, floods, terrorist attacks, biological disasters, critical infrastructures, chemical accidents, nuclear accidents and Natech accidents.

1 Introduction

Decision No 1313/2013/EU on a Union Civil Protection Mechanism[2] (UCPM) calls participating states[3] to **develop risk assessments periodically** (by 22 December 2015 and every three years afterwards) and make the summary of their National Risk Assessment (NRA) available to the European Commission every three years. NRAs identify and assess the disaster risk of the natural and man-made hazards, which would require a response at a national or supra-national level. The aim of the periodic reporting is to promote an effective and coherent approach to prevention of and preparedness for disasters by sharing non-sensitive risk information and best practices within the Union Mechanism.

In 2011 the Council[4] asked the Commission to develop an **overview of natural and man-made disaster risks** in the EU based on national risk assessments. Based on the documents shared by Member States in 2013 (first exercise), the European Commission produced the first overview of the risks that EU may face (Commission Staff Working Paper, 2014) and based on the documents shared by Member States in 2015 (second exercise), the European Commission produced already the second overview (Commission Staff Working Paper, 2017). NRAs are, therefore, the most important disaster risk evidence for identifying the landscape of disaster risks across Europe which is an essential input to reinforce the collective ability to prepare and respond to disasters in Europe. Most importantly, NRAs also ensure a common understanding, with all relevant stakeholders, of the risks faced in a country and their relative priorities. The evidence extracted from the exercises serve as base for an integrated approach to disaster risk management, linking prevention, mitigation, preparedness, response, recovery, restoration and adaptation actions.

In order to facilitate Member States' actions in these areas, the Commission developed the **guidelines** "EU Risk Assessment and mapping guidelines for disaster risk management" (Commission Staff Working Paper, 2010) in a concerted action with Member States to ensure better comparability between methods and results.

The last NRA reporting revealed how challenging it was for Member States (MSs) to do National Risk Assessment despite the guidelines due to the diversity in disaster risk management (DRM) governances that are in place around Europe, and, most importantly, due to the different level of available risk information (hazard, exposure, vulnerability, coping capacity, disaster losses) and experiences from the past risk assessment efforts in each country. Especially the latter can benefit a lot from the scientific input. So enhanced disaster risk understanding would make the follow-up decision making more evidence based. The more complete and advanced the NRAs are the more effective the exercise is in both, at the National and the European level. MSs have already expressed through different meetings the need for an updated and more detailed version of the guidelines that date back to 2010.

The first in a series of periodic reports "Science for disaster risk management 2017: knowing better and losing less" [Poljanšek et al., 2017] started the continuous process of **summarizing knowledge** globally across the disciplines and made it available to the DRM community. In the light of this report the process of risk assessment calls for a more collaborative approach across sectors, a multihazard risk assessment, and more tools for prioritizing and for risk mapping to help policymakers to develop evidence base regional and global disaster risk reduction (DRR) frameworks. All of these require extra

[2] The European Union Civil Protection Mechanism (UCPM) was established to promote swift and effective operational cooperation between national civil protection services. It has two main objectives. Firstly, it aims to strengthen the cooperation between the Union and the UCPM's Participating States (Member States plus six non-EU countries). Secondly, it aims to facilitate coordination in the field of civil protection in order to improve the effectiveness of systems for preventing, preparing for and responding to disasters (EN, 2016).

[3] In this report Member States (MSs) will refer to participating states of UCPM

[4] Council conclusions on a Community framework on disaster prevention within the EU, 2979th Justice and Home Affairs Council meeting, Brussels, 30.11.2009.

resources and expertise to take up new challenges such as data, standards and guidelines, risk assessment methodologies and risk metrics, for better understanding of limitations and uncertainty. Therefore, it is important to take necessary action not only to improve knowledge base on disaster risks but, above all, facilitate the sharing of knowledge, the results of scientific research, best practices and information which is already identified as the main prevention priority of the UCPM as well as of the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015).

Many of these challenges have been tackled by the **Disaster Risk Management Knowledge Centre** (DRMKC), an initiative of the European Commission launched in 2016. The DRMKC provides a networked approach to the science-policy interface in disaster risk management fostering partnership, collective knowledge and innovative solutions. The DRMKC brings together different European Commission's services, European countries and different communities, experts, practitioners and policymakers, within and beyond the EU dealing with disasters to manage disaster risk in a more coordinated way, linking prevention, mitigation, preparedness, response, recovery, restoration and adaptation actions. The DRMKC aims to integrate and consolidate existing scientific multi-disciplinary knowledge to provide solutions for existing needs as well as to identify gaps to guide new research programs. The DRMKC also addresses cross-cutting topics to allow an enhanced coordination across policies to increase their effectiveness.

The DRMKC fosters **partnership**, co-develop **collective knowledge** and support **innovative solutions** through a variety of activities which can in many ways benefit the NRA process. DRMKC is providing a database of DRM research projects and results (Project Explorer[5]), is running a process of publishing periodic Science reports (Science for DRM[6]) to create a collective knowledge base in a format to be used by disaster risk management authorities, such as civil protection and policy-makers, and is developing holistic repository of risk information (Risk Data Hub[7]) to link research results with policies, disaster loss data (past) with risk assessment (future), and governance at European level with local level as well as supporting the development and monitoring of DRR strategies.

1.1 The purpose, scope and the focus of the report

The purpose of this report is to **provide scientific support** to UCPM participant countries and national authorities in charge of the preparation of the NRA process as well as to as well as to link the NRA exercise to the whole disaster risk management planning.

The scope of the report is to collect scientific contributions to the **potential update of the guidelines** "EU Risk Assessment and mapping guidelines for disaster risk management". The main goal of the guidelines is to improve coherence and consistency among the risk assessments undertaken in the Member States at national level and to make these risk assessments more comparable between the Member States. In view of this, the objectives of existent guidelines are still relevant and can be used as an input for this report, especially if brought up to date:

- improve the use of good practices and international standards across the EU and help to gradually develop coherent and consistent risk assessment methodology and terminology;
- enhance coherence across the different disciplines dealing with disaster risk assessment;
- provide a risk management instrument for disaster management authorities, and also other policy-makers, public interest groups, civil society organisations and

[5] https://drmkc.jrc.ec.europa.eu/knowledge/Projects-Explorer#project-explorer/631/projects/map
[6] https://drmkc.jrc.ec.europa.eu/knowledge/Challenges-Sharing
[7] https://drmkc.jrc.ec.europa.eu/risk-data-hub

other public or private stakeholders involved or interested in the management and reduction of disaster risks;

- inform the debate in international fora (Sendai Framework for Disaster Risk Reduction, Sustainable Development Goals, UNFCC Paris Agreement);
- contribute to the development of knowledge-based disaster prevention policies at different levels of government and among different policy competencies, as national risk assessments involve the integration of risk information from multiple sources;
- inform decisions on how to prioritise and allocate investments in prevention, preparedness and reconstruction measures;
- contribute to the raising of public awareness on disaster prevention measures;
- contribute to a risk assessment and mapping process across the EU which can serve as a basis for the overview of the major risks the EU may face in the future;
- contribute to the information required to establish an assets database for emergency assistance.

The focus of the report narrows down into recommendations in terms of **instructions for robust and usable approaches for the risk assessment process** in the context of NRA to inform disaster risk management planning.

Our aim is to make NRA relevant, robust, sound and technically accurate (Abt et al, 2010). Based on the review of NRAs given by countries at 2015 (Commission Staff Working Paper, 2017), it was concluded that:

- The dynamic nature of risk is not well covered, not considering how the risk factors change, and how those support DRM planning and finally action.
- Emerging risks are not always identified.
- The scope of the exercise in time is too short to facilitate prevention and cross-sectorial/trigger events.
- Quantitative approaches should be boosted in order to replicate and compare results at EU level.

Potential users of the documents are principally civil protection authorities, ministries and agencies, and research groups at European countries engaged in the NRA process. The aim is to maximize the national capacity in achieving the objectives above with the current knowledge, best available data, and already existing risk information in the country.

1.2 The structure of the report

The report answers the question of (1) why and how to do a risk assessment, (2) how to use the results of risk assessment within the NRA context and (3) how science can help. The report is the result of the collaborative effort of the Disaster Risk Management Knowledge Centre team and nine Joint Research Centre expert groups who provided their insight on tools and methods for specific risk assessment related to certain hazards and assets.

The first chapter provides the introduction, the second chapter discusses what the NRA is, the role of risk assessment processes within, and how to tackle the whole process at the national level. The third chapter introduces the risk concept, the importance of the risk metrics in order to establish a common understanding of risk and identifies the most important scientific input for the disaster risk management planning. The fourth chapter describes the common steps in risk assessment process based on ISO 31010 (2018) to improve the coherence and consistency among the risk assessments and eventually assure that different risk assessment processes fit into NRA. The fifth chapter summarizes the challenges put forward by different expert groups. Finally, their contributions on specific risk assessment related to certain hazards or certain assets are introduced in the chapters 8-16 in the following order: drought, earthquakes, floods, terrorist attacks, biological disasters, critical infrastructures, chemical accidents, nuclear accidents and Natech accidents[8].

[8] Natech accidents are natural-hazard triggered technological accidents

2 National Risk Assessment

In order to reach a **common understanding among stakeholders** of the risks faced in a country, NRAs identify and assess natural and man-made disaster risks that require a response at national or supra-national level. NRAs should enable to understand:

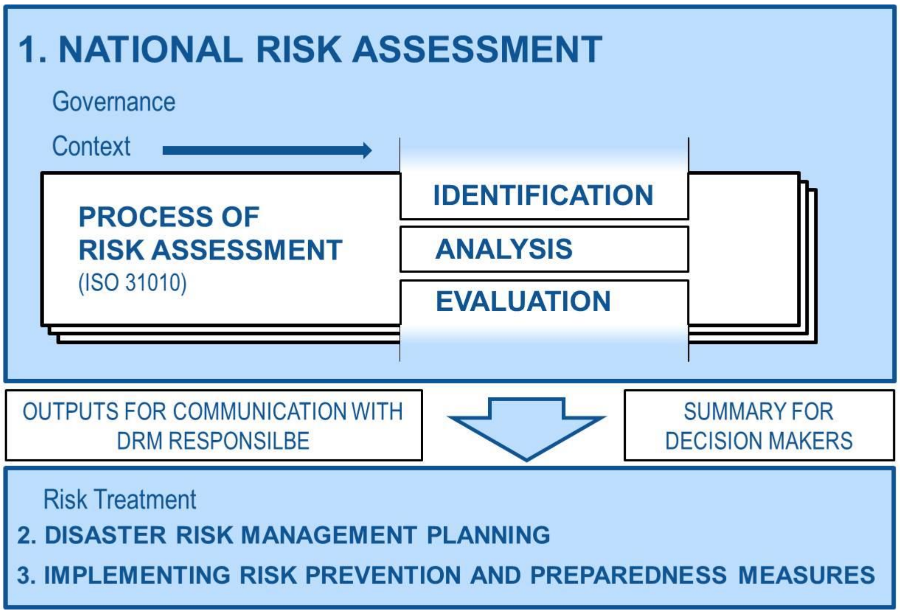
- the relative importance of different risks for a given country,
- how underlying disaster risk drivers relate (Chapter 3) to components of risk to address a range of measures to reduce risk.

Only then, the design of DRM policies, regulations and measures can be prioritised to optimally arrive to societally acceptable levels of risk and the resources to manage disaster risk are efficiently allocated.

Risk is treated particularly to the hazard that materializes and impacts the assets, if possible, and at the level of asset, considering the characteristics of it when facing a hazard.

The related actions would encompass considering the asset and the hazard that emerge in the different phases of DRM (prevention/mitigation, preparedness, response and recovery).

Figure 1. *UCPM strategy for disaster risk management planning: National Risk Assessment (point 1) and Risk Management Capability Assessment (point 1, 2, 3)*



Source: Authors

National risk assessment is a process much wider than the process of assessment of one risk (**Figure 1**). National Risk Assessment is a compound of **many** processes of risk assessment. Different hazards as well as different assets require very different analysis of their risk. To ensure the successful aggregation of the results of different risk assessment and useful outputs, NRA should at the beginning of the process accommodate:

- the governance model (Chapter 2.1),
- the context for each and every risk assessment process (Chapter 2.2),
- the protocol for the aggregation process of the risk assessment results (Chapter 2.3) and

- the format of the outputs for communication with authorities and stakeholders (Chapter 2.4).

Furthermore, NRA is part of Risk Management Capability Assessment [Commission Staff Working Paper, 2010] where NRA (**Figure 1**) is integrated into the whole disaster risk management cycle: risk assessment, risk management planning, and the implementation of risk prevention and preparedness measures.

Disaster risk management planning sets out the specific objectives for reducing disaster risk with related actions to accomplish these objectives. It should consider the future improvements as well as how they can be coordinated within relevant development strategies, resources allocation and programme activities. Furthermore, linkages to sustainable development and climate change adaptation plans should be made where possible.

Implementing risk prevention and preparedness measures includes the allocation of responsibilities and resources, the monitoring duties (such as loss and damage collection after the disaster happens) as well as an evaluation and lessons learned process.

2.1 Governance of National Risk Assessment

The multi-disciplinary nature of the disaster risk assessment requires information and knowledge of many parties from different communities to conduct the comprehensive process of NRA. A robust and flexible **governance model of NRA** in which **one authority has the mandate** to coordinate all parties involved is essential. The goal of the governance model of NRA is to enhance coherence across portfolios and to create a working environment based on the same set of evidences.

The governance model of NRA should consist of **a number of working groups** for different types of natural and man-made hazards as well as for different assets consisting of scientific experts, practitioners and representatives from all relevant sectors and governments departments or agencies responsible for DRM planning. The goal is to have at the same table data providers, end-users, and all technical support. The National Platforms for Disaster Risk Reduction as promoted by the UNISDR (2017a), are an example of a national mechanism for coordination and policy guidance on disaster risk reduction that is multi-sectoral and inter-disciplinary in nature, with public, private and civil society participation involving all concerned entities within a country. It is often the case that national platforms are also the best suited to link the Sendai Framework for Disaster Risk Reduction with other strategies, such as the Sustainable Development Goals (SDG, 2015), the UNFCC Paris Agreement (UN, 2015), and the Covenant of Mayors (2008).

Top down coordination is important to establish priorities but bottom up approaches should not be neglected either. Each process of risk assessment is performed by a technical team that should not work in isolation. Each process of risk assessment should be conducted collaboratively with stakeholders and interested parties, including central and regional levels of government and specialised departments and drawn on the knowledge and views of all involved. Only then the risk assessment processes can be carried in the context of NRA. It is a matter of:

- getting relevant, appropriate and up-to-date information and input data for the analysis;
- identifying risk and applying proper **risk metrics** and be aware of risk criteria (acceptable risk) which is largely a political decision;
- understanding which are the assets to be protected and which are the potential impacts that are of main concern;
- supporting the design of realistic risk scenarios and
- providing useful and usable results.

In an ideal case they should be fully embedded in national sustainable development strategies, they should address all relevant issues and EU directives/policies and they should enjoy the support of all stakeholders/sectors from the beginning of the risk assessment process. Relevant EU policies, among others, are (Marin Ferrer et. al, 2018):

- The EU Flood directive (Directive 2007/60/EC),
- The Seveso III directive (Directive 2012/18/EU),
- The European programme for Critical Infrastructure (Council Directive 2008/114/EC),
- EU Solidarity Fund (Council Regulation (EC) No 2012/2002),
- EU strategy on adaptation to climate change (COM(2013)216),
- Directive on serious cross-border threats to health (Decision No 1082/2013/EU).

2.2 Context of National Risk Assessment

The NRA governance identifies the context with the support of all involved stakeholders. The context defines the commonalities of all risk assessment processes related to all stages (Chapter 4) and assures the consistency and comparability of results, essential for the risk aggregation. All parties involved should at the start of the process agree on:

- **What needs to be protected in the country** – the list of assets that should be considered in the risk assessment processes, such as population, buildings, infrastructure, environment, etc., that are broken down to a **level of detail** meaningful for making decisions and allowing to assign vulnerabilities.
- **Which are the hazards that the country is exposed to** – the set of scenario for different hazards and different probabilities (likelihood) of occurrence (discrete values). Consideration should be given to both, extensive, frequent, low-impact and intensive, occasional, high impact events.
- **Which are the risks to be considered, that is, the potential impacts**, direct and indirect, and what are the risk metrics to measure them: human impact, economic impact, environmental impact and political/social impact. The criteria for selection are based on the assets to be protected and the values they present.
- **What is the time window for the potential impacts to be considered** – the temporal horizon of risks to be assessed is decided. The process should consider risks that may occur in the immediate future (1-5 years) and in the long term (25-35 years) to accommodate the prioritisation of high probability/low impact events and low probability/high impact events, respectively. Long term periods are also considered to identify emerging risk, such as climate change, also cyber security, volatility of geopolitical landscape, etc.[9]. With enlarging the time window for the scenarios also more distant direct and indirect impacts should be covered, and with considering more than one time window, information can be included to propose prevention and recovery measures.
- **Classification** of impact and likelihood levels should be defined (Chapter 2.4). The choice of the criteria for classes is largely a political decision. The selection of criteria is related to the risk tolerance in the country. For example, one country might define "insignificant" a human impact of 10 fatalities while the other no fatalities. The number of classes depends on the expected uncertainties introduced mainly through different risk assessment approaches: higher the uncertainties, smaller the number of classes introduced. The impact classes are defined for each type of impact and are derived from impact criteria. In case of

[9] Insurance and reinsurance companies monitors the evolution of the risk landscape on a continuous basis (Swiss Re SONAR: New emerging risk insights) protect their clients and themselves against undue uncertainties, but many of identified future risks unveiled could be also of national concern

likelihood levels it is recommended to carefully select a likelihood scale that can effectively cover the risks of intensive as well as extensive disasters.

- **Quality criteria** in terms of acceptable levels of uncertainty arising from the input data and models used in different stages of risk assessment (Chapter 4): from the identification of events and scenarios to analyse to the evaluation of risk (Zio and Aven, 2013). Uncertainty, though, can provide interesting information for the exercise and for future actions to implement the management of risk. Some frameworks can be found in the literature to guide scientists and other stakeholders to deal with it (Refsgaard et al., 2007; van der Sluij, 2005; Walker et al, 2003).
- Design of a **protocol for the use of expert opinion** and for the design of a procedure to document the whole process of the risk assessment process to assure **transparency and consistency**.
- **Risk criteria** need to be agreed on in order to be used in the risk evaluation stage (Chapter 4.4) as a term of reference against which the significance of a risk is evaluated and determine whether the risk assessed is acceptable or not **.** However, partial knowledge of risk criteria should be known in advance as they dictate the risk metrics (Chapter 3) and level of detail (resolution).

With periodic reporting (every three years) the context should be updated. Risk is dynamic and it should be treated as such. The start of the new NRA process is also the opportunity for improvements:

- to introduce experiences gained from previous NRAs,
- further development in the datasets and risk assessment methodologies,
- changing hazard landscape due to climate change and emerging risks as well as
- considering increased DRM capacities due to implemented risk prevention and preparedness measures.

Box 1. UNISDR Definitions (UNISDR, 2018): extensive disaster risk, intensive disaster risk

Extensive disaster risk

The risk of low-severity, high-frequency hazardous events and disasters, mainly but not exclusively associated with highly localized hazards.

Annotation: Extensive disaster risk is usually high where communities are exposed to, and vulnerable to, recurring localized floods, landslides, storms or drought. Extensive disaster risk is often exacerbated by poverty, urbanization and environmental degradation.

Intensive disaster risk

The risk of high-severity, mid- to low-frequency disasters, mainly associated with major hazards.

Annotation: Intensive disaster risk is mainly a characteristic of large cities or densely populated areas that are not only exposed to intense hazards such as strong earthquakes, active volcanoes, heavy floods, tsunamis or major storms but also have high levels of vulnerability to these hazards.

2.3 The aggregation process of National Risk Assessment

National Risk Assessment is a compound of **many** processes of risk assessment. The **process of risk assessment** is an approach to estimate the potential impacts, their levels and probabilities of occurrence. The results of risk assessments covering different types of hazards and different asset types are often presented with a different risk metrics. To derive to the potential impacts at the national level for different hazard types and different probability of occurrence, the results of different risk assessments are subjected to **high level of aggregation** (**Figure 2**).

Even more, the risks related to the same scenario may be the results of different risk analysis methodologies, qualitative, semi-quantitative or quantitative. For that reason it is suggested in European guidelines (European Commission, 2010) to use risk matrices (Chapter 2.4) to illustrate comparative risks derived from different risk analysis methodologies in a complementary way. For that purpose, the results of a fully probabilistic approach are downgraded. For example, it is assumed that the probability of impacts equals the probability of the event.

The scale (granularity) and **the scope (coverage)** of risk assessments are dictated by the NRA context and guide the choice of the RA methodologies. The scale is defined with a level of detail which allows estimating the relative importance of the impacts, while the scope is national or appropriate sub-national. Furthermore, the risk assessment methodologies vary depending on available data on hazard, assets and vulnerability, the impact to be assessed and the further use of the results, as well as available resources and time. However, RAs should be always considered in the context of NRAs to enable the aggregation process leading to results which are usable, useful and used by those who are responsible for DRM.

The result of the **aggregation process** (**Figure 2**) are the **points in the risk matrix** (Chapter 2.4), correlating the aggregated potential impact to the likelihood and hazard of the scenario. Each risk assessment process focuses on one type of asset exposed to one scenario and assesses one type of the potential impact. Finally, the assessment should be made for the potential impacts of all the assets on the list of what each country needs to protect when exposed to one scenario for a specific hazard type and probability of occurrence. Then the potential impacts (the deterministic value or the expected values, depending on the analysis) of all the assets are summed. This is the value which is then categorized according to the impact classification, presented in the risk matrix where it is correlated to the likelihood levels of the hazardous event and the hazard type.

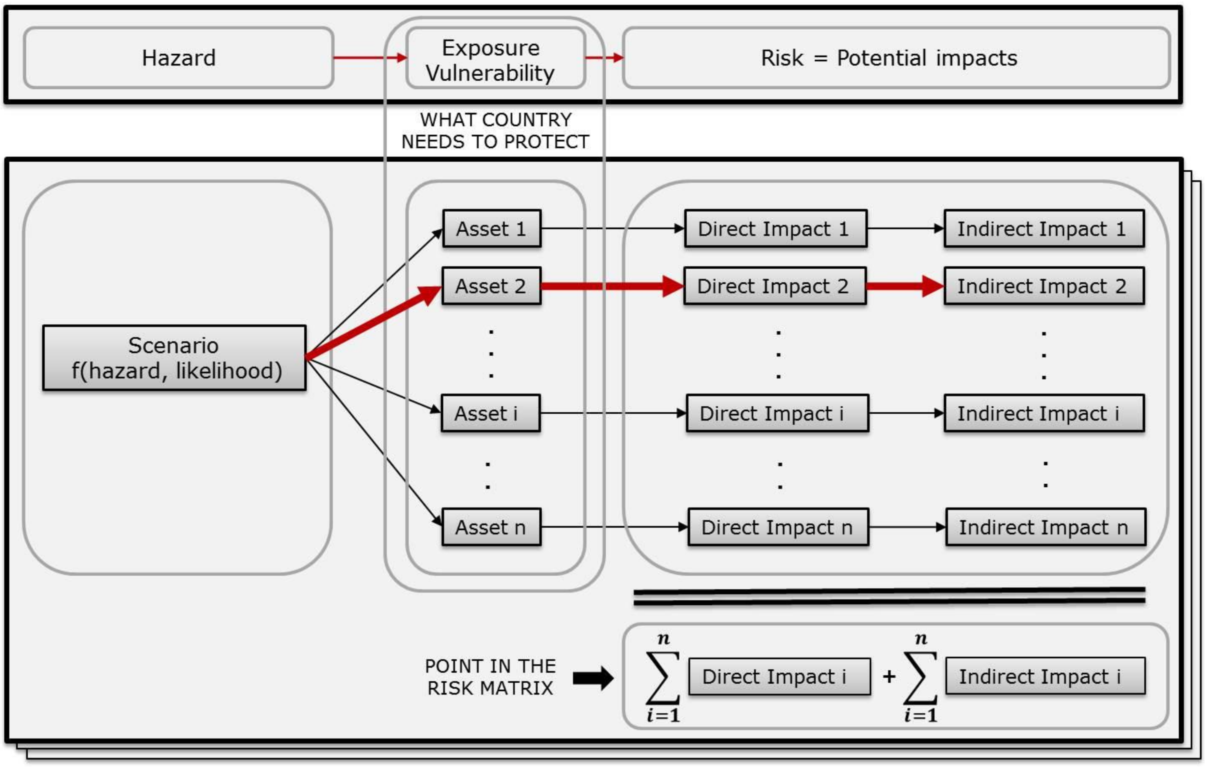
Scenario is characterized by hazard type and probability of occurrence (likelihood). The number of scenarios for a specific hazard and its likelihood of occurrence depends on the size of the Member State and the level of advancement (ability of propagating the uncertainties through the process) of the risk assessment process (Chapter 4.3). However, for each hazard a set of multiple scenarios with various likelihoods of occurrence will provide a more complete picture of risk. Scenarios should cover all significant hazards of varying likelihood of occurrence.

List of assets should be the same for all scenarios to ensure comparability in terms of assets included. If the aggregation process becomes too complicated because of the diversity of risks addressed, more sub-lists of assets can be prepared. Each sub-list joins the assets (e.g., only population or only residential buildings) which can be analysed with the same methodologies that can yield comparable results in terms of risk metrics. In such case each sub-list would have its own risk matrix.

Potential impacts should be identified within the context of NRA. Risk metrics should coincide with loss indicators used in the national disaster loss databases. National disaster loss databases are a set of systematically collected records about disaster occurrence, damages, losses and impacts. If the country doesn't have a multihazard disaster loss database, the reference point should be loss indicators developed to measure global progress in the implementation of the Sendai Framework for Disaster Risk Reduction (UN, 2016). Furthermore, direct and indirect impacts should be considered. Indirect impacts (e.g., flow for the production of goods and services) often result from direct impact (e.g., physical damage to property) and are even more difficult to assess (De Groeve et. al, 2013).

For the sake of aggregation **direct and indirect impacts** should be converted to monetary value, most often used as a common denominator, which entails the need of economic models. Certain direct or indirect impacts cannot be converted into monetary value simply because the lost item cannot be bought or repaired for money (killed, injured, cultural heritage, extinction of species). Impacts related to population can be measured in number of persons. Other non-market impacts are difficult to measure and are called intangible damages. Furthermore, intangible damage is a catch-all term for even more undefined effects, that are impossible to quantify or are even difficult to identify, like loss of memorabilia, human suffering, impact on national security and many other similar factors related to well-being and quality of life (De Groeve et. al, 2013). Following the guidelines (Commission Staff Working Paper, 2010) they are referred to as political/social impact and can be measured in a qualitative scale of five classes (e.g. 1-insignificant, 2 – minor, 3 – moderate, 4 – significant, 5 - catastrophic). In that case each common denominator requires its own aggregation process and risk matrix.

Figure 2: *Example of aggregation processes of risk assessment results within NRA for one scenario.*



Source: Authors

This report (Chapters 8-16) provides concrete instructions/guidance at the level of single risk assessment processes focusing on one type of asset exposed to one scenario and assesses one type of potential impact with defined risk metrics (red arrows in **Figure 2**).

2.4 The outcomes of National Risk Assessment

National risk assessment provides evidences for Disaster Risk Management planning. This is the answer to why doing the National risk assessment in the first place. But how is this accomplished? The results of NRA should be quantified and presented in a way that is useful to the stakeholders. So, it matters a lot how the results of NRA are formulated to properly combine information on the **level and probability of potential impacts**. Once these metrics are in hand, disaster risk management strategies can be assessed.

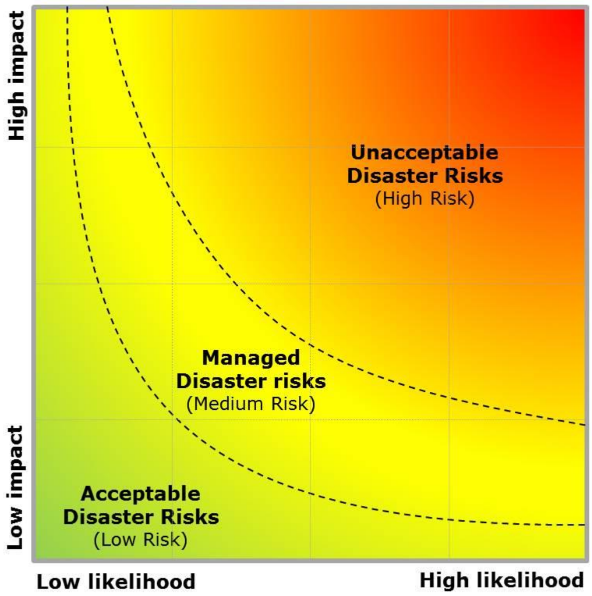
The format of NRA's results varies and depends on the risk analysis models applied and their ability to propagate the uncertainties arising in different stages of risk assessment to the end results. Furthermore, for the purpose of DRM planning it would be great to compare the potential impacts among spatial (subnational) entities among different hazards, among different time windows and depending on risk drives and capacities in place. Considering these, there are different tools for presenting the results that can be used:

- **risk mapping**, with emphasis on spatial component of risk;
- **risk matrix**, which allows comparison of risks arising from different hazards;
- **risk curves** with temporal component of risk;
- **risk indices** to present the links between risk drives and capacities with risk components: hazard, exposure and vulnerabilities.

Risk mapping is in the form of maps showing the levels and natures of risk, different for each return period (or annual probability or likelihood) and hazard type (e.g., a GIS map of the potential impacts). Risk mapping is therefore a process of establishing the **spatial extent of risk**.

Risk matrices are a commonly used form for **qualitative presentation of risk.** It is employed **to compare risks** from different hazards of specific likelihood. The risk matrix (**Figure 3**) is a table where one dimension represents the likelihood of the event while the other dimension categorizes the hazard's potential impact. Classification of impact and likelihood levels is essential. Sorting the potential impact and the event's likelihood into classes introduces ranges of estimated values to compensate the uncertainties that have not been introduced during the analysis. They facilitate the communication the results of a semi-quantitative analysis (Chapter 4.3) and the output of fully probabilistic analysis. In such complementary way a risk matrix can illustrate comparative risks derived from different risk analysis methodologies. As such risk matrix is an essential input for DRM planning (Chapter 4.4).

Figure 3: *Risk matrix template. The classification of impact (e.g., from low to high impact: insignificant, minor, significant, disastrous) and likelihood levels (e.g., from low to high likelihood: very unlikely, unlikely, likely, very likely), conversions from quantitative values as well as risk criteria should be provided within NRA context.*

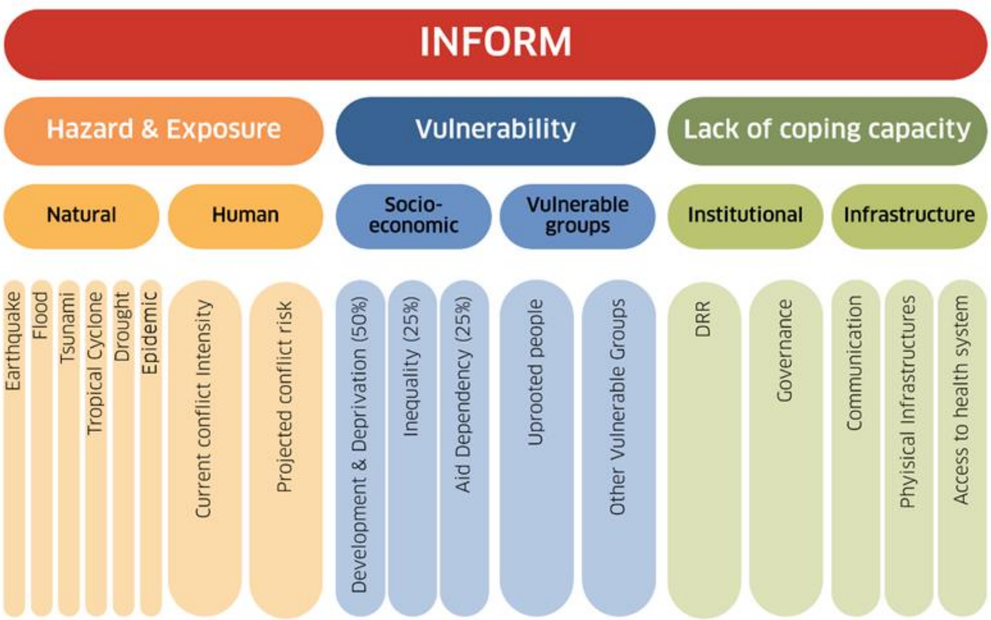


Source: Adapted by TorqAid, 2019

In case of availability of quantitative data for the presentation of risk, a **risk curve** can be constructed. The risk curve relates the level of impact that will be surpassed in a given time period with the actual probability. It is also called the exceedance probability curve and it is the usual output of the full probabilistic approach. It is specific for each hazard type. From the risk curve two useful risk metrics can be derived. The first is the **average annual loss (AAL)**, which is the expected loss per year, averaged over many years and equals the area under the risk curve. The advantage of AAL is that it accounts the cumulative damage of small impact and frequent events next to rare and big impact events. It also provides a useful, normalized metric for comparing the risks of two or more hazard types, despite the fact that hazards are quantified using different metrics. The second risk metrics is the **probable maximum loss (PML)** that describes the maximum loss that could be expected in a given time period. It is a subjective risk metric as it is associated with a given probability of exceedance chosen by the user that specifies the acceptable risk level. In case of earthquakes, the most commonly used probability of exceedance is 10 percent, and the most commonly used time period is 50 years which corresponds to return period of 475 years. Therefore, PML limits are often framed in terms of return period[10]. As such, PML is relevant to define the size of reserves that insurance companies or government should have available to manage losses.

Then, there are **risk indices**, which provide the opportunity to explain how **underlying risk drivers and capacities** affect disaster risk components and final risk. Risk indices present the relative importance of the risk (e.g., in terms of ranking) arising from different hazards, different drivers and coping capacities within different spatial (also subnational) units. Therefore, risk indices can be used as a risk assessment tool that unfolds the range of activities to reduce risk. An example of such risk index is INFORM Global Risk Index (**Figure 4**) and its version of INFORM Subnational Risk Index[11].

Figure 4: *INFORM GRI Conceptual Framework*



Source: Poljansek et. al, 2018

Furthermore, with each process of risk assessments there should be also an opportunity to share and explain information on components of risk (hazard, exposure and

[10] Statistically, the loss which has a 10 percent probability of exceedance in 50 years also has approximately 0.2 percent probability of exceedance in 1 year, and an effective return period of 475 years. By definition, the return period is the inverse of the probability that the event will be exceeded in any one year. For example, the 100-year hazardous event a 1/100 = 0.01 or 1% chance of being exceeded in any one year.

[11] http://www.inform-index.org/

vulnerability) and underlying risk drivers, risk metrics as well as risk itself, related levels and probabilities.

Finally, the outcomes of the NRA should be useful for effective decision making by the authorities responsible for DRM. Therefore, it is highly recommended that they are involved as a part of the governance body of the NRA from the very beginning when agreeing on a set of methodologies for analysing risk from various hazards, so as to help shaping the outcomes in a common format according to their needs for evaluation, comparing risks and communicating results. Above all, authorities should understand what has been lost in the aggregation process while still being aware of the wealth of risk information generated. However, this is also the opportunity to see the gaps and challenges which hinder the calculation or increase the uncertainty of the desired results. Only then the actions to resolve them (e.g., the need of disaster loss database) can be taken as part of **integrated DRM planning,** so that the future NRA processes can be brought to the next level.

3 Risk Concept and Risk Metrics

Scientific community can help civil protection authorities and ministries preparing NRA that will effectively provide scientific evidences for **disaster risk management planning**, and as such reach the objectives of EU guidelines (Chapter 1). This series of report is an opportunity for scientific community to:

- provide the guidance in common understanding of risk, risk concept and risk metrics (Chapter 3);
- explain step by step the process of disaster risk assessment (Chapter 4);
- provide approaches to assess **the potential impact** and their probabilities (Chapters 8-16);
- and provide information on **underlying disaster risk drivers and capacities** (Chapters 8-16)**.**

This chapter introduces basis for a common understanding of risk in terms of a concept to be followed from the very beginning and in terms of the results and appropriate risk metrics to be used in NRA.

Box 2. UNISDR Definitions (UNISDR, 2018): disaster risk assessment, disaster risk, hazard, exposure, vulnerability

Disaster risk assessment

A qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend.

Disaster risk

The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

Hazard

A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity or magnitude, frequency and probability. Hazards include, as mentioned in the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2105) biological, environmental, geological, hydro-meteorological and technological processes and phenomena.

Exposure

The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Vulnerability

The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

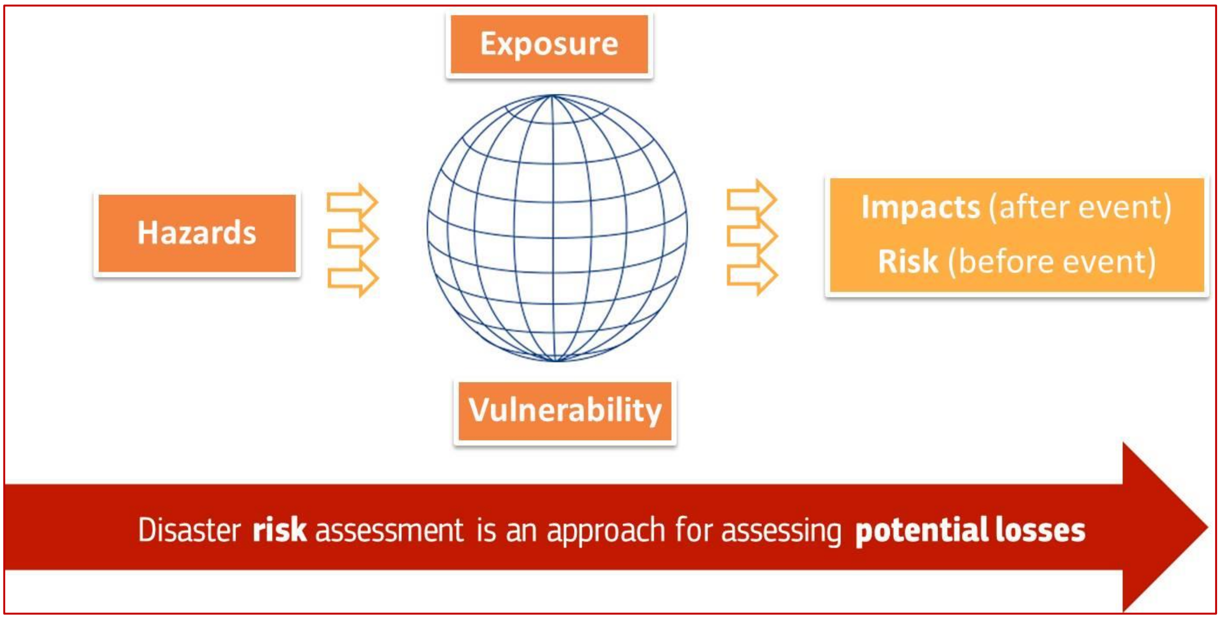
Regarding the terminology (Box 2) we follow the UNISDR (2018), but to connect all definitions into one story, we need to know the **risk concept**:

- **What is risk?** Risk is a **potential loss/impact**[12] (**Figure 5**). The notion of potential loss requires information of the level of potential loss to be accompanied with the probability of its occurrence.
- **What is disaster risk assessment**? Disaster risk assessment is an approach for assessing potential losses. Disaster risk assessment **combines the results of hazard, exposure and vulnerability models**. (**Figure 6**).
- **How to measure risk?** A **risk metric** is the attribute of risk being measured. In terms of the unit used it coincides with loss indicators. Impacts/losses are the output of risk assessment models. Therefore, the disaster loss databases can be used to validate the results of disaster risk assessments. Risk metrics should also allow conveying the probability of occurrence related to each level of impact. When following the probabilistic approach, these can be summarized through annual average loss (expected loss per year) and probable maximum loss (maximum loss that could be expected corresponding to a chosen likelihood) both derived from the exceedance probability curve (also known as risk curve).

***Figure 5**. What is risk?*

Source: Authors

***Figure 6.** What is disaster risk assessment?*



Source: Authors

Ideally, **risk metrics** are related to the asset and not to the hazard. However, different approaches differ substantially according to the hazard or asset in question. Collaboration among experts from different fields should be encouraged not only to transfer the

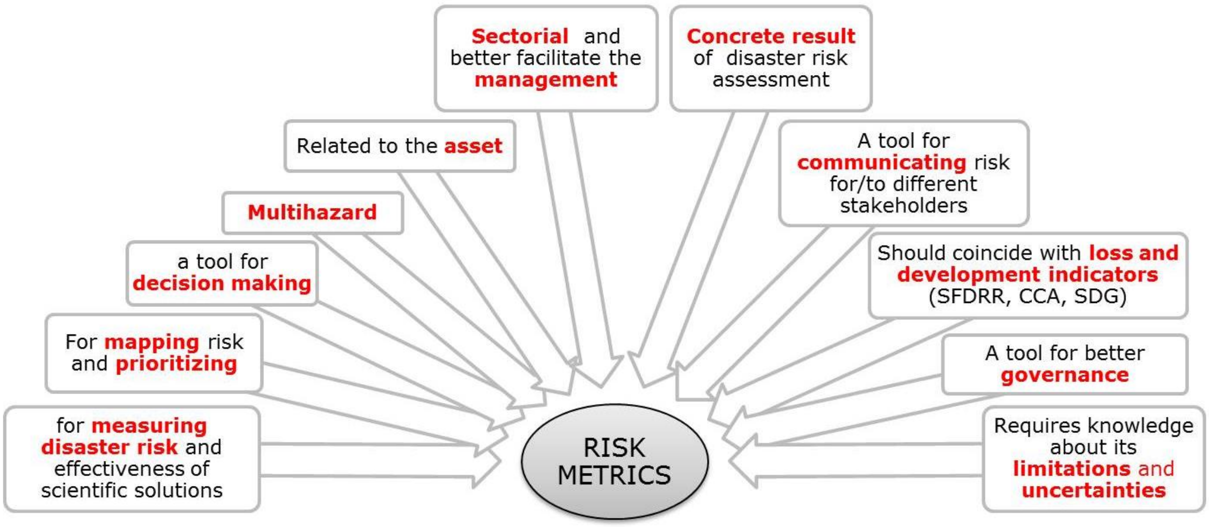
[12] Losses are subset of impacts. Impacts are negative and positive consequences of hazardous event, while losses are only negative one. (De Groeve et. al, 2013)

existing methods and models that work in one field and might be applicable in others, but also to find **common risk metrics**. Such **harmonisation is needed**:

- to find a way to more coherent and consistent RA methodologies to make risks arising **from different hazards comparable** and to make risks arising from the same hazard **in different regions comparable** (cross-border and regional risk)**;**
- to understand the **relative importance** of different risks for a given region;
- to assist decision makers in DRM in their **prioritising** of DRM planning and actions.

Furthermore, common risk metrics offer even more possibilities of application (**Figure 7**) and all contribute to more effective and transparent disaster risk management planning as long as the users are familiar with the limitations and uncertainties related to the methodologies for assessing the potential impacts.

Figure 7. *The advantages of common risk metrics.*



Source: Authors

The process of disaster risk assessment in general is more in detail explained in Chapter 4 while Chapters 8-16 tackle the hazard or asset specific risk assessment. However, we would like to draw special attention to the two results of the risk assessment process: potential impacts with related probabilities of occurrences, and information on underlying risk drivers and required capacities which presents the most valuable scientific input for the disaster risk management planning (**Box 3**).

Box 3. Scientific input for disaster risk management

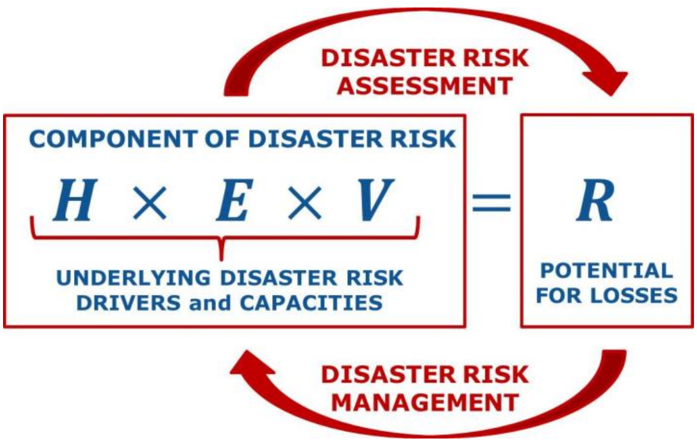
— Potential impacts (=risk) are the scientific input for disaster risk management planning.

— The understanding of underlying risk drivers and required capacities are the scientific input for disaster risk management planning.

Risk assessment models are the scientific tool to assess the potential impacts and their probability of occurrence. Only when we know what the potential impacts are we can do disaster risk management planning. Prioritizing is possible only when potential impacts (=risk) arising from different hazards are comparable.

Understanding underlying disaster risk drivers and capacities. Risk assessment provides the opportunity (**Figure 8**) to better understand the underlying causes of risk (i.e., disaster risk drivers). Sometimes the phenomena/pattern behind each component of risk is known but is not yet being modelled. Nevertheless, explaining the correlations, phenomena and patterns between risk drivers and capacities with the components of disaster risk are one of the most important parts of the risk assessment. Such information may be used to inform DRM on the root causes of risk that can be addressed and acted upon to target the various components of risk to reduce disaster risk.

Figure 8. *Risk assessment provides an opportunity to better understanding of the underlying disaster risk drivers and informs disaster risk management measures (H: Hazard, E: Exposure, V:Vulnerability, R: Risk).*



Source: Authors

Box 4. UNISDR Definitions (UNISDR, 2018): Underlying disaster risk drivers, Capacity, Coping capacity

Underlying disaster risk drivers

Processes or conditions, often development-related, that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity.

Annotation: Underlying disaster risk drivers — also referred to as underlying disaster risk factors — include poverty and inequality, climate change and variability, unplanned and rapid urbanization and the lack of disaster risk considerations in land management and environmental and natural resource management, as well as compounding factors such as demographic change, non disaster risk-informed policies, the lack of regulations and incentives for private disaster risk reduction investment, complex supply chains, the limited availability of technology, unsustainable uses of natural resources, declining ecosystems, pandemics and epidemics.

Capacity

The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience.

Coping capacity

Coping capacity is the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks.

Coping capacity is one of the underlying risk drivers that can be influenced the most with DRM actions and can significantly change the outcome of disaster as well as improve the resilience of the society. **Coping capacity is so important that it is sometimes considered as one of the risk components**, next to hazard, exposure and vulnerability (UNISDR, 2015). It refers to the ability of a country to cope with disasters in terms of formal, organized activities and the effort of the responsible authorities as well as of the existing infrastructure. All together coping capacity covers all the phases of DRM cycle; prevention, preparedness (early warning systems) as well as emergency response and recovery. Among the components of risk (**Figure 8**), coping capacity has the strongest influence on the vulnerability.

SDG (Sustainable Development Goals) indicators capture many underlying disaster risk drivers and capacities affecting the vulnerability component of risk, especially the hazard independent aspect of it. Using the methodology of composite indicators to assess risk (Chapter 4.3), the SDG indicators can be used to design the vulnerability index which is widely used approach in the socioeconomic filed.

Partial results of the risk assessment can be useful. Sometimes the uncertainties are too high to effectively apply the whole risk assessment approach to arrive to the risk. Disaster risk assessment is combination of three models: hazard, exposure and vulnerability models. Each of these models provides the linkages with the underlying factors (drivers and capacities) which can already be useful for DRM actions planning.

4 Risk Assessment process

The process of risk assessment is an approach to estimate the potential impacts, their levels and probabilities of occurrence. Each risk assessment process within the NRA context focuses on one type of asset exposed to one scenario and assesses one type of the potential impact. The purpose of a NRA is to define appropriate measures to control and reduce risks in a determined space and time when used in many areas and sectors.

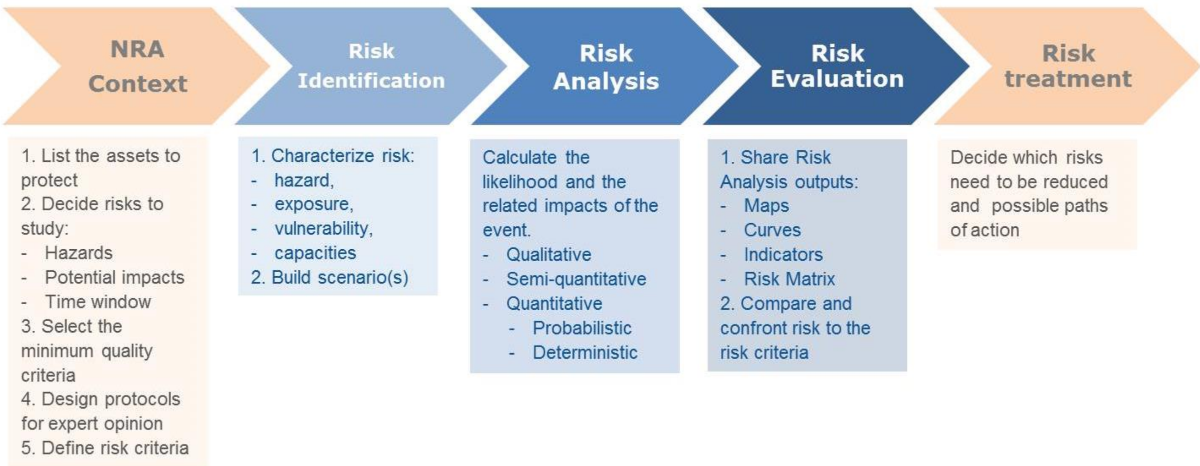
In order to guide the process and having in mind that the outcomes of the exercise should support the decision-makers in treating (or not) risk, it is necessary to know the **context** (Chapter 2.2) of national risk assessment and the expected outcomes of each risk assessment for the **aggregation process** (Chapter 2.3).

4.1 Following the format of ISO 31010

ISO 31030 (ISO, 2018) provides a common and very general approach to managing any type of risk. It is not hazard or asset specific. It divides the risk assessment process (**Figure 9**) into **three stages: risk identification, risk analysis and risk evaluation.** There are several advantages when risk assessment processes follow the same format within the NRA context:

- helping **target readers/users** to find themselves around (where to start, what to expect) in topics perceived as complex and tackled with a variety of different approaches.
- helping **experts** to fit their expertise into predefined modules, thus transforming the complex phenomena into complicated process, that is into a set of feasible tasks, that are normally executed by different actors to reach the desired results.
- Facilitating the usage of the same **terminology**.
- supporting the documentation of the whole process to assure **transparency and consistency**.

Figure 9*: Stages of risk assessment process according to ISO 31010.*



Source: Authors

4.2 **Risk Identification**

According to ISO 31030 (ISO, 2018) the purpose of risk identification is to find, recognize and **describe risks** that a country would like to reduce using existing risk information The main task here is to collect relevant, appropriate and up-to-date risk information from national and international sources. For example (and more in detail in Chapter 4.2.1):

- information on past losses (national disaster loss database, European platform of risk data Risk Data Hub[13] or online database with global coverage EMDAT[14]),
- map of relevant research projects(Project Explorer[15]),
- past efforts of risk assessments within the country(past NRA exercises 2013 and 2015),
- international efforts related to national risk profiling (INFORM[16]).

For each of the risks to be studied, it is necessary to gather the available **information on the risk components** relevant to the NRA context (Chapter 2.2) to prepare:

- hazard models,
- exposure models,
- vulnerability models and
- relevant selection of risk drivers and capacities.

It is necessary to **study which are the causal mechanisms of risk** (Powel et al, 2016): characterize the activities and conditions that trigger the hazard; the factors that drive the assets' exposure and vulnerability; and which are the capacities (at the level of asset but also beyond it) in place for:

— preventing the event,

— mitigating its effects,

— prepare for and respond to the hazard once it materialises, and

— recover from it.

There is **no one-approach-fit-all-the-risk.** For each hazard or asset related risk there are different solutions efficient in different phases of the DRM cycle. If the risk appears to be non-acceptable for the standards established by the decision-makers, the actions planned in order to manage disaster risk will tackle some or all the risk factors mentioned.

It is also important to identify also the risks (e.g., emerging risks, cross-border risks) which sources are not under control and that can result in a variety of tangible and intangible consequences. This is also an opportunity to address issues such as lack of data, limitation of knowledge, reliability of information and corresponding uncertainties.

All the information produced in the stage of risk identification is actually the formulation of a problem, which will help risk analysts to design a model or methodology to obtain the outcomes of the potential impacts with their probability of occurrence on the assets at risk.

4.2.1 Tools to support risk identification

The elements listed below can be used to guide the team in charge of characterizing risks:

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[13] https://drmkc.jrc.ec.europa.eu/risk-data-hub
[14] https://www.cred.be/projects/EM-DAT
[15] https://drmkc.jrc.ec.europa.eu/knowledge/Projects-Explorer#project-explorer/631/projects/list
[16] http://www.inform-index.org/Countries/Country-Profile-Map

1. *Loss and damage databases*, which usually informs about the occurrence, magnitude and, sometimes, losses suffered. The data recorded after an event not only indicates the level of exposure of a society but also helps identifying the key drivers of losses (De Groeve et al, 2014).
2. Hazard identification techniques, which are quite common in the industrial sector, such as HAZOP studies, fault trees, checklists, etc. (Mannan, 2012). Some methods can serve to describe the causes and conditions that favour hazard to happen.
3. The risk identification stage is directly linked with the formulation of (a) problem, and as pointed out by Powell et al. (2016), the use of *soft Operations Research* methods can be useful to structure and formulate complex problems, where different stakeholders have different interests and require different expertise to describe these problems.
4. *Accident investigations or post-disaster reports*, including documents containing lessons learned. These documents and the experience of the those engaged in responding and recovering from past disasters can support teh understanding of the underlying causes leading to consequences. These reports usually serve in taking corrective actions and improving protocols, and in displaying changes in risk factors. For example, some industries, such as aviation and chemical processing, commonly record near-miss events, which are a valuable source of learning from the past (Phimister et al, 2003).
5. *Scientific projects and loss projections*. Besides learning from the past, and considering the effect that climate change will have on disaster risk, it is necessary to consider the potential future losses due to changes in assets' exposure, vulnerability and the nature of the hazard.
6. *Monitoring and Early Warning Systems* in place. These are constantly collecting and analysing data of precursors of risk. Detecting trends and changes in the data collected can facilitate the team engaged in the RA to picture how risk is or is changing. Besides the traditional and operational warning systems for protecting people's lives and properties, the team can also exploit foresight approaches, citizen sciences and media monitoring (DG ENV, 2016).

4.2.2 Scenario Building

The scenarios have become a form of **communication model** and help bridge the theoretical models and the needs to solve practical problems (Alexander, 2000).

At the first place scenarios are a replacement for describing future disaster events in terms of their magnitude and probabilities which can be based solely on known science. Instead the information about what can happen in the future disaster can be better described with **sets of scenarios**. These scenarios comprise the triggering events together with the description of possible consequences from cascading events to the impacts on societal systems while considering the capacities in place. Therefore, the scenario building process requires input from scientists, practitioners, policymakers and different parts of communities that complements with community's experience of past events and knowledge of social, cultural, economic and political context.

This co-development process (Davies et al., 2015) is beneficial not just because such engagement allows mutual learning, the sharing of existing knowledge and the co-production of new knowledge, but also because the knowledge that emerges is much more likely to have societal and scientific consents, because it will be perceived as relevant by all involved (Mercer, 2012; Wistow et al. 2015)

Scenarios can be used for modelling all phases of the disaster risk management cycle. For the purpose of emergency preparedness, recovery and reconstruction planning the "maximum credible" or "plausible worst case" scenarios are of interest. For the purpose of the risk assessment process their aim is to analyse the potential impacts and their likelihood. Therefore, it is recommended to have **multiple scenarios with various likelihoods of occurrence** to obtain a more complete picture of risk (UNISDR, 2017b).

A scenario presents just *a* possible future, but should be internally consistent and plausible (Börjeson et al, 2006), covering all possible events and related effects so as to reach the desired information of risk impact. Shoemaker (1995) proposes three tests to ensure internal consistency and plausibility: compatibility of trends, outcome combinations and reactions of major stakeholders. There would always be events and their characteristics that will remain *unknown unknowns*, but we reduce this by having relevant stakeholders on board (Aven, 2015). Assumptions are an inherent part of the scenario building, as such should be examined and reported.

4.3 **Risk Analysis**

Risk analysis is the process of combining the risk components of hazard, exposure and vulnerability to determine the level of risk. For every risk and risk scenario identified in the risk identification stage, risk analysis determines the potential impacts and the probability of occurrence. Risk analysis approaches vary in various degrees of detail depending on the purpose of the analysis and data available as well as on how they address uncertainties arising in different stages of the RA process. Each risk analysis approach has different limitations as well as advantages. They differ among **qualitative**, **semi-quantitative** (risk matrix and indicator based) and **quantitative** (deterministic and probabilistic) methods. The most suitable methodology should be chosen based on:

- purpose of the analysis (prioritization, planning, analysing the effect of changes, etc.);
- the agreed level of detail;
- the time spam of the assessment;
- the agreed level of uncertainty;
- the availability and reliability of information;
- the existing models to produce these results;
- the resources at hand (in terms of time, money, expertise, etc.) for the exercise.

Here it is worth mentioning that the knowledge base of risk, as inherently uncertain (Covello and Merkhofer, 1994), can be limited. It is often the case that the knowledge base is decisive in deciding the approach for the analysis. Ideally, quantitative approaches would be favoured in front of qualitative ones and probabilistic models instead of deterministic analysis, to ensure that the outcomes of the analysis are objective and replicable.

Qualitative risk analyses are risk narratives based on expert judgment. They are commonly used for screening risks to determine whether they merit further investigation. Sometimes it is the only option when almost all components of risk are not quantifiable or have a very large degree of uncertainty. It may be the case that a qualitative assessment provides the risk manager or policy-maker with all the information they require. For example, if there are obvious sources of risk that can be eliminated, one does not need to wait for the results of a full quantitative risk assessment to implement risk management actions. An important criticism for qualitative approaches is its subjectivity, which affects its reliability. In order to facilitate its replicability, the processes need to be clear and structured, so different experts can repeat the analysis.

Semi-quantitative risk analysis seeks to categorize risks by comparative scores (e.g., tolerable, intermediate, intolerable). They permit to classify risks based on expert knowledge with limited quantitative data (Haimes, 2008; Jaboyedoff et al., 2014). They can be a useful stepping stone towards a full quantitative approach, particularly where detailed data are lacking and can be used as a means to capture subjective opinion which makes it a good basis for discussing risk reduction measures (Simmons et al., 2017).

Risk matrix is a mean to communicate the results of a semi-quantitative analysis. The risk matrix is made of classes of frequency of the hazardous events on one axis, and the consequences (or expected losses) on the other axis.

Following the limitations of risk scoring systems (Cox et al., 2005), if some data is available, even rough, it is recommended to use quantitative methods in order to recognize uncertainty and the correlations existing between the components of risk (hazard, exposure and impact). In the case of high uncertainties, by trying to quantify them and identifying their contributors, it is possible to not only increase the knowledge base, but also to better allocate funds and resources for future research developments (Apostolakis, 2004). Nonetheless, expert judgement could be necessary when the underlying mechanisms are not well understood (Abrahamsson, 2018).

Another semi-quantitative approach to measure risk is based on the methodology of composite indicators. Such **indicator-based approach** is useful when there is not enough data to quantify all the components of risk over large areas to carry out a quantitative analysis, but also as a follow-up of a quantitative analysis, as it allows taking into account other aspects than just physical damage. As a matter of fact, the indicator-based approach is the only method that allows carrying out a holistic risk assessment, including social, economic and environmental vulnerability and capacity. Indicator-based approaches allow incorporating the risk concept where each risk component (hazard, exposure, vulnerability and capacity) is composed by risk drivers defining it and presented by indicators. Data for each of these indicators are collected at a particular spatial level, for instance by administrative units. These indicators are then standardized (e.g. by reclassifying them between 0 and 10), weighted internally and composed with arithmetic or geometric average. Although the individual indicators normally consist of quantitative data (e.g. population statistics), the resulting hazard, exposure, vulnerability, and risk results are scaled between 0 and 10. These relative data allows comparing the indicators and indices (i.e., composite indicator) for the various administrative units. These methods can be carried out at different levels, even at communities (e.g. INFORM subnational risk index[17]). **The resulting risk is relative** and doesn’t provide information on the level and probability of the potential losses.

Quantitative risk assessment can assess potential impacts in two ways: deterministically or probabilistically.

Deterministic risk assessment estimates impacts from a single hypothetical scenario or combination of scenarios but do not necessarily consider neither the probability of the events in quantitative terms nor guarantee that all possible events are captured within a deterministic scenario set. Even though the probability of the events is not considered, risk analysis can still quantify **the uncertainties** that permeate the different steps of the computations. It can take into account uncertainties from the input parameters and models related to exposure and vulnerabilities to get the ranges of risk estimates for each scenario. The distribution of these risk estimates can be queried with statistical procedures to arrive at quantitative probabilities that can be assigned to the risk levels. Therefore, the probability of impacts differs from the probability of an event.

Probabilistic risk assessment attempts to associate probability distributions to frequency and severity of hazards and then run many thousands of simulated events in order to assess the likelihood of impacts at different levels.

Probabilistic approaches face their particular challenges. Some decision-makers may be reluctant to change approach if the education of probability is not widespread enough, especially among those making the final decision (Lund, 2008). It is necessary to communicate these model results in a specific, judicious and unambiguous way with

[17] http://www.inform-index.org/Subnational

sufficient scientific evidence and uncertainty (Jansen et al, 2017). Lund (2008) also indicates that the costs of probabilistic risk analysis may be higher than other methods, and is recommended in situations where large expenditures need to be studied or when the impacts of disaster would have very large consequences.

The outcomes of the risk analysis are the potential impacts over an agreed period of time. This result is linked to a particular uncertainty level that ideally has been aggregated from different sources of uncertainty. A sensitivity analysis provides information about the parameters of the model or other assumptions taken, determining their weight in the final outcomes obtained, facilitating to identify pitfalls while helping to verify and validate the model (Frey and Patil, 2002).

4.4 **Risk Evaluation**

According to ISO (2018) risk evaluation is the process of comparing the results of risk analysis with risk criteria to determine whether further action is required.

Passing the results, passing the responsibility. Experts involved in risk assessment process should have a control also over the "evaluating risk" stage (**Figure 1**), in spite of not being the experts those who advocate the risk criteria. However, partial knowledge of risk criteria should be known in advance as it dictates the risk metrics and the level of detail (resolution). This is the stage when the outputs of risk analysis are prepared for communication outside the expert group. This is a very delicate step because the experts are not only passing the results but also the responsibilities to the users of the results. Therefore the results should be accompanied with the instruction for use. The results should be understood correctly among all DRM responsible parties, only then the comparison and prioritization is possible as well as the risk criteria established. For example, the scale (resolution) of input data dictate also the scope of the results and their suitability for the decision making process at national, subnational or local levels. Or for example, the information on the time window considered can be important to determine whether climate change effects can be reflected in the results.

The outcomes provided must be **accompanied also with the overall uncertainty**, that should have been aggregated from the different phases and limitations of the methods used: due to the context, input data, models structure and outcomes, and the model parameters (Walker et al, 2003). The uncertainties can be again represented in various ways depending on the approach. Quantify uncertainty as much as possible, in order to avoid linguistic ambiguity. A particular quantification of uncertainty can be provided together with a description of the non-quantified uncertainties. Expert judgment may be used if necessary, but it must be openly reported.

Preparing outcomes of risk assessment process for DRM responsible is crucial. The evaluation stage requires input from those who owns the results and those who are responsible for DRM (**Figure 1**). The outcomes should be presented considering that the mentioned audience may not have a technical background, so risk should be represented in different and suitable ways: percentages, "natural frequencies", bar charts, pie charts, among others (Riesch, 2013). The tools, such as maps, matrices, indices and curves, showing risk and the components of risk, as well as different aspects of it, are explained in Chapter 2.4.

Risk metric is the common point. It is an essential tool for decision making and for engaging other stakeholders in DRM. The challenge is to assure the comparability of the risks obtained from different RA process. The outcomes of each risk assessment should fit in the aggregation process where the outputs from various analyses are merged into a common format for evaluating and comparing risk and communicating results.

The outcomes of the analysis are then presented to decision-makers, to compare and confront them to a set of criteria to reduce risk to an acceptable or tolerable level[18].

In the context of NRA, the risk criteria reckon with the socio-economic and political context of the country, such as:

- Costs, in monetary terms of the potential impacts, versus the benefits gained from taking the risk.
- Legislation in place, codes or standards of practice.
- Reversibility of impact – the possibility to reverse the negative consequences.
- Immediate effects on critical services.
- Controllability of consequences.
- Societal Perception, as "people respond to the hazard they perceive" (Slovic et al 1982). This information can be extracted from social surveys, attitude surveys and behavioural intentions and psychometric scaling techniques (Gough, 1990). Some of the dimensions underlying perceived riskiness listed by Vlek (1966) can actually be used as evaluation criteria, such as social distribution of risks and benefits or the voluntariness of exposure.

The results obtained from risk evaluation are a response, a decision. The results should display the expected (direct and indirect) losses for each risk, indicating which should be tackled first. Rather than going back to the characteristics of the risk, it is easier to detect which actions are more suitable. In this case a new round of risk analysis should be carried out; this time with the alternatives of which actions, to choose which actions would reduce the overall risk considering resources at hand.

Explicitly stating the uncertainty and limitations of the outcomes of risk analyses helps decision-makers to agree in additional actions regarding the exercise (such as investing more time and money to collect new data or revise the model, if results are not good enough for decision makers) while boosting future research in the areas that should be further developed.

In some sectors such as industrial manufacturing and energy production it may be easier to detect the need to treat the risk, and the possible options to do so. Klinke and Renn (2002) state to propose options beyond the typical risk-based management: the precaution-based management (for highly uncertain probabilities and related impacts or scarce knowledge on the causality of the agent to the possible assets and impacts) and the discourse-based management (when the impacts are known but ignored – because they materialize time after the event happens – or for such cases that scientifically have proved to be not an important threat, but are socially rejected, population feel frightened or unwelcome).

[18] Tolerable risk is defined as the level of risk that society is ready wot live with as long as the risk is managed to reduce it, while acceptable risk represents the level to which society is prepared to accept without any risk management option put in place (Bell et al, 2005)

5 Overview of the experts contributions

The process of disaster risk assessment in general has been in detail explained in Chapter 4. Authors of Chapters 8-16 tackled the hazard or asset specific risk assessment in the following order:

- drought,
- earthquakes,
- floods,
- terrorist attacks,
- biological disasters,
- critical infrastructures,
- chemical accidents,
- nuclear accidents,
- Natech accidents.

Authors were asked to structure the contributions in a harmonized way, as much as appropriate, and to follow ISO 31030 (ISO, 2018) for the stages of the risk assessment process and to follow the UNISDR terminology regarding the risk concept. Chapters addressing the risk assessments by hazard communities are put first as they have to address issues relevant for scenario building which are important input for the rest of the chapters focusing on risk assessment from the asset perspective.

Different hazards as well as different assets require very different analysis of their risk. **Scientists shall explain disaster risk assessment step by step.** Experts contributing to the report will provide guidance for using existing risk assessment methodologies, terminology used for their understanding, data, knowledge and software needed for the analysis and what results can be expected/feasible for each of the methodologies.

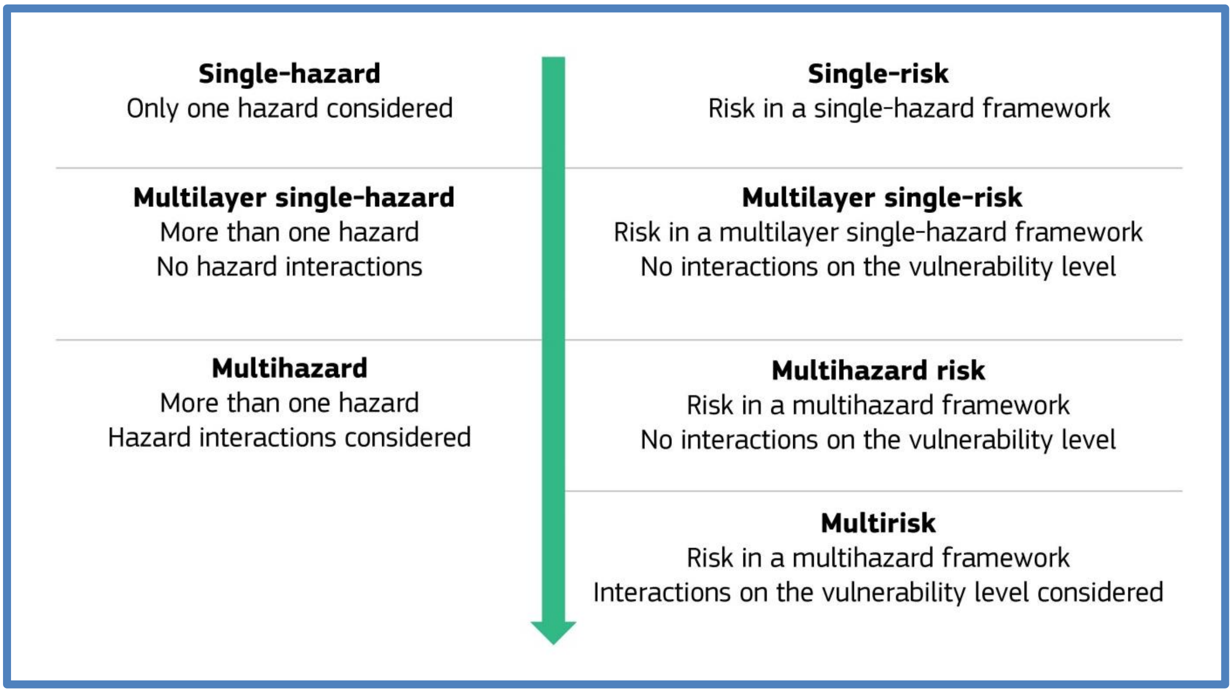
In order to assist decision makers in their prioritising of mitigation actions, we have to understand the relative importance of different hazards and risks for a given region. This requires that risks arising from different hazards to be comparable with each other. Different hazards differ in their nature, return periods, intensity and impacts which dictates different metrics to measure them. This doesn't only hamper **the comparability** among the risks arising by different hazards but it also makes difficult to aggregate the impacts from a single hazard in a meaningful way to assess the total risks coming from all hazards in a region. **All this issues should be treated in the context of a multilayer single-risk framework.**

Knowing the differences among risk assessment approaches related to different hazards/assets will eventually help us to find the framework covering all of them in terms of terminology, set of methodologies, risk metrics, data needed and results required for further treatment of risk. Hopefully, it will also pave the way to **multihazard** or even multirisk assessment approaches (**Figure 10**). Therefore, harmonising and standardising the assessment processes as well as risk metrics among different hazards risk is the first step towards a full multirisk assessment that covers the interactions on the hazard (cascading effects) and vulnerability level.

Not to raise expectations too high the following level of sophistications (**Figure 10**) will be covered:

- risk in a single-hazard framework (in the majority of hazard specific topics)
- risk in a multilayer single-hazard framework when focusing on specific asset (e.g., critical infrastructure)
- risk in multihazard framework (e.g. Natech accidents)

Figure 10. *From single-risk to multi-risk assessment: terminology.*



Source: Zshcau, 2017

Where do we stand? At this stage not all the topics could be addressed with the same level of attention in each of the hazard fields. Most probably because:

- the risk related available knowledge and current research focus vary among hazards fields
- risk assessments for different hazards/assets have to tackle different challenges
- disaster risk management is hazard and asset related, e.g., for each hazard related risk there are different solutions efficient in different phases of the DRM cycle

The methodologies and processes to carry out disaster risk assessment have advanced in the last decade*,* as highlighted by many of the contributions in Chapters 8-16. National risk assessments should consider the requirements of **EU legislation**. EU legislation (see **Table 1**) and research projects seem to boost disaster risk assessment exercises. These two elements have served to encourage the scientific community to work for specific outputs, having particular and common objectives to reach, and to work in the validation and credibility of methods, as many stakeholders are usually engaged in RA exercises and the outcomes of it must help governmental officials to make decisions. Furthermore, as said in Chapter 3, the information produced about the **disaster risk drivers** point out which actions could be taken in order to reduce future disaster risk.

Table 1. Summary of the legal framework and standards in place for assessing the risk of different hazard at the EU, and the need to report about it to EU institutions.

Hazard	**EU legislation/Standards**	**Reporting**
Earthquakes	Eurocode 8: Design of structures for earthquake resistance (CEN, 2005)[19]	✘

[19] Eurocode 8 is introduced in the legal framework of some EU/EFTA MS as obligatory, but in other MS it is voluntary. The situation with the obligatory use of the Eurocode 8 Parts in the different countries is presented by Dimova et. al (2015).

Earthquakes	Commission Recommendation 2003/887/EC on the implementation and use of Eurocodes for construction works and structural construction products	✓[20]
Floods	The Flood directive: Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks.	✓
Threats of biological, chemical, environmental and unknown origin	Decision 1082/2013/EU of the European Parliament and of the Council on serious cross-border threats to health Commission Implementing Decision implementing Decision No 1082/2013/EU	✓
Zoonoses and zoonotic agents	Directive 2003/99/EC of the European Parliament and of the Council on the monitoring of zoonoses and zoonotic agents	✓
Critical Infrastructure	The European programme for Critical Infrastructure: Council Directive 2008/114/EC on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection	✓
Chemical accidents	The Seveso III directive : Directive 2012/18/EU of the European Parliament and of the Council on the control of major-accident hazards involving dangerous substances	✓
Nuclear accidents	Council Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation Council Directive 2014/87/EURATOM amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations	✗
Natech accidents [21]	The Seveso III directive : Directive 2012/18/EU of the European Parliament and of the Council on the control of major-accident hazards involving dangerous substances	✓

[20] There is a non-binding piece of EU legislation (Commission Recommendation 2003/887/EC) which recommends to the EU and EFTA MSs to notify the European Commission on the Nationally Determined Parameters chosen for their territory.

[21] The term Natech accidents covers technological disasters triggered by natural hazards. In case of the chemical facilities the regulations are provided by the Seveso III directive, while for the other facilities, such as off-shore structures and pipelines the standards by industry are applied.

Establishing a framework facilitates different communities to work together, and networks to grow and mature in their understanding of risk. As shown by the teams dealing with technological accidents, **lessons learned** are a valuable source for improving risk identification and analysis.

One of the main challenges highlighted by the majority of groups is **data quality and availability***.* Data is many times recorded by different institutions for their own purposes, not necessarily matching the ones of single-hazard assessments. European-wide databases are proposed by the authors although local one is preferred in the guidelines (Commission Staff Working Paper, 2010). However, the objective of DRMKC Risk Data Hub is to improve the access and share EU-wide curated risk data either through hosting relevant datasets or through linking to national platforms for fostering Disaster Risk Management (DRM).

There seems to be room for improvement regarding **scenario building***.* Scenarios should consider different triggers of a hazard together with the conditions that lead to these to happen, while the socio-political and economic context and possible future trends are included. The advantage of the scenario approach is to include also the capacities in place to prevent/mitigate, recovery actions after the disaster as well as cascading events. Furthermore, to assure the comparability among the scenarios the list of assets considered should be kept the same. If technological facilities are on the list then Natech accidents should be part of all scenarios.

Reach the impact*.* The different hazard communities have developed methodologies to calculate the potential losses on assets commonly affected by the materialization of the hazard of their expertise. The dynamic nature of the hazard together with the difficulties to characterize the different dimensions of vulnerability and integrate these in the methods, sometimes lead to general and highly uncertain outputs. Some teams struggle to calculate the most direct (in time and space) impact suffered by an asset, considering the resources and time that decision-makers would require to act *in time* on the assets they would like to protect. Socio-economic implications of an event are a challenge for all the risk assessment contributions. Nonetheless, characterizing the risk and using comprehensive and balanced approaches, even if simplified ones, is supported by the authors to plan measures to reduce risk.

Methodologies diversification and sophistication can be fruitful, but it might be a double-edged sword. As shown by the authors, assumptions are inevitably introduced. As recommended, these should be reported together with the limitation of the methods. It is responsibility of scientific teams to **clearly state the advantages and disadvantages** of the steps followed and how these affect the results presented. Actually the preferred method to be used would consider many criteria (data availability, transparency, consistency of the method, reliability of estimates, the possibility to assess uncertainty, etc.). This way, scientific teams secure providing all information at hand for decision-makers to carry out their duties.

6 Way Forward

NRA is a **demanding process** and presents a challenge for each and every Member State in terms of resources, time and complexity. The complexity is introduced through the **multi-disciplinary** nature of the disaster risk assessment per se that requires the involvement of many affected sectors and parties from different communities. This is necessary to fully consider their perspective, information, experiences and knowledge. The most important objective of NRA is to **find a common understanding** with all relevant stakeholders of the risks faced and their relative priority in a transparent way. This will serve to make DRM planning efficient and finally to **increase the country's resilience** in a steady but timely manner.

The Version 0 of this report has started the process of involving the scientific community to help overcome obstacles that national authorities in charge of the preparation of NRA process are confronting. The whole NRA process is split into smaller feasible tasks executed by different groups and the gaps which hinder each group to provide the results that would fit together into the bigger picture are revealed. **National Risk Assessment is a compound of many processes of risk assessment** each engaging different set of sectors but have the context of NRA in common.

From a scientific point of view, the main challenges we are facing are mainly true:

1. consistent disaster risk assessment processes that would allow the comparability and aggregation of risks arising from different hazards as well as different assets,
2. the better understanding of how underlying risk drivers and required capacities define the level of risk.

The first challenge would support decision makers to prioritize risks, while the second, is required for an effective reduction of disaster risk. Both together are essential part of integrated approach in DRM, linking prevention, mitigation, preparedness, response, recovery, restoration and adaptation phases.

Different hazards as well as different assets require specific methods to analyse their risk. Therefore, this report collects the **contributions from several JRC expert groups** that provide guidance for disaster risk assessment processes related to their scientific field, hazard or asset specific. Knowing the **differences among risk assessment approaches** related to different hazards/assets will eventually help us to find the framework covering all in terms of terminology, set of methodologies, risk metrics, data needed and results required for further treatment of risk. In majority of cases the science can, at the moment, provide advice for risk in a single-hazard framework. Rare are the cases with more advanced level of risk assessment considering more than one hazard, hazard interactions or even vulnerability interactions. They are usually driven by the strong presence of industry where the asset is the virtue, such as critical infrastructure, chemical and Natech accidents. These latter examples become the model for the way forward.

Risk comparability should be treated in the context of risks in a multilayer single-hazard framework. Harmonising and standardising the assessment as well as the risk metrics among different hazards is the first step towards a multi hazard assessment. One of the key messages of "Science for disaster risk management 2017: knowing better and losing less" [Poljanšek et al., 2017] is asking for multihazard risk assessment. This will be the challenge of the following versions of this report. To find the common risk metrics, the focus will be shifted to the **assets to be protected** and potential impacts of the specific asset arising from different hazards will be compared.

To improve the **understanding of underlying risk drivers and needed capacities** can be dealt with the better knowledge base of risk, availability of data to describe hazard, exposure and vulnerability as well as development of the risk analysis methodologies that enables to model links between underlying risk drivers and capacities, risk components and risk levels. The disaster loss databases are of major importance. For example, using past even losses it is possible to identify and quantify a wide range of socio-politic-economic drivers associated with the vulnerability.

With the next version it is planned to expand also in a number of disaster risk scientific communities involved to introduce risks not mentioned herein, such as **forest fires risk, extreme weather risk or cyber security risk**, that are also identified as the most frequent disaster risks among MS according to the last EU risk overview (Commission Staff Working Paper, 2017).

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8 Drought

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8.1 **Context of drought risk assessment**

The Member States of the European Union report every three years on the national risk assessment for various disasters that occur on their respective territories. In order to assess priorities at European level an initiative was started aiming to make the reporting between the various Member States comparable.

In this section, recommendations for the development of national drought risk assessments and for reporting on drought disasters are presented. The recommendations are mainly based on the methodologies presented in a recently published JRC Technical Report on drought risk assessment and management (Vogt et al. 2018) and the guidelines developed by the Global Water Partnership for Central and Eastern Europe in 2015 (GWP-CEE, 2015). Also some recommendations from the reporting obligations under the Water Framework Directive and from scientific literature are presented.

This first version of recommendations aims to help the various existing assessments to converge over time, allowing the Member States to learn from experiences in neighbouring countries with similar issues and problems.

Drought is for many countries one of the most expensive weather and climate related disasters. This affirmation is true for both, the world and particularly for Europe. Estimations of the losses due to drought in the US are in the order of 232.5 billion US$ in the period 1980 to 2017 (NOAA, 2017) and in Europe the annual losses were estimated around 3.2 billion € (Water Scarcity and Droughts in Europe, 2017). This situation is highlighted by the following statement of Swiss Re, one of the main reinsurance companies worldwide: "The big drying – growing water stress: While the U.S. Southwest is in an on-going water crisis, similar situations can be found today and in the future around the world – from Southern Europe and the Mediterranean to Africa, parts of Asia and Latin America. The risks range from wildfires, competition for water among the energy and agricultural sectors to mass migration and wider conflict potentials." (Egloff et al. 2017).

8.2 **Risk identification**

According to the main characteristics of the water deficit and the related impacts, droughts are often divided in four main types: **Meteorological Drought**, which is related to a lack of precipitation and/or high evaporative demand, lasting from weeks to months or even years, **Agricultural Drought**, which is a period with reduced soil moisture resulting in a deficit in plant water supply with related impacts on agricultural crops and/or natural vegetation, and **Hydrological Drought,** which is characterised by reduced river and groundwater flows. Hydrological drought can provoke a reduction of the accessibility of waterways and access to cooling water for industrial and energy generating processes.

Finally, a **socioeconomic drought** is a condition in which important services such as energy and drinking water supply are reduced.

The effect of a drought disaster can be exacerbated if it coincides with a heatwave. Warmer conditions increase evapotranspiration, depleting surface and soil water resources quicker. Moreover, a heat wave constitutes a disaster in itself in which access to clean water becomes essential both for humans as well as (wild) animals.

Since droughts are a recurring feature of all climates and can occur almost everywhere (excluding deserts and very cold regions) every Member State should have a drought management plan to cope with possible impacts. However, in Europe there are areas more prone to recurrent droughts such as the Mediterranean or parts of central Europe, in which Member States are more susceptible to suffer the negative effects of severe droughts.

Unlike other natural hazards such as earthquakes, floods, or wind storms that result in immediately noticeable and structural damage, droughts develop slowly and can last for long periods of time from some months up to several years. Frequently, drought conditions remain unnoticed until water shortages become severe and adverse impacts on environment and society become evident. Drought impacts may be influenced by adaptive buffers (e.g. water storage, purchase of livestock feed) or can continue long after precipitation has returned to normal conditions.

The slowly developing nature and long duration of droughts, together with a large variety of impacts beyond commonly noticed agricultural losses, typically makes the task of quantifying drought impacts difficult.

Impacts of droughts can be classified as direct or indirect. Vogt et al., (2018) present a detailed characterization of the many different sectors that might be adversely affected by droughts. Examples of direct impacts are a reduction of water levels, reduced crop and forest productivity, increased wild fire occurrence, increased livestock mortality, and damage to ecosystems, and tourism among many others.

Similarly, many economic sectors and livelihoods are indirectly affected by droughts as they rely in different ways on water availability. These indirect effects can propagate or cascade quickly through the economic system, affecting also regions far from where the drought originates. Indirect impacts relate to secondary consequences on natural and economic resources. They may affect ecosystems and biodiversity, human health, commercial shipping and forestry. In extreme cases drought may result in temporary or permanent unemployment or even business interruption, increased prices of food, and can lead to malnutrition and disease in more vulnerable countries (Vogt et al. 2018).

The main sectors potentially affected by droughts might be identified by consultation with the main stakeholders as a first step of the risk assessment. Once the main sectors are recognised the assessment should be tailored to these specific needs and several complementary risk layers could be drafted for the different users. For instance, the information relevant for a farmer is not necessarily relevant for a water manager working in an inter-basin water transfer system and vice versa.

8.3 **Drought risk analysis and characterization**

There are several ways to approach drought risk, however, the most commonly applied are the so-called outcome and contextual approach (Van Lanen et al. 2017). The **outcome or impact approach** is based on the interactions between stressor and response. In this case, the endpoint of the analysis is the vulnerability (the more damage a society suffers, the more vulnerable it is). This approach relies on the use of quantitative measures of historical impacts as proxies for the vulnerability estimation. However, relying on historical impacts has several limitations, mainly because impact data are often unavailable or not directly comparable between different regions.

The **contextual approach** is based on intrinsic social or economic factors that define the vulnerability. Here the vulnerability is the starting point, allowing understanding why the exposed population or assets are susceptible to the damaging effects of a drought. It is more suitable for setting targets for disaster risk reduction. This approach generally relies on combined indicators, which are mathematical combinations of risk determinants that have no common unit of measurement.

Agriculture (crop and livestock production) is often the first sector affected by droughts. Globally, almost 86 percent of agricultural damages and losses were caused by drought events. A reduction in water availability and increases in solar radiation and temperature during a drought event can be directly translated into a significant reduction of crop productivity.

End users, water managers and policy makers rely on drought risk assessments that usually are developed with emphasis on agricultural and primary sector impacts. The conceptual framework presented here as an example of drought risk assessment was applied in an operational global risk assessment[22]. This system is mainly oriented to agriculture and other primary sectors. However, the described methodology can be applied at different scales (regional to local) and to different sectors.

According to this framework, drought risk can be conceptualized as a combination of the natural hazard, the exposed assets and their inherent vulnerability (susceptibility to drought and adaptive capacity). Following this definition, the risk to be subject to damages and economic losses from a drought event depends on the combination of the severity and probability of occurrence of a certain event, the exposed assets (crops, livestock, critical infrastructure) and/or people, and their intrinsic vulnerability (susceptibility and adaptive capacity) to cope with a disaster (Carrão et al. 2016).

8.3.1 Hazard characterization

Droughts affect different economic sectors and sector-specific risk assessments need to be developed. The characterization of the drought hazard should identify the most suitable drought indicator to represent the water resources necessary to meet the specific needs and uses of each sector. For instance, precipitation and/or soil moisture anomalies are key for rainfed agriculture, while river low flows, groundwater and reservoir storage are important for water supply systems.

8.3.2 Exposure identification

Drought exposure is linked to the location of assets and persons that could potentially be affected by droughts. This information has to be represented through spatially explicit geographic variables. For instance, Carrão et al. 2016, proposed an approach taking into account different proxy indicators characterizing agriculture and primary sectors, namely crop areas and livestock distribution (agricultural drought), industrial domestic water stress (hydrological drought) and human population (socioeconomic drought).

8.3.3 Vulnerability identification

Drought **vulnerability** is a key risk component as it allows identifying the policy relevant variables to be targeted (Naumann et al. 2018). Since it is not possible to reduce drought frequency and severity, interventions to reduce drought impacts have to focus on reducing vulnerability of human and natural systems.

As illustrated in Carrão et al., 2016, a multidimensional model composed by social, economic and infrastructural dimensions can represent vulnerability. Social vulnerability is linked to the level of well-being of individuals, communities and society; economic vulnerability is highly dependent upon the economic status of individuals, communities and nations; and infrastructural vulnerability comprises the basic infrastructures needed to support the production of goods and sustainability of livelihoods.

According to this approach, each dimension is represented by generic proxies that reflect the level of development of different constituents of civil society and its economy. In that

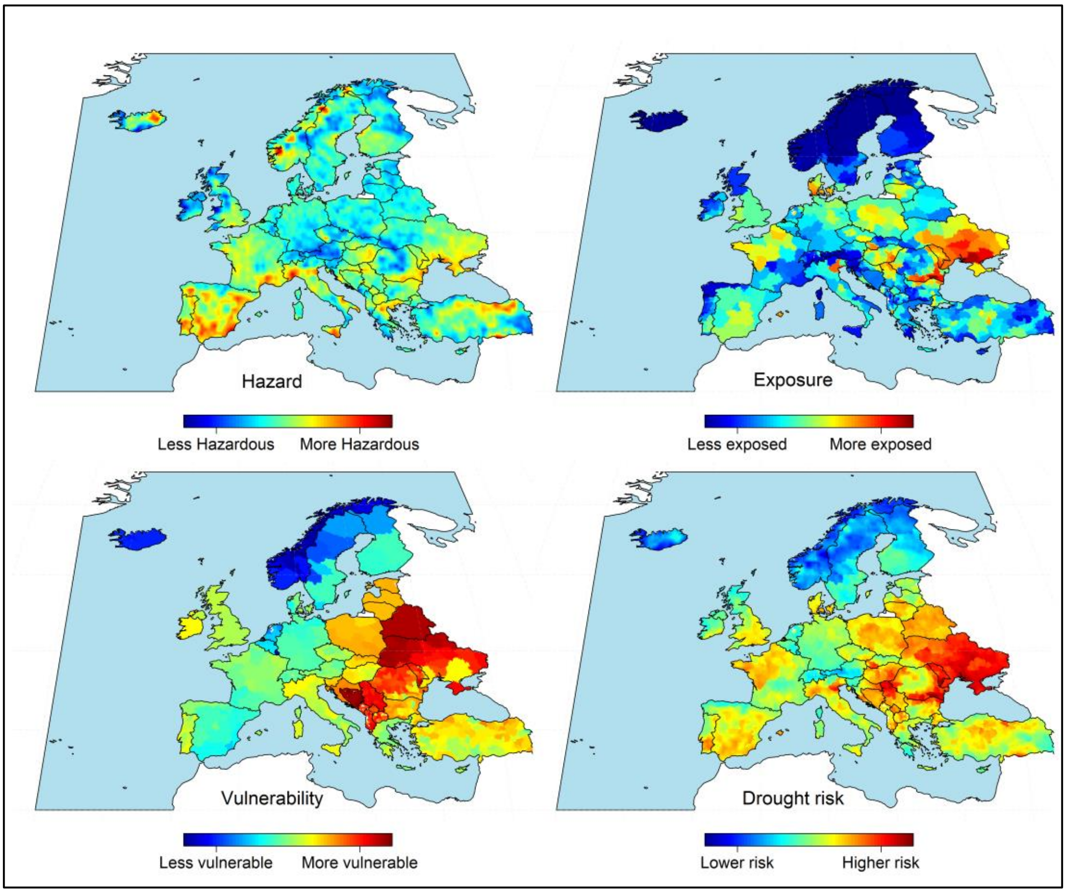
[22] Global Drought Observatory (GDO): www.edo.jrc.ec.europa.eu/gdo/

sense, individuals and populations require a range of independent factors or capacities to achieve positive resilience to drought impacts while no single factor on its own is sufficient to yield the varied livelihood outcomes that a society needs in order to cope with droughts.

Some variables that could be included into the vulnerability assessments are listed below as an example:

- Dependency on agriculture for livelihoods,
- Energy use,
- Farmers with crop/livestock insurance,
- Market fragility,
- Adult literacy rate,
- Availability of functioning drought early warning systems,
- Volume of water storage in a safe reservoir,
- Population without access to improved water,
- Institutional capacity and government effectiveness,
- Fertiliser consumption,
- Availability of water infrastructure, like reservoirs and irrigation systems.

Figure 11: Drought hazard, exposure, vulnerability and risk for agricultural production in Europe according to the conceptual approach (after Carrao et al. 2016 and Vogt et al. 2018).



As an example, **Figure 11** shows the three determining factors of drought risk (hazard, exposure and vulnerability) as well as their combination that results into the drought risk map for agricultural production in Europe. In this case, the scores for each component are not an absolute measure, but a relative statistic that provides a regional ranking of hotspots where to target and prioritise actions to reinforce adaptation plans and mitigation activities. This kind of analysis could be refined at higher resolution to obtain meaningful results at different scales of analysis. These can range from the farm level to the continent allowing an assessment of the spatial distribution of the drought risk within a given area of interest (e.g. farm, province, river basin or country). As this framework is data driven, to obtain reliable estimates the main limitation is the availability of data at the different levels.

8.4 **Risk treatment (actions to prevent drought impacts)**

To reduce the drought risk Member States need to present an inventory of the legal and institutional tools available in the country to perform the actions (Iglesias et al. 2009) briefly presented in the following chapters. After this short introduction for every action, a quantification method will be proposed, allowing comparing the readiness between the Member States.

The preparation of Drought Management Plans should be linked to an agreed conceptual framework for drought management and based on clear drought definitions (Vogt et al. 2018). A good example can be found in the National Drought Management Policy Guidelines published by the Integrated Drought Management Programme (IDMP) (WMO and GWP 2014) and adapted to regional circumstances by the Global Water Partnership for Central and Eastern Europe (GWP-CEE 2015).

As presented in EC (2007) two basic approaches for drought risk management are currently applied. Their related legal and institutional tools can be divided into **reactive** and **proactive** actions. The proactive approach is linked with plans to prevent or minimize drought impacts in advance; these are mainly long-term actions, aimed to make the territory and the economy more robust to cope with droughts. The reactive approach includes actions after a drought event has started and is linked to short-term actions that can be executed during an emergency.

8.4.1 Organizational issues

It is recommended that the Member State establish a Drought Scientific and Advisory Committee. This Committee consists of scientific and practical experts in Land and Water Management and must be able to advice the various government bodies freely and openly. Care must be taken that the Committee is not representing so-called stakeholders. Stakeholders should be represented using the normal political decision process.

The Committee should set out rules on when to gather during an emerging catastrophe and have the power to advice the government on declaring the state of emergency. The committee can also set out the relevance of the various actions mentioned in this document considering the local climatological, geographical and economical context of the Member State.

In Member States with differing climates or federalization, more than one of these committees can co-exist.

8.4.2 Short Term Actions, during and immediately after the emergency

In order to mitigate the effects of an emerging drought disaster the Member State needs to be able and have legislation in place, to perform the following actions.

Water Demand Reduction:

- Information campaigns for water saving

- Restrictions (e.g. car washing, gardening etc.)
- Irrigation restrictions
- Mandatory Rationing

Water Supply Increase:
- Temporary use of additional sources (river, seawater)
- Temporary exploitation of groundwater reserves

Impact minimization:
- Temporary reallocation of water resources
- Public aids to compensate income losses
- Tax reduction or delay of payment deadlines
- Public aids for crop insurance

8.4.3 Long term actions, National Strategy

In order to make the territory and the economy less prone to drought disasters the Member State can develop a policy using a Drought Management Plan. Such a plan can focus on the following long-term actions:

Water Demand Reduction:
- Economic incentives for water saving
- Pricing policy
- Agronomic techniques for reducing water consumption
- Drought resistant crops replacing of irrigated crops
- Dual distribution network for urban use
- Water recycling in industries

Water Supply Increase:
- Reuse of treated waste water
- Leak detection programs
- Inter-basin and within-basin water transfers
- Reservoir construction or amplification of existing reservoirs
- Construction of farm ponds
- Desalinization
- Control of seepage and evaporation losses
- Keeping water longer in the ecosystem by naturalization of channelled rivers and creation of ponds
- Counter actions on cementation (surface sealing), increasing soil water storage capacity
- (Re)Forestation policy

Impact minimization:
- Education / awareness campaigns
- Reallocation of water resources based on water quality requirements
- Development/improvement of early warning systems
- Implementation of Drought Management Plan
- Programs for areas with soils subjective to additional hazards during droughts
    - Peatlands, leaking – drainage problems
    - Clayey soils, cracking – construction problems
    - Sandy soils, lack of moisture holding capacity– quick dryness of soils
    - Percolation of salty sea water in groundwater resources in coastal areas
- Insurance programs

8.4.4 Quantification of the actions

The following table gives a short overview of the actions previously presented and accompanied by a quantification method allowing them to be comparable between the Member States.

The list is not exhaustive, and some measures are not relevant in very wet climates and/or in areas with a low population density.

Besides the quantification, it is recommended to notice the source on which the quantification is based as well as a judgement on the quality of the quantification (poor, good, excellent).

Table 2: Overview of the actions accompanied by a quantification method allowing them to be comparable between the Member States

Action	Impact	Quantification	Remark
Information/Education Campaigns	Change of behaviour in quantity of water use	€ / per citizen / per year	Measure effect, divide state and private sector campaigns
Restrictions in water use	Prioritizing the available resource	Effort in enforcing the law in €	Description of the law
Restrictions in irrigation	Prioritizing the available resource	Loss of crops in € in year	Description of the law
Mandatory rationing	Prioritizing the available resource	Effort in enforcing the law in €	Description of the law
Temporary use of additional water sources	Increasing resource, of lower quality	Realization price of the effort	m^3 potential available
Temporary use of groundwater	Increasing resource	m^3 potential available, in emergency	Description of installations
Temporary reallocation of water resources	Prioritizing the available resource	m^3 potential available, in emergency	Description of installations
Public aids to compensate income losses	Preservation of the economic structure of the food production sector	In €, total available funds, total used fund in year	Reference to the law
Tax reduction or delay of payment deadlines	Preservation of the economic structure of the food production sector	In € and time for year	Reference to the law
Public aids for crop insurance	Preservation of the economic structure of the food production sector	In € and for year	Reference to the law
Economic incentives for	Gradually spilling	In € per year	Potential of water saving should be

Action	Impact	Quantification	Remark
water saving	less water		quantified
Agronomic techniques for reducing water consumption	Gradually spilling less water	# of researchers working on the topic	Peer reviewed articles on the subject produced by researchers of the Member State
Dry crops in place of irrigated crops	Reducing vulnerability	Percent decrease in irrigated area per year	Mark if official policy objectives
Dual distribution network for urban use	Optimizing use of resource	€ invested per citizen per year, # of citizens connected to a dual system	Mark if official policy objective
Water recycling in industries	Optimizing resource, avoiding pollution	€ invested per year, m^3 water extracted per year, per major river	Reference to River basin plan of the WFD
Reuse of treated waste water	Increasing quantity of resource	m^3 water reused per year	
Leak detection programs	Avoiding loss, also economic	Length of water piping system, m^3 water loss through leaks, K€ investment per year. Maintenance investment per year in national water pipe and sewage system.	
Inter-basin and within-basin water transfers	Flexibility increase	Description of the possibilities in m^3 water per basin (from to)	Reference to River basin plan of the WFD
Reservoir construction or amplification of existing reservoirs	Flexibility increase	Storage capacity in the existing reservoirs (m^3), m^3 storage capacity in planned reservoirs. K€ planned investment for next 3 years	
Construction of farm ponds	Increasing coping capacity	# of existing ponds, # of planned ponds for next 3 years	Reference to River Basin Management Plan of the WFD
Desalination	Straight increase of availability resource	Capacity in m^3 and percentage reliance on renewable energy of Desalinization.	Provide planning for the next 3 years both public and private (guess)
Control of seepage and	Improving agricultural	Investment in K€ per	

Action	Impact	Quantification	Remark
evaporation losses	practices	year	
Keeping water longer in the ecosystem, naturalization of channelled rivers and creation of ponds	Adaptation of the hydro geographical system, correction of past errors	Investment in K€ and capacity potential	
Counter actions on cementation, enhancing Soil Water Storage capacity increase	Increasing the storage capacity of water in the landscape	Investment in K€ in projects regarding the subject	
Reallocation of water resources based on water quality requirements	Enhancing flexibility during hazard	m^3 of potential water resources	
Stimulation of silvo-pasture and agroforestry	Connecting vegetation with groundwater	Km^2 increase of area under silvo-pasture or agroforestry	Provide government measurements to enhance change
Development/improvement of early warning systems	Timely information flow	Qualitative description	Reference to the systems, relation to setting state of emergency
Implementation of a Drought Management Plan	Coordination between various agents	Qualitative description	Relation to upstream and downstream plans in neighbouring countries
Programs for areas with soils subjective to additional hazards during droughts	Minimize impact	Mapping of the areas with sensitive soils for example with cracking	Description of the programs, soils with changing properties if drought lasts long.
Insurance programs	Enabling restart after the hazard	M€ of harvest insured against drought	Also M€ claimed and reimbursed to be marked.
Drought Scientific Advisory Board	Counteracting focus on short term interests	Members of the Board and their affiliations	Did the board create an advice in the last 3 years?

8.5 **Gaps and challenges**

Assessing the risk for drought-related impacts to society and environment is a complex task, complicated by the very nature of the phenomenon, its often large spatial extent and temporal duration, leading to cascading impacts that may affect areas far distant from the actual drought and may last long after the actual drought has ceased. Lack of standardized data on historical impacts (both damage and loss) are a further complication.

The interlinkages with other hazards such as wildfires, heatwaves and even floods and the combined risks arising from different hazards need to be explored. These risk assessments need to be sector specific, requiring an adequate set of environmental and socio-economic data related to the respective sectors.

However, together with more efforts in the collection and standardisation of impact data, the use of conceptual models that rely on policy relevant variables or proxies of socio-economic vulnerability can help stakeholders and policy makers to spot the most vulnerable sectors and the goals to be achieved in the high risk areas.

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9 Earthquakes

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9.1 **Introduction**

Earthquake is the fourth most common hazard assessed in the recent national risk assessments prepared by the countries participating in the Union Civil Protection Mechanism[23]. Indeed, 19 countries (Austria, Bulgaria, Croatia, Cyprus, France, Germany, Greece, Hungary, Iceland, Italy, Malta, Norway, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain and Sweden) performed risk assessment for earthquake phenomena and in some cases considered cross-border and cascading effects, such as tsunami, landslides, disruption of infrastructure and industrial accidents.

The effects of earthquakes can vary from localised events to dramatic impacts on communities, infrastructure, the economy and the environment, across large regions. Occurrence of a major seismic event in an urban area can have a particularly severe impact, resulting in the complete disruption of economic and social functions in the community. **Table 3** shows that important earthquakes that occurred in Europe during the last 15 years affected whole regions and caused significant damage that reached billions of euros.

Table 3. Earthquakes in Europe since 2002, for which the EU Solidarity Fund intervened

Occurrence	Country	Category	Damage (million €)
October 2002, Molise	Italy	Regional	1558
April 2009, Abruzzo	Italy	Regional	10212
May 2011, Lorca	Spain	Regional	843
May 2012, Emilia Romagna	Italy	Regional	13274
January 2014, Kefalonia	Greece	Regional	147
November 2015, Lefkada	Greece	Regional	66
August 2016 – January 2017, Central Italy	Italy	Major	21879
June 2017, Lesbos	Greece	Regional	54
July 2017, Kos	Greece	Regional	101

Source: EU Solidarity Fund, 2018 (http://ec.europa.eu/regional_policy/index.cfm/en/funding/solidarity-fund).

Seismic risk is often expressed in terms of a combination of the magnitude of the consequences of an earthquake and the likelihood of these consequences to occur. It is normally obtained considering the seismic hazard of the site or region, the exposed assets that may be impacted by an earthquake and the vulnerability of those elements at risk, for instance, the vulnerability of different types of buildings or constructions.

This Chapter presents the main components of seismic risk assessment, i.e. hazard, exposure and vulnerability assessment, and the available methodologies for impact assessment at a regional scale. Other specific models and methodologies apply for the seismic risk assessment of individual assets. It provides references to state-of-the-art models, as well as a list of software for seismic risk assessment and of relevant European

[23] Commission Staff Working Document, Overview of natural and man-made disaster risks the European Union may face, SWD(2017) 176 final

research projects on this issue. The practical use of models and tools is illustrated through three risk assessments that were recently performed in European countries.

9.2 **Hazard assessment**

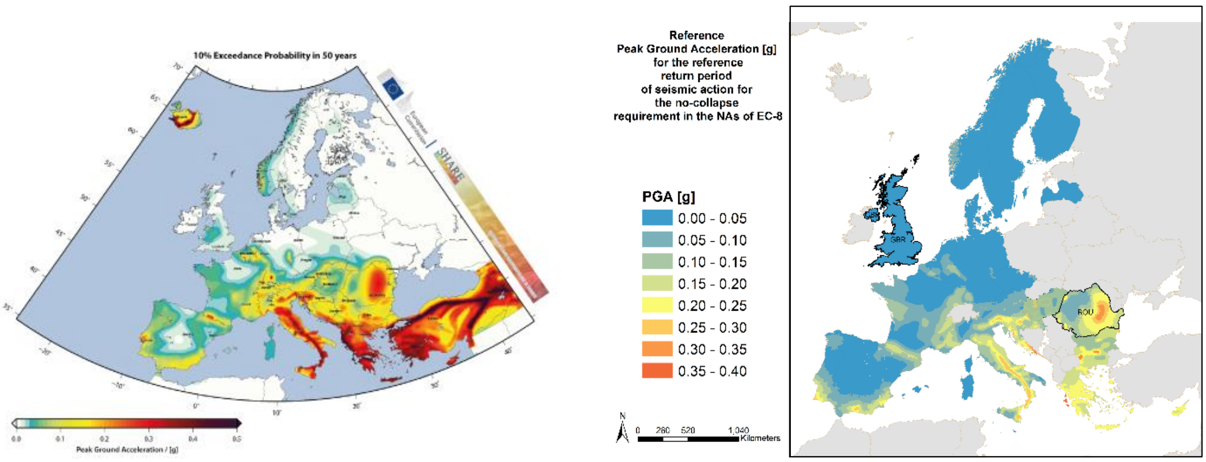
Many countries in the South-Eastern part of Europe are particularly exposed to earthquakes, which is consistent with the main fault lines in Europe located where the Eurasian plate meets the African plate and runs through the Mediterranean Sea. Active zones of seismicity in countries' border regions may result in cross-border impacts of earthquake events.

Earthquake hazard may be assessed with deterministic or probabilistic methods. Scenario studies, e.g. Coburn and Spence (2002), frequently refer to a maximum probable or maximum credible earthquake based on a deterministic seismic hazard assessment (see Chapter 9.4.2). Probabilistic methods for seismic hazard analysis have evolved significantly in the last decades and are widely used nowadays. Depending on the available data, they make use of historical and instrumental seismic records, seismogenic models, geological and geodetic data, time-dependent trends in earthquake recurrence, and ground motion prediction equations. Uncertainties in seismic hazard assessment originate from the models for the seismogenic source and ground motion, from the parameters used in those models and from the random nature of seismic events (Silva et al., 2017).

The European Plate Observing System (EPOS)[24], facilitates integrated use of data, data products, and facilities from distributed research infrastructures for solid Earth science in Europe. EPOS comprises thematic core services that are relevant to seismic hazard assessment, namely on seismology (waveform data, earthquake parametric data and hazard data), near fault observatories, geological data and modelling.

The results of seismic hazard analysis are obtained in terms of an intensity measure, such as peak ground acceleration, peak ground displacement, spectral acceleration and spectral displacement for the fundamental period of the structure, spectrum intensity, etc.

Figure 12. *Peak ground acceleration from the SHARE project (Giardini et al., 2013) for 475 years return period (left) and peak ground acceleration from the National Annexes to Eurocode 8 for 475 years return period, except for 100 years in Romania and 2500 years in UK (right)*



Source: Adapted from Palermo et al, 2018.

In probabilistic seismic hazard assessment methods, the reference values of intensity measures are calculated for a prescribed return period (e.g. 475 years) or for probability

[24] www.epos-ip.org

of exceedance of an intensity level in a period of time (e.g. 10 % in 50 years). A hazard curve provides a continuous relationship between intensity and probability of exceedance. A harmonised Seismic Hazard Model for Europe (Woessner et al., 2015) was produced within the SHARE[25] project (**Figure 12**) and is currently being updated and extended in the framework of the SERA[26] project.

Hazard studies serve also to produce maps of seismic zones that are included in design codes, such as Eurocode 8 (CEN, 2004). Within the suite of Eurocodes[27], Eurocode 8 applies to the design and construction of buildings and civil engineering works in seismic regions. For this purpose, national territories are subdivided into seismic zones, depending on the local hazard. By definition, the hazard within each zone is assumed to be constant and is most often expressed in values of peak ground acceleration. It is noted that the seismic zone maps and peak ground acceleration levels given in the National Annexes to Eurocode 8 (**Figure 12**) were produced in different times and with different hazard models and data.

9.3 Exposure and vulnerability assessment

Assets that may be impacted by earthquakes include buildings, people, business and economic activities, basic services (health facilities, emergency services, educational facilities, etc.), infrastructures (transportation, water, sewage, gas, communication, etc.), cultural heritage and the environment.

Exposure data for buildings have been collected for a few cities around Europe, often at a high level of geographic disaggregation. Another significant source of information on the building stock, albeit not fully harmonised across countries, are the cadastres and national housing censuses that may furnish an exhaustive picture of the housing stock in a region. In the framework of the Prompt Assessment of Global Earthquakes for Response (PAGER) system, a global building inventory has been compiled based on harmonised data from various sources (Jaiswal et al., 2010). It provides fractions of building types present in urban and rural regions of each country by their functional use. The quality of data in the PAGER database for most of the high-seismicity countries in Europe is judged medium or high. The NERA project followed a similar procedure with focus on European countries (Crowley et al., 2012). The Global Exposure Database developed by the Global Earthquake Model (GEM) Foundation (Gamba, 2014) is structured at country, region, local and building level, and distinguishes between urban or rural areas, and residential or non-residential buildings. The Global Human Settlement[28] (GHS) framework produces global spatial information about the human presence on the planet, in the form of built up maps, population density maps and settlement maps.

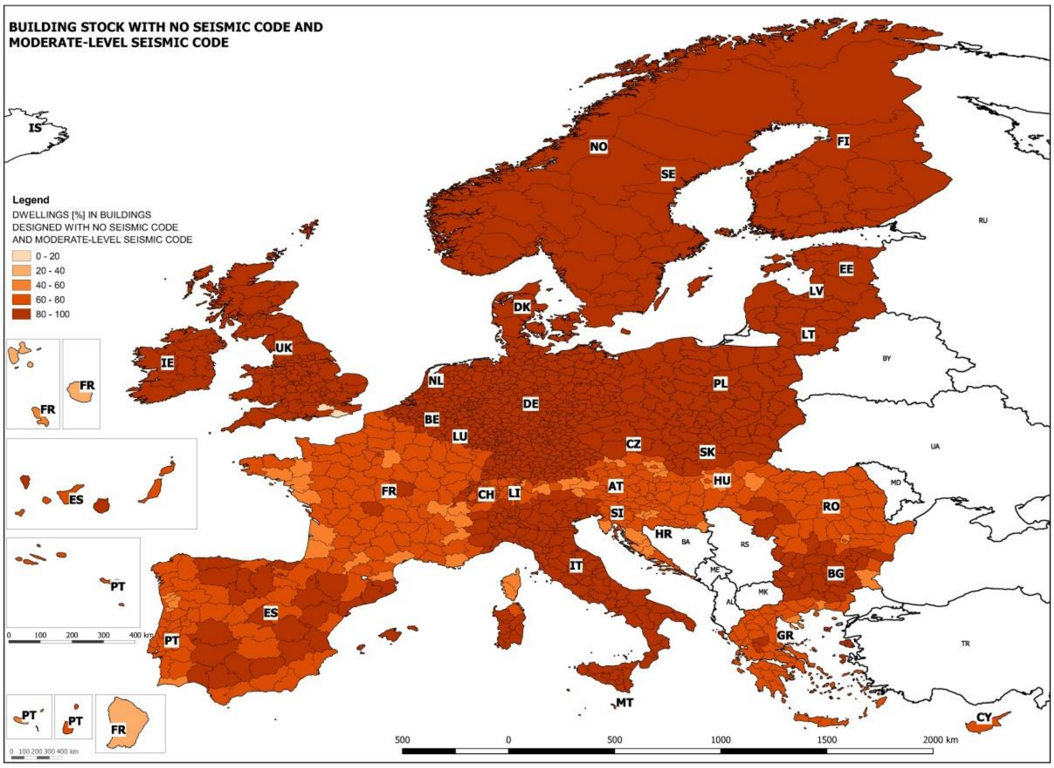
The vulnerability of physical assets at risk is described by means of fragility functions that describe the probability that, for a given value of the earthquake intensity, structures of a certain typology will exceed different damage levels. Empirical fragility functions are based on observed damage data from past earthquakes, while numerical ones are produced from the results of numerical simulations of varying degrees of sophistication. Uncertainties in probabilities of damage originate from the variability of the seismic action, geometric and material parameters of the studied structures, type of structural model and analysis, resistance models, definition of damage states, etc. A collection of fragility curves for buildings, bridges, highway and railway infrastructure, harbour elements, health care facilities, electric power stations, gas and oil distribution networks, water and waste-water systems, may be found in Pitilakis et al. (2014) and Yepes-Estrada et al. (2016).

The majority of buildings in the European stock are vulnerable to earthquakes, as they have been designed without earthquake resistance or with moderate-level seismic codes

[25] www.share-eu.org
[26] www.sera-eu.org
[27] http://eurocodes.jrc.ec.europa.eu
[28] https://ghsl.jrc.ec.europa.eu

(**Figure 13**). This is particularly relevant for the countries of moderate and high seismicity in south and east Europe (**Figure 12**).

Figure 13. *Seismic vulnerability of buildings in Europe.*



Source: Palermo et al, 2018.

9.4 **Impact assessment**

9.4.1 General

Ground shaking is the most damaging effect of earthquakes. It results from the passage of seismic waves through the ground, affecting built and natural environments. Ground shaking triggers other hazards, like liquefaction and subsidence, which can disrupt lifelines, harbours and originate bridge and building foundation failures. Examples of earthquake-induced environmental effects are rock falls and landslides. Those were observed to cause significant soil erosion or to block river streams creating quake lakes of major concern to neighbouring urban regions. Severe shallow earthquakes causing vertical displacements on the ocean floor may generate tsunami waves able to produce destruction over large areas. Surface faulting and ground failure can cause the disruption of tunnels, railroads, powerlines, water supply networks and other lifelines. Fires following earthquakes, linked for instance to the rupture of gas mains, are important secondary effect of earthquakes, eventually aggravated by the disruption of water supply systems. Potential disastrous secondary damage caused by earthquakes, can also result in Natech accidents, *i.e*., Natural Hazard Triggering Technological Disasters, such as the release of hazardous materials and the destruction of vital transport and technical infrastructure, industrial buildings and facilities. Other examples of earthquake secondary effects are air pollution due to burning of chemicals, demolition of damaged buildings and traffic congestion after a major earthquake (Gotoh et al., 2002; Lin et al., 2008). In the reconstruction phase, the increased demand for construction materials in a very short time may lead to shortage of natural building materials and subsequently to environmental impacts like coastal erosion, saline intrusion and illegal mining (Khazai et al., 2006).

Earthquake ground shaking intensity may be calculated for a deterministic scenario or in a probabilistic way. Models of ground shaking, fragility or vulnerability functions and the distribution of exposed assets in a region are used to estimate damage and losses. Loss estimation methods with reference to a region are fundamental for assessing seismic risk, and for government and insurance companies evaluating the economic consequences of earthquakes. For instance, they provide a useful first order estimate for planning and analysing funding requests in the aftermath of a seismic event (De Martino et al., 2017).

In practice, the models and methodologies for seismic risk assessment are able to estimate several Sendai Framework Indicators[29], such as, number of deaths, injured people, people whose dwellings were damaged or destroyed, direct economic loss in relation to global gross domestic product, direct economic loss in the housing sector, damage to critical infrastructure, and disruptions to basic services.

9.4.2 Methodologies for risk assessment

Earthquake scenarios may be assessed using deterministic or probabilistic methods as referred in section 9.2. An example of an earthquake hazard scenario is the maximum probable or credible earthquake, i.e., the largest earthquake that is reasonable to expect in a region. It is often based on a deterministic seismic hazard assessment, like the estimation of the magnitude of the worst historical event reported in a region and its best guessed location derived from known geological faults, or seismic source zones. The evaluation of the effects of deterministic earthquake scenarios is a way to prepare emergency plans for civil protection, to model seismic losses for a region, or to obtain time histories and duration of ground motion to be used in seismic design and retrofitting (Sousa and Campos Costa, 2009).

Probabilistic seismic risk assessment considers all possible earthquakes that may affect a site and a probabilistic estimation of damage and losses, including relevant uncertainties. Results are obtained in terms of risk metrics, such as, loss exceedance curves or averaged earthquake socio-economic losses. Thus, seismic risk may be described, among others, by (i) the probability that various levels of loss will be exceeded, (ii) by average annualized earthquake losses, (iii) or by average annualized earthquake loss ratio, AELR (FEMA, 2017). AELR is a useful metric to compare the relative risk across different regions, since it is normalized by the replacement value.

Several open-source tools are available for the assessment of loss scenarios and the evaluation of the earthquake impact in a region (Chapter 9.8).

9.4.3 Damage-to-loss models

Generally, damage-to-loss models assess the total repair cost for a class of buildings, or building typology, correlating a given damage threshold to the repair cost, knowing the building replacement cost in the region (ATC, 1985, D'Ayala et al., 2015, De Martino et al., 2017, FEMA, 2018, Martins et al., 2016, Wehner and Edwards, 2013). There exist also empirical models to estimate debris resultant from building collapse (FEMA, 2018, Santarelli et al., 2018). Similar methodologies are used to estimate damage and losses in cultural heritage, taking into consideration the particularities of these structures. Empirical models, e.g. by Lehman et al. (2004) and Mackie and Stojadinović (2006) for bridges, relate the functionality of basic services and infrastructures to structural damage. The latter can be obtained, as function of earthquake ground shaking intensity, by means of numerical or empirical models (fragility functions). Empirical models are also available for business interruption (ATC, 1985, FEMA, 2018) as a function of structural damage.

[29] www.preventionweb.net/drr-framework/sendai-framework-monitor/indicators

9.5 **Estimation of casualties**

Injuries and casualties during earthquakes are caused by structural and non-structural damage, accidents, heart attacks, etc. Coburn and Spence (2002) report that the majority (more than 75 %) of deaths in past events were due to building collapse and propose a 'lethality ratio', i.e. the ratio of people killed to the number of people present in a building, to estimate casualties for each building class. This ratio depends on the characteristics of the ground motion, the building type and function, collapse mechanism, occupancy, behaviour of occupants, and search and rescue effectiveness. The model provides, for each typology of collapsed building, the percentage of people that are lightly, moderately or seriously injured, or killed. A large number of casualty models with different degrees of sophistication have been developed (e.g. ATC, 1985, Balbi et al., 2006, Cavalieri et al., 2012, Erdik et al., 2011, Jaiswal et al., 2009, Jaiswal and Wald, 2012, Khazai et al., 2014, So and Pomonis, 2012, So and Spence, 2013, Spence et al., 2011).

9.5.1 Estimation of shelter needs

Data from past earthquakes show that the number of displaced people is almost an order of magnitude higher than the number of collapsed and severely destroyed buildings. Multi-criteria models for estimating displaced households and short-term shelter needs consider the physical habitability of buildings together with the occupants' desirability to evacuate and to seek public shelter (Khazai et al., 2014, FEMA, 2018). The habitability of buildings is based on the physical damage, the loss of utilities (such as water and energy supply) and the weather conditions. The desirability to evacuate depends on a number of social factors, such as the household tenure and size, household type, age of occupants and perception of security in the area. Lastly, the desirability to seek public shelter is influenced by the fear of aftershocks, residents' income, employment and education level, as well as by the distance and ease of access to shelters. Data for these indicators are available through the national statistical institutes and Eurostat.

9.6 **Software for seismic risk assessment**

In the last decades several open-source tools with high degree of sophistication and capabilities have been developed for the assessment of loss scenarios, or for the evaluation of earthquake impact on critical infrastructures. Most of the software include libraries with pre-defined hazard and vulnerability models and also allow the user to input new ones. Examples include:

- HAZUS[30] is a standardised methodology for estimating potential losses from disasters that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses GIS technology to estimate physical, economic, and social impacts of disasters. It is used for mitigation and recovery, as well as preparedness and response.
- The CAPRA[31] probabilistic risk assessment platform is an initiative that aims to strengthen the institutional capacity for assessing, understanding and communicating disaster risk, with the ultimate goal of integrating disaster risk information into development policies and programs.
- AFAD – RED is the Turkish national operational tool for seismic risk assessment, prevention, preparedness and response. In its real-time operational configuration, the system combines seismic data with an extensive inventory of buildings, critical facilities and population to provide damage and fatality loss estimates.
- The REAKT[32] project produced the Earthquake Qualitative Impact Assessment (EQIA) tool that uses earthquake data (location and magnitude) and modelling

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[30] www.fema.gov/hazus
[31] https://ecapra.org
[32] www.reaktproject.eu

(fault geometry, slip distribution, directivity effects, wave propagation, site effects, etc.) to produce real-time "heads-up" alerts for global earthquakes.

- The SELENA[33] open risk software is a tool to provide earthquake damage and loss estimates. It uses a logic tree approach and allows for deterministic analysis, probabilistic analysis and real-time ground motion data.
- The OpenQuake[34] engine is the Global Earthquake Model Foundation's (GEM) state-of-the-art, free, open-source and accessible software collaboratively developed for earthquake hazard and risk modelling.
- The RASOR[35] project developed a platform to perform multi-hazard risk analysis to support the full cycle of disaster management, including targeted support to critical infrastructure monitoring and climate change impact assessment.
- Rapid-N[36] has been developed by the European Commission for the assessment of natural-hazard triggered technological (Natech) accidents risks at local and regional levels, and has currently been implemented for earthquakes.

Andredakis et al. (2017) provide further details on these tools. Example applications with pre-loaded exposure data showed that these tools are able to produce an early impact assessment within 5-15 minutes. Comparison of predicted losses with data recorded after real earthquakes demonstrated that, in general, the order of magnitude of economic losses is accurately predicted, but casualties are overestimated.

Near-real time loss assessment systems provide rapid estimates of ground motion, damage and losses following a seismic event, its magnitude, time of occurrence and location are known. PAGER37 is a well-known near-real time loss assessment system, which provides first order estimates of human and economic losses at a global scale.

9.7 Recent research

The European Union has provided within the Framework Programmes for research and innovation, significant funding for collaborative research projects dealing with the impact of earthquakes. The projects listed in **Table 4** involved experts from across Europe. They produced state-of-the-art methodologies and models for hazard, vulnerability and risk assessment, developed tools that can be deployed in practice for preparedness, mitigation, planning and risk management activities. The methodologies, models and tools were used for a large number of illustrative case studies at local (city) or regional level.

Table 4. European research projects related to seismic risk assessment.

Project	Title	Duration	Website
LESSLOSS	Risk mitigation for earthquakes and landslides	2004-2007	https://cordis.europa.eu/project/rcn/74272_en.html
NERIES	Network of research infrastructures for European seismology	2006-2010	https://cordis.europa.eu/project/rcn/79877_en.html
SERIES	Seismic engineering research infrastructures for European synergies	2009-2013	www.series.upatras.gr

[33] www.norsar.no/r-d/safe-society/earthquake-hazard-risk/the-selena-open-risk-software
[34] www.globalquakemodel.org/oq-getting-started
[35] www.rasor-project.eu
[36] http://rapidn.jrc.ec.europa.eu
[37] https://earthquake.usgs.gov/data/pager

SHARE	Seismic hazard harmonization in Europe	2009-2012	www.share-eu.org
SYNER-G	Systemic seismic vulnerability and risk analysis for buildings, lifeline networks and infrastructures safety gain	2009-2013	www.vce.at/SYNER-G
NERA	Network of European research infrastructures for earthquake risk assessment and mitigation	2010-2014	https://drmkc.jrc.ec.europa.eu/knowledge/Projects-Explorer#project-explorer/631/projects/detail/3922/nera/main-info
REAKT	Strategies and tools for real time earthquake risk reduction	2011-2014	www.reaktproject.eu
STREST	Harmonized approach to stress tests for critical infrastructures against natural hazards	2013-2016	www.strest-eu.org
INDUSE-2-SAFETY	Component fragility analysis and seismic safety assessment of special risk petrochemical plants under design basis and beyond design basis accidents	2014-2017	www.induse2safety.unitn.it
SERA	Seismology and earthquake engineering research infrastructure alliance for Europe	2017-2020	www.sera-eu.org

Furthermore, the Global Earthquake Model (GEM)[38] is engaging with a very diverse community to i) share data, models, and knowledge through the OpenQuake platform, ii) apply GEM tools and software to inform decision-making for risk mitigation and management, and iii) expand the science and understanding of earthquakes.

9.8 Examples of seismic risk assessment studies

A probabilistic method was adopted for the assessment of seismic risk in 40 cities in metropolitan France (AFPS, 2014). The study employed hazard curves for cities in different seismic zones, fragility functions for buildings belonging to four vulnerability classes, and models that relate structural damage to the number of victims and to economic losses. The results are given in terms of probability of collapse of buildings, expected annual losses and probability of casualties.

A scenario-based approach was followed for the seismic risk assessment in Spain (DGPCE, 2015). This study used the national seismic hazard maps, census and cadastral data respectively for population and buildings, vulnerability classes according to the period of construction of buildings, and empirical models for impact on people. The analysis yielded the number of buildings at different damage states, the number of casualties and injuries and the number of homeless people in the event of earthquakes with return period equal to 500 and 1000 years.

[38] www.globalquakemodel.org

The Portuguese National Authority for Civil Protection with the collaboration of several research institutions coordinated two projects for assessing the seismic risk in the metropolitan region of Lisbon and in Algarve, the two regions in mainland Portugal which historically have most suffered the impact of earthquakes (ANPC, 2010, Campos Costa *et al.*, 2010, Costa *et al*., 2012, Sousa *et al*., 2010). The projects aimed at providing scientific foundations to support decision-making concerning seismic disaster preparedness and management for the regions. The projects included studies on seismotectonics, seismic catalogues updating, ground motion at the bedrock and considering site effects, vulnerability to landslides, exposure and vulnerability of buildings, critical infrastructures, lifelines and population. A near-real time loss assessment GIS system was developed to evaluate damages and losses considering strong motion seismic scenarios similar to historical earthquakes that affected both regions. Particularly in Algarve region, tsunami hazard and vulnerability of the littoral coast to tsunami incursion was evaluated.

9.9 **Seismic risk mitigation**

Preventive measures such as seismic retrofitting of buildings and infrastructure and the wide application of building codes that ensure low damage can considerably reduce the severity of human, structural and economic impacts of earthquakes. The provisions of Eurocode 8 contribute to reducing the vulnerability of buildings by ensuring that, in the event of earthquakes, lives are protected, damage is limited and civil protection structures remain operational. This has been demonstrated in all major earthquakes that occurred worldwide, e.g. the 1995 Kobe, Japan, earthquake (Ranghieri and Ishiwatari, 2014) and the 2009 earthquake in L'Aquila, Italy (Dolce and Manfredi, 2015), where the large majority of damaged buildings were built with no or low-level provisions for earthquake resistance. The lesson learnt is that building codes have proven to be a valuable mechanism to implement effective mitigation measures and significantly reduce the high costs of post-disaster reconstruction in many countries. Moreover, post-disaster reconstruction offers an opportunity for introducing or reforming regulatory processes, aiming to "Build Back Better", *i.e.*, to improve the quality and safety of the built environment, to strength the resilience of communities to earthquakes and to capitalise long-term earthquake risk reduction efforts.

Besides building codes, state incentives are a useful instrument to upgrade the building stock. For example, Italy introduced a tax reduction equal to up to 85% of the cost for structural interventions that improve the seismic vulnerability of existing buildings[39].

Another way to save lives is by implementing advanced early warning systems in urban regions. Early warning systems rely on the difference of arrival time between warning messages and destructive shaking waves. The former are transmitted almost instantaneously when triggered by an earthquake, whereas the latter may take seconds to minutes to arrive to a location. People and automated systems may use this short time delay to activate measures to protect life and property. Japan and Mexico are examples of countries where early warning systems are functioning (Cuéllar, 2014, Fujinawa and Noda, 2013).

9.10 **Limitations and gaps in seismic risk analysis**

The research community is continuously refining seismic hazard, vulnerability and damage-to-loss models that will be included in upgraded versions of the software for seismic risk analysis. While most software tools are user-friendly, their high degree of sophistication requires they should be operated by trained expert staff. In addition, for specific risk assessment studies, the software tools may require user-supplied data that is costly and time-consuming to obtain.

It is worth pointing out the high uncertainty on the estimation of casualties, resulting from the wide variability of the number of earthquake victims subject to a similar ground

[39] Legge 27 dicembre 2017, n. 205. Bilancio di previsione dello Stato per l'anno finanziario 2018 e bilancio pluriennale per il triennio 2018-2020.

motion, and from the poor reliability and large gaps in post-earthquake statistics for casualties.

The major gap in seismic risk analysis is the absence of inventories of georeferenced exposure data, designed specifically for assessing the vulnerability of the built environment at a local scale. Exposure data is mainly available for residential buildings and aggregated at large regions. Inventories should preferably include as many as possible assets (e.g. industrial, commercial and other buildings, networks, critical infrastructures, etc.) in order to provide a more accurate and detailed risk assessment.

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10 Floods

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A flood can be defined as the temporary covering by water of land not normally covered by water (EU, 2007). While floods are natural phenomena that may occur everywhere, human activities (such as encroaching in floodplains and land use changes) and climate modifications may increase the likelihood and adverse impacts of flood events, creating a risk for people and assets. Specifically, "flood risk" means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event (EU, 2007).

Every year floods cause enormous losses to economies and societies worldwide. In Europe, direct economic losses from floods (e.g. economic losses due by physical damage) are estimated to be ≈EUR 6 billion per year, and 250 000 people per year are estimated to be exposed (Alfieri et al., 2016). These figures are comparable to recent estimates based on observed impacts (EEA 2010).

10.1 Legal framework of flood risk assessment in the European Union

Flood risk assessment in the European Union is regulated by the Floods Directive of the 2007 [EU 2007; FD in the following text], which is now integrated in the national legislation of EU countries. The Directive describes the steps that each Member State should take to implement flood risk assessment:

1. Preliminary Flood Risk Assessment: based on available information on past studies, evaluate impacts on human health and life, the environment, cultural heritage and economic activity.
2. Risk Assessment: identify the areas at significant risk to produce flood hazard and risk maps, including detail on the flood extent, depth and velocity for three risk scenarios (high, medium and low probability).
3. Flood Risk Management Plans to indicate to policy makers, developers, and the public the nature of the risk and the measures proposed to manage these risks

Moreover, the Floods Directive foresees regular updates and review of each part of risk assessment. The following **Table 5** summarizes the relevant steps identified by the Floods Directive and the milestones for implementation and review (EU, 2016a). The first round of implementation of the Floods Directive has been finalized in 2016 and the results have been described in a number of reports (EU 2016a,b; WGF 2017).

Table 5. List of steps identified by the Floods Directive and the milestones for implementation and review. WFD: Water Framework Directive

Subject	Main Article	Other Articles	Responsibility	To	Report Due date	Frequency/ review
Transposition	17		MS	COM	26/11/2009	
Competent Authorities and Units of Management (if different from WFD)	3.2 (annex 1 WFD)		MS	COM	26/05/2010	3 months after any changes
Preliminary Flood Risk Assessment	4	13.1(a) and 13.1(b)	MS	COM	22/03/2012	22/12/2018, every 6 years thereafter

Flood Hazard Maps and Flood Risk Maps	6	13.2	MS	COM	22/03/2014	22/12/2019, every 6 years thereafter
Flood Risk Management Plans	7	13.3	MS	COM	22/03/2016	22/12/2021, every 6 years thereafter
Progress by MS in implementation	16		COM	COM	22/12/2018	Every 6 years thereafter

Source: EC, 2000.

Given its relevance, the description of methods for flood risk assessment in the following sections will mostly refer to the prescriptions of the Floods Directive, integrated with additional considerations based on the current state of the art (or good practices) in the field.

10.2 Risk Analysis

In the risk assessment framework outlined by the Directive, the first requirement is the identification of relevant flood processes than can produce significant consequences in the areas of interest. The identification of relevant processes is generally based on the analysis of past flood events in the area of interest, which had significant adverse impacts on human health, the environment, cultural heritage and economic activity. Such analysis should be complemented by preliminary simulations or investigations, to evaluate whether similar future events might occur and cause impacts.

Several natural and man-made processes can give origin to flood events. In practical applications, flood events are classified according to the main drivers and the water bodies that cause the event itself. The following list is taken from Poljanšek et al. (2017).

- Fluvial floods occur when river levels rise and burst or overflow their banks, inundating the surrounding land. This can occur in response to storms with higher than normal rainfall totals and/or intensities, to seasonal strong weather systems such as monsoons or winter storm tracks, or to sudden melting of snow in spring.
- Flash floods can develop when heavy rainfall occurs suddenly, particularly in mountainous river catchments, although they can occur anywhere. Strong localised rainfall, rapid flood formation and high water velocities can be particularly threatening to the population at risk and are highly destructive.
- Heavy rainfall may cause surface water flooding, also known as pluvial flooding, particularly in cities where the urban drainage systems become overwhelmed.
- Floods can also be generated by infrastructure failure (e.g. dam breaks), obstructions caused by avalanches, landslides or debris, glacial/ lake outbursts and groundwater rising under prolonged very wet conditions, which cause waterlogging
- Coastal flooding is caused by a combination of high tide, storm surge and wave conditions. Note that floods caused by tsunami events are generally considered as geophysical hazards, and therefore are analyzed with different techniques (Poljanšek et al., 2017).

In many cases, flooding occurs as a result of more than one of the generating mechanisms occurring concurrently, making the prediction of flood hazards and impacts more challenging.

Following the identification of relevant flood processes it is necessary to select adequate models and methodologies to evaluate risk components. These include flood hazard modelling tools and methods (to define probability, magnitude and extent of flood-prone areas), and flood impact models, relating hazard variables with consequences such as physical damage to buildings.

Parallel to model selection and setup, it is indispensable to identify and collect any relevant data related to risk components, such as topographic and geographical data, hydrological data related to water bodies in the area of interest, maps of population distribution and land use, information on flood protection structures. Risk assessment tools must be chosen according to flood process(es) of interests and data availability.

As stated in the Flood Directive, risk assessment should aim at identifying people, economic activities and critical infrastructures potentially affected. In standard practice, risk evaluation can be undertaken with qualitative approaches (e.g. classifying the territory into risk classes) or quantitative methods (e.g. taking into account potential economic damage). It is important to note that the Floods Directive does not provide specific indications on the methodologies to be applied for evaluating flood hazard and flood risk, thus leaving to Member States the choice of the most suitable approach.

10.2.1 Hazard

Flood hazard is defined as the combination of probability and magnitude of relevant flood events that may affect the area of interest. In practical applications, flood hazard is quantified providing a spatial and temporal evaluation of the following variables, as mentioned in the Floods Directive (EU 2007):

— probability of occurrence,

— flood extent,

— water depth,

— flow velocity,

— sediment load,

— pollutant load.

The probability of occurrence of a specific flood event is usually expressed as a return period. For instance, a 100-year flood event means that the event is expected to have 1% probability of occurring every year. Flood extent, water depth and flow velocity are usually characterized as spatial maps, as prescribed by the FD. Sediment load may be a crucial variable where floodwaters have a potential to transport relevant quantities of sediments at high velocity, as in the case of flash floods involving areas with steep slopes. Pollutants load is important in case of flood events affecting infrastructures such as chemical industries and wastewater treatment plants.

Evaluating the probability of occurrence requires to calculate the frequency and distribution of extreme floods events in the area of interest, which can be done once the meteorological and hydrological regime of the area is known.

In case of small areas with limited river network, the hydrological regime can be defined using empirical methods or hydrological models. In both cases, the aim is to estimate the runoff regime and hence extreme values based on available meteorological data (e.g. precipitation, temperature, humidity) and characteristics of the river hydrographic basins (e.g. geological, soil and land use maps). There is a wide range of existing commercial and research hydrological models that can be used (see for instance Beven 2011), as well as a large variety of empirical methods for more rapid runoff estimation, such as the Curve Number method, developed by the Soil Conservation Service of the United States [USDA, 1986].

In case of complex river networks, river hydraulics models are needed to simulate water flow in the river network, including man-made structures such as dams and retention basins. In this case, extreme flow values can also be directly estimated from water and flow level measurements in rivers. Alternatively, coupled hydrological-hydraulic models can be set up to derive river flow regime from observed meteorological data. Moreover, hydrological and hydraulic models can be coupled with meteorological forecasts to create a flood early warning system, which can provide real-time indication of expected flood hazard. Data requirements include hydrological data for the water bodies in the area of interest, such as time series of water level and flow measured from gauge stations, as well as the characterization of the river reaches (cross section shape, bed slope, geometry and location of hydraulic structures, etc.).

Finally, flood hazard maps can be derived by applying inundation models to simulate flooding processes. These models might be integrated with the hydraulic models used for simulating river network flow, or they can use results to derive flood scenarios (e.g. dike breaches, dike overtopping at specific locations). Simulations are often combined with Geographic Information System (GIS) techniques to improve the development of flood maps. Alternatively, methods based on topography and geomorphological indices can be applied to quickly evaluate flood prone areas, however these methods do not allow to estimate all the hazard variable requested for a complete risk evaluation.

Besides results from hydraulic models, the application of inundation models requires a relevant amount of data. Digital terrain models (DTMs) are also needed to describe the morphology of the study are, together with information about past flood events, such as flood extent maps (nowadays often available as satellite-derived maps) and high water marks, to calibrate and validate model results.

As for hydrological models, researchers and practitioners nowadays can count on wide variety of commercial and research models to model river flow and flooding processes (see for instance Teng et al., 2017). As an example, the HEC-RAS model, developed by USACE (http://www.hec.usace.army.mil/software/hec-ras) is a free software well known and used worldwide.

10.2.2 Exposure

In the definition of flood risk maps, the Floods Directive indicates how flood exposure should be characterized in order to map potential adverse consequences associated with flood scenarios. Specifically, the following elements of exposure have to be considered (EU 2007):

(a) the indicative number of inhabitants potentially affected;

(b) type of economic activity of the area potentially affected;

(c) installations which might cause accidental pollution in case of flooding and potentially affected protected areas as by the Water Framework Directive (EU 2000).

(d) areas subject to floods with a high content of transported sediments, or with significant sources of pollution.

Other aspects of exposure that are mentioned by the FD are critical infrastructures (such as transport and energy networks, hospitals etc) and cultural heritage buildings.

As such, the requirements of the FD make necessary to characterize the spatial exposure of population, relevant assets (e.g. industrial and commercial districts), critical infrastructures and protected natural areas. For population, the standard approach is to use population maps derived from national-scale census data. The exposure of economic activities and builtup areas is generally evaluated with land use maps, which describes the extent and location of built-up and natural areas with similar characteristics (e.g. residential areas, industrial districts, forests etc). These maps can be based on national-scale census data or derived from satellite images. For instance, the Corine Land Cover map is a satellite-derived product available for all the EU Member states (Copernicus LMS, 2017). Finally the location and characterization of critical infrastructures, cultural heritage buildings and other points of exposure requires detailed information al local scale. Exposure maps are usually combined with hazard maps using Geographic Information System (GIS) techniques.

10.2.3 Vulnerability

The evaluation of vulnerability is crucial to quantify flood impacts on population, economic activities and the environment, and thus to produce flood risk maps as requested by the FD.

In standard practice, economic consequences of floods are usually evaluated distinguishing between direct and indirect damages. Direct damages are defined as physical, short term consequences such as physical damage to buildings and consequent repair costs. These impacts are usually evaluated using flood damage curves, which relate hazard variables (such as water depth and flood duration) with physical consequences to different types of buildings and their related content (e.g. residential buildings and furniture, industrial buildings and machinery). Conversely, indirect losses identify impacts that are not directly caused by floods, such as consequences of electricity cut-offs, roads closures, or loss of revenue due to closing of commercial activities. These impacts are evaluated using economic models that simulate the effect of floods on the economy of the affected areas. A detailed review of the existing methods is reported in Merz et al. (2010). Similar approaches can be used to evaluate impacts on critical infrastructures, although in this case specific models are requested.

Consequences of floods on population are generally evaluated considering resident population in the flood prone areas and quantifying the number of people exposed to the flood events of interest. Even though flood risk for people include the risk of death and major injuries, they are not usually addressed as it is more complex to evaluate. When performing risk assessment at municipality or limited scales, personal safety risk models based on precise hydro-dynamic analysis may be applied (e.g. Arrighi et al. 2016), although with a relevant uncertainty. Conversely, in larger scale applications probabilistic risk methods (e.g. de Bruijn et al., 2014) and the use of mortality rates calculated from previous flood events (e.g. Jongman et al., 2015; Tanoue et al., 2016) are more feasible.

For a correct evaluation of flood risk it is also important to take into account flood risk management plans, if available for the area of interest. Risk management plans are foreseen by the Floods Directive and should contain objectives for the reduction of the likelihood and potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity, including non-structural initiatives. In particular, these plans should consider all the prevention, protection and preparedness measures in place, such as protection measures, flood forecasts and early warning systems, emergency plans, interventions to improve water retention and flood attenuation.

10.3 Gaps and Challenges

The implementation of the Floods directive can be considered a success story in the field of natural hazards risk management. It allowed to establish a common ground in flood risk assessment in the European Union, introducing minimum requirements while leaving flexibility in its application. Despite this progress, there are a number of gaps and challenges that still need to be tackled in order to progress further.

Regarding flood hazard maps, the surveys conducted among Member States highlighted a number of possible improvements. For instance, only 14 MS (out of 28) considered pluvial flooding among the possible drivers of flood hazard, even though pluvial flooding is a widespread problem. More in general, flash flood and pluvial floods are not always considered in flood risk management plans, as well as hazard deriving from multiple flood processes (e.g. combination of pluvial and river floods) or from multiple natural hazards (e.g. combination of landslides, debris flows and flash floods in mountain areas).

Regarding flood Risk Maps, all MS included the number of people potentially affected, adverse consequences on economic activity and on the environment. However, in many cases risk evaluation is still based on qualitative approaches (e.g. classifying the territory into risk classes) rather than quantitative methods (e.g. taking into account potential economic damage). While quantifying all aspects of risk is crucial to carry out reliable cost-benefit analyses as requested by the FD, the application of impact models is not straightforward and there are relevant limitations in both modelling tools and loss data for model setup and validation. First, comparing and quantifying different flood impacts can be complex (e.g. economic losses, human impacts and consequences on cultural and natural heritage). Furthermore, flood loss data collection is still at the beginning in most of the EU Member States. Official estimates are still affected by the absence of clear standards for loss assessment and reporting, although progresses have been made in the last years (Corbane et al., 2015; IRDR, 2015). Moreover loss reports are rarely complete and can strongly deviate from true extents and damages, thus complicating the validation and set up of impact models (Thieken et al. 2016). Finally, indirect losses due to floods are rarely quantified in flood risk assessment works, due to the complex application and verification of the related economic models.

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11 Biological disasters

ANNE SOPHIE LEQUARRE

11.1 Introduction

Biological disasters gather all the events linked to the uncontrolled spread of pathogens or pests affecting humans, animals or even plants. Well-known examples with huge economic costs are the food and mouth crisis in UK in 2001 with the culling of over 6 million of cows and sheep or, right now, the wipe out of millions of ancient olive trees in Italy due to the infection by deadly bacteria with no cure [40]. In human a number of epidemics (e.g. cholera or Spanish flu) have had previously devastating consequences on our populations but thanks to the development of vaccines or appropriate treatments health crisis are now fortunately scarce in most countries. However this stability can be shaking down as illustrated by the recent outbreak of measles after a decrease in vaccine coverage, especially in Ukraine[41] or the threat of the Ebola virus leading to thousands of deaths in West Africa with a few imported cases reported in Europe in 2014.

Outbreaks, the sudden rise in the incidence of a disease, occur when pathogen agents and target hosts are present in adequate numbers. It may result from an increase in the amount or in the virulence of the agent, but also a change in the susceptibility of the host and/or the introduction of the agent into a setting where it has not been before (emerging pathogen). International transportation, trade, urbanization, environmental change, agricultural practices could pave the way to new emerging epidemics in Europe or globally. Accidental release of an infectious agent from a laboratory or from the importation of goods has also to be taken into consideration. Potential malicious discharge should not to be discarded either.

Anticipating and managing outbreaks is complicate. In contrast with other disasters, outbreaks have very different profiles and impact according to the responsible agent and targeted host. Drafting generic risk assessment is challenging as this exercise strongly depends on the pathogen accountable and its host(s).

Epidemic (or outbreaks) refers to a sudden increase in the number of cases of a specific disease. Pandemic is an epidemic affecting a large number of people and spreading over several countries. Zoonosis is any disease or infection that is naturally transmissible from vertebrate animals to humans.

11.2 Risk identification and characterisation

As said the extent of an outbreak depends on pathogen's features (host range, transmission mode, virulence, pathogenicity, etc.), characteristics of the host (numbers, especially population density, natural or acquired resistance, possibility of asymptomatic carriers, vaccination status, etc.) and finally the availability of countermeasures (vaccine, treatment, isolation and quarantine, possibility of culling or cutting down in case of animals or trees).

The first step in risk assessment for biological crisis is the identification and characterisation of all pathogens that could be responsible for outbreaks in our countries as well as the host populations that would be affected.

11.2.1 Human epidemics

The impact of an epidemic depends on the number of cases, the severity of the disease but also the burden on society (missed work, hospital capacity, and public services). Unlike disasters such as earthquakes or floods, basic physical infrastructures will remain

[40] https://ec.europa.eu/food/plant/plant_health_biosecurity/legislation/emergency_measures/xylella-fastidiosa_en

[41] http://www.euro.who.int/en/countries/ukraine/news/news/2018/05/ukraine-restores-immunization-coverage-in-momentous-effort-to-stop-measles-outbreak-that-has-affected-more-than-12-000-this-year

intact but the danger is a lack of personnel for public services. For example at the height of a pandemic flu up to 40% of employees could be out of work for a period of at least two weeks. Key measures to be taken include plans for maintaining a workable level of staff and ensure the continued health of necessary workers. In consequence national governments have to build scientific mechanisms to anticipate, identify, and address such threats.

A. International Public Health policies

After the SARS outbreak (severe acute respiratory syndrome due to a coronavirus) in 2005 the new International Health Regulations (IHR)[42] entered into force binding on 196 countries across the globe. The IHR define the rights and obligations of countries to report all public health emergencies of international concern in order to help the international community to prevent and respond to acute health risks having the potential to cross borders and threaten people worldwide. The diseases under concerns are all epidemic prone diseases, food borne diseases, accidental and deliberate outbreaks, toxic chemical accidents and radio nuclear accidents as well as environmental disasters.

B. EU policies controlling human communicable diseases

Decision 2119/98/EC[43] established the network for epidemiological surveillance and control of communicable diseases, with implementing measures and a reference list of communicable diseases and case definitions. In 2013 it was replaced by Decision No 1082/2013/EU[44] on serious cross-border threats to health. This new Decision revived the network for the epidemiological surveillance of communicable diseases. It laid down rules on *data and information that national competent authorities should communicate and provided for coordination of the network by the European Centre for Disease Prevention and Control (ECDC)*. The list of diseases and case definitions are regularly updated to reflect changes in disease incidence and prevalence, and in light of new scientific information, and evolving laboratory diagnostic criteria and practices.

Apart from communicable diseases, a number of other sources of danger to health, in particular related to *other biological or chemical agents or environmental events*, which include hazards related to climate change, could by reason of their scale or severity, also endanger the health of citizens in the entire Union and *are included in the regulation*.

Once a year, all EU MS & 3 EEA countries (Iceland, Liechtenstein, Norway) send data from their surveillance systems to ECDC. All data relate to occurrences of cases of communicable diseases and health issues under mandatory EU-wide surveillance. A number of conclusions drawn from these data are presented in the ECDC Annual Epidemiological Report.

List of human priority diseases: To perform a ranking of human pathogens and zoonosis ECDC has developed a tool based on a multi-criteria decision analysis (MCDA), with several steps to follow[45] for prioritisation such as criteria to assess a disease (e.g. probability of exposure, vulnerability of the population, consequences) and the weighting of criteria according to their importance in the society.

11.2.2 Animal diseases

A distinction is made between epizootic – not transmittable to humans (e.g. foot-and mouth disease) and zoonotic – diseases transmittable from vertebrate animals to humans (e.g. avian influenza). Zoonosis are under higher concerns as they may represent a threat for human health however epizooties can impact heavily the economy

[42] https://www.who.int/topics/international_health_regulations/en/
[43] https://eur-lex.europa.eu/legal-content/FR/ALL/?uri=CELEX:31998D2119
[44] https://ec.europa.eu/health/sites/health/files/preparedness_response/docs/decision_serious_crossborder_threats_22102013_en.pdf
[45] https://ecdc.europa.eu/sites/portal/files/documents/Tool-for-disease-priority-ranking_handbook_0_0.pdf

of a country deeply involved in livestock production. The amount of animals concerned by a specific disease, their density, the contamination process and the breeding system used are all significant factors to be considered for assessing the risk of an outbreak. Similarly the measures to fight against a transmissible disease are based on the nature of the agent, its transmission route (direct contact or indirectly via contaminated equipment), geographical distribution, health impacts and evolution in the population.

A. International Animal Health policies

Diseases previously classified by the World Organisation for Animal Health (OIE) within the list A represent fast spreading diseases of major economic importance. Such epidemics can result in substantial losses for governments, farmers and all stakeholders involved in the livestock production chain. In countries with a highly industrialised agricultural sector, vulnerability to the spread of such diseases is particularly high. Here is the list:

Foot and mouth disease	Vesicular stomatitis
Swine vesicular disease	Rinderpest
Peste des petits ruminants	Contagious bovine pleuropneumonia
Lumpy skin disease	Rift Valley fever
Bluetongue	Sheep pox and goat pox
African horse sickness	African swine fever
Classical swine fever	Highly pathogenic avian influenza
Newcastle disease	

The OIE lists A & B have now been replaced by one single list of notifiable terrestrial AND aquatic animal diseases (117 diseases in total)[46] counting several severe zoonotic diseases such as anthrax, Crimean Congo haemorrhagic fever, brucellosis, Rift Valley fever virus, Japanese encephalitis, Q fever, Tularemia and West Nile fever. OIE standards represent an international reference with no "legal" power of enforcement if not transcribed into the national legislation. OIE standards are only "binding" for Members which are Parties to the WTO (World Trade Organisation) SPS (*Sanitary and Phytosanitary* Measures) Agreement.

B. EU policies controlling animal diseases

Under Directive 2003/9947[48] MS shall ensure that all data on zoonotic agents and antimicrobial resistance are collected, analysed and published. These data should allow the identification of hazards and assessment of exposures. Monitoring must take place at the food chain level. Each MS shall transmit to the EC every year a report on trends and sources of those hazards. The reports are analysed by the European Food Safety Authority (EFSA) for the publication of annual summary Reports.

Since 2016 one single, comprehensive EU animal health law[49] (AHL: EU2016/429) supports the livestock sector with early detection and control of animal diseases, including emerging diseases linked to climate change. The Regulation lays down general and specific rules for the prevention and control of transmissible animal diseases (with a risk based approach) and ensures a harmonised approach to animal health across the Union. Diseases targeted are:

- Foot and mouth disease

[46] http://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2018/
[47] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32003L0099
[48] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32003L0099
[49] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0429

- Classical swine fever
- African swine fever
- Highly pathogenic avian influenza
- African horse sickness

As well as around forties of them listed in the Annex II.

11.2.3 High-security level biological laboratories:

The presence of laboratories manipulating pathogens, toxins or GMOs needs also to be taken into consideration for assessing biological risk. The consequences of laboratory acquired SARS infections in Asia (2004) raised concerns and triggered the improvement of national biosafety policies. WHO has published a laboratory biosafety manual[50] (2004) and a biosecurity guidance[51] (2006). Organisms targeted are pathogens and toxins but also biological materials such as reference strains, GMOs, vaccines or other pharmaceutical products for the sake of health and biodiversity.

A. International conventions and agreements on biosecurity

The *Cartagena Protocol on Biosafety* (2003)[52] aims to ensure the safe handling, transport and use of living modified organisms (LMOs). Under the *Biological Weapons Convention* (1972), States Parties have accepted to provide annual reports on specific activities[53] with data on research centres & laboratories, information on vaccine production facilities, information on national biological defence research, information on outbreaks of infectious diseases and occurrences caused by toxins, publication of results and contacts, information on legislation, regulations and other measures.

B. EU policies on biosafety and biosecurity

The *EU Directive 2000/54/EC*[54] lays down minimum requirements for the health and safety of workers exposed to biological agents at work and the *Directive 2009/41/EC*[55] governs the contained use of genetically modified micro-organisms. Reporting of incidents and/or accidents in laboratories is included in national regulations but there is no common European mechanism. Furthermore facilities and practices in containment level 3 laboratories throughout the EU are not of a comparable standard.

11.3 Risk Analysis and Risk Evaluation

Risk assessment terminology is well established for chemical hazards to health (OECD, 2003)[56], but the terms used in the areas of diseases differ somewhat as hazard characterisation and consequence assessment both deal with the effects of exposure.

11.3.1 Human epidemics

When an *alert* is notified (when a communicable disease from the reference list or another event which could endanger the health of citizens in the entire Union is reported), the *Commission shall make* promptly available to the national competent authorities *a risk assessment of the potential severity of the threat to public health*, including possible public health measures. The risk assessment shall be carried out by:

(a) ECDC in accordance in the case of communicable diseases

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[50] https://www.who.int/csr/resources/publications/biosafety/WHO_CDS_CSR_LYO_2004_11/en/
[51] https://www.who.int/csr/resources/publications/biosafety/WHO_CDS_EPR_2006_6.pdf
[52] https://www.cbd.int/doc/legal/cartagena-protocol-en.pdf
[53] https://www.unog.ch/80256EDD006B8954/(httpAssets)/DE1EE44AFE8B8CF9C1257E36005574E4/$file/cbm-guide-2015.pdf
[54] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32000L0054
[55] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0041
[56] http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2003)15&docLanguage=En

(b) European Food Safety Authority (EFSA) in matters of food safety and animal health

(c) Other relevant Union agencies.

If the risk assessment needed is totally or partially outside the mandates of the agencies, and it is considered necessary for the coordination of the response at EU level, the Commission shall, upon request of the Health Security Committee (HSC) or its own initiative, provide an ad hoc risk assessment.

The Commission shall make the risk assessment available to the national competent authorities promptly through the EWRS57 (Early warning and response system, centralized mechanism for the secure exchange of information in the occurrence of events with the potential to endanger public health in the EU). Where the risk assessment is to be made public, the national competent authorities shall receive it prior to its publication. The risk assessment shall take into account, if available, information provided by other entities, in particular by the WHO in the case of a public health emergency (PHE) of international concern. A guide for RRA methodology of PHE was released in 2012 by WHO[58].

Risk Assessment methodology for human diseases

ECDC technical report "*Operational guidance on rapid risk assessment methodology*" https://ecdc.europa.eu/en/publications-data/operational-guidance-rapid-risk-assessment-methodology

The risk from a communicable disease is dependent on the likelihood of transmission in the population (*probability*) and the severity of disease (*impact*). Risk may be influenced by the environment in which the threat occurs, including political, public, media interest and perception of risk. Probability and impact are based on both the nature of the infectious agent (i.e. incubation period, mode of transmission, available interventions, vectors/reservoir species) and details of the incident (e.g. characteristics of the population at-risk including immune status, prevention, treatment and control measures available, and potential for international spread).

Rapid risk assessment, undertaken at the initial stages of an event of public health concern, is a core part of public health response, widely undertaken by public health professionals. However it is not often done in a formalised way but based on consensus opinion of experts. There are a limited number of examples of a more systematic and transparent approach to rapid risk assessment in the literature:

- ✓ A qualitative method for assessing the risk from emerging infections in UK (Morgan et al. 2009) using algorithms to consider the probability of an infection occurring in the population, its potential impact, and identifying gaps in knowledge or data.

- ✓ A prioritisation approach to rank emerging zoonoses posing the greatest threat in the Netherlands, based on 7 criteria (including probability of introduction, likelihood of transmission, economic damage, morbidity and mortality) to aid decision-making[59].

Rapid Risk Assessment methodology (when an outbreak is occurring, produced in a short time period with often limited information and circumstances possibly evolving quickly).

1. Collecting event information: who has reported the incident, where, what is the agent, what are the symptoms, how many cases, what are the specimens taken

[57] https://ewrs.ecdc.europa.eu/
[58] http://www.who.int/csr/resources/publications/HSE_GAR_ARO_2012_1/en/
[59] https://www.rivm.nl/bibliotheek/rapporten/330214002.html

and tests performed, what is the potential exposure to the agent, what are the protection means, etc.?

2. Performing structured literature search/systematically collecting information: Identify basic facts about the disease and aetiological agent from a reference text (ideally less than 5 years old). Basic disease information/determinants are:
   - Occurrence: time, place, person, endemic, routes of introduction, Seasonal/temporal trends.
   - Reservoir (if zoonotic, which species affected).
   - Susceptibility: are specific risk groups at increased risk of exposure/infection.
   - Infectiousness: Mode of transmission, Incubation period.
   - Clinical presentation: Disease severity (morbidity; mortality); Complications, specific risk groups.
   - Laboratory investigation and diagnosis.
   - Treatment and control measures.
   - Previous outbreaks/incidents.
3. Extracting relevant evidence: Role of the experts: Identify and seek advice from key experts, including public health, microbiology, infectious disease and other disease-specific experts or specialists within country and internationally.
4. Appraising evidence: The quality of evidence is the confidence in the truth of the information or data. Triangulation of evidence, including specialist expert knowledge, may be important to reach a consensus. Ensure a minimum of 2 to 3 data sources and agreement between these.
5. Estimating the risk: assess the risk posed by the threat using the risk assessment algorithms. Two approaches are presented, one combines probability and impact into a single algorithm resulting in a single overall risk level, the second assesses probability and impact separately.

Option 1 (combined approach) includes consideration of the following (**Figure 14**).

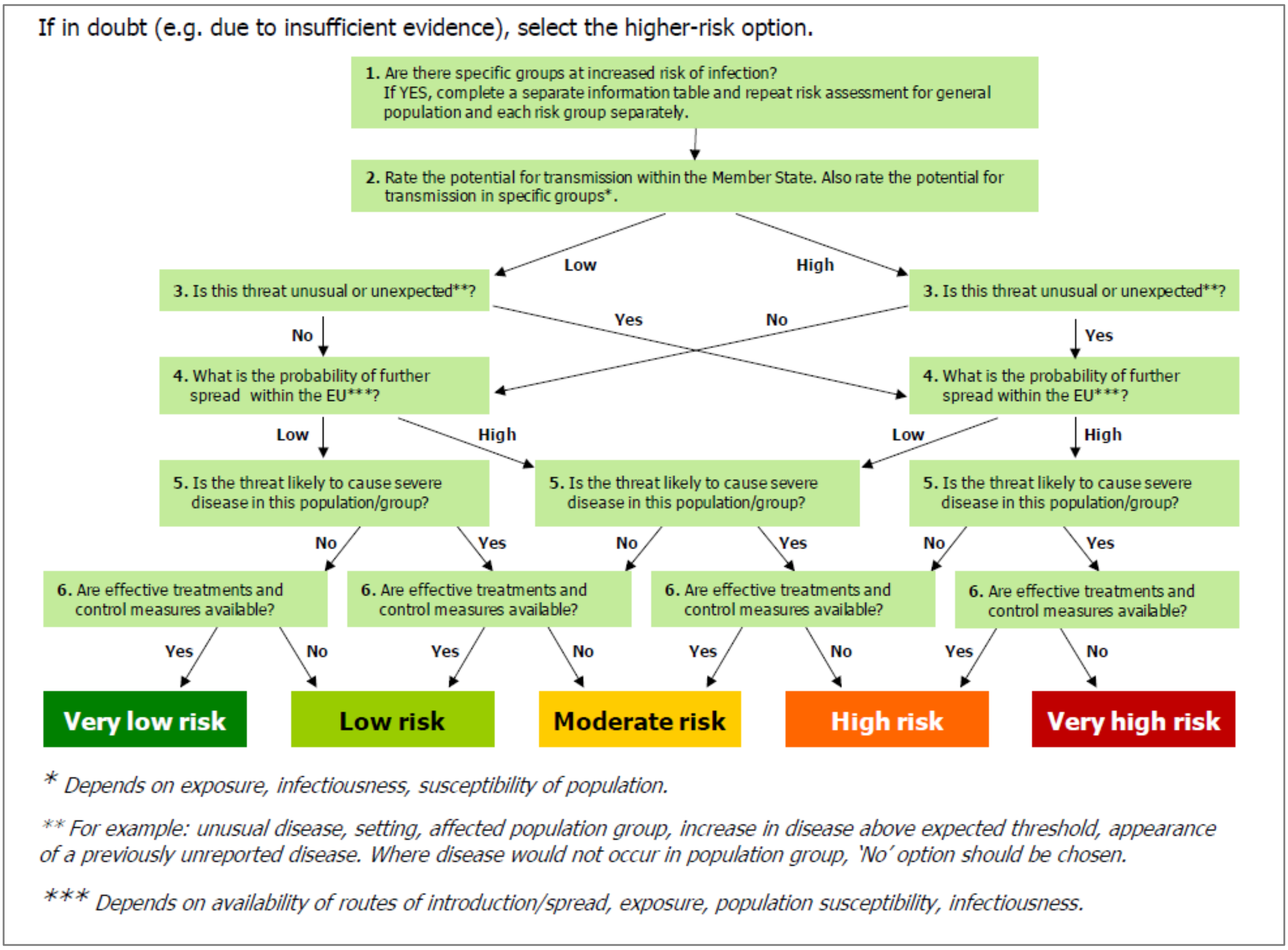
- Potential for transmission within the Member States:
- Potential for transmission within the EU (routes of introduction/spread)
- Threat unusual or unexpected,
- Availability of interventions (alters the course, influence the outcome)
- Severity of disease in this population/risk group

Option 2 (separate algorithms for probability and impact) (**Figure 15**)**:** 3 separate algorithms:

1. Probability of infection in the MS (depends on likelihood of further exposure, infectiousness of the disease, susceptibility of the population).
2. Probability of infection in the EU (depends on availability of routes of introduction/spread, exposure, population susceptibility, infectiousness).
3. Impact: severity of disease in the population (morbidity, mortality, complications), infectiousness, mode of transmission, period of communicability, length of incubation and asymptomatic period, availability of treatment, prophylaxis and other control measures.

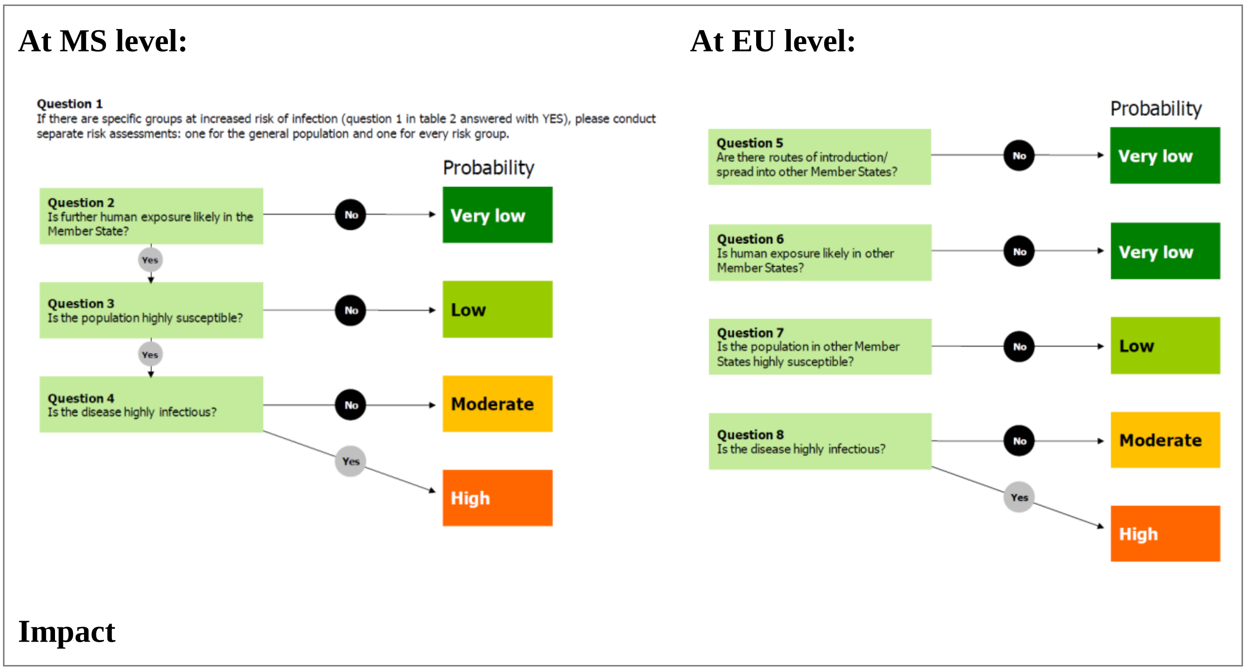
These algorithms are gathered in the risk-ranking matrix to produce an overall risk level (**Figure 16**).

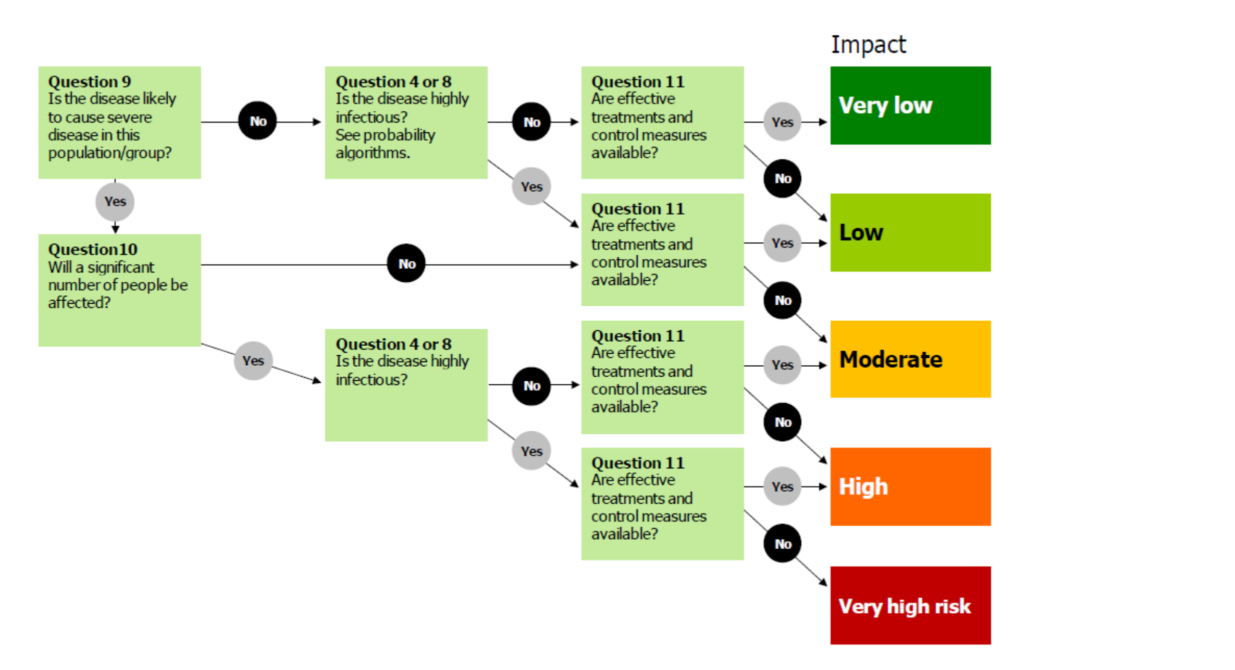
***Figure 14**. Single algorithm for the single overall risk level (option 1).*



Source: ECDC, 2011

***Figure 15.** Algorithm for calculating probability and impact (option 2).*





Source: ECDC, 2011

Figure 16. *Matrix for risk-ranking (option 2).*

Probability (part A) x impact (part B) = risk (part C)

Impact \ Probability	Very low	Low	Moderate	High
Very low	Very low risk	Low risk	Low risk	Moderate risk
Low	Low risk	Low risk	Moderate risk	Moderate risk
Moderate	Low risk	Moderate risk	Moderate risk	High risk
High	Moderate risk	Moderate risk	High risk	High risk
Very high	Moderate risk	High risk	High risk	Very high risk

Source: ECDC, 2011

11.3.2 Animal diseases

As reported, in matters of food safety and animal health, risk assessment shall be carried out by the European Food Safety Authority (EFSA)[60].

EFSA also provides guidance to national authorities on how to carry out monitoring and reporting activities on zoonoses, food-borne outbreaks and antimicrobial resistance. MS collect data and transmit a yearly report to EFSA for analysis. EFSA identifies risk factors that contribute to the prevalence of zoonotic micro-organisms in animal populations and makes recommendations on prevention and reduction measures for these pathogens.

Risk assessment for animal disease is a multi-analysis decision-support system, involving different type of experts. First, the responsible pathogen is identified with a range of adverse events it might cause (e.g. clinical disease, death, spread within the same species or to other species, maybe public health consequences if it is a zoonotic pathogen

[60] https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2007.550

or a pathogen carrying antibiotic resistance). A recent understanding of the problem should be made available (e.g. sources of pathogen, susceptible species, nutrition or space required by the species, import routes, exposure routes, import quantities etc.). Then the epidemiology of the infection should be described in time and space (modelling). The time component refers to the incidence over time, while space means the description of the geographical entities of interest with meaningful epidemiological or political boundaries. The latter often determine the disease control policy and options. Finally the potential management options must be described. They include measures which might control or eradicate the risks, current policy etc. The wider impact (e.g. economic, welfare) are also defined. Only realistic management measures merit consideration, it includes practicality (time and cost), and effectiveness with respect to infection, disease, animal welfare, and public health consequences. Risk assessment consequently is strongly dependent on the responsible pathogen; an illustration of such modelling exercise is given for an epidemic of classic swine fever (*Gamado K* et al. 2017). For new/emerging pathogens risk assessment means the evaluation of the likelihood and the biological and economic consequences of entry, establishment and spread of a *hazard* within the territory of an *importing country*. A risk assessment framework for emerging vector-borne livestock disease is comprehensively explained in a report from Wageningen University (de Vos et Al.)[61]

For zoonosis, the figure hereunder categorizes the evidence of zoonotic potential into 4 levels (**Figure 17**) by considering three key stages in the transmission of zoonoses (*Palmer et al*, 2005).

11.3.3 High-security level biological laboratories

The outcome of a pathogen risk assessment is its risk group (see WHO biosafety manual 2004)[62], which helps determining the minimum physical containment requirements, operational practice requirements, and performance and verification testing requirements for the safe handling and storing of the pathogen.

However international standards for biosafety and biosecurity are lacking which could lead to significant risk of accidental releases of infectious agents. National biosecurity risk management frameworks are often inconsistent. Several guidance documents are trying to integrate biosafety and biosecurity into a comprehensive biorisk management framework (*Johnson B and Casagrande R*. 2016).

At EU level the CWA15793[63] (CEN Workshop Agreement) was released in 2011, it sets the requirements necessary to control the risks associated with handling or storage and disposal of biological agents and toxins in laboratories and facilities. This standard is voluntary, without the force of regulation. It aims at improving biorisk management system with adequate resources (*X. Abad* 2014, with RA process) (**Figure 18**).

For GMOs a network of inspectors, the European Enforcement Project (EEP) was founded in 1997 with the aim to exchange knowledge and experience from inspection of GMO contained use laboratories and of field (deliberate) releases of GMOs and resolve challenges and impasses and promote the harmonization of enforcement practice and strategies across the EU and beyond (*de Wildt* et al. 2015).

Finally, according to the EU CBRN action plan (2014) each MS should establish:

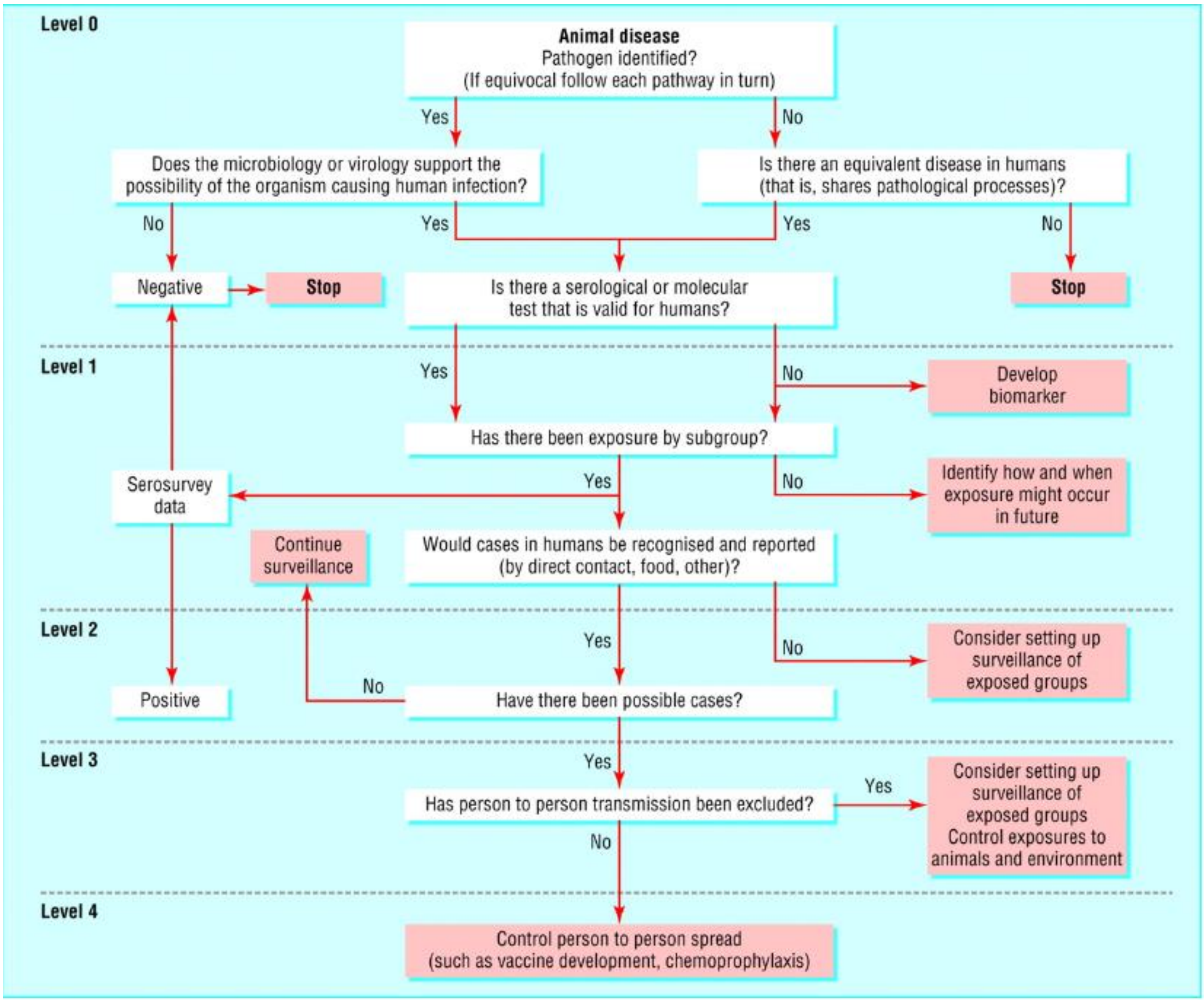
• a registry of facilities possessing any of the substances on the EU list of high risk biological agents and toxins.

• a process to verify whether security arrangements of these facilities are adequate, including diagnostic laboratories.

[61] https://www.wur.nl/upload_mm/5/f/8/d77e2ef6-cfe2-4b14-8cca-70bce8d355c5_RiskAssesmentFrameworkEmergingVectorBorneLivestock.pdf
[62] https://www.who.int/csr/resources/publications/biosafety/WHO_CDS_CSR_LYO_2004_11/en/
[63] ftp://ftp.cenorm.be/CEN/Sectors/TCandWorkshops/Workshops/CWA15793_September2011.pdf

• a mechanism within facilities storing those biological agents and toxins to regularly review the need of such biological agents and toxins while keeping a good record of stored materials.

Figure 17. *Categorization of zoonotic potential.*



Source: Palmer et al, 2005.

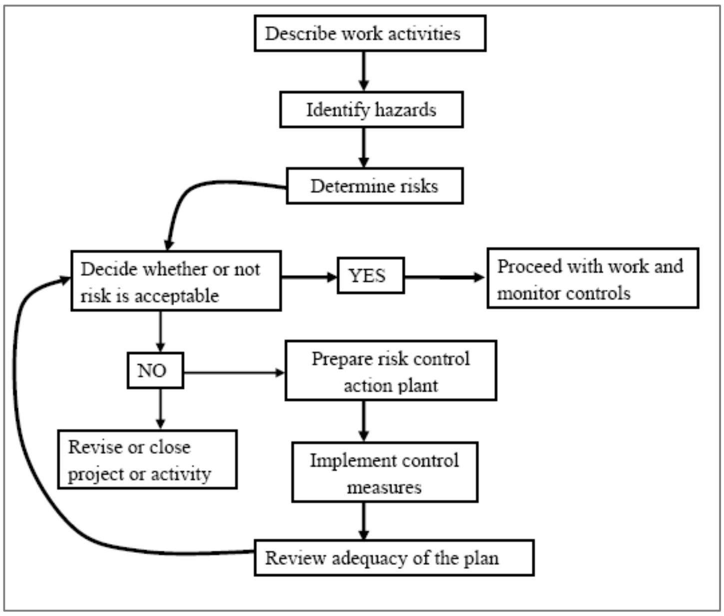
11.1 Risk Treatment

As said drafting a generic risk assessment for communicable diseases is challenging as it strongly depends on the pathogen accountable, its host(s) and the environmental conditions. Consequently it is highly important to support extensive surveillance systems for all hosts (human, animal and plant) in order to react quickly and to build national capacities for a proper response customised for each species and diseases.

11.1.1 Human epidemics

The decision on cross-border threats to health44 lays down rules on epidemiological surveillance, monitoring, and early warning of serious threats and includes preparedness and response planning, in order to coordinate and complement national policies. The MS shall, on the basis of the information from their monitoring systems, inform each other through the EWRS about developments of the threat. The EC collaborates with MS within the Health Security Committee (HSC), with relevant EU Agencies, in particular ECDC, and international organizations, such as the World Health Organization (WHO), to organise preparedness planning, alerts and appropriate assessment of the risks for the EU, and to coordinate the response.

Figure 18. *Framework for decision-making in a facility.*



Source: Abad, 2014.

MS shall provide every 3 years an update on the latest situation with regard to preparedness and response planning at national level[64] with the following:

— Status of the implementation of the core capacity standards for preparedness and response planning as determined at national level for the health sector, in accordance with IHR.

— Measures for ensuring interoperability between the health sector and other sectors including the veterinary sector, identified as critical in the case of an emergency, in particular:

  - Coordination structures in place for cross-sectoral incidents;
  - Emergency operational centres (crisis centres);

— Description of the business continuity plans, measures or arrangements aimed at ensuring the continuous delivery of critical services and products.

11.1.2 Animal diseases

The animal health law[65] is laying down the rules for the prevention and control of animal diseases. These rules provide for surveillance, early detection, notification and reporting of diseases, as well as for disease awareness, preparedness and control. The competent authority in MS shall conduct appropriate surveillance to detect the presence of listed diseases and *MS shall submit* their surveillance programme to the Commission with *regular reports on the results*. MS shall *immediately notify* the Commission and other MS of *any outbreaks of listed diseases*. The competent authority should initiate the first investigations to confirm or rule out the outbreak, put in place preliminary disease control measures to prevent the spread of the disease, and should undertake an epidemiological enquiry.

[64] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0504&from=EN
[65] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0429

For preparedness MS shall draw up and keep up to date, *contingency plans* and detailed instruction manuals laying down the *measures to be taken in the event of the occurrence of a listed disease or of an emerging disease*, in order to ensure a high level of disease awareness and preparedness and the ability *to launch a rapid response*. The competent authority shall ensure that simulation exercises concerning the contingency plans are carried out regularly.

As soon as a listed disease is confirmed, the competent authority should take the necessary *disease control measures*, if necessary including the *establishment of restricted zones*, to eradicate and prevent the further spread of that disease. The Commission should adopt immediately measures such as stocking, supply, storage, delivery of antigen, vaccine and diagnostic reagent banks, special rules on movements for animals, emergency measures, and the listing of third countries and territories for the purposes of entry into the Union.

The measures taken are based on a risk assessment elaborated on the available scientific evidence and undertaken in an independent, objective and transparent manner. Due account should also be taken of the opinions of the European Food Safety Authority (EFSA).

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12 Terrorist attacks

VASILIS KARLOS, MARTIN LARCHER

12.1 Introduction

Terrorism over the last years has grown into one of the main concerns at EU level, as shown in the latest Standard Eurobarometer survey (Eurobarometer 88, 2017). The threat of terrorism contains unique characteristics, as it is responsible for spreading irrational fear and terror in the population (**Figure 19**). It is interesting to note that while the number of fatalities in road traffic accidents in Europe is high (e.g. 26100 in 2015, Eurostat), the number of victims due to terrorist attacks is relatively small (383 between 2014-2017, on average 96 per year). This means that the probability of a citizen being killed as a result of a road accident is approximately 270 times higher than by a terrorist attack. Therefore, violent terrorism acts may be considered rare events, whose psychological, economic and political impact on society can be disproportionally high, as for example after the bombing attacks in Brussels and the vehicle-ramming attack in Nice in 2016. Even though terrorist events are of low frequency, a comprehensive understanding of the parameters that influence their likelihood is required for establishing a robust risk assessment and management framework.

Figure 19. *Terrorist risk.*

Terrorist events can be defined as **intentional violent acts** performed under the pretext of **political, religious or nationalistic motives**, whereas crime is usually driven by economic or retaliation intentions. The borderline between terrorism and military conflicts (encounters in which armed combat among military forces takes place either at international or national level) might be hard to be distinguished, since both rely on the extensive use of violence and could be guided by similar motives. Weapons (firearms, knives etc.), vehicles, CBRN (Chemical, Biological, Radiological and Nuclear) devices and improvised explosive devices (IEDs) that are either homemade or purchased in the black market are the preferred attack methods of terrorist groups, lone actors and extremists. However, it is important to consider that the modus operandi of the aggressors (in both terrorist acts and military conflicts) can rapidly transform, as has been demonstrated in the recent past. This transformation depends on a number of factors, such as the current political and religious status, the skills and capabilities of the perpetrators, the availability of financial and human resources, the instructions and guidance available in terrorist propaganda sites and magazines. A tendency has recently appeared to target unprotected public spaces of mass congregation (also known as soft targets) by using easily obtained weapons like knives, axes or vehicles. Such attacks may generate cascading effects on the societal level as the objectives of the terrorists include, but not limited to, causing casualties, gaining media attention, spreading fear and inflicting a sense of insecurity upon the public.

The risk of terrorism exists in both developed and developing countries and it still poses a major concern in certain regions that are mainly located in Africa, the Middle East and Asia. Nevertheless, the recent attacks in the Western world have clearly demonstrated that terrorism is a worldwide phenomenon, featuring complex direct (e.g. victims, injuries, loss of property) and indirect (e.g. psychological) consequences on the society. Unfortunately, the unique characteristics of terrorism risk are often neglected, resulting in a lack of dedicated guidance material for assessing and managing the relevant risk. Therefore the establishment of a national terrorism risk assessment plan is crucial for identifying critical zones and tactics and get the overall picture about the economic, social and political consequences in case of a successful attack.

The varied, cross-border and cross-sectorial nature of terrorist attacks is addressed at the EU level in the European Agenda on Security (2015), which aims at assessing Member States in ensuring security through coordinated and effective response at the European level. As a result, several operational measures have been proposed to significantly reduce the number of inherent vulnerabilities that were exposed in previous terrorist attacks and enhance the overall security of potential targets.

12.2 Lessons learned from prior terrorist attacks

The majority of terrorist attacks are not random, but have been carefully planned (or at least to a certain degree) to maximize the number of casualties, increase the generated damage and draw the attention of the media. Targets are usually selected according to their vulnerability and past experience has shown that unprotected sites have higher chances of being attacked. Predicting locations of a potential attack is a challenging task, since there exist many different factors that affect the reaction of the aggressors. In this section, a selection of indicative cases of terrorism incidents, which resulted in a large number of victims and injuries, is presented, emphasizing on their common characteristics and underlining any lessons-learned that could serve as an asset for future risk assessments.

- One of the most notorious terrorist acts resulting in a great death toll is the attack against the World Trade Centre in New York, USA on 11th September 2001, which took place in parallel to additional attacks in the US. The attack included sophisticated and detailed planning, aiming at structures of symbolic value, while guaranteeing a great number of victims and provoking panic and fear to the population. The use of asymmetric warfare techniques led to the realization that both public spaces and critical infrastructures could be potential targets of terrorist attacks and that different strategies need to be adopted for resisting the aggressors. The business and economic activities at the affected sites were disrupted for many weeks due to the widespread destruction causing severe consequences at the financial sector. The 19 terrorists who hijacked four airplanes, were members of the Al-Qaeda and four of them had received specific pilot training in the US without raising any suspicion to the secret services.
- On 19th April 1995 in Oklahoma City, USA a vehicle borne explosive device was detonated in front of the A. P. Murrah building resulting in the collapse of approximately one third of the structure. The attack was performed by two US citizens that had undergone military training, though not belonging to a terrorist group. It was extensively planned targeting a structure that housed several state facilities, as the aggressors wanted to disapprove several governmental actions. Bomb ingredients were acquired from local stores and the bomb was placed in a rental truck that was later parked on the curb outside the nine-storey building. The remaining standing structure was demolished due to safety reasons and several years were required for a new facility to be constructed that would substitute the old one.

- On 13th November 2015, Paris experienced a series of coordinated terrorist attacks that resulted in a great number of victims and injuries. The aggressors used person-borne improvised explosive devices (suicide bombers) and assault rifles attacking a sport stadium, a music theatre and several restaurants and bars. The perpetrators belonged to the ISIL and claimed that the motives behind the attacks were the ideological objections to the western lifestyle. Clearly, the simultaneous attacks against multiple targets, reveal the existence of a sophisticated plan against places of mass congregation that would guarantee maximizing the number of victims and drawing the attention of the media.
- One of the deadliest vehicle-ramming attacks took place at the city of Nice against the thousands of people gathered at the city's waterfront during the Bastille Day celebrations. On 14th July 2016 a 20-ton rented cargo truck attacked the public by managing to attain a speed of 70-80km/h as the promenade leading to the pedestrian zone is an almost straight path. Because of its mass and speed, the truck managed to force its way through the existing light protection measures (crowd control portable barriers, lane dividers etc.) and covered a total distance of approximately 1.7km before being stopped by the police. In order to increase the number of victims, the terrorist, who had not been involved in major crimes before, was driving the truck in a zigzag fashion boarding the crowded sidewalks whenever possible. Analysis revealed that the aggressor had been planning the attack for over a year and that he had surveyed the attack site while driving the rented truck on numerous occasions before the assault date. He was born in Tunisia and had been living in France for more than 10 years, and had been previously involved in minor crimes and was radicalized, sharing the views of the Islamic State, shortly before the vehicle-ramming incident.

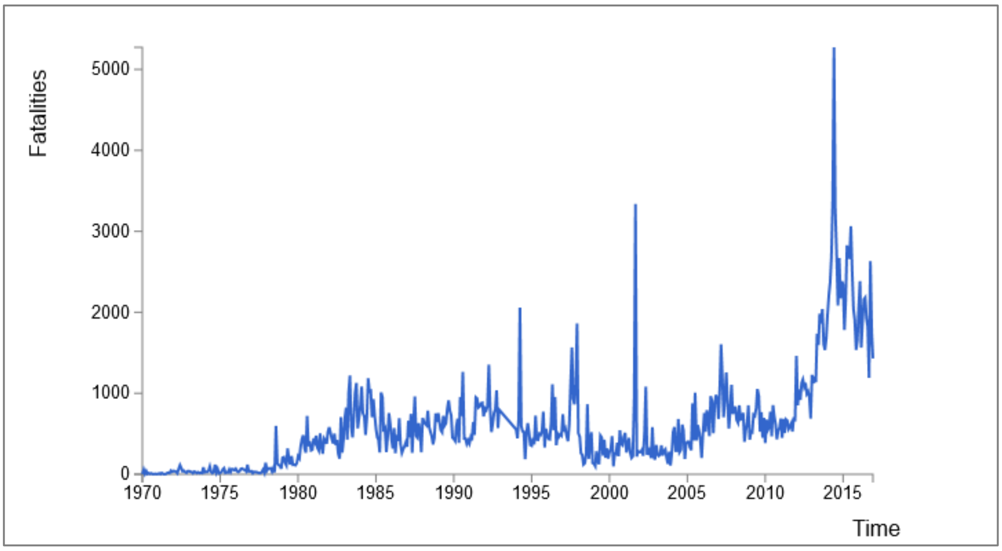
The above-mentioned events are only a fraction of the number of terrorist attacks that have been performed over the last years (**Figure 20**), but constitute a typical sample (including the use of airplanes, explosives, weapons and vehicles as the preferred attack methodology) that shares a substantial number of characteristics. It is clear, that the majority of such incidents were carefully planned in advance, as the aggressors had examined the attack sites beforehand to mark their vulnerabilities. The targets were iconic structures and places of mass congregation that would cause mass casualties, gain media attention and spread terror and fear. The attack sites were characterized by the absence of (or the presence of insufficient) protective measures that would be able to deter or mitigate the consequences of the assaults. The results of the attacks may include substantial damages on the infrastructure, effects on the local economy and an important psychological impact on the society. Moreover, the majority of the aggressors were not considered a threat by the local intelligence agencies, as they had never been arrested before, even though that in many occasions their attack planning communications were unencrypted.

A common feature among the majority of the attacks was the role of radicalisation (especially for Jihadist related attacks), as many of the aggressors had adopted violent extremism after being inspired from radicalised preachers. Tackling radicalization is a major challenge that requires the collaboration of different stakeholders at both national and local level. There are various reasons and different paths that push individuals to violent extremism but since most of them are part of the local community, detection and prevention activities need to mainly focus at the local level. The most effective prevention is to deter people from performing acts of terrorism in the first place, which shows the importance of the local authorities and community in the fight against extremism. The European Commission has set up the Radicalisation Awareness Network (Migration and Home Affairs-RAN, 2018) working on the fight against terrorism that has provided guidance material on assessing the relevant risk and suggested actions that guarantee resilience against violent radicalisation.

It is has already been highlighted that aggressor tactics and targets may quickly change introducing attack techniques that were not considered before. For instance, Radiological Dispersion Devices (RDD's, also known as "dirty bombs") are feared to be of interest to terrorist groups as they can be constructed by combining conventional explosives with radioactive material normally used in nuclear medicine and industrial applications. The aim of such an attack is generating a panic reaction in the public and inflicting high economic damage due to the required cleaning actions and the consequences from the disruption of affected services. As the immediate number of casualties from such attacks is small, a target may be selected not because of its high concentration of people, but depending on the favourable dispersion conditions for the radioactive particles.

However, not all terrorist attacks are extensively planned and may be of opportunistic character resulting in smaller number of fatalities. The impact of an attack on the society is not only related to the number of fatalities and injuries, as even a failed attack can have significant psychological implications for the public. Depending on the information source, the worldwide number of terrorist attacks in the last years is approximately 20,000 per year and the number of yearly casualties about 25,000.

Figure 20. *Fatalities per month from global terrorism database (year 1994 is missing in the recordings)*



12.3 Risk identification and assessment

The most common approach for assessing the risk of a certain site can be divided in three distinct steps that can help decision-makers in prioritizing their security needs (**Figure 21**). In the first step, potential terrorist threats are identified and their likelihood of occurrence is estimated. In the second step, the exposed assets where the potential consequences would be the highest are evaluated and in the third the inherent vulnerabilities of potential targets are examined. The establishment of the risk profile of potential targets can considerably assist in the implementation of tailor-made protection measures that can effectively deter and/or mitigate terrorist attacks.

12.3.1 Threat assessment

The first step in the risk assessment process is the identification of potential terrorist threats that are relevant for the region and the target under consideration.

Threat assessment focuses on pinpointing potential terrorist tactics and providing the framework for determining effective prevention and/or mitigation measures. For estimating the likelihood of occurrence of a terrorist attack and formulate possible attack scenarios, one has to resort to available statistical data from recent incidents and investigate information that is available from counterterrorism units, intelligence services, state and emergency agencies and the internet.

Figure 21. *Risk assessment process.*

Attack scenarios should be rated according to their feasibility and probability. For example, the probability of vehicle ramming incidents is usually higher compared to attacks with the use of explosives due to the terrorists' direct accessibility to a variety of vehicles, the minimal required expertise and the easy planning. In general, during assessing terrorist threats, decision makers and assessors tend to put more emphasis on past events failing to "think the unthinkable". Additionally, new tactics may emerge that, even though they might be characterized by a smaller probability, could result in higher societal, economic or political impact. This transformation of actions and tactics depends on a number of factors, such as the current political and religious status, the skills and capabilities of the perpetrators, the availability of financial and human resources, the instructions and guidance available in terrorist propaganda sites and magazines.

12.3.1.1 Threat assessment on country level

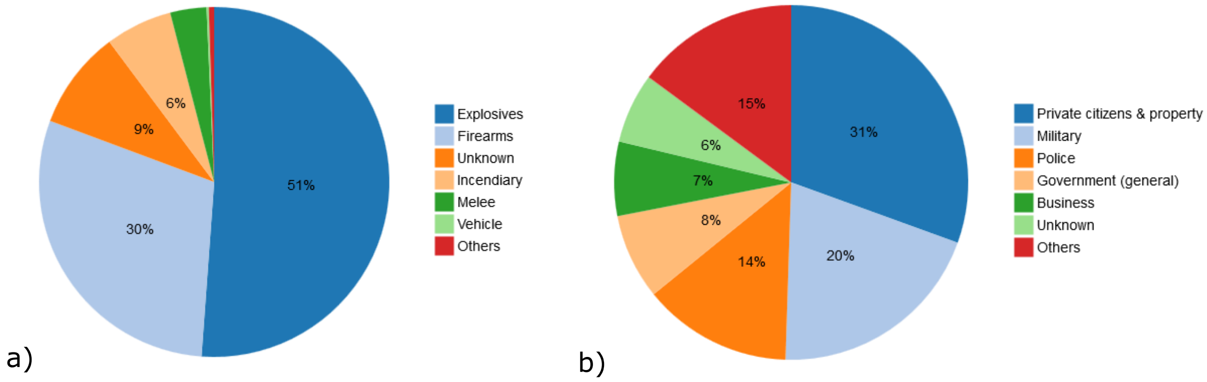
The nature of extreme manmade events with malicious intent, such as terrorist attacks, makes them different from most usual risk types. Their intentional character means that they are rarer events, than for example small scale earthquakes, floods or droughts. Classical statistical approaches may provide an indication for calculating future risk, but detailed data from additional sources, such as intelligence agencies, could be required for a more rigorous analysis. Information included in propaganda sites and magazines can greatly contribute in assessing the probability of occurrence of attacks against specific targets. Nevertheless, information concerning potential terrorist threats is not always readily available due to its sensitive nature and access may be granted only to authorized individuals and not to private stakeholders. Moreover, the risk needs to be re-assessed in regular intervals to analyse any new security related information and relevant threats, especially since a major part of malicious events is politically motivated and can rapidly transform, as has been demonstrated in the recent past.

For assessing the terrorism threat, one has to resort to statistical and other types of data from prior attacks. The **likelihood of occurrence** of an attack can be estimated by examining any observed criminal activity in the area of interest and possible recorded incidents or security breaches over a certain time period. Possible data sources are:

- Global terrorism database (University of Maryland, 2018), which is freely available but updated on an annual basis, which means that latest data are not readily available
- Commercial security risk providers like Jane's (IHS Markit, 2018) or Control Risks (Control Risks Group Holdings Ltd, 2018) databases
- European Media Monitor (European Commission-EMM, 2018) system that analyses information from both traditional and social media. The usability of the provided terrorism tool is apparently tested by the JRC

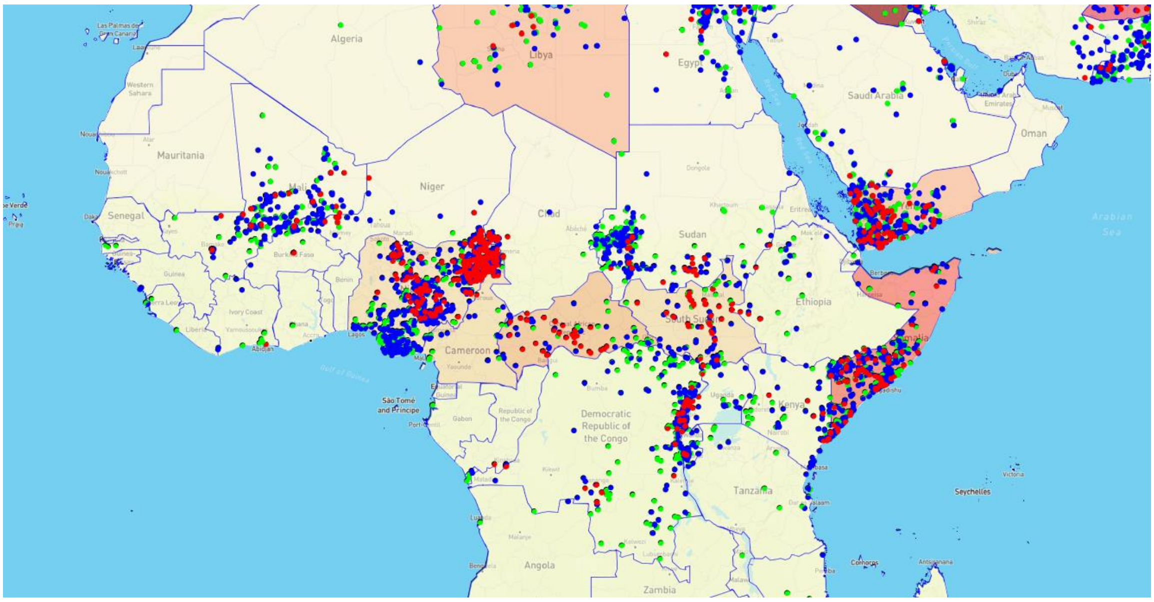
Since terrorist threats can completely change over time, special attention should be paid on very recent events, thus it is advised that higher statistical weighing factors are assigned to such events during the threat assessment process compared to older ones. Supporting information that can prove valuable during this threat assessment process may be located in organized crime databases, such as the number of firearms in circulation, the terrorism funds obtained via drug trafficking etc. For example, the pie charts presented in **Figure 22** highlight the worldwide predominant assault types and targets over a four-year period (2014-2017).

Figure 22. *Worldwide terrorist attacks by a) utilized modus operandi and b) target.*



Assessing the risk of terrorism on a country level, can prove useful in identifying critical countries, yet the results are usually too general for recommending and implementing specific actions. A breakdown of risk to smaller regions is also questionable, since the statistical significance of available data might not be adequate for performing a reliable assessment. The development of worldwide critical terrorism-affected zone maps (e.g. Niger, Afghanistan, Yemen) that demonstrate terrorist incidents, like the one presented in **Figure 23**, can assist in classifying hot spots and issuing travel advices, but are impractical if the introduction of specialized protective plans is of interest.

Figure 23. *Threat level from terrorist attacks in central Africa in 2015. Red: 10 or more fatalities, blue: between 1 and 10 fatalities, green: no fatalities*



12.3.1.2 Threat assessment on local level

Carrying out a threat assessment on a local level is a challenging process, as a definite "yes or no" answer concerning imminent attacks cannot be provided. Quantifying the probability of a terrorist attack against a specific target may seem futile, as by nature it contains many uncertainties. The introduction of a universally applicable method for calculating the likelihood of a specific attack type against a certain target is problematic due to the frequently opportunistic character of attack planning. Even though no concrete conclusions can be drawn from analysing the potential modus operandi of the aggressors, it still provides valuable information since places of people congregation could potentially prove attractive targets for terrorists and extremists. Examining statistical data from previous similar events at the region and target of interest using the databases that have been described in the previous section, can provide valuable indications concerning threat rating.

The **likelihood** of an attack against a specific target, can be evaluated by responding to several questions that may arise during the risk assessment process including, but not limited to:

- Are there any indications of an imminent terrorist attack?
- Does the potential target represent a religious/ethno-nationalist ideology that is against the political or religious agendas of active terrorist groups?
- Is the target of symbolic or historical value?
- Which is the maximum attendance?
- Are there any high profile events hosted that are attended by famous people and covered by the media?
- Are there any trained security officials present?
- How easily accessible are the target's premises and by what means (vehicles, motorcycles, on foot etc.)?

12.3.2 Exposed asset identification

A crucial step in the risk assessment process is the identification of the assets that have to be considered in the analysis. Recent terrorist attacks have shown that there is a recurrent targeting of unprotected public spaces of mass congregation of various gathering purpose, as shown in **Table 6**.

Table 6. Soft target categories.

Target category	Places of people congregation
Recreational	Stadiums, concert halls, entertainment venues, festivals, parks, markets, shopping malls, theatres, cinemas, clubs, restaurants, bars, cultural events, parades, pedestrian areas etc.
Commercial	Hotels, apartment buildings, office complexes, shops etc.
Public	Hospitals, medical centres, universities, schools, museums,

	libraries, etc.
Religious	Churches, religious events, places of worship, etc.
Transportation	Train and subway stations, airports, bus and port terminals, transportations sites, etc.
Governmental	Town halls, ministries, official residences, monuments, landmarks governmental office complexes, etc.

The majority of terrorist attacks are not random, but have been carefully planned (or at least to a certain degree) to maximize the number of victims and draw the attention of the public and the media. Unprotected public spaces pose an attractive target, but several other sectors may become exposed to terrorism resulting in great consequences, such as critical infrastructures, as has already been described in the relevant chapter in the current good practice document.

The weighing factors for evaluating the criticality of each exposed target may be different among the different countries, but some common indicators (e.g. people attendance, site symbolism, facility size, importance of facility etc.) may be used for identifying the sites where potential consequences have the greatest impact. Such a process guarantees improved, custom-made security and mitigation actions, though differences may appear depending on the stakeholder responsible for performing the identification. For instance, the criticality of a certain target from the building/site owners' perspective is usually related to its operation, whereas state organizations and policymakers may be more attentive to the public's safety and needs. Consequently, during the design of an effective physical security strategy the harmonic collaboration of all relevant stakeholders is crucial for effectively tackling the interdependencies between the different assets.

12.3.3 Vulnerability assessment

Vulnerabilities are the inherent weaknesses of a potential target that may render it susceptible to the destructive consequences of a terrorist attack and are directly related to its risk level. These vulnerabilities can be exploited by perpetrators in their effort to strike, thus effective mitigation measures and identification of optimal strategies are required for minimizing exposure and enhancing resilience. A detailed examination of the site under consideration can disclose deficiencies and flaws that may encourage the formulation of an attack plan, as the lighter the security measures, the more attractive a target is deemed to the eyes of terrorists. An objectively assessment of the vulnerability degree of a public space or infrastructure is a challenging task, as there are many different factors that should be taken into account, such as the target's accessibility, its significance, its location, its shape and the current protective measures (entry checks, video surveillance, security guards, perimeter protection etc.). DG HOME is in the process of developing a vulnerability assessment tool that can prove valuable in the assessment process of potential targets. An example of a vulnerability assessment categorization is shown accordingly,

<u>Low vulnerability</u>: The examined infrastructure or public space is equipped with adequate security countermeasures (controlled access, safeguards, perimeter protection etc.) to drive away potential aggressors and is unattractive as a potential target.

<u>Moderate vulnerability</u>: The examined infrastructure or public space may be equipped with some security countermeasures (no controlled access, some safeguards, partial perimeter protection etc.) and is well-known only at a local scale.

<u>High vulnerability</u>: The examined infrastructure or public space is characterized by inadequate security countermeasures, while it is well-known at a national scale.

Very high vulnerability: The examined infrastructure or public space is characterized by inadequate security countermeasures, while it is well-known at a global scale.

Site assessments from experienced professionals can recognise the main elements that should be considered as weaknesses and specify appropriate protective measures that can be applied to reduce these vulnerabilities. For assessing the vulnerability of the built infrastructure specialized engineers need to be engaged so that special attention is paid to security aspects of the engineering design, such as:

- Resistance against progressive collapse. Robust infrastructures, similar to the ones designed for resisting the effects of severe earthquakes, demonstrate improved resistance to blast and progressive collapse incidents.
- Resistance of glazing material. Glass, that is a main window element in nearly every building's facade, fails instantly under blast loads, due to its extreme fragility. The created glazed fragments are responsible for a large fraction of the injuries and fatalities observed during explosive events. The use of laminated glass panels or anti-shatter films guarantees a higher resistance to blast loads and reduces the relevant risk.
- Protection of soft targets/people. A combination of perimeter security measures in public spaces (fences, controlled access, security guards, video surveillance etc.) can effectively reduce the risk of a terrorist attack. Moreover, the introduction of stiff protective elements and barriers that are harmonically integrated into the surrounding urban environment can substantially reduce the risk of vehicle-ramming events and provide cover in case of explosions or active shooter incidents.

12.4 Risk analysis

It is observed that in the last years the majority of attacks have been performed against the so-called soft targets (described in **Table 6**), meaning targets characterized with high concentration of people and absence of specific security measures. They are the opposite of "hard targets" that indicate grounds equipped with heightened protection and surveillance. Target attractiveness depends on many different factors that are associated with both the terrorist group and the characteristics of the target. For instance, aggressors may choose a target that is against their political, social or religious ideology, while the selection may be also influenced by the availability of funds and the number of terrorist members. This means that religious or cultural symbols that are considered to be promoting the western life style, capitalism and/or democracy may become the target of Jihadist terrorists. Iconic and recognizable locations have higher chances of being attacked, especially if they are mentioned in terrorist propaganda magazines. Popular tourist locations, open-air festivals, sport events, landmarks and areas that are typically characterized with high people presence and lack of security guards are also appealing to terrorist groups.

There exists a lack of risk assessment methodologies for terrorist attacks as the majority of the required information is of restricted nature. Nevertheless, various approaches may be employed for addressing the complexity of the risk management process. For attaining a desired protection level, a holistic creative approach is needed, that favours the assessment of possible **attack scenarios** and their consequences if successfully executed. A scenario-based approach at potential targets is bound to simplify the complexity of the risk assessment process and assist in the evaluation of the different targets in terms of criticality (i.e. consequences severity). Some of the necessary data for the development of potential attack scenarios may be acquired through the sources that have already been described in the threat assessment section.

The impact of an attack is directly linked to the type of target selected by the terrorists and its conditions at the time of the assault. For instance, an attack against a city square will have a completely different aftermath if it is performed during peak hours or during social events when the crowd attendance is at its highest. The **consequences** of past attacks, such as the effects on human life (injuries, fatalities etc.) and the economy (repair cost, disruption of services etc.), can be used as input for assessing the repercussions of potential future events. Indirect consequences from a terrorist attack are more difficult to be assessed, as they include the social and economic costs, such as the effects on the population's psychology and the impact on the tourism industry (Larcher, 2018). Cascading phenomena may also appear through the interconnections between infrastructure systems, such as for instance during a terrorist attack against a power plant which, apart from the immediate life losses, would also result in disruptions in many other companies and the public. Consequence assessments serve as a tool for estimating the outcome of different attack scenarios at various sites and categorize them in terms of severity.

Since specialized quantitative approaches for measuring the consequences of an attack are still missing, qualitative methods and expert judgement may provide valuable insight at the dependencies among the different affected elements of public life. For example, part of the indicators included in the (Sendai Framework for Action on Disaster Risk Reduction 2015-2030) may be used for analysing the consequences and eventually reducing disaster loss in terms of lives and other types of damage. For example, Global Target A aims at reducing disaster mortality (A-2 compound), while Global Target B highlights the number of people injured by a disaster (B-2 compound). Similarly, Global Target D mentions the damage to critical infrastructures (D-1 compound) and the disruption to basic services (D-5 compound).

Using number of fatalities and injuries for developing an impact factor is a rather straightforward process, as they can be easily measured from prior attacks. The use of other parameters, such as the effect of assaults on public morale or the economic damage due to the disruption of services are hard to be measured since they do not constitute quantitative values. Nevertheless, the global targets set out by the Sendai Framework for the disaster risk management include indicators, some of which (e.g. economic loss, disruption of basic services etc.) may be employed during the assessment of a terrorist attack's impact factor. Assessing the risk of a terrorist attack has certain disadvantages as a significant statistical sample is required for the prediction to be accurate. This can be the case in high terrorist risk countries where many events have occurred in the past, but in countries with hardly any attacks, as commonly observed in the western world, this approach leads to unreliable results.

12.5 Risk evaluation

Terrorist groups usually aim at exploiting the intrinsic vulnerabilities of their targets, such as public spaces, critical infrastructures, landmarks etc., in an effort to cause casualties, attract the media's attention and spread fear to the public. The risk of terrorism needs to be properly evaluated either as an individual, separate risk or as part of an overall risk assessment national strategy. The consequences of a successful attack may span across different sectors (human lives, economy, tourism, psychological effects, critical infrastructures etc.) both at a local and at a regional/national level. Therefore, during the risk assessment process these interconnected, cascading consequences have to be considered for establishing a thorough quantification.

As is the case in other risks that are described in the present document, the potential consequences of a terrorist attack depend heavily on the specific target. Moreover, the different stakeholders and decision bodies that are involved in the assessment process and its various uncertainties make the consequences evaluation a challenging task. As the probability of occurrence of an imminent terrorist attack is difficult to be calculated due to its usual opportunistic character and the religious or political motivations of the aggressors, a "judgement call" might be required from the decision makers when evaluating the relevant risk. One of the main concerns during these evaluation procedures, is the definition of an acceptable risk level, since providing protection against all possible terrorist threats is not feasible in both economic and practical terms.

National risk assessment strategies should be updated on a regular basis, since threat types and terrorist tactics alter with time. When reviewing terrorism risks different factors, such as the global and local political scene, religious tensions and the availability of potential weapons (explosives, vehicles, guns, biological agents etc.), should be considered. The various attack scenarios that may be examined during the risk evaluation process should be regularly reassessed and updated to be in line with the latest threat developments. Furthermore, the implementation of mitigation and protective measures need to follow, whenever possible, a security-by-design approach, so that the selected solutions may be harmonically integrated in the surrounding environment, reaching a proper balance between security and the protected asset's characteristics. These measures should focus on increasing the redundancy of the potential target in order to be effective for a variety of different threats and be adequate for new emerging risks.

12.6 Key messages and challenges

Given the diverse targets and tactics selected by terrorists in their effort to cause victims and draw public attention, a multidimensional response is needed, one that includes innovative new approaches in the assessment of the relevant risk. A holistic and individualised risk evaluation approach is crucial for drawing together all terrorism-related data and providing tailor-made suggestions for effectively reducing and/or mitigating the risk of a terrorist attack. Past incidents may provide valuable information concerning the vulnerability of various sites, the potential consequences should an attack materialize and common tactics used by the aggressors. Clearly, protection of all public spaces is impractical in both economic and technical terms, so a cost and benefit analysis needs to be followed for the zones that have to be protected in order to introduce an efficient protection plan with reduced installation and running costs.

Since a universally accepted risk assessment methodology for terrorism is still missing, efforts should focus on identifying potential threats utilizing available terrorism databases, evaluating the impact of potential attacks and assessing the vulnerability of targets. Terrorism-affected zone maps are available at country level, but breaking down the information to smaller regions is questionable, as the samples usually lack the statistical significance for drawing concrete conclusions. However, they may provide hints regarding the preferred terrorist tactics and potential targets, which are essential inputs for the vulnerability and consequences assessment procedure.

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13 Critical Infrastructures

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13.1 Introduction

In Council Directive 2008/114/EC, a Critical Infrastructure (CI) is defined as *"an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions"*[66]. In time, various characterizations and categorizations have been proposed for CIs, especially to promote their protection and resilience[67].

When discussing risk assessment and related good practices in this context, we have to consider that both exogenous (e.g. natural, man-made) and endogenous (e.g. aging) factors may lead CIs to failure. Moreover, generally CIs play multiple roles during disasters and crises. In particular,

- they may be directly affected by critical events;
- the failure of a CI may provoke consequences and trigger emergencies;
- a CI may mediate response and mitigation actions[68].

It is then interesting to evaluate how these three aspects are taken into account in current risk assessment practices.

Based on the latest Commission Staff Working Document on National Risk Assessment (NRA) results[69], CI-related risk scenarios assessed by the majority of Member States (MSs) focus predominantly on the first two aspects. In particular, such scenarios refer to either: (a) major accidents or energy shortages or (b) infrastructure failures induced by other kinds of hazards. Several NRAs also assess potential infrastructure-to-infrastructure cascading effects, including cross-sectoral consequences. Besides, correlated hazards such as the loss of CIs or nuclear and industrial accidents have been linked to increased exposures to terrorism and cyber-risks. In this regard, a recent JRC report[70] identified some gaps in the way CIs are addressed during risk assessment processes performed by MSs. These findings were based on the NRA report published in 2015[71], but similar observations can be made for recent NRAs, as reported in 2017[72].

Since CIs mediate the flow of goods and allow the provision of essential services to the society, bolstering their resilience against critical events requires a comprehensive analysis of the failure-recovery cycle. To this end, it is often inadequate to evaluate the coping capabilities of an infrastructure in isolation. Exposures, for instance, may emerge from the accumulation of those specific to each asset, or be inherent to the way systems are interconnected. Global supply chains are one of the clearest examples in this sense,

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[66] Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection. URL: https://eur-lex.europa.eu/eli/dir/2008/114/oj.

[67] See www.cipedia.eu.

[68] Rome E., Doll T., Rilling S., Sojeva B., Voß N., Xie J., The Use of What-If Analysis to Improve the Management of Crisis Situations Chapter 10 in: Setola R., Rosato V., Kyriakides E., Rome E. (Eds.): Managing the Complexity of Critical Infrastructures A Modelling and Simulation Approach, Springer, DOI 10.1007/978-3-319-51043-9_10.

[69] Commission Staff Working Document on Overview of Natural and Man-made Disaster Risks the European Union may face, SWD(2017) 176 final, Brussels, 23.5.2017.

[70] Theocharidou M, Giannopoulos G, Risk assessment methodologies for critical infrastructure protection. Part II: A new approach, EUR 27332 EN, 2015.

[71] Commission Staff Working Document on Overview of Natural and Man-made Disaster Risks in the EU, SWD(2014) 134 final, Brussels, 8.4.2014.

[72] Commission Staff Working Document on Overview of Natural and Man-made Disaster Risks the European Union may face, SWD(2017) 176 final, Brussels, 23.5.2017.

and they demonstrate how systemic vulnerabilities may enable cascading effects and amplify losses.

Interdependencies and associated risks are often complex to assess, due to the articulated geospatial layouts of CIs, their many mutual interactions, the integration of technological sectors and many other factors. Traditional asset-based, hazard-specific risk assessment methodologies are sometimes ineffective in coping with this challenge. On the other side, new trends emerge in this area, such as the so-called service-based approaches. These, instead of focusing on damages to specific assets, capture interdependencies on the basis of exchange of services between infrastructures of the same or different sectors.

In this sense, moving from the definition of risk proposed in standard ISO 31000:2009 *("effect of uncertainty in objectives"*), [73] discusses the concepts of systemic risk *("the risk of having not just statistically independent failures, but interdependent"*) and hyper-risk *("implied by networks of networks"*). The same reference also points out some key shortcomings of current risk-assessment methods. These include poor estimates of probability distributions and parameters for rare events, underestimation of likelihoods of coincidence of multiple rare events, scarce accounting for feedback loops in fault/event tree analysis, insufficient consideration for joint probabilistic analysis and complex dynamics analysis, human/social factors, lack of questioning about established ways of thinking, economic/political/personal incentives.

Awareness about the aspect of interdependency and direct/indirect effects is also clear in standard ISO 31000:2018, which we will reference for our discussion on risk assessment phases[74] and, throughout most of this document, for risk-related terminology. In the standard's definitions, for instance, term "consequences" receives a comprehensive interpretation, which includes both direct and indirect effects.

In the rest of this chapter, we will first overview some recent policy background relevant to CI risk, starting from the Sendai Framework for Disaster Risk Reduction 2015-2030, the European Union framework and some other significant experiences on a global scale. Secondly, we will introduce aspects of interest and good practices related to risk assessment for CIs, notably in risk identification, analysis and evaluation. Emerging trends interpret risk assessment as part of a broader, circular risk management process. We will, therefore, introduce techniques (frameworks, methodologies and tools) supporting this process in the case of CIs, also including the concept of resilience and the implementation of related strategies. Finally, we will discuss risk treatment and some important gaps and challenges that both policymakers and CI operators are facing today.

13.2 **Policy background**

The multi-dimensional aspect of disaster risk reduction in the case of CIs is taken into account with increasing emphasis in international policies and agreements. A notable example is found in the Sendai Framework for Action on Disaster Risk Reduction 2015-2030, which promotes actions devoted to reducing disaster losses in various areas and expressed in terms of lives as well as material/non-material damages. As part of the framework, Global Target D proposes to *"substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030"*. More in details, the target articulates the aspect of *"damage to critical infrastructures attributed to disasters"* (target D1-compound) and *"number of disruptions to basic services attributed to disasters"* (target D5-compound). Interestingly, the latter conceptualization equally

[73] Helbing, Dirk. "Globally networked risks and how to respond." Nature 497.7447 (2013): 51.

[74] For further discussion on terminology, see also:

Theocharidou M., Giannopoulos G. 2015. Risk assessment methodologies for critical infrastructure protection. Part II: A new approach. Report EUR 27332 EN, Luxembourg: European Union — Publications Office.

stresses the aspect of damage/disruption to assets and to services, which clearly binds with the discussion on interdependencies proposed above.

Observe that CIs are also mentioned in other portions of the Sendai Framework, notably in Global Target C. There, within the general framework of economic losses reduction *("reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030")*, target C5 refers to *"direct economic loss resulting from damaged or destroyed CI attributed to disaster"*. This is a case where consequences emerging from CI failing are taken into account, emphasizing once more the multiplicity of roles played by CIs in disaster scenarios.

At the EU level, the designation of CIs is accompanied by the attention to their protection and ability to withstand and overcome crises. However, the landscape within the EU remains diverse[75]. Indeed, the MSs follow different approaches with respect to CI designation, with the notable exception of the Energy and Transport sectors[76], which are commonly accepted due to Council Directive 2008/114/EC. This diversity is also reflected in the associated best practices, such as the Operator Security Plan for designated infrastructures. Risk assessment is the cornerstone for the design of such plans at the CI level or at a sectoral level, and can be performed either by the CI operator, the sector regulator, or in a collaboration involving local or national authorities.

A relevant example in this context is the integrated approach for CI protection established in the Netherlands in May 2015 as part of the National Safety and Security Strategy developed by the Dutch Ministry for Security and Justice. This approach identifies what is considered as CI, based on criteria stemming from the National Risk Assessment process. The degree of criticality depends upon the identified consequences of a failure involving the considered critical sectors, and cascading effects are taken into account in the assessment. Then, the vulnerability assessment provides insight into the most relevant risks, threats, vulnerabilities and the degree of resilience of each infrastructure. According to the results of the assessment, particularly risks, threats and vulnerabilities, plans are formed to maintain or increase the resilience of the infrastructure. In addition, CIs can be incorporated into the national crisis management structures.

Beyond the EU, USA's 'National Infrastructure Protection Plan (NIPP) 2013: Partnering for Critical Infrastructure Security and Resilience'[77], includes a CI risk management approach which can be applied to all threats and hazards, including cyber incidents, natural disasters, manmade safety hazards, and acts of terrorism. It is designed in a way that complements and supports the Threat and Hazard Identification and Risk Assessment (THIRA) process conducted by regional, State, and urban area jurisdictions. Similarly, the Canadian government recognizes that the impacts of disruptions can cross sectors and jurisdictions, and provides practical guidance for implementing a coordinated, all-hazards approach to CI risk management[78].

As observed in [79], *"complementing traditional risk management, security, and protection practices, resilience gains a prominent role as the 'umbrella' term to cover all stages of crisis management. This aspect is also prominent in emerging EU policy trends, wherein*

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75 Lazari, A. & Simoncini, M. (2016). Critical Infrastructure Protection beyond Compliance. An Analysis of National Variations in the Implementation of Directive 114/08/EC. Global Jurist, 16(3), pp. 267-289, doi:10.1515/gj-2015-0014.

76 See www.cipedia.eu for the 'Critical Infrastructure Sector' per country.

77 https://www.dhs.gov/publication/nipp-2013-partnering-critical-infrastructure-security-and-resilience#

78 Risk Management Guide for Critical Infrastructure Sectors, Public Safety Canada, July 2010. Available at: https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/rsk-mngmnt-gd/index-en.aspx.

79 Theocharidou M., Galbusera L., Giannopoulos G. Resilience of critical infrastructure systems: Policy, research projects and tools. In Linkov I., Trump B., Florin M.V. (Eds.) IRGC Resource Guide on Resilience (volume 2) Domains of Resilience for Complex Interconnected Systems in Transition, to appear, 2018.

CI resilience acquires increasing importance and links to a number of strategic priorities". Selected key policy documents at the EU level related to the topic include:

- Communication from the Commission to the Council and the European Parliament - Critical Infrastructure Protection in the fight against terrorism[80];
- Green Paper on a European programme for critical infrastructure protection[81];
- Communication from the Commission on a European Programme for Critical Infrastructure Protection[82];
- Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection (Text with EEA relevance)[83];
- Commission Staff Working Document on a new approach to the European Programme for Critical Infrastructure Protection: Making European Critical Infrastructures more secure[84];
- Directive (EU) 2016/1148 of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union[85];
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - An EU Strategy on adaptation to climate change[86];
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - The European Agenda on Security[87];
- Joint Communication to the European Parliament and the Council - Joint Framework on countering hybrid threats a European Union response[88];
- Joint Communication to the European Parliament, the European Council and the Council - Increasing resilience and bolstering capabilities to address hybrid threats[89];
- Joint Communication to the European Parliament and the Council - Resilience, Deterrence and Defence: Building strong cybersecurity for the EU[90].

Figure 24 illustrates the conceptual evolution of the emerging policies from the context of CI risk, security and protection to that of CI resilience. The EU-funded H2020 IMPROVER project[91] uses the following definition of CI resilience: *"the ability of a CI system exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, for the preservation and restoration of essential societal services."*[92] However, through six interactive workshops with infrastructure operators organized by the IMPROVER project, what has become apparent is that the definition of resilience isn't what matters; what does matter is the way resilience changes the outlook of operators[93]. Indeed, resilience is an optimistic approach

[80] COM/2004/0702 final
[81] COM/2005/0576 final
[82] COM/2006/0786 final
[83] Directive (EU) 2016/1148
[84] SWD(2013) 318 final
[85] Directive (EU) 2016/1148
[86] COM/2013/0216 final
[87] COM/2015/0185 final
[88] JOIN/2016/018 final
[89] JOIN/2018/16 final
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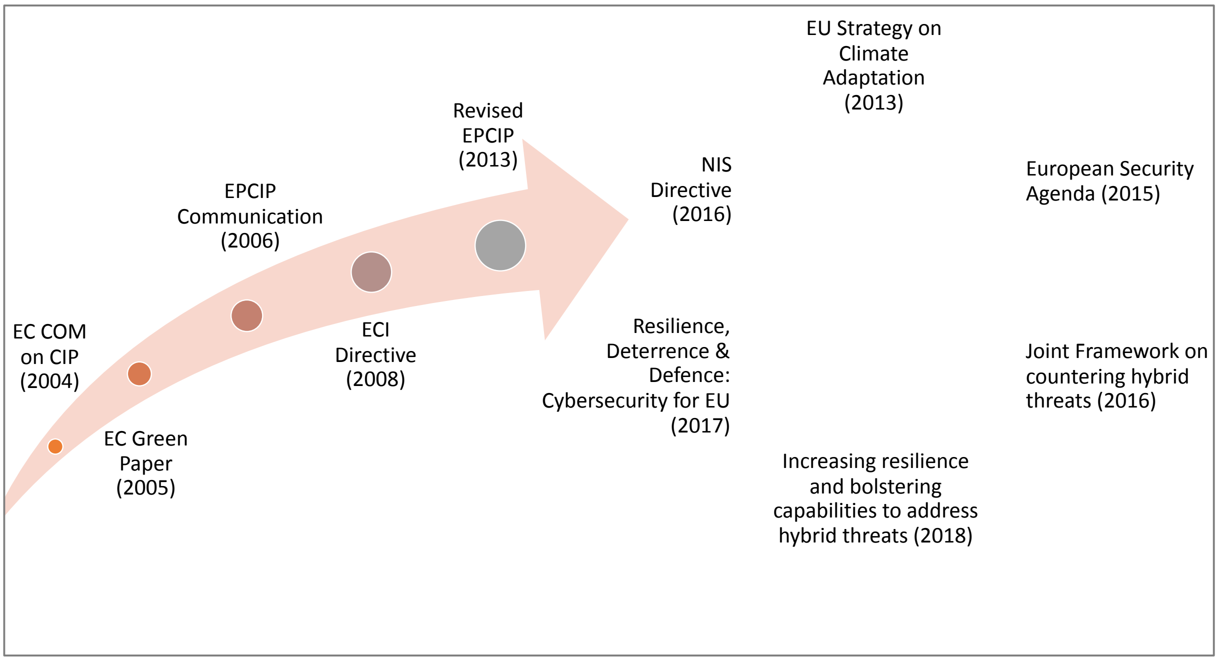
[91] www.improverproject.eu
[92] The definition has been adapted from: 2009 UNISDR Terminology on Disaster Risk Reduction, United Nations International Strategy for Disaster Reduction (UNISDR), Geneva, Switzerland, May 2009.
[93] Petersen L., Theocharidou M., Lange D., & Bossu R. (2018). Who cares what it means? Practical reasons for using the word resilience with critical infrastructure operators. The Third Northern European Conference on Emergency and Disaster Studies (NEEDS 2018).

when compared to current risk management practices, allowing operators to be actors in responding to crises, as opposed to simply being subjects exposed to risks.

From the perspective of CI protection, there are main two schools of thought regarding the relationships between risk management and resilience management[94]. Some see resilience management as part of risk management; others interpret resilience management as a separate process. Regardless of the most correct interpretation, considering the relationships between these two concepts is unavoidable when discussing CI resilience. Indeed, in many respects both approaches find justification. Resilience management can be a separate process with respect to risk management, while it can also be performed in a way such that the two processes enrich and support each other. At the time of writing, a proposal for a new ISO resilience standard is been prepared under the ISO 31000 family of standards on risk management, exploring the potential benefits of a resilience-based approach. Moreover, many of the methods, frameworks and tools described below in this chapter implement risk approaches which comprise resilience elements as well.

***Figure 24**. EU policy milestones towards the resilience of CIS.*



Source: Theocharidou et al, 2018[95].

13.3 Risk assessment

According to ISO 31000:2018, risk assessment is the overall process comprising risk identification, risk analysis and risk evaluation. However, when applying such a standard to the case of CIs, there are some issues that pose challenges or require particular consideration.

[94] Theocharidou M., Lange D., Storesund K. (2018). Guideline on implementation of organisational, societal and technological resilience concepts to critical infrastructure, IMPROVER D5.2, September 2018.

[95] Theocharidou M., Galbusera L., Giannopoulos G. Resilience of critical infrastructure systems: Policy, research projects and tools. In Linkov I., Trump B., Florin M.V. (Eds.) IRGC Resource Guide on Resilience (volume 2) Domains of Resilience for Complex Interconnected Systems in Transition, to appear, 2018.

13.3.1 Defining the scope

A risk assessment related to CIs can be performed at various levels:

- at the level of specific infrastructures, typically conducted by the CI operator;
- at the sector level, conducted by governmental authorities or the sector's regulator with input by the CI operators; or
- at local (e.g. for a city) or national (e.g. as part of the NRA) level, where the process should involve all relevant authorities and stakeholders.

<u>Goal definition</u>

In general, the goal of the assessment could be to identify those critical components where potential consequences would be highest and where security and resilience enhancement activities can be mainly focused. It is clear that, depending on the level of analysis, such goals are likely to vary across sectors, organizations, and policymakers. CI operators may view criticality or risk differently, as their goals relate to their operations, while a policymaker's goals may relate more to public needs and priorities.

<u>Stakeholder identification</u>

In all cases, when focusing on infrastructures, the consequences to the society and the presence of interdependencies are parameters that highlight the importance of collaboration. An important step is, therefore, to identify and engage all stakeholders relevant to the assessment.

<u>CI identification</u>

Another key step is the identification of the CIs to be included in the analysis. As we briefly mentioned in the previous section, different countries have different interpretations about what is considered to be critical. Some practices in this domain include[96]:

- adopting definitions of CI sectors and services from other countries;
- introducing methodologies to identify CI sectors and services systematically;
- performing (national and cross-border) dependency analysis.

<u>Data collection challenges</u>

One of the early questions to be faced, even in defining the scope of the assessment, is whether or not adequate data support can be provided. A number of actions have been completed or are ongoing in order to address the availability or data relevant to risk assessment, for instance through initiatives such as the OFDA/CRED International Disaster Database EM-DAT[97] and JRC's Risk Data Hub[98].

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[96] The GFCE-MERIDIAN Good Practice Guide on Critical Information Infrastructure Protection for governmental policy-makers, Luiijf E. (Ed.), 2017. Available at: https://www.thegfce.com/documents/reports/2017/10/22/the-gfce-meridian-good-practice-guide-on-critical-information-infrastructure-protection-for-governmental-policy-makers.

[97] This resource provides disaster information for an extensive and increasing number of disasters. In particular, "the main objective of the database is to serve the purposes of humanitarian action at national and international levels. The initiative aims to rationalise decision making for disaster preparedness, as well as provide an objective base for vulnerability assessment and priority setting". URL: https://www.emdat.be/.

[98] This platform *"adopts the comprehensive framework of policies and guidelines, data sharing initiatives and spatial data infrastructure with the purpose of setting the bases for knowledge for DRM at local, national, regional and EU-wide level"*. The platform also comes with a collection of good practices to the development of risk web-platforms and risk data. Data are available at different levels of aggregation, while country corners allow MS to manage their own risk assessment, covering both the prevention and preparedness assessment and the response and recovery assessment. URL: https://drmkc.jrc.ec.europa.eu/risk-data-hub.

Risk analysis data requirements vary depending on the situation and the tasks to be completed, spanning from prevention measures to real-time status assessment and decision making just after a critical event has hit a region. Different information sources may complement each other in order to address the various situations more comprehensively (e.g. institutional information, crowd-sourced crisis information).

Moreover, best practices in the area of risk data management are also developed in the private sector. Often, these also manifest a need for smoother interaction with regulatory bodies and partnering entities. Indeed, guidelines for the creation of sound infrastructure risk data and management methods can be found in the experience of CI operators. For example, four aspects are identified in [99] for achieving effective risk data infrastructures in the financial sector:

- efficiency, which may be affected by siloed and incompatible data, while suffering from the more time is spent on data management than on risk treatment;
- flexibility, needed in order to provide quick response with limited manual work, when non-standard scenario analysis and reports are needed, or when regulators request information;
- quality, which can be compromised by incompatible definitions, inconsistency, incompleteness, and duplication;
- ownership, which expresses the need for risk governance, accountability and commitment to quality, especially when data are collected by multiple stakeholders.

Finally, observe that concerns have also been raised about the public availability of CI data, which in some cases might represent a threat in itself[100].

13.3.2 Risk Identification

The purpose of this stage is to identify and describe the risks that may or are expected to affect a CI or a CI sector. Sources for the selection of scenarios of interest include:

- events that may affect the functionality of the CI;
- vulnerabilities of the CI (e.g. its age or location);
- indicators of emerging risks;
- intelligence information for man-made threats;
- time-related factors, etc.

An all-hazards approach to risk management does not mean that all hazards will be assessed, evaluated and treated, rather that all hazards will be considered. When analysts are developing scenarios to identify potential risks for an assessment, these should be selected in such a way as to cover the full scope of the assessment.

It is important to observe that service loss for a CI can result from:

- causes inherent to the infrastructure (e.g. technical failures, accidents, aging),
- external causes (hazards, man-made threats), or
- the service loss of another infrastructure.

In some cases, relevant scenarios can be driven not only by service loss but also by increased demand for service provision, as in the case of an emergency.

[99] KPMG, Rebuilding and reinforcing risk data infrastructure. An extract from KPMG's Frontiers in Finance. April 2014. Available at: http://kpmg.com/frontiersinfinance.

[100] Abbas, R, The Threat of Public Data Availability on Critical Infrastructure Protection (CIP), and the Level of Awareness Amongst Security Experts in Australia, Bachelor of Information and Communication Technology (Honours), University of Wollongong, 2006,129p.

13.3.3 Risk Analysis

At a minimum, risk analysis should determine:

- the likelihood of the threat or hazard; and
- the consequences of the threat or hazard, taking into account the disruption of critical services and products.

For CIs, risk often includes the frequency of service loss and the resulting consequences for the concerned people[101]. Important factors to consider include complexity (CI interdependency), time-related factors and the effectiveness of existing controls. By definition, CIs provide essential services to the public, and their disruption is associated with significant consequences. The emphasis of an assessment is often placed more on the consequences when CIs fail to some degree, with a lack for precise definitions about the cause and the associated probabilities. Regardless of the initiating factor, CI operators often mostly focus, for their planning or training, on the consequences of service loss. This allows them to plan and exercise against disruptions of unknown probability and to focus more on the effects to the service provision.

When assessing the consequences of CI loss or failure, one should not only consider economic aspects such as the reconstruction costs or the expenses for building or system recovery, but also the effects of service inoperability on the population or a country. For example, FP7 project Casceff considers various types of consequences from infrastructure failures[102]. In particular,

- technical consequences encompass the damage and loss of technical components and physical assets, loss of production etc.;
- organizational consequences relate to the organisations and institutions that manage the systems (CI owners or operators), encompassing impacts on organisational capacity, coordination, and information management, etc.;
- social consequences encompass impacts on the community, such as political instability and civil unrest;
- human consequences are about impacts on population such as health-issues, reduced well-being, casualties and injuries;
- economic consequences encompass impacts in terms of direct costs;
- environmental consequences relate to the effects on natural resources, flora and fauna.

Secondly, as we mentioned above, CIs can be affected by a hazard. As an example of direct effects caused by a flood scenario, FP7 project CIPRNet considers and identifies the following possible disruptions[103]:

- transport disruptions due to flood-related accidents (derailment, collision of road vehicles;
- collision of maritime vehicles, structural elements collapse or overflow, e.g. tunnels, bridges, airports etc.;
- transport disruptions due to large-scale evacuation of civilian causing traffic congestion;
- disruptions of water supply or contamination of drinking water or other health hazards;

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[101] E. Zio, Challenges in the vulnerability and risk analysis of critical infrastructures, *Reliability Engineering and System Safety* 152 (2016) 137–150.

[102] http://casceff.eu/media2/2016/02/D2.1-Deliverable_Final_Ver2_PU.pdf.

[103] Y. Barbarin, M. Theocharidou, and E. Rome, "CIPRNet deliverable D6.2: Application scenario," CEA, JRC, Fraunhofer IAIS, Tech. Rep., May 2014. [Online]. Available at: https://www.ciprnet.eu/.

- hazardous substances (CBRN) incidents due to structural damages/flooding on facilities;
- hazardous substances (CBRN) incidents due to accidents to transporting vehicles;
- collapse of sewage systems;
- electrical power supply disruptions;
- telecommunications disruptions;
- medical care facilities disruptions, due to power shortage, flooding, increased number of patients or inability of the personnel or supplies to reach the location;
- industrial or business disruptions, due to power or communication disruptions.

Here observe that a flood can cause multiple damages to CIs of various sectors (e.g. transport, ICT, energy), beyond the direct consequences to the population. These may refer to damages to a specific building or infrastructure element, and they are calculated based on exposure of the element to the hazard and its vulnerability level. While the list is not exhaustive and these disruptions are unlikely to happen all simultaneously, they highlight the complexity of mapping the direct and indirect effects of a scenario to national CIs. An additional parameter to consider is whether the disruptions described above can hinder the emergency response capabilities. For example, the disruption of transportation nodes can delay assistance in reaching affected areas, and potentially amplify the consequences to the population.

Calculating the overall societal impact of a scenario is a difficult process, especially in cases when parallel disruptions take place or double counting of losses is difficult to avoid, likely leading to poor quality impact estimations. The case of previous incidents may allow for more realistic assessments, but this is not always the case when examining unknown or rare events.

As a third point, cascading effects between infrastructures need to be considered[104]. The impact of a disruption, or failure, may spread both geographically and across multiple sectors. The 2017 World Economic Forum's Global Risks Report[105] observes that *"greater interdependence among different infrastructure networks is increasing the scope for systemic failures – whether from cyberattacks, software glitches, natural disasters or other causes – to cascade across networks and affect society in unanticipated ways"*. This observation highlights a key parameter with respect to CIs that should be considered when performing a NRA.

Identifying dependencies is, therefore, an important task[106]. While various classifications of dependencies can be found in the literature[107], such as physical, geographical, cyber, social, etc., a more recent empirical study[108], shows that events can be classified as cascade-initiating (i.e., an event that causes an event in another CI), cascade-resulting (i.e., an event that results from an event in another CI), and independent (i.e., an event that is neither a cascade-initiating nor a cascade-resulting event). The empirical findings indicate that:

[104] L. Franchina, M. Carbonelli, L. Gratta, M. Crisci and D. Perucchini, An impact-based approach for the analysis of cascading effects in critical infrastructures, International Journal of Critical Infrastructures, vol. 7(1), pp. 73–90, 2011.

[105] https://www.weforum.org/reports/the-global-risks-report-2017

106 Setola, R., Theocharidou, M. (2016). Modelling Dependencies Between Critical Infrastructures. In: R. Setola et al. (eds.), Managing the Complexity of Critical Infrastructures, Studies in Systems, Decision and Control 90, DOI 10.1007/978-3-319-51043-9_2.

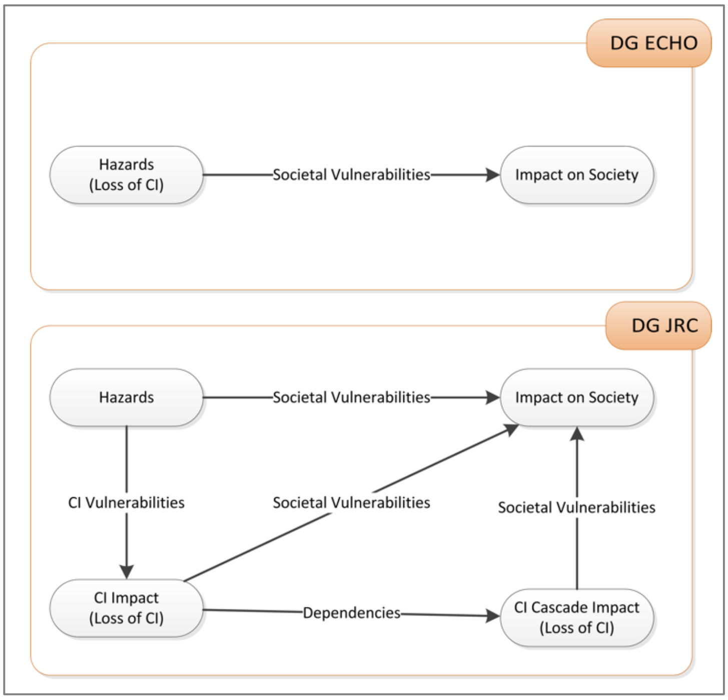
107 Rinaldi SM, Peerenboom JP, Kelly TK (2001) Critical infrastructure interdependencies. IEEE Control Syst Mag, 11–25.
De Porcellinis S, Panzieri S, Setola R (2009) Modelling critical infrastructure via a mixed holistic reductionistic approach. Int J Crit Infrastruct 5(1–2):86–99.

[108] Van Eeten M, Nieuwenhuijs A, Luiijf E, Klaver M, Cruz E (2011) The state and the threat of cascading failure across critical infrastructures: the implications of empirical evidence from media incident reports. Public Adm 89(2):381–400.

- cascade-resulting events are more frequent than generally believed, and that cascade initiators are about half as frequent;
- dependencies are more focused and directional than often thought;
- energy and telecommunications are very frequent cascading initiating sectors.

A JRC report observed the lack of CI dependency modelling and analysis in most NRAs[109]. This is also highlighted by[110], which includes *"dependencies and interdependences identification and modelling"* and *"dynamic analysis (including cascading failures)"* as two of the steps required in CI vulnerability and risk analysis (*"hazards and threats identification"* and *"physical and logical structure identification"* are also part of the approach). If MSs select to perform a risk assessment method that considers both dependencies among CIs and the direct or indirect consequences of hazards, then the method for analysing a risk scenario needs to include more steps and iterations, as illustrated in **Figure 25**.

Figure 25. *Risk Assessment for CI Loss.*



Source: Theocharidou and Giannopoulos, 2015 [111].

Such an approach would allow to establish closer links between Disaster Management or Civil Protection and Critical Infrastructure Protection within a MS or across MSs, when examining hazards of cross-border scale.

13.3.4 Risk Evaluation

The purpose of risk evaluation is to support decisions. In general, the output of this step includes a prioritized list of risks, information gaps, and lessons learned. The outcome of

[109] Theocharidou M, Giannopoulos G, Risk assessment methodologies for critical infrastructure protection. Part II: A new approach, EUR 27332 EN, 2015. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC96623/lbna27332enn.pdf.

[110] Zio, Enrico. (2016). Challenges in the vulnerability and risk analysis of critical infrastructures. Reliability Engineering & System Safety. 152. 137-150. 10.1016/j.ress.2016.02.009.

[111] Theocharidou M, Giannopoulos G, Risk assessment methodologies for critical infrastructure protection. Part II: A new approach, EUR 27332 EN, 2015. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC96623/lbna27332enn.pdf.

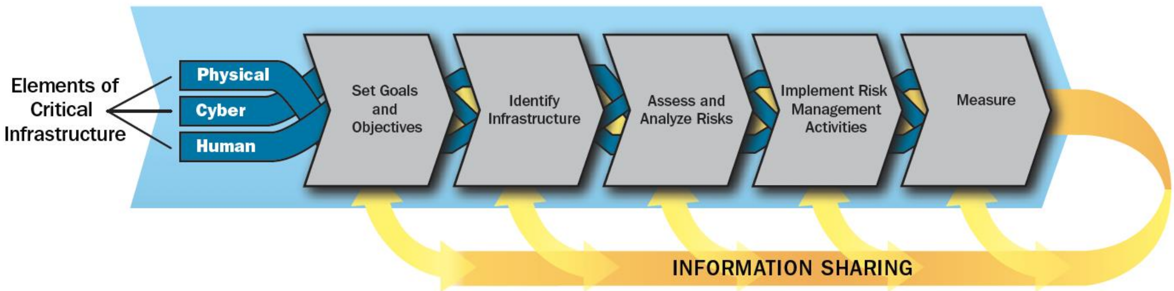
risk evaluation should be recorded, communicated and then validated by the decision-makers. In the case of CIs, this step allows to focus on critical assets or services, and amend plans for their protection and resilience. It is the basis to create a plan with short-term and long-term actions that need to be taken to mitigate risk. It can also be the input for national funding or the trigger for a new regulation.

See also reference[112] for a comparative analysis of risk assessment methods for CIs, with an emphasis on security. Therein, the authors discuss both institutional risk assessment standards (NIST risk assessment framework SP800-30/30rev1, ISO/IEC 27 005:2008 and BS-7799-2006) and enterprise models (OCTAVE, Fair, Microsoft).

13.4 Frameworks, methodologies and tools

In the previous section, referring to the ISO 31000:2018 standard's risk assessment framework, we discussed some key elements that contextualize this process to CI risk assessment. Similar aspects can be traced in other risk management frameworks, including those specifically devoted to CIs. For instance, in **Figure 26** we report a representation of the NIPP's Critical Infrastructure Risk Management Framework.

Figure 26. *NIPP's Critical Infrastructure Risk Management Framework*



Source: US Department of Homeland Security, 2013 [113]

In many of the merging contributions about CI risk management, there is an attempt to cope with the diversity of perspectives and to offer support all along the failure/recovery processes, through a circular process striving for improved response to risk. In this sense, as mentioned above in this chapter, emerging policies, methodologies and studies in the CI domain stress the importance of the overall risk management process and the aspect of resilience[114].

Therefore, in the rest of this section, we discuss methodologies, frameworks and tools significant to risk management and resilience enhancement processes for CIs[115]. It has to be observed that some of the tools in place are not limited to the risk assessment step, but instead reach the full extent of the risk management process.

[112] Tweneboah-Koduah, Samuel, and William J. Buchanan. "Security Risk Assessment of Critical Infrastructure Systems: A Comparative Study." The Computer Journal (2018).

[113] NIPP 2013 Supplemental Tool: Executing A Critical Infrastructure Risk Management Approach, US Department of Homeland Security, 2013.

[114] See also the Resource Guide on Resilience (available at https://irgc.org/risk-governance/resilience) by the International Risk Governance Council, whose first volume has been issued in 2016 and whose second volume is in preparation. This is *"an edited collection of authored pieces comparing, contrasting and integrating risk and resilience with an emphasis on ways to measure resilience"*, and it contains various resources relevant to the case of CIs.

[115] See also https://www.dhs.gov/critical-infrastructure-resources for a list of further CI resources.

13.4.1 Frameworks

A number of frameworks are in place to tackle the broader risk management process and, to some extent, resilience enhancement. Many of the existing methodologies emphasize the convergence of competences, the cyclic nature of assessment and the implementation of multistep evaluation procedures. In a number of cases, the scope of such frameworks also includes the provision of practical guidance, to support the formulation and actuation of risk and resilience assessment initiatives relative to either specific CIs or the same in a broader context, such as at regional levels.

While an exhaustive review of the existing frameworks is out of the scope of this chapter, next we describe some instances of recent proposals in this domain. Our examples are partly drawn from ongoing research projects and partly from institutional initiatives.

National Infrastructure Protection Plan (NIPP) 2013: Partnering for Critical Infrastructure Security and Resilience

The 2013 NIPP[116] *"elevates security and resilience as the primary aim of critical infrastructure homeland security planning efforts"*. It *"focuses on establishing a process to set critical infrastructure national priorities determined jointly by the public and private sectors"*. In formulating the framework, reference is made to the DHS Risk Lexicon – 2010 Edition[117]. Additional documents that aim at facilitating the implementation of the plan are:

- supplement *"Executing a Critical Infrastructure Risk Management Approach"*, which offers practical guidance towards the construction of CI risk management approaches comprising the following activities: set goals and objectives; identify infrastructure (including the cyberinfrastructure); assess and analyse risks (through documented, reproducible and defensible assessments); implement risk management activities; measure effectiveness (also towards continuous improvement);
- supplement *"Critical Infrastructure Threat Information Sharing Framework: A Reference Guide for the Critical Infrastructure Community"*, which outlines a *"multidirectional, decentralized network of formal and informal channels through which government entities and the private sector share information"*.

An important aspect of NIPP 2013 is the collaborative dimension of CI security and resilience, which calls for a *"partnership-based collective action"*. As such, it involves the delivery of training courses and other initiatives, such the security and resilience challenges issued to foster the cohesion and the capabilities of the CI community[118].

NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems

The guide[119] has been created with the objective *"to help communities address these challenges through a practical approach that takes into account community social goals and their dependencies on the 'built environment' – buildings and infrastructure systems"*. The proposed six-step process to planning for community resilience comprises the following aspects: form a collaborative planning team; understand the situation; determine goal and objectives; plan development; plan preparation, review, and approval; plan implementation and maintenance.

The planning guide is organized into two volumes, wherein the first volume addresses the steps of the process in details and including practical examples, while the second volume contains support information and deals with the social dimension of resilience, as well as the aspect of buildings/CI interdependencies.

[116] https://www.dhs.gov/publication/nipp-2013-partnering-critical-infrastructure-security-and-resilience
[117] http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf
[118] https://www.dhs.gov/nipp-challenge
[119] https://www.nist.gov/topics/community-resilience

NIST Framework for Improving Critical Infrastructure Cybersecurity

The Cybersecurity Framework[120] (v.1.1, April 2018) *"focuses on using business drivers to guide cybersecurity activities and considering cybersecurity risks as part of the organization's risk management processes"*. A joint related document is the NIST Roadmap for Improving Critical Infrastructure Cybersecurity.

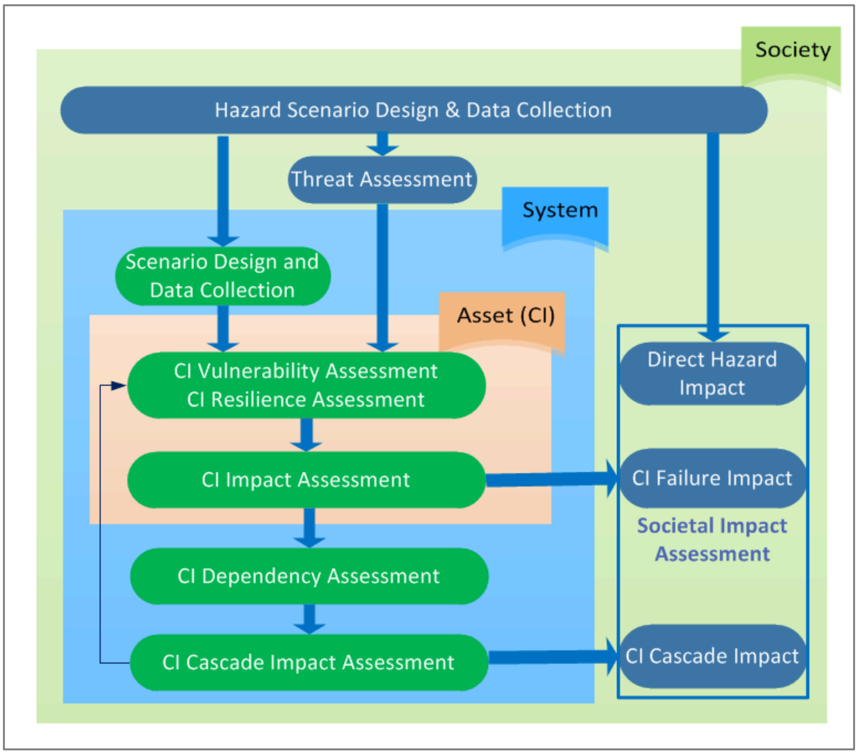
Based on the NIPP Risk Management Framework and the NIST Framework for Improving Critical Infrastructure Cybersecurity, Department of Homeland Security (DHS) risk assessments have been issued[121] for the assessment of threat-vulnerability-consequence triads relative to selected CI sectors. These operations see the involvement of multiple DHS offices and take into account sector-specific regulatory environments.

JRC's CRitical Infrastructures & Systems Risk and Resilience Assessment Methodology (CRISRRAM)

The CRISRRAM methodology developed at the JRC[122] proposes a generic approach that could be applied by MSs for their NRA scenarios. As illustrated in **Figure 27**, it involves the asset, system and society levels and it designs a multistep, cyclic assessment procedure leading to the evaluation of impacts of various nature.

The first step is to define a hazard scenario that may directly have an impact on the society (e.g. flooding, earthquake) but, at the same time, may impact a CI (Society Layer). As described in the NRA guidelines, risk is calculated according to a risk matrix, based on threat likelihood and (societal) impact assessment. However, this approach also considers impacts due to the failure of a CI or other dependent ones (cascade impact). These are assessed based on the direct impact of the threat on a CI (Asset Layer) or due to the indirect impact of the hazard to other CIs (System Layer).

Figure 27. *Critical Infrastructures & Systems Risk and Resilience Assessment Methodology.*



120 https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.04162018.pdf

121 https://www.gao.gov/assets/690/688028.pdf

122 Theocharidou M, Giannopoulos G, Risk assessment methodologies for critical infrastructure protection. Part II: A new approach, EUR 27332 EN, 2015.

Source: based on Theocharidou and Giannopoulos, 2015 [123]

Direct impact on one or more directly affected CI (Asset Layer), can be calculated on the basis of historical data, the results of vulnerability assessment of the CI or the presence of resilience mechanisms, in collaboration with CI operators or owners. This is usually assessed in terms of inoperability level or economic loss per asset. This direct effect to each CI – i.e. service degradation, disruption or failure – is related to an impact at the societal level. If this is not the case, then this infrastructure should not be considered as a CI at first hand. This approach to assessment links asset level disruptions with societal impact. In the System Layer, dependency assessment is introduced in the risk assessment framework. Identifying and assessing dependencies can allow a MS to take into account the additional impact from the cascading failure relative to other CI/sectors. However, one limitation to consider is the presence of cyclic dependencies among infrastructures, which may lead to a limited-quality estimation of impacts at the societal level.

IMPROVER project's Critical Infrastructure Resilience Framework (ICI-REF)

H2020 project IMPROVER (*"Improved risk evaluation and implementation of resilience concepts to Critical Infrastructure"*) considers the relationship between a CI risk analysis and a CI resilience analysis and tries to link the two aspects, proposing an approach that could also inform NRAs[124]. This framework, ICI-REF, aims at addressing *"the integrated process of risk and resilience management"*[125]. In particular, it maps resilience management to the risk management process from ISO 31000:2018 discussed above in this chapter. See **Figure 28** for an illustration.

Establishing the context is the first stage in both risk and resilience management, and this includes the identification of best practices as well as national or sector-specific legislations and methods of interest. It also comprises the identification of any nationally identified hazards which may be relevant for the considered infrastructure. While establishing the context, it is also needed to identify the evaluation criteria to be applied. These could be based, for instance, on land use planning curves in the case of risk evaluation. For resilience evaluation, assessment criteria might be based on societal tolerances, past performance, or minimum quality/quantity of service for a community to survive. Establishing the context acts as input to both the risk assessment process and the resilience assessment process, regardless of whether these processes are undertaken independently of one another or not. Risk identification only needs to be done as part of the risk assessment process, as some resilience assessment methodologies are independent of hazards and, thus, the risk assessment phase does not actually contribute here.

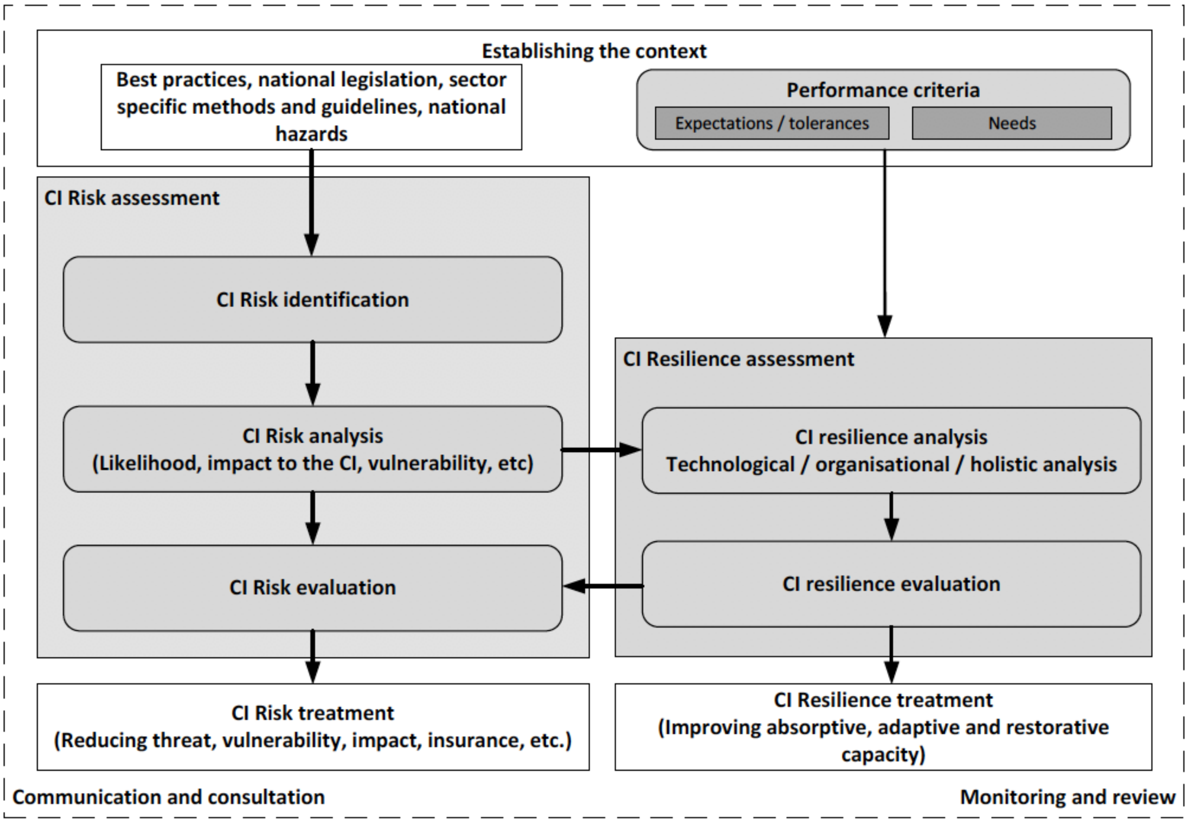
Typically, a risk evaluation would determine whether or not the assessed risk is below an acceptable threshold or if remedial action is necessary. While risk assessment has a focus on the consequences of an incident, resilience goes beyond, to include the recovery phase. Resilience evaluation, therefore, can be used to enrich the risk evaluation process. Risk treatment and resilience treatment are independent processes achieving different objectives. In the case of risk treatment, the objective is the reduction of threat, vulnerability, impact and, indeed, it can affect associated costs such as insurance premiums. In the case of resilience treatment, the objective is to improve the absorptive, adaptive or restorative capacity of the infrastructure. The implementation of this framework can be done by selecting appropriate tools or methodologies for the different stages.

[123] Theocharidou M, Giannopoulos G, Risk assessment methodologies for critical infrastructure protection. Part II: A new approach, EUR 27332 EN, 2015.

[124] Lange, D. et al. (2017b). Incorporation of resilience assessment in Critical Infrastructure risk assessment frameworks, In: Safety and Reliability – Theory and Applications, ISBN 978-1-138-62937-0, p. 1031-1038.

[125] Lange et al. IMPROVER Deliverable 5.1 Framework for implementation of resilience concepts to Critical Infrastructure, 2017. Available at: www.improverproject.eu.

Figure 28. *ICI-REF: integration of resilience management in risk management*



Source: Lange et al, 2017 [126]

13.4.2 Methodologies

A number of risk assessment methodologies relevant to CIs have been thoroughly reviewed in [127]. Moreover, a recent classification was proposed in[128], where the following aspects were taken into consideration:

- purpose: risk identification, risk assessment, risk prioritization, risk mitigation planning, and effectiveness evaluation (following the phases of the NIPP framework);
- technical modelling approach: empirical approaches, system dynamics based approaches, agent based approaches, network based approaches, and other approaches[129].

[126] Lange et al. IMPROVER Deliverable 5.1 Framework for implementation of resilience concepts to Critical Infrastructure, 2017. Available at: www.improverproject.eu.

[127] Giannopoulos G., Filippini R., Schimmer M., "Risk assessment methodologies for critical infrastructure protection. part I: A state of the art," European Commission, Tech. Rep. EUR 25286, 2012.

[128] Stergiopoulos G., Vasilellis E., Lykou G., Kotzanikolaou P. and Gritzalis D. Classification and Comparison of Critical Infrastructure Protection Tools. M. Rice and S. Shenoi (Eds.): Critical Infrastructure Protection X, IFIP AICT 485, pp. 239–255, 2016. doi: 10.1007/978-3-319-48737-3 14

[129] This is based on a classification by:
Ouyang, M.: Review on modeling and simulation of interdependent critical infrastructure systems, Reliability Engineering and System Safety, vol. 121, pp. 43–60 (2014).
Empirical approaches analyse interdependencies *"according to historical accident or disaster data and expert experience"*; system dynamics approaches *"take a top-down method to manage and analyse complex adaptive systems involving interdependencies"*; agent-based

We will now briefly make reference to some key methodologies addressing the various areas of the risk and resilience management process. The presentation is articulated in accordance with the stages of the CRISRRAM framework discussed above; see also [130] for further details and references about many of the mentioned projects and methodologies.

Scenario Design and Data Collection

We observe that only a limited number of existing methods and tools focus on designing scenarios. One such example is the Risk and Vulnerability analysis (RVA) by DEMA[131], which dedicates a specific step to scenario design. Most methods usually address particular, predefined threat scenarios or apply the same methodology for selected case scenarios. Only in limited cases threat likelihood assessment is included (e.g. COUNTERACT, DECRIS, EURACOM, BMI, CIPDSS, etc.). A scenario-based approach to NRA was both recommended by DG-ECHO and applied by several MSs. It is also supported by the DHS guidelines for National CI Risk Management[132]. A clever definition of scenarios is considered a means to tackle the complexity of the problem; a key objective is to *"divide the identified risks into separate pieces that can be assessed and analysed individually"*. The use of such scenarios should identify which infrastructures are more critical (potential consequences would be highest) and also where security and resilience activities should be focused more[133].

CI Vulnerability assessment

Regarding vulnerability assessment, the BIRR method introduces the concept of Vulnerability Index (VI) and Protective Measures Index (PMI), CARVER assesses the accessibility to a physical location, COUNTERACT evaluates the safeguards in place for the corresponding risks for the various assets, DECRIS uses a vulnerability analysis step to identify which threats should be examined further, and RVA follows a qualitative five-levels scale for vulnerability assessment. The Sandia Risk Assessment Methodology takes into account the protection system effectiveness, expressed in terms of its ability to reduce the threat success probabilities.

CI Resilience Assessment

In terms of CI resilience assessment[134], BIRR introduces a Resilience Index (RI) to provide an evaluation of how resilient an asset is, based on Robustness, Resourcefulness and Recovery mechanisms. CARVER2 similarly considers the presence of redundancy mechanisms, even if resilience is not explicitly mentioned. RAMCAP-Plus includes a Risk and Resilience Management step, highlighting how central this aspect is in the methodology.

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approaches *"adopt a bottom-up method and assume the complex behaviour or phenomenon emerge from many individual and relatively simple interactions of autonomous agents"*; network based approaches *"describe the interdependencies by interlinks"*, with the associated possibility to portray connectivity and flows. Finally, the other approaches mentioned in (Stergiopoulos et al., 2016) summon a number of additional techniques, including economic interdependency models and various other methods.

[130] Giannopoulos G., Filippini R., Schimmer M., "Risk assessment methodologies for critical infrastructure protection. part I: A state of the art," European Commission, Tech. Rep. EUR 25286, 2012.

[131] http://brs.dk/eng/inspection/contingency_planning/rva/Pages/vulnerability_analysis_model.aspx

[132] "Supplemental tool: Executing a critical infrastructure risk management approach," U.S. Department of Homeland Security, Tech. Rep., 2013. [Online]. Available at: http://www.dhs.gov/sites/default/files/publications/NIPP-2013-Supplement-Executing-a-CI-Risk-Mgmt-Approach-508.pdf.

[133] Haimes YY, Jiang P (2001) Leontief-based model of risk in complex interconnected infrastructures. J Infrastruct Syst 1–12.

[134] G. Giannopoulos, R. Filippini, and M. Schimmer, "Risk assessment methodologies for critical infrastructure protection. part i: A state of the art," European Commission, Tech. Rep. EUR 25286, 2012.

CI Consequence Assessment/CI dependency assessment

Interdependencies are covered by most methods being proposed, as this is a key feature for CIs. At the same time, the techniques involved and the level of detail varies significantly from case to case. Indirect consequences needing to be assessed include the social and economic costs inflicted to the society by the unavailability (or scarce availability) of essential services. One way to assess consequences is based on Service Availability Wealth (SAW) Indexes, which are implemented in CIPRNet's Decision Support System[135]. These indexes refer to perceived societal consequences expressed in terms of *"reduction of wealth"* in various societal domains: citizens, availability of primary services, economic sectors and the environment. SAW indexes indicate the relevance of a specific service supplied by a CI to a given societal domain. The consequences estimation enables to weigh the different disaster scenarios and to compare their severity[136]. An improvement to the model also takes into consideration the mobility of people, to allow for a more dynamic and accurate assessment of consequences[137].

Another approach used to assess spreading consequences is through the application of input-output inoperability models (IIMs). These are based on the input-output approach proposed by Wassily Leontief, which is regarded as a key tool for the quantitative representation of interdependencies between different sectors within an economy. Input-output models are also supported by a number of publicly available economic datasets that portray dependencies between different economic sectors at regional, national and international levels. In IIMs, the concept of inoperability refers to the inability of a sector to perform its prescribed functions, and it can be caused by internal failures as well as external perturbations affecting the delivery of a system's intended output. IIMs have been applied to quantify the economic losses triggered by terrorism and other disruptive events to economic systems (or industry sectors). In recent years, extensions have been proposed in order to dynamically assess resilience to critical events, such as a disruption affecting some sectors and propagating through the economy depending on mutual dependencies, the centrality of the trigger points, and the response capabilities to the overall economy. In this context, a key factor towards the mitigation of monetary losses is represented by preparedness, which can be fostered by factors such as the availability of inventories able to ensure business continuity despite the temporary unavailability of some upstream services. In this perspective, IIMs can support the choice and prioritization of actions devoted to enhancing operability levels during and after crises.

[135] Di Pietro A., Lavalle L., La Porta L., Pollino M., Tofani A., Rosato V. (2016) Design of DSS for Supporting Preparedness to and Management of Anomalous Situations in Complex Scenarios. In: Setola R., Rosato V., Kyriakides E., Rome E. (eds) Managing the Complexity of Critical Infrastructures. Studies in Systems, Decision and Control, vol 90. Springer.

[136] This *"reduction or loss of well-being"* indicator is composed of four terms: (a) reduction of well-being of the most vulnerable population (categories concern old, young, disabled people and others), (b) reduction of primary services that affect the wealth and the well-being of the population; (c) economic losses due to services outages; (d) direct and indirect environmental damages (if any) caused by the outages (release of pollutants in the environment etc.). The previous criteria are affected directly by the event, but also by the lack of primary technological and energy services on different territories, over different time frames. The consequences of the scenario on each criterion are calculated on the basis of: (i) the quality of the considered services which contribute to wealth (electricity, telecommunication, gas, water and mobility), i.e. their level of availability during the event (this is a function of time), (ii) the relevance of each service to the achievement of the maximum level of the wealth quantity for a given aspect of the criteria, and (iii) the reduction of well being of people (for example the number of people affected, in a population segment, during a considered time period).

137 Grangeat A., Sina J., Rosato V., Bony A., Theocharidou M. (2017) Human Vulnerability Mapping Facing Critical Service Disruptions for Crisis Managers. In: Havarneanu G., Setola R., Nassopoulos H., Wolthusen S. (eds) Critical Information Infrastructures Security. CRITIS 2016. Lecture Notes in Computer Science, vol 10242. Springer.

13.4.3 Tools

Next, we provide some examples of tools that can offer support to risk assessment and resilience enhancement of CIs. The first three tools focus on this issue of dependency modelling, while the fourth one assists policy makers to define performance goals for infrastructures.

JRC's Geospatial Risk and Resilience Assessment platform (GRRASP)

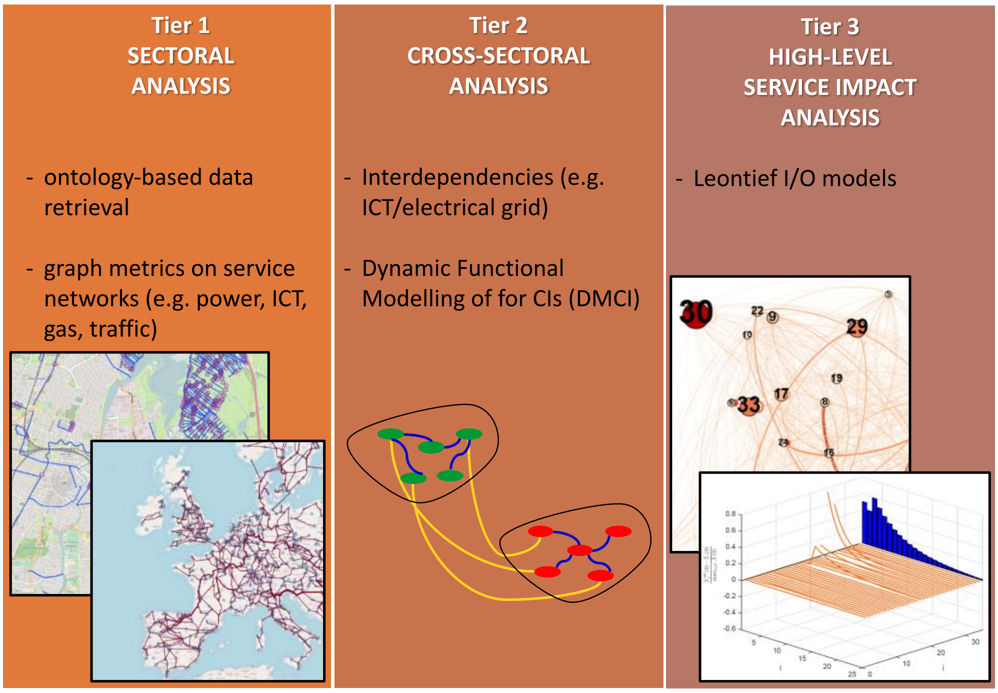
JRC has developed the Geospatial Risk and Resilience Assessment Platform (GRRASP)[138]. This is a World Wide Web-oriented architecture bringing together geospatial technologies and computational tools for the analysis and simulation of CIs. It allows information sharing and constitutes a basis for future developments in the direction of collaborative analysis and federated simulation. Moreover, it takes on board security concerns in the information sharing process, in terms of users, roles and groups. Based entirely on open source technologies, the system can also be deployed in separate servers and used by EU MSs as a means to facilitate the analysis of risk and resilience in CIs. Examples of GRRASP modules are reported next:

- Network metrics, a module to perform graph analysis on directed/undirected networks, with a focus on CIs;
- DMCI (Dynamic Functional Modelling of Vulnerability and Interoperability of Critical Infrastructures), a module to perform time analysis of service loss of interdependent CIs against critical events;
- CINOPSYS, a module to analyse economic losses during critical events according to an inventory dynamic input-output inoperability model.

See **Figure 29** for a representation of the tiered approach to analysis implemented in GRRASP.

[138] https://ec.europa.eu/jrc/en/grrasp

Figure 29. *Tiered approach to analysis of CIS in GRRASP.*



Source: Thocharidou et al, 2018 [139]

<u>Anytown tools</u>

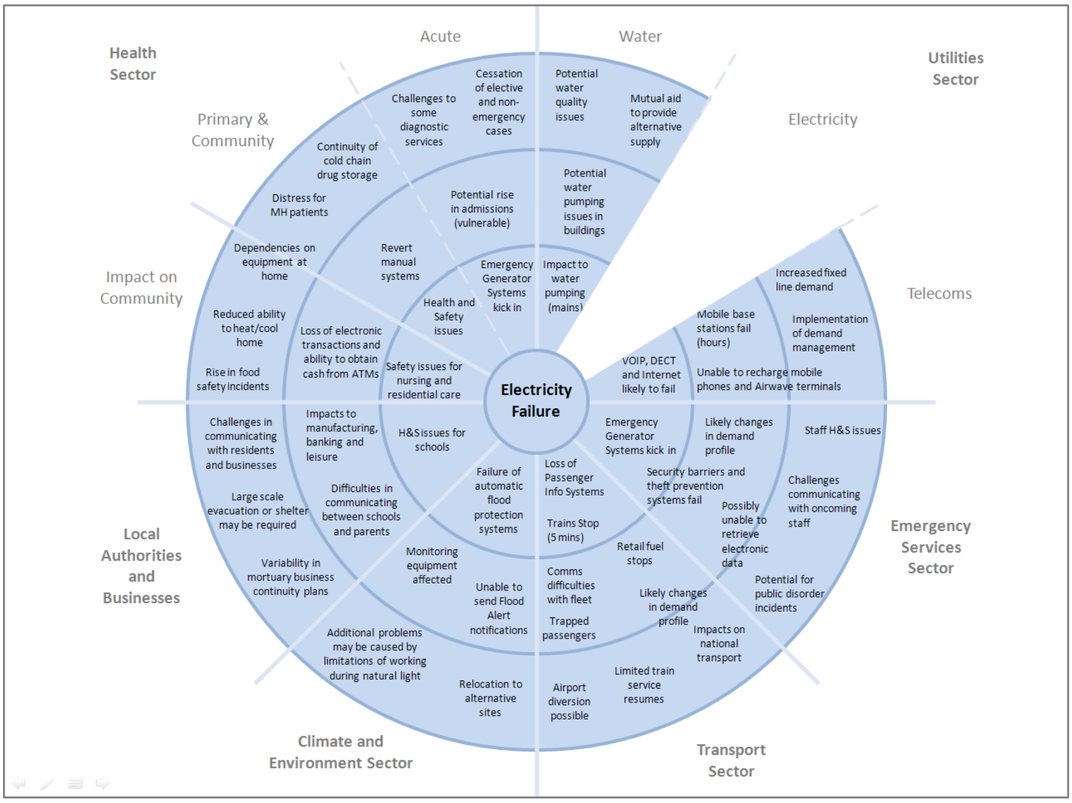
Tools of interest in order to assist users (e.g. at the city level) to map their dependencies have been developed in Anytown, an initiative by the London Resilience team[140]. These tools include mind maps and onion-skin diagrams mapping the impacts of infrastructure disruptions for a variety of initial triggers[141]. **Figure 30**, for instance, refers to the case of electricity failure and its cascading effects on various sectors. In this representation, *"the concentric circles capture the ripple effect showing spreading consequences from an initiating incident"*, which can be considered *"a useful metaphor in describing chains of causation"*.

[139] Theocharidou M., Galbusera L., Giannopoulos G. Resilience of critical infrastructure systems: Policy, research projects and tools. In Linkov I., Trump B., Florin M.V. (Eds.) IRGC Resource Guide on Resilience (volume 2) Domains of Resilience for Complex Interconnected Systems in Transition, to appear, 2018.

[140] https://www.london.gov.uk/about-us/organisations-we-work/london-prepared/

[141] Hogan M., Anytown: Final Report, London Resilience Team, 2013. Available at: http://climatelondon.org/wp-content/uploads/2016/11/Anytown-Final-Report.pdf.

Figure 30. *Onion-skin diagram of Anytown relating to Electricity Failure.*



Source: Hogan, 2013 [142]

<u>CIrcle tool</u>

Another tool that supports CI operators in identifying cascading effects together with other stakeholders in workshop settings is the 'Critical infrastructures: relations and consequences for life and environment' (CIrcle) tool[143], developed by Deltares. It was designed to map CIs and facilities relevant for an area (e.g. a city) and then visually represent the dependencies of these infrastructures, especially in order to address critical events. A representation of dependency mapping can be seen in **Figure 31**, while an application of the tool to a case study can be found in [144] for a flood scenario relative to Cork, Ireland.

<u>NIST Planning Guide Performance Goal Tables</u>

Performance goal tables are provided as a complement to the above-mentioned NIST Community Resilience Planning Guide for Building and Infrastructure Systems[145]. In this framework, tables are provided for specific sectors (buildings, transportation, energy, water, wastewater, and communications) taking into account different building clusters (critical facilities, emergency housing, housing/neighbourhoods/businesses, and community recovery). Considering the possible diversity in hazard types and levels, affected area and disruption level, performance is evaluated in the short-, intermediate- and long-term. The specific results are then summarized in an overall performance goal table, as illustrated in **Figure 32**.

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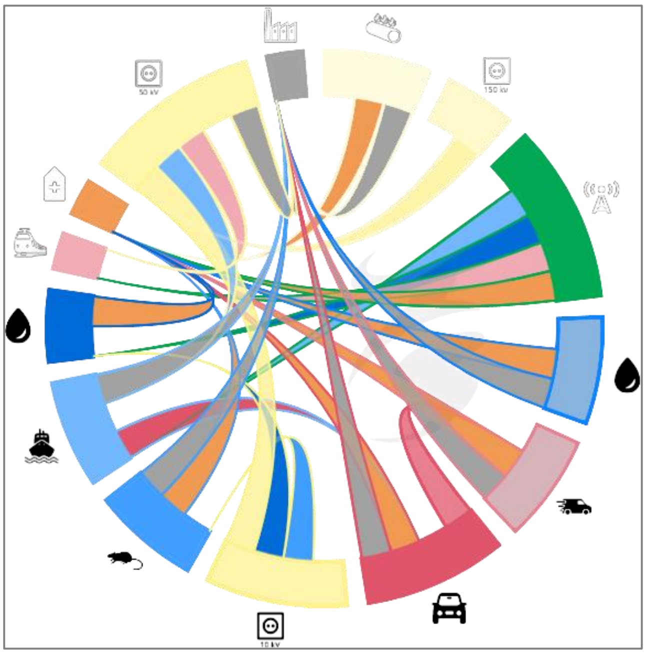
142 Hogan M., Anytown: Final Report, London Resilience Team, 2013. Available at: http://climatelondon.org/wp-content/uploads/2016/11/Anytown-Final-Report.pdf.

143 https://circle.deltares.org/

144 de Bruijn K. M., Cumiskey L., Ní Dhubhda R., Hounjet M. and Hynes W., Flood vulnerability of critical infrastructure in Cork, Ireland, E3S Web Conf., 7 (2016) 07005 doi:10.1051/e3sconf/20160707005.

145 https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1190GB-9.pdf

Figure 31. *CIrcle diagram of dependencies.*



Source: Deltares[146]

13.5 Risk Treatment

While this document focused mainly on risk assessment, the results of the assessment have limited value if they are do not form the basis for examining alternative risk treatment options.

IRGC's 2017 Risk Governance Framework[147] discusses the challenges related to dealing with complexity, uncertainty and ambiguity. These are aspects that also MSs face when performing NRAs. Four risk management strategies are then identified for simple, complex, uncertain, ambiguous risks. The following two decision-making strategies seem most relevant to MSs[148]:

— *"Complex risks should be dealt with by risk-based decision-making involving internal or external experts and relying on scientific models. Complex risks can be addressed by acting on the best available scientific expertise and knowledge, aiming for a risk-informed and robustness-focused strategy. […] Uncertain risks should be managed using precaution-based strategies to avoid exposure to a risk source with large uncertainties, and resilience-focused strategies to reduce the vulnerability of the risk-absorbing systems".*

— Practical examples of risk treatment options can be found in the London Risk Register[149], which lists the controls in place together with the risk assessment results.

[146] https://circle.deltares.org/

[147] IRGC. (2017). Introduction to the IRGC Risk Governance Framework, revised version. Lausanne: EPFL International Risk Governance Center.

[148] The framework also refers to ***Simple risks***, which can be managed using a routine-based strategy, such as introducing a law or regulation, or to ***ambiguous risks*** which require discourse-based decision-making, by involving all stakeholders in order to eventually reconcile conflicting views and values.

[149] London Risk Register, Version 7.0, February 2018. Available at: https://www.london.gov.uk/sites/default/files/london_risk_register_v7.pdf.

The US DHS offers a list of measures[150] on how to treat risk and increase resilience. The list is not exhaustive but offers some best practices and practical solutions for risk treatment. Here we list a selection of indicative examples from this guide:

- *"working with partners to develop a picture of how this infrastructure investment will fit into the regional landscape of critical infrastructure*";
- *"developing a comprehensive incident response plan that includes such components as scenario planning for the most likely risks and clearly articulated roles and responsibilities for all partners"*;
- *"building redundancy into an infrastructure system so it can handle a localized failure"*;
- *"budgeting for infrastructure mitigation during the development of a project to ensure the resilience of the infrastructure to threats and hazards*";
- *"developing a business continuity plan to ensure rapid recovery from disasters or other disruptions"*;
- *"planning to conduct periodic updates for the infrastructure asset that can incorporate new technologies and/or upgrades that could enhance mitigation"*;
- "determining whether environmental buffers (e.g., dunes or wetlands) can be incorporated into the infrastructure design to mitigate the effects of natural disasters";
- "ensuring there are manual overrides and physical backups built into automated systems".

150 https://www.dhs.gov/sites/default/files/publications/NIPP-2013-Supplement-Incorporating-Resilience-into-CI-Projects-508.pdf

Figure 32. *NIST Community Resilience Guide: performance goals summary table.*

Summary Performance Goal Table

Disturbance [1]	
Hazard Type	Any
Hazard Level	Routine, Design, Extreme
Affected Area	Localized, Community, Regional
Disruption Level	Usual, Moderate, Severe

Restoration Levels [2,3]	
30%	Function Restored
60%	Function Restored
90%	Function Restored
X	Anticipated Performance

Building Clusters	Design Hazard Performance								
	Phase 1: Short-Term			Phase 2: Intermediate			Phase 3: Long-Term		
	Days			Weeks			Months		
	0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Critical Facilities									
Buildings									
Transportation									
Energy									
Water									
Wastewater									
Communications									
Emergency Housing									
Buildings									
Transportation									
Energy									
Water									
Wastewater									
Communications									
Housing/Neighborhoods/Businesses									
Buildings									
Transportation									
Energy									
Water									
Wastewater									
Communications									
Community Recovery									
Buildings									
Transportation									
Energy									
Water									
Wastewater									
Communications									

Footnotes:

1 Specify hazard type being considered
Specify hazard level – Routine, Design, Extreme
Specify the anticipated size of the area affected – Local, Community, Regional
Specify anticipated severity of disruption – Minor, Moderate, Severe

2 30% / 60% / 90% Desired restoration times for percentage of elements within the cluster

3 x Anticipated performance for 90 % restoration of cluster for existing buildings and infrastructure systems
Cluster recovery times will be shown on the Summary Matrix

Source: NIST, 2018[151]

13.6 Gaps and Challenges

— The body of knowledge on CI risk and resilience management is quite rich and can be a valuable source for authorities and operators to explore. Enabling the operationalization of resources, models and tools still requires substantial efforts and this report is a contribution in this direction. A potential approach could include inventories of models, methods and tools provided by specialists. Work on the interoperability of models is also needed, especially in relation to current risk management practices. Moreover, as discussed, an issue is about the availability and quality of data needed for CI risk management.

— Another key challenge for regulators and governments is to encourage private industries to invest in risk reduction and resilience, especially within the current

[151] Available at: https://www.nist.gov/document/performancegoalstemplatexlsx.

economic conditions and considering the changing environment infrastructures operate in. Moreover, operators have varying technical, financial, political, reputational, legal priorities and constraints, which the policymakers need to comprehend when elaborating strategies for risk and resilience. To this end, stakeholder involvement and information sharing can be enhanced via the participation in networks. For example, Finland's National Emergency Supply Organisation (NESO) sectors and their respective pools provide an interesting example of voluntary collaboration between public sector and industry. These business-driven groups are responsible for operational preparedness in their fields. The pools are tasked with monitoring, analysing, planning, and preparing measures for the development of security of supply within their individual industries, as well as with determining which enterprises are critical to the security of supply. Similarly, Sector-Based Information Sharing and Analysis Centres can be a solution for exchange between stakeholders. In the United States, several sector-based Information Sharing and Analysis Centres (ISACs) assist federal and local governments with information pertaining to cyber threats. Australia's Trusted Information Sharing Network (TISN) is another example of a national engagement mechanism for business-government information sharing and resilience building initiatives. It provides a secure environment in which CI owners and operators across seven sector groups meet regularly to share information and cooperate within and across sectors, in order to address security and business continuity challenges. In the EU, examples of such networks are the European Reference Network on Critical Infrastructure Protection (ERNCIP)[152],[153] with its expert groups and its established series of CI Operators Workshops, or the Thematic Network on Critical Energy Infrastructure Protection (TNCEIP)[154], which is made up of European owners and operators of energy infrastructures in the electricity, gas and oil sectors. Both networks allow stakeholders to exchange information on threat assessment, risk management, cybersecurity, and other security-related topics, on a voluntary basis and within a trusted environment.

— Finally, an identified gap remains the need to perform joint exercises to better comprehend dependencies between CIs, thus generating more accurate risk assessments, and to jointly test risk treatment options. Such exercises need to be designed with a different mentality than civil protection exercises which focus mainly on the operational capabilities of emergency responders. Crisis scenarios that involve both public authorities and infrastructure operators are not widely analysed, but they can be a valuable tool to test risk and resilience strategies and plans, as well as to enhance collaboration.

[152] https://erncip-project.jrc.ec.europa.eu/

[153] Gattinesi P. (2018). European Reference Network for Critical Infrastructure Protection: ERNCIP Handbook 2018 edition, May 2018.

[154] https://ec.europa.eu/energy/en/topics/infrastructure/protection-critical-infrastructure

14 Chemical accidents

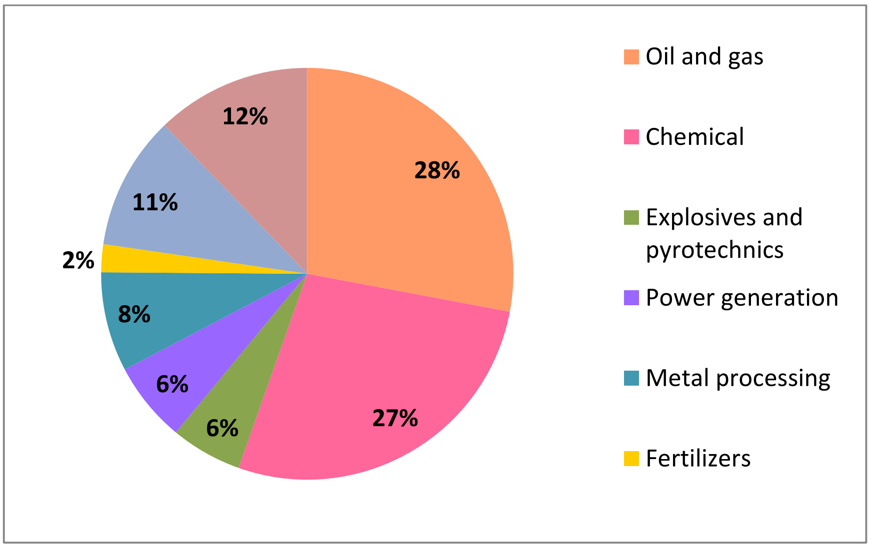
14.1 Overview of chemical accident risk

Chemical incidents are significantly different from natural hazards and even distinctly apart from other kinds of well-known technological disasters, notably in the nuclear industry and aviation. Unlike these technological disaster types, the term "chemical accident" is not associated with a specific industry. Rather, significant chemical accident risks are present in a wide variety of industries characterized by vast differences in the substances, processes, technology and equipment that create the risk. Chemical accident risk[155] consists of several components and therefore, understanding accident causality, i.e., why chemical accidents happen in the first place, is critical to effective risk management and finding dependable means to measure risk management performance.

Chemical accident risk is highly dependent on the activity of the site, the processes it operates and the types of dangerous substances it uses. There are hundreds of processes in oil and gas or chemicals processing industries alone. They may be present in land-based establishments (also known as "fixed facilities), pipelines, transport by rail, road and water, and offshore oil exploration platforms. Explosives industries, involving manufacture and/or storage of explosives, fireworks and other pyrotechnic articles, are also prominent sources of chemical accident risk. The high use of dangerous substances, such as cyanide and arsenic, in metals processing also has elevated the mining industry into the high risk category.

Figure 33 shows the distribution of the ~10,000 Seveso Directive sites (high hazard fixed facilities) in the European Union as reported by countries in 2014. In addition, numerous other industries that are not part of these hazardous chemicals industries also can be sources of chemical accident risk.

Figure 33. *Distribution of Seveso Directive sites (high hazard fixed facilities) in EU and EEA countries in 2014.*



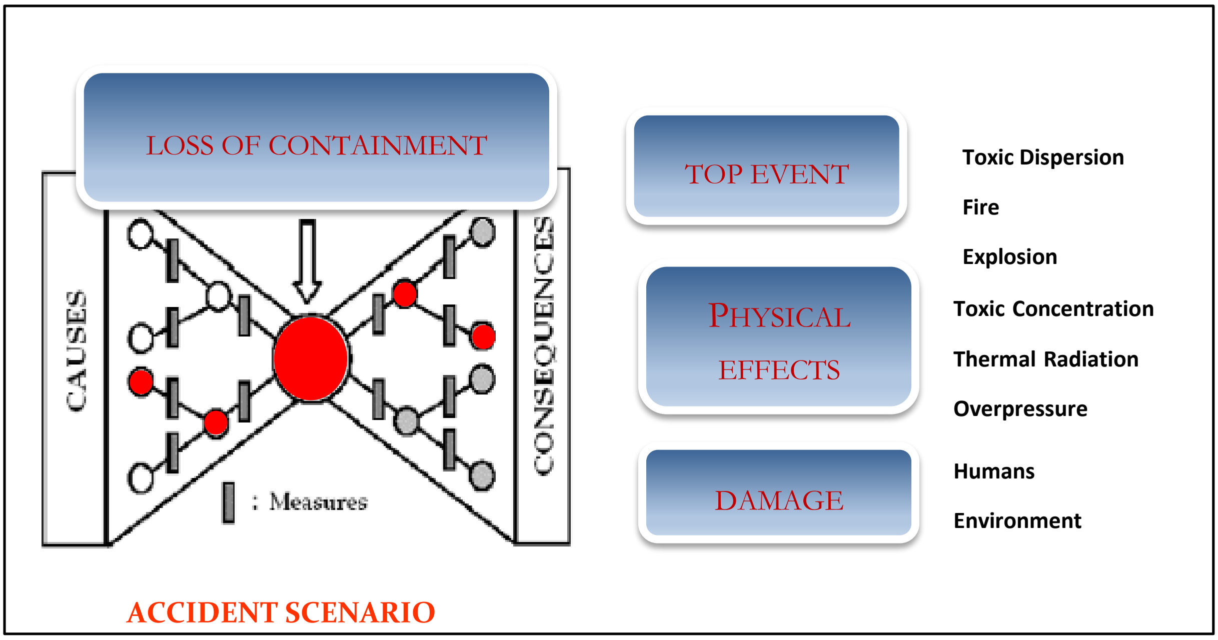
Source: EC-JRC eSPIRS database, 2018

[155] In this section, we will refer to chemical accident risk for the sake of simplicity, but the principles can equally applied to analysis and management of chemical incidents from intentional acts (e.g., sabotage, terrorism). While the causality may require different prevention and mitigation solutions, the potential consequences (fire, explosion or toxic release) are the same and the analysis of the scenario to make decisions about how to prevent, control or respond to it, is the same.

14.2 Prevention and mitigation of chemical releases

The bow tie diagramme is commonly used for illustrating the dynamics of a chemical accident and for focusing attention on prevention and mitigation opportunities. As noted in **Figure 34,** the Loss of Containment is the point that distinguishes between measures that are prevention (measures implemented before the loss of containment) and measures that are part of mitigation (measures taken after the loss of containment). That is, once the substance has escaped from its pipe or vessel, prevention measures have failed and mitigation measures must be launched to keep the event from turning into a dangerous phenomenon, that is, a fire, explosion or toxic release.

Figure 34. *Bow Tie Illustration of Chemical Accident Sequence of Events*



The main factors that directly contribute to chemical accident risk are usually defined as

- The dangerous substance(s) involved (flammable, toxic, or explosive and any combination thereof)
- Process and equipment, that is, their properties and conditions (e.g., pressure, temperature, reactions involved, pipes and vessel, safety controls, equipment age and mechanical condition, etc.)
- Safety management systems, including operations, hazard assessment, maintenance, inspections, resource planning, personnel selection and training, performance monitoring, and emergency preparedness
- The dangerous phenomena produced (fire, explosion, toxic release) as a result of substances, involved, process, equipment and various site conditions.

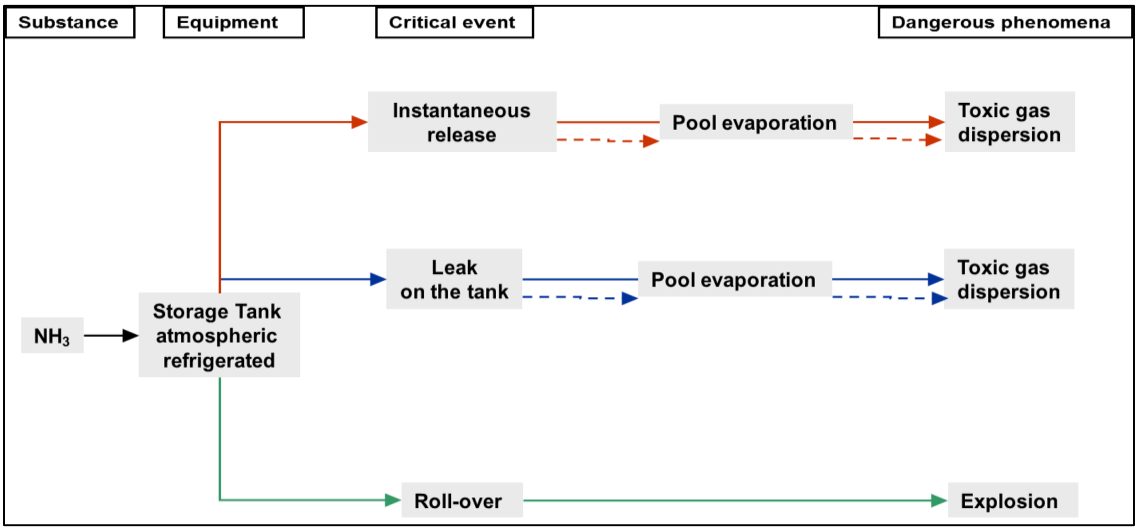
To illustrate, **Figure 35** shows a typical scenario associated with the storage of anhydrous ammonia from Gyenes et al., 2017[156]. The "critical event" column indicates that three different types of loss of containment that can occur in connection with this process. They are 1) an instantaneous release (rupture of the tank, e.g. from an external shock, or excess of pressure or temperature), 2) a leak on the tank, and 3) roll-

[156] Gyenes, Z., M. Wood and M. Struckl. 2017. Handbook of Scenarios for Assessing Major Chemical Accident Risks. European Commission Joint Research Centre. EUR 28518 EN https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/publications

over (rapid release of vapours caused by stratification of the liquid into different layers of density).

Using this scenario, an operator will implement a number of risk management measures, to prevent and mitigate a potential release, and to control any dangerous phenomenon that may result. A first set of measures, typically embedded in equipment design, maintenance routines, and operating practices, will be intended to prevent the loss of containment. These are measures represented on the left-hand side of the bow tie. In the event that these measures fail, and a rupture, leak or roll-over event occur, measures would be in place to detect that a release has occurred, e.g., ammonia sensors, maintenance and inspection practices, at which point some automated mitigation measures, such as pressure relief valves and ventilation systems may be activated. These measures are on the right-hand side of the bow tie. Trained emergency responders may initiate further actions to prevent the release from turning into a major emergency, and precautionary measures, such as site evacuation, may be launched. At the very far right end of the bow tie, that is, the very last element of preparedness in the potential sequence of events, are emergency response measures to combat the toxic release, contain secondary impacts from any explosion, and to limit damages to workers, the community and the environment.

Figure 35. *Scenarios for anhydrous ammonia atmospheric pressure refrigerated storage tank*



Source: Gyenes et al., 2017

Controlling and eliminating all causes of chemical accidents is theoretically possible but logistically difficult. Such control requires perfect understanding of process and equipment conditions at any point in time and how process substances will behave under these conditions. It also means controlling all the decisions that govern any particular process and ensuring that they too are perfect at all times. Given this reality, most experts are skeptical that chemical accident risks can be reduced sufficiently such that they are no longer a concern for society. Therefore, *mitigation* of chemical accident risks to reduce impacts as well as *land-use planning* and *emergency response* are equally important elements of risk management strategy.

14.3 **Principles of effective risk assessment and management**

The likelihood of an accident occurring depends significantly on how well the risks are managed (the safety management system) and by decisions of the organisation(s) that affect the functional effectiveness of the safety management system. (These causal factors are usually referred to as "underlying causes".) In current times, there is considerable agreement on the fundamental principles of process safety management which, if understood and properly applied, would prevent a large majority of chemical accidents that still occur today.

Risk assessment for chemical accident risk follows a similar simple structure that is generally applicable to all technological risks. This structure is composed of three simple questions, often called the risk triplet:

- What can go wrong?
- How likely is it that it will happen?
- If it does happen, what are the consequences?

14.4 Performing a risk assessment

The scope of this section is to describe different decision pathways bridging the risk analysis to land-use and emergency planning for chemical accident risk. Criteria for decisions may vary depending on the national context, but generally depend on various social and economic conditions, cultural attitudes towards industrial risk and historical events that may have shaped these attitudes.

The core of risk assessment is the consequence analysis, that is, the fire, explosion or toxic release that could result from an unplanned release of a dangerous substance. The core of the consequence analysis is the accident scenario (or scenarios), that is, the specific sequence of events that could lead to a major fire, explosion or toxic release.

All approaches require a consequence analysis. The consequence analysis has numerous and very specific data requirements. Typical inputs include data on substance properties (boiling point, vapour pressure, etc.), the source term (how the substance was released, e.g., whether a leak or a rupture, how big was the size of the hole, etc.), process conditions (pressure, temperature, etc.), the surrounding environment (outside temperature, open space versus a building, etc.), human health thresholds in relation to certain impact thresholds (toxicity, thermal and explosive effects), population in the surrounding area, and other data of specific relevance to the accident scenario selected. With the exception of substance properties, the data cannot be generalized but must be based on actual conditions at the site in question. The Seveso Directive requires operators of upper tier sites (highest hazard sites) to produce risk estimates in the safety report. The site operators are generally responsible for providing risk estimates but regulators may run their own calculations using the data provided by the site.

Risk managers have several options in terms of risk assessment methodology.

The options for risk assessment approaches are divided into two categories and then divided further into two subcategories. The main difference between the two categories is whether or not numeric frequencies of accident events are taken into account. The categories and subcategories are as follows:

- Probabilistic approaches
    - Quantitative approach producing a numeric risk estimate
    - Semi-quantitative approach producing a numeric risk estimate
- Deterministic approaches
    - Deterministic approach that estimates spatial distribution and severity of effects and implicitly takes account of frequencies
    - Distance approach that uses table of fixed distances based on generalized estimates of the results of the deterministic approach

The decision to choose a particular method depends on national attitudes to chemical risk. Years of experiencing in implementing the Seveso Directive in the European Union has proved that the decision on risk assessment of chemical accidents is closely identified with the country's culture, history, and economic, and social conditions. In addition, the decision to use a probabilistic approach may require a consideration as to whether adequate data on frequency for certain types of chemical processes are readily available. For example, it may be important to know how many times a pressure relief valve did not function as expected under certain process conditions. If these data are not available, it may be necessary to choose a deterministic approach.

The **probabilistic approach** (sometimes called the quantitative approach) is characterized by a final decision based on a numerical risk figure, that is, an estimate of the probability of an event, e.g., 1 X 10-5. The numeric estimate of frequency is combined with a numeric estimate of severity to produce a risk figure. It is very important to understand that this risk estimate represents a relative risk, rather than an absolute risk. Data inputs to produce this figure are usually generalized from datasets that are not necessarily representative of the universe of possibilities Therefore, these inputs carry with them a high degree of uncertainty. The resulting estimates of probability are characterized by uncertainty as well. Based on these results, risks are classified in terms of ranges of probability, with the probability estimates considered as indicative rather than absolute measures.

In contrast, the **deterministic approach** does not select scenarios on the basis of a numeric likelihood, nor does it produce a numeric estimate of risk. The selection of data inputs (e.g., the volume of hazardous substance released, threshold of harmful effects, etc.) is selected on the assumption that they represent higher frequency events. The output is generally framed in terms of the distribution of certain effects across a certain area, usually divided into spatial zones within a certain distance from the source relative to higher likelihood of death or level of injury. The fixed distance approach simply calculates a fixed distance on the basis of scenarios involving specific substances based on calculations of these spatial zones.

14.5 Selecting accident scenarios for the risk assessment

The selection of accident scenarios follows the risk triplet, by first identifying what can go wrong and then subsequently determining how likely it is to happen and how serious the impacts will be.

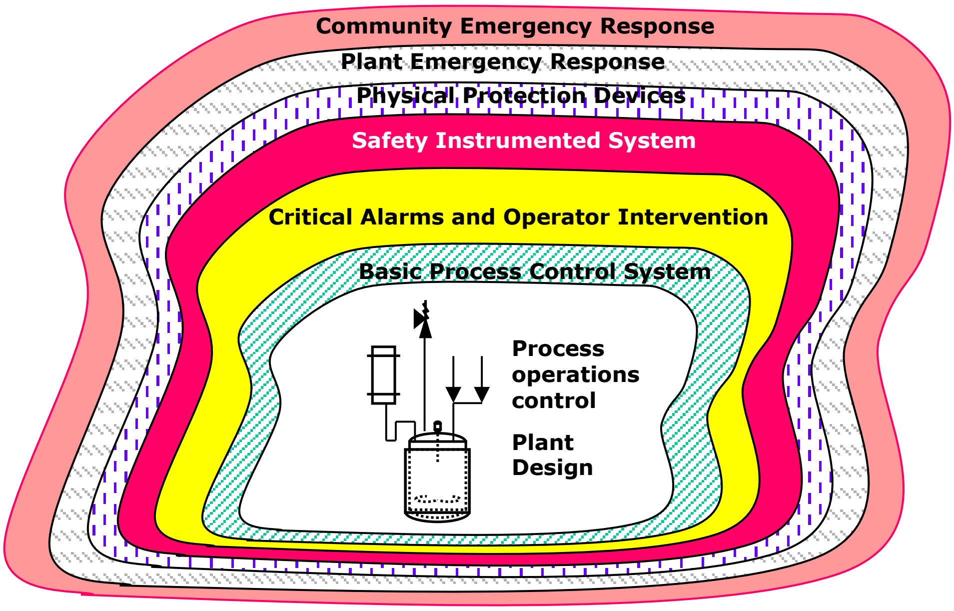
14.5.1 Hazard identification (what can go wrong)

The consequence analysis relies on the selection of an accident scenario or scenarios. A major hazard site may have one or many accident scenarios, with different likelihood of occurrence or severity. The number of scenarios depends on the complexity of the site. For example, a large petroleum refinery could have 50 or 100 process units and each one of them may have one or more scenarios. On the other end of the spectrum, an LPG storage facility may have only a few scenarios.

The selection of scenarios generally starts with the hazard identification that has been conducted by the operator. There are numerous hazard evaluation methods, of which the most common include, checklists, relative ranking systems (e.g., the Dow Index, the Substance Hazard Index), preliminary hazard analysis, What – If Analysis, What – If & Checklist Analysis, Hazard & Operability Analysis (Hazop), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis, Event Tree Analysis, Cause – Consequence Analysis, Human Reliability Analysis, and Layer of Protection Analysis (LOPA) as shown in **Figure 36** from CCPS[157].

[157] Center for Chemical Process Safety. 2001. Layer of protection Analysis – Simplified Process Risk Assessment. ISBN 0-8169-0811-7

Figure 36. *Layers of Protection Model for a Chemical Plant.*



Source: according to CCPS 1993

These methods each help the operator to make a systematic assessment of potential hazards associated with a particular process involving dangerous substances. The output of the process often relies substantially on expert judgement. Often methods may be used in combination to produce independent outcomes that can then be compared. Some methods, such as Hazop and LOPA, require substantial input from a multidisciplinary team of experts. The operator will ideally choose hazard identification methods that are suited for the processes and substances present on the site.

A hazard identification produces a list of possible undesirable scenarios. From these scenarios, a subset of scenarios will be selected as the subject of the risk assessment.

14.5.2 Selecting the accident scenarios (How likely is it that it will happen and if it does happen, what are the consequences?)

The selection of the accident scenario(s) for the risk assessment depends on the risk assessment approach selected.

14.5.2.1 Deterministic approach

The selection of scenarios may be based on a qualitative estimate of the consequences only, which means an expert judgment of the expected damage (severe, medium, low). But the main problem is the definition of the scenarios before this step. The selectin is not based on a numeric evaluation of the risk, but selects incidents judged by experts to be undesirable events. Selection criteria often include one or more of the following:

- An assumption of a release, or loss of containment (LOC) of all the contents of the equipment (vessel or pipe)
- Assumption of a specific type of LOC (e.g., leak from a pipe of 25cm diameter)
  - Expectation that preventive measures could avoid the LOC (so that the scenario is no longer considered for the risk assessment)
  - Qualitative criteria to accept or exclude certain preventive measures for a scenario (e.g., based on the expected reliability of a measure) For example, automated protections, such as pressure relief valves, are often considered more reliable than prevention measures that rely solely on human intervention

Applying the criteria will generally result on some accident scenarios ranked higher in severity than others and on the basis of this ranking, the operator will select scenarios for the risk assessment.

14.5.2.2 Probabilistic approach

This approach requires sufficient data on the likelihood of plant' system failures. The frequency data may refer to the so-called "top event", i. e., the LOC or Loss of Containment, or to the sequence of events leading to the top event, on the left-hand side of the bow tie, or to the performance of any preventive measures (left-hand side) or mitigation measures (right-hand side). Despite the fact that specific data referring to the individual case is always the most favourable option, generic data are widely used in order to avoid extensive research to identify numbers, especially when complete datasets from past events occurring on the site may not be available.

The so-called Dutch "Purple Book"[158], the FRED database of the HSE[159160], the so-called "Taylor-Study"[161], NS the "AMINAL-Study"[162]are all well-known sources of generic frequency data for chemical accident risk analysis. An example of the values for a pipe leak is shown in **Error! Reference source not found.**.

Table 7. Example of pipe failure frequencies

	Small leak (effective diameter of 10% of the nominal diameter	Leak (effective diameter of 22% of the nominal diameter	Leak (effective diameter of 44% of the nominal diameter) (Large leak)	Full bore rupture
Nominal diameter < 75 mm	$1.18.10^{-5}$	$7.93.10^{-6}$	$3.3.10^{-6}$	$1.22.10^{-6}$
75 mm ≤ nominal diameter ≤ 150 mm	$2.5.10^{-6}$	$1.11.10^{-6}$	$4.62.10^{-7}$	$3.5.10^{-7}$
Nominal diameter > 150 mm	$1.75.10^{-6}$	$6.5.10^{-7}$	$2.7.10^{-7}$	$1.18.10^{-7}$

The second main element of the scenario selection in probabilistic assessment is the application of reliability figures for control measures that may prevent the accident from occurring or reduce its severity. Similar to the deterministic approach, measures may be grouped into the following categories:

- "Avoid Measures": the scenario will not occur (example: burying a vessel will prevent a BLEVE).
- "Prevention Measures": the frequency of a scenario is reduced (example: automated systems to prevent overfilling).

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158 Committee for the Prevention Disasters (CPR), 1999, "Guideline for Quantitative Risk Assessment-"Purple Book" CPR18E, SDU, The Hague

159159 UK Health and Safety Executive. 1999. Failure rate and event data for use in risk assessment (FRED). Issue 1. Nov 99 (RAS/99/20).

160 UK Health and Safety Executive. 2003. New failure rates for land use planning QRA Update. Chapter 6K: Failure rate and event data for use within risk assessments. 2/09/2003. RAS/00/22.

161 Taylor, J. R. 2006. Hazardous Materials Release and Accident Frequencies for Process Plant. Volume II Process Unit Release Frequencies. Version 1 Issue 7. http://efcog.org/wp-content/uploads/Wgs/Safety%20Working%20Group/_Nuclear%20and%20Facility%20Safety%20Subgroup/Documents/Reldat%20II%207.pdf

162 Handboek Kanscijfers voor het opstellen van een Veiligheidsrapport 1/10/2004, AMINAL – Afdeling Algemeen Milieu- en Natuurbeleid.

- "Control Measures": the size, severity or extent of the scenario is reduced (example: gas detectors operating block valves).
- "Mitigate Measures": the size, severity or extent of the effects is reduced (example: firewalls).

It is up to the individual user or the national system to determine which types of measures are taken into account and what and how the efficiency is assessed. Some approaches may only consider passive measures (no human intervention or measurement of parameters necessary).

The third part of the quantitative selection of accident scenarios is the definition of "cut – off". The cut-off is a set of numerical values that are fixed and indicate the threshold of selection, that is, which scenarios have likelihood that is too low for the risk assessment.

14.6 Evaluating the consequence analysis

The outcome of the risk assessment, regardless of approach is an estimate of the risk in terms of likelihood and severity. The likelihood measure may be expressed either numerically, e. g., yearly occurrence of an undesirable event in the range of 10^{-3} – 10^{-9}, or qualitatively (e. g. very likely to very unlikely). The severity may be expressed quantitatively by numerical effect (e.g., how many deaths), or qualitatively from "low" to "high".

14.6.1 Evaluating impacts and severity

14.6.1.1 Dangerous phenomena produced by a chemical accident scenario

The risk assessment will identify phenomena that can be produced from the accident scenario. The main types of potential dangerous phenomena that may be generated by a chemical accident are shown in **Table 8**. The consequence analysis will identify which phenomena are produced by the accident scenario.

Table 8. Effects related to different kind of scenarios

Dangerous Phenomenon	Scenario Types		
	Thermal	**Overpressure**	**Toxic Effects**
Fireball	x	x	
Flashfire	x		
Jetfire	x		
Poolfire	x		
VCE	x	x	
Toxic Clouds			x
Solids Fire	x		

14.6.1.2 Human health effect evaluation

The risk assessment will identify potential human health effects from dangerous phenomenon, mainly a fire (thermal radiation), explosion (overpressure) or toxic release.

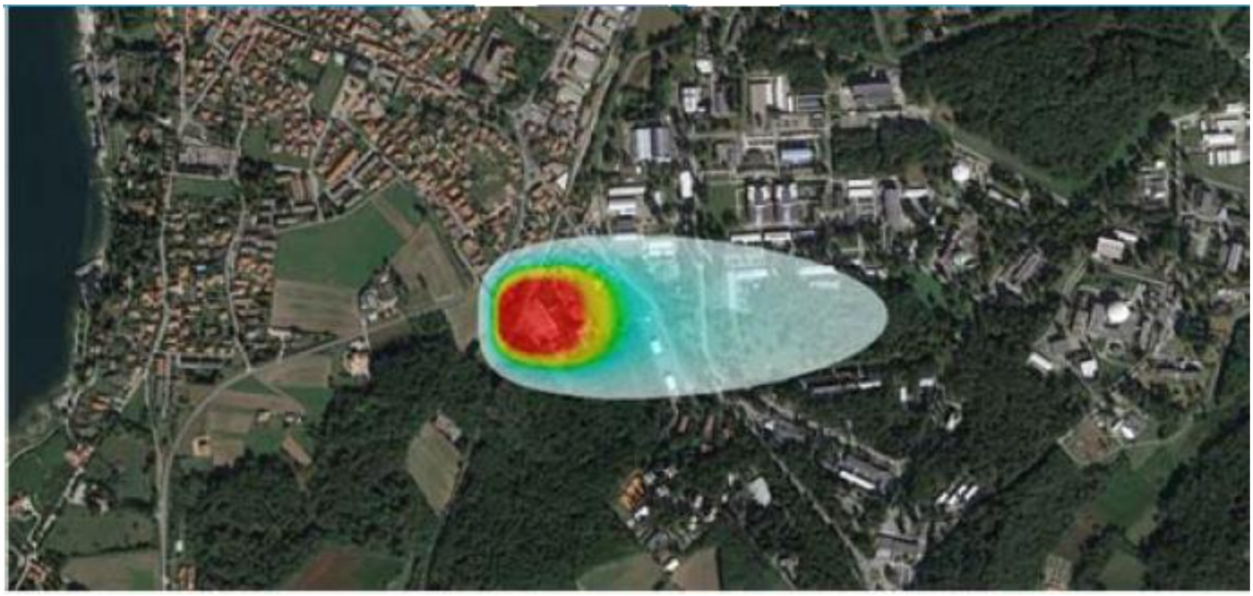
Table 9 below is an example of severity classifications for human health effects.

Table 9. Consequence classification for human and environmental impacts.

Consequence Classification	
Effects on human health	**Effects on the environment**
No injury or slight injuries without sick leave	No action needed but surveillance
Injuries leading to an hospitalization	Serious effects on the environment inside the establishment
Irreversible injuries or death inside the establishment, reversible injuries outside the establishment	Reversible effects on the environment outside the establishment
Irreversible injuries or death outside the establishment	Irreversible effects on the environment outside the establishment

The severity level is determined by reviewing the expected intensity of the impact (heat, overpressure, lethality and concentration of the toxic substance) and the spatial area over which each level of intensity is sustained. Impacts of consequences are usually expressed in terms of spatial distribution and number of people affected, often displayed as a map as in **Figure 37**.

Figure 37. *Toxic disperson from a catastrophic rupture of a tank wagon containing sulphur dioxide.*



Source: JRC, 2018

14.6.1.3 Physical effects of fire and explosions

The definition of physical hazards is comparatively easy. The divergence of accepted thresholds is not wide and the main difference lies in the decision which levels of effects should be taken into account. For thermal radiation and overpressure the following values may serve as default figures:

Table 10. Endpoints values of fires and explosions for different severity levels

Level	Stationary Radiation	Non – stationary Radiation	Overpressure
No effect	1,6 kW/m^2		
Small effects	< 3 – < 5 kW/m^2	< 125 kJ/m^2	< 30 mbar
Reversible effects	< 3 – < 5 kW/m^2	125 – < 200 kJ/m^2	30 - < 50 mbar
Irreversible effects	5 – 7 kW/m^2	200 - 350 kJ/m^2	50 – 140 mbar
Lethality	> 7 kW/m^2	> 350 kJ/m^2	> 140 mbar

Another distinction concerns the duration of the effect, as shown below:

Table 11. Stationary, non-stationary and fixed effects.

Dangerous Phenomenon	Effect Type		
	Stationary Radiation	**Non – stationary radiation**	**Overpressure (fixed value)**
Fireball		x	x
Flashfire		x	
Jetfire	x		
Poolfire	x		
VCE		x	x
Solids Fire	x		

"Non – stationary" means that the effect is calculated on the basis of an equation that takes into account the actual time of exposure which may be very short in the case of certain scenarios.

14.6.1.4 Toxic effects

For toxic effects the situation is more complex than for physical hazards, taking into account the following limitations:

- Countries with existing concepts only agree one threshold, which is the level corresponding to the start of the certain effects (for example irreversible health effect).
- There are various exposure guidelines; the selection of one of them based on scientific expertise is difficult (finding evidence of the effects of a given toxic substance in humans is often unmanageable, so the experimentation is usually done in animals and the values obtained extrapolated to humans).
- Each source guideline (e.g., American Institute of Industrial Hygienists Emergency Response Planning Guidelines – ERPGs) covers only a limited number of substances.

- The effects of toxic substances on humans are in some cases related to the dose and not to a given concentration.
- The dose may depend not only on the concentration value and the exposure time but also on other parameters which depend on the substance and may be unknown.
- The effects on exposed persons is greatly affected by their health condition, age etc, Currently three databases for toxic effects are widely used: IDLH, ERPG and AEGL.
- Immediately Dangerous for Life and Health (IDLH) Threshold Levels[163]
- Emergency Response Planning Guidelines (ERPG) Threshold Levels[164]

14.6.2 Consequence and risk assessment modelling tools

Given the complex nature of consequence and risk assessment of chemical accidents, various organisations have developed tools. The following tools are the most well-known, but other tools are also available:

- **The JRC ADAM (Accident Damage Assessment Model) Tool.** The JRC created this versatile application for competent authorities implementing the EU Seveso Directive. It models consequences for a wide range of substances and scenarios and also can incorporate frequency data and produce a risk assessment figure. It is available for free to competent authorities. For more information, go to the website https://adam.jrc.ec.europa.eu/en/adam/content
- **The ALOHA software tool** created by the U.S. Environmental Protection Agency is is used widely to plan for and respond to chemical emergencies. ALOHA allows users to enter details about a real or potential chemical release, and then it will generate threat zone estimates for various types of hazards. ALOHA can model toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fires, pool fires, and vapor cloud explosions. It is available for free at https://www.epa.gov/cameo/aloha-software
- **EFFECTS** is a commercial software developed by TNO and available at cost for safety professionals to calculate and analyse the effects of accident scenarios. More information is available at: https://www.tno.nl/en/foccus-areas/circular-economy-environment/roadmaps/environment-sustainability/public-safety/effects-advanced-easy-to-use-consequence-analysis/
- **PHAST** is DNV's commercial software for modeling releases and dispersions including modelling of pool spreading and evaporation, and flammable and toxic effects. More information is available at: https://www.dnvgl.com/services/process-hazard-analysis-software-phast-1675

14.7 Presenting the risk assessment outcome for decision-making

The final result of the risk assessment combines the impact analysis with likelihood of the event for each accident scenario. This product gives the necessary information for decision-makers. Some common mechanisms for communicating the results of the risk assessment are as follows:

A **risk matrix**, representing the compatibility between defined level of risk and urban/ environmental development (see **Figure 38**).

The following matrix is derived from the U.K. Health and Safety Executive publication 'Reducing Risks Protecting People' and the UKHSE final report on the Buncefield fire and

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[163] National Institute for Occupational Safety and Health, USA. Online: http://www.cdc.gov/niosh

[164] Online: http://www.aiha.org

explosion. Report: U.K. Health and Safety Executive publication: Safety and Environmental Standards for Fuel Storage Sites.

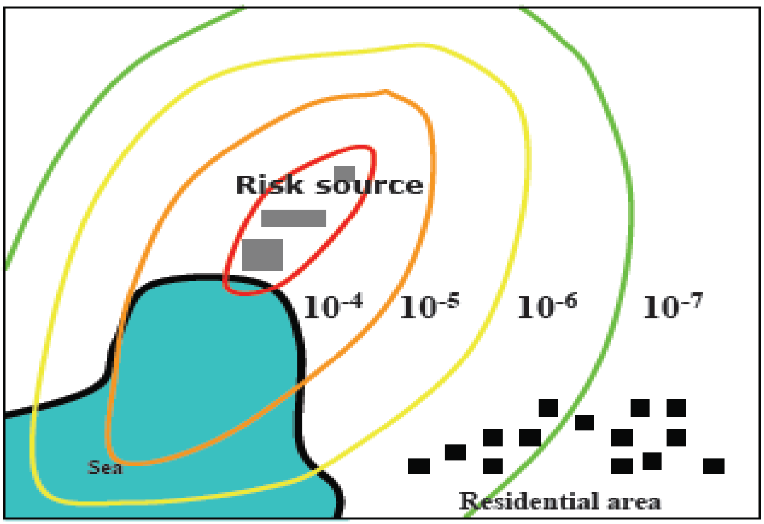
Figure 38. *Example of a Risk Matrix*

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

A **spatial distribution** of the consequences expressed on a geographic map of the area (as in **Figure 39**).

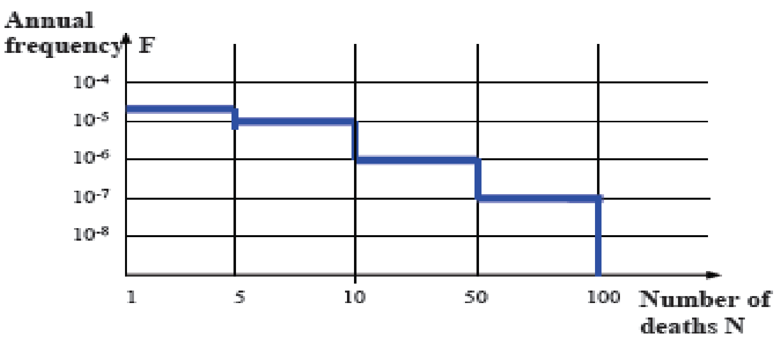
A chart that shows different zones of risk of any individual being harmed by an accident scenario. The individual risk curves are associated with impact areas with different frequency endpoints. The numeric frequencies in **Figure 40** can only be produced through a probabilistic risk assessment. However, similar charts can also be produced from a deterministic risk assessment, with the zones described qualitatively (e.g., likelihood of fatalities or irreversible injury, likelihood of reversible injury, etc.). Such charts may be used to create land-use planning zones or emergency response intervention zones. For example, 10-6 irreversible damage area where only limited residential developments are allowed. The **societal risk graph** (F/N-curve), is a single measure of the chance that an accident (or accidents) could harm a number of people. It can only be produced through a probabilistic risk assessment.

Figure 39. *Example of an individual risk curve*



These outputs can be used directly by decision makers to determine whether the site has achieved an acceptable level of risk. The risk assessment of each accident scenario must be within the range of acceptable risk. When probabilistic risk assessment is used, acceptable risk is defined as a numeric risk figure, e.g., 10^{-5}, established by the operator, or sometimes by national legislation. The F/N curve usually represents the collective risk of the entire range of critical accident scenarios at a site. It can generally only be produced through a probabilistic approach.

Figure 40. *Example of an F/N diagramme*



These outputs can also be used by governments to create standardised distances.

Table 12. Example of a risk matrix with quantified likelihood.

Frequency/ Likelihood		**Single fatality**	**2-10 fatalities**	**11-50 fatalities**	**50-100 fatalities**	**100+ fatalities**
Likely	>10-2/yr	Intolerable	Intolerable	Intolerable	Intolerable	Intolerable
Unlikely	10-4/yr – 10-2/yr	Tolerable (Intolerable if individual risk of fatality >10-	Intolerable (Intolerable if individual risk of fatality >10-3/yr)	Intolerable	Intolerable	Intolerable

		3/yr)				
Very unlikely	10-6/yr – 10-4/yr	Tolerable	Tolerable	Tolerable	Tolerable	Intolerable
Remote	10-8/yr – 10-6/yr	Broadly Acceptable	Broadly Acceptable	Tolerable	Tolerable	Tolerable

14.7.1 Making decisions based on the risk assessment

The output of any risk assessment provides an indicator of the magnitude of the risk associated with the hazard. Organisations can use this output in numerous ways, depending on their role in the process.

- Operators will use the risk assessment to make decisions about strengthening risk management and where to invest resources in a way that reduces risk most effectively.
- Inspectors may make decisions about whether the site is safe and can continue operations without significant changes.
- Land-use planners will use the outputs to make rules about where certain uses can be developed, and also to impose restrictions on certain development when necessary.
- Emergency planners will use the information to determine the types of equipment, knowledge, and training that emergency personnel will require. They may make decisions about when and how to evacuate certain populations, setting up medical services around the site, and other intervention components.

The outputs of risk assessment of chemical incidents have a high degree of uncertainty that can make them difficult to communicate to politicians and the public. They are complicated to explain and the fact that they are not entirely certain, may undermine their importance. In the case of numeric estimates, there can be tendency to underestimate the need to prevent and prepare for low frequency high severity events On the other hand, the public may see these numbers as frightening. Nonetheless, the advantage of having more knowledge about chemical accident risk far exceeds some of the challenges it creates.

14.8 References from the European Commission Joint Research Centre

https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/publications

Basta, C., M. Christou and M. Struckl. 2008. Overview of Roadmaps for Land-Use Planning in Selected Member States. European Commission Joint Research Centre. EUR 23519 EN.

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Gyenes, Z., M. Wood and M. Struckl. 2017. Handbook of Scenarios for Assessing Major Chemical Accident Risks. European Commission Joint Research Centre. EUR 28518 EN

15 Nuclear Accidents

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Objective of this contribution is to present the steps to follow in order to carry an analysis of a single hazard (nuclear accident), stressing the limitations of the methods and the opportunities to link them with other hazards. Focus is made on the methodologies and tools existing to assess the hazards, exposure and vulnerability to ionising radiation, pointing out the requirements of data and expertise, the assumptions made and the limitations of the results.

15.1 Context

It is generally recognized the dichotomy between the advantages and disadvantages provided by facilities and activities dealing with ionising radiation. Among the benefits, they range from power generation to medicine, industry and agriculture uses. On the contrary, the radiation risks to workers, public and environment that may arise from a potential accident generate its rejection. The radioactive material once released, dispersed and deposited on different environments, causes a situation of exposure to the population through different pathways that can lead to doses and health risks. It creates that ionising radiation have to assessed and, if necessary, controlled.

The EU has radiation protection legislation in place to protect human health against the dangers arising from ionising radiation. This includes the Basic Safety Standards (Council Directive 2013/59/EURATOM), which is supplemented by a number of acts ensuring a high level of protection for the public, workers, and patients. In addition, the EU requires EU countries to monitor radioactivity in the air, water, soil and foodstuffs. The full test of all EU-level provisions currently valid in radiation protection can be consulted in https://ec.europa.eu/energy/en/overview-eu-radiation-protection-legislation

15.2 Risk identification

The International Atomic Energy Agency (IAEA) defines nuclear accident in its Safety Glossary (IAEA, 2016) as "any event involving facilities or activities from which a release of radioactive material occurs or is likely to occur and which have resulted or may result in an international significant transboundary release that could be of radiological safety significance for another State". The radiological significance of nuclear accidents is categorized by the IAEA on the International Nuclear and Radiological Event Scale (INES) (IAEA, 2008). INES Scale facilitates consistent communication on the safety significance of nuclear and radiological events. Based on a numerical rating, from one to seven, the scale rates events into incidents (levels 1-3) or accidents (levels 4-7), while events without safety significance are rated as level 0. Nuclear and radiological events are included in each level by considering three areas of impact:

- People and the Environment: It considers the radiation doses to people close to the location of the event and the widespread, and unplanned release of radioactive material from an installation;
- Radiological Barriers and Control: It covers events without any direct impact on people or the environment and only applies inside major facilities. It covers unplanned high radiation levels and spread of significant quantities of radioactive materials confined within the installation;
- Defence-in-Depth: It also covers events without any direct impact on people or the environment, but for which the range of measures put in place to prevent accidents did not function as intended.

As an example of the INES scale application, nuclear power plant (NPPs) accidents at Chernobyl and Fukushima Daiichi were rated 7 within the People and the Environment area. On the contrary, the event in the Three Mile Island NPP was categorized as level 5 within the Radiological Barriers and Control area.

Successfully response arrangements has often turned out to be a major challenge – if not impossible – where no prior risk assessment and proper preparedness planning had taken place. The main target of nuclear risk assessment is to improve safety and minimize risks related to nuclear energy. Risk assessment denotes the total process, and the results, of assessing the radiation risks and other risks associated with normal operation and possible accidents involving facilities and activities, from which a release of radioactive material occurs or is likely to occur (IAEA, 2016). This process normally includes consequence assessment, together with some assessment of the probability of those consequences arising.

The NERIS platform (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery) (https://www.eu-neris.net/), established in 2010, is a forum for dialogue and methodological development between all European organisations and associations taking part in decision making of protective actions in nuclear and radiological emergencies and recovery in Europe. Among the activities supported and developed under the umbrella of the NERIS platform, as training courses, workshops, or user and working groups, NERIS is also linked to research projects, such as the PREPARE project on innovative integrative tools and platforms to be prepared for radiological emergencies and post-accident response in Europe (https://www.eu-neris.net/projects/prepare.html). After three years of research (2013-2016), PREPARE has improved tools and methods in topics such as long lasting releases, source term estimation, model improvements, knowledge gathering and exchange of trustworthy information, and it has provided tools and methodologies which are either used in national organisation and implemented in decisions support systems such as ARGOS and RODOS (Raskob et al., 2016).

15.3 **Risk analysis**

Targets of risk assessment are the people and the ecological systems close to the location of the event, as well as those potentially under the influence of the radioactive material released due to its transport. With this in mind, the final product should be the information to determine appropriate defence-in-depth strategies, to develop policies by decision makers and public information at global, regional and national levels, as well as list of corrective measures that are feasible, rational and in line with social and economic objectives.

In general, risk assessment is included within the scope of safety assessment, which covers all aspects of facilities and activities that are relevant to protection and safety of technological systems (IAEA, 2016). The evaluation of safety can be addressed by a bottom-up approach, i.e., it starts with postulated failures and proceeds to identify their consequences, or by a top-down approach, i.e. it starts with postulated end states (adverse consequences) and proceeds to identify a set of disturbances to normal operation which can lead to the end state (initiating events) (Apostolakis, 2003). While the Probabilistic Safety Assessment (PSA) follows the bottom-up approach, the Quantitative Risk Assessment (QRA) applies the top-down approach.

The evaluation of the nuclear infrastructure vulnerability against, for example, human errors, terrorist attacks and natural disasters, as well as preparation of emergency response plans is vital to assurance safety nuclear operations and national security (Kostadinov., 2011). The international community has agreed to strengthen the Convention on the Physical Protection of Nuclear Material, and in establishing nuclear security guidance (IAEA, 2011).

The role and importance of PSA as a technique to numerically quantify risk measures in NPP is defined and emphasised in many national and international safety standards (e.g

IAEA, 2010a, 2010b, 2012). PSA is a comprehensive and structured approach to identifying failure scenarios, constituting a conceptual and mathematical tool for deriving numerical estimates of risk (IAEA, 2016). PSA makes possible to examine a complex system's potential risk and to study the new design features and evaluate which of the safety improvements brings the required safety upgrading in NPP. Therefore, PSA provides insights into the strengths and weaknesses of the design and operation of a NPP. In all European countries, PSA methodology is used to confirm and enhance the safety of NPPs in complement to the deterministic approach. As an example of this use, the Nordic project "The Validity of Safety Goals" (2006-2010) (Bengtsson et al., 2011) had the aim to provide a general description of the issue of probabilistic safety goals for NPPs, of important concepts related to the definition and application of safety goals in Finland and Sweden.

PSA estimates the final measure of risk by combining the consequences with their respective frequencies. To this purpose, NPP's PSAs deal with "internal events" – those that start inside the power plant or the electric system it serves – and "external events" such as earthquakes, tsunamis, floods, hurricanes, fires and malicious events. The technique in this kind of probabilistic studies is to work with many hypothetical events covering a large range of possible outcomes. This allows assessing the probabilities and severity of loss. PSA combines estimations of three levels of risk (https://www.nrc.gov):

- Level 1 PSA estimates the frequency of accidents that causes damage to the nuclear reactor core, commonly called core damage frequency (CDF). This Level models from the various plant responses, called "accident sequences", to an "initiating event" that challenge the plant operation. Therefore, this level models all of a reactor's protective and accident mitigation systems.

The ASAMPSA_E project (2013-2016) (http://asampsa.eu/context/), aims at promoting good PSActices for the identification of initiating events (e.g. earthwakes, tsunamis,…) and external hazards with the help of PSAs and for the definition of appropriate criteria for decision-making in the European context. The project gathered experts from 28 organisations in 18 European countries and tried to cover the consequences associated with extreme external events, in particular flooding, that went beyond what those considered in the initial NPP design.

- Level 2 PSA, which starts with the Level 1 core damage accidents, estimates the frequency of accidents that release radioactivity from the nuclear power plant. Such core damage sequences are typically referred to as severe accidents. This Level analyses the progression of an accident by considering how the containment structures and systems respond to it. Once the containment response is characterized (timing and location parameters, thermal energy release rate and quantities of radionuclides releases), the analyst can determine the amount and type of radioactivity released from the containment.

SOURCE TERM is an international research programme carried out by IRSN *(L'Institut de Radioprotection et de Sûreté Nucléaire)* and CEA (Commissariat à l'Energie Atomique). This programme sets out to reduce uncertainties when evaluating the environmental release of radioactive products such as iodine or ruthenium following a core meltdown accident in a pressurised water reactor (PWR). The experimental data gained from this programme are used to develop and validate numerical simulation tools needed to assess the consequences of such an accident and to evaluate the efficiency of the prevention means.

- Level 3 PSA, which starts with the Level 2 radioactivity release accidents, estimates the consequences that might result in terms of health effects resulting from the radiation doses to the population around the plant such as short-term injuries or long-term cancers and economic losses that may result when radioactive material reaches the environment. Consequences are estimated based on the characteristics of the radioactivity release calculated previously, conditioned by several factors such as the dispersion of the plume, the deposition pattern, the land contamination and land use, the exposure of population and the early countermeasures applied.

Therefore, only the Level 3 PSA estimates the health and economic impact in terms of different offsite consequence measures. U.S. NRC 2013 provides guidance to develop a technical analysis approach plan for Level 3 PSA to be used in performing the full-scope site Level 3 PSA. However, integrated assessments of the risk emanating from the operation of facilities from which a release of radioactive material occurs (e.g. NPPs) is scarce, and there is not a state-of-the-art guidance material to address this Level 3 PSA. Performance of the full-scope site Level 3 PSA study involves an extensive number of technical tasks, and, consequently, the need to obtain or develop numerous models and substantial data. The level of effort to accomplish this work is a function of the amount of information and models. In general, it is required careful selection of suitable models for description of natural phenomena and effects of pollution exposure.

15.4 Risk evaluation

Two examples of approaches to the Level 3 PSA are the FlexRisk (Arnold et al., 2012; Seibert et al., 2013) and the ANURE project (García-Puerta et al., 2018). Both activities are performed with the purpose of estimating the contamination risk from the atmospheric dispersion of radionuclides released by NPPs accidents. The common characteristic of this kind of analysis is the consideration of many events to cover a large range of possible outcomes, and to assess the probabilities and to create a distribution of exceedance probability.

The flexRISK project studies the geographical distribution of the risk due to severe accidents in nuclear facilities, especially NPP in Europe. Starting with source terms and accident frequencies, the large-scale dispersion of radionuclides in the atmosphere were simulated for about 2800 meteorological situations (ten years period). The transport and dispersion model FLEXPART simulated the dispersion in the atmosphere and produce the contamination patterns of the ground and near-surface concentrations of relevant radionuclides. Radiation doses derived from the dispersion calculation are calculate to assess the consequences of severe accidents. Maps and diagrams indicate, e.g., where in Europe the risk to be affected by a severe accident is especially high, or which contribution is incurred by the NPPs of a specific country.

The ANURE project aims at developing a methodology to elaborate nuclear risk maps, considering local factors, to be used by the decision-makers in the preparedness and management of a nuclear post-accident exposure situation. The Almaraz NPP in Spain is taken as reference in this feasibility study. The methodology and the ANURE's results are based on 1825 numerical dispersion calculations from 5 consecutive years (2012-2016) using the Lagrangian mesoscale atmospheric dispersion model RIMPUFF, which is implemented in the JRODOS Decision Support System. For this period, the dispersion of two different source terms has been simulated, 1) severe accident with relative large release and 2) severe accident with small release. The outputs of each dispersion calculation, among others, consist of ground contamination on an irregular geographical grid. This information is useful to establish the affected area and the probability of exceedance of thresholds of contamination. This deposit probability combined with detailed information of soil vulnerability and the food chain impact provides an estimation of the risk distribution associated with both kinds of nuclear releases.

15.5 Risk treatment

Here, and as case study, is explained the elaboration of a risk map for rainfed cereals and ^{137}Cs deposit based on offsite radionuclide release from the Almaraz NPP. Rainfed cereals is one of the most widely produced crops in Spain, and therefore, it has large health, social and economic impact. The methodology applied to achieve this purpose is the one suggested under the ANURE project. For more details about the methodology, the reader is referred to García Puerta et al., 2018. The methodology combines the predicted deposition patterns of the release obtained from a large amount of numerical dispersion simulations (severity deposition map) with the knowledge of factors that influence the behaviour of radionuclides in soils and its transfer to food chain (vulnerability map).

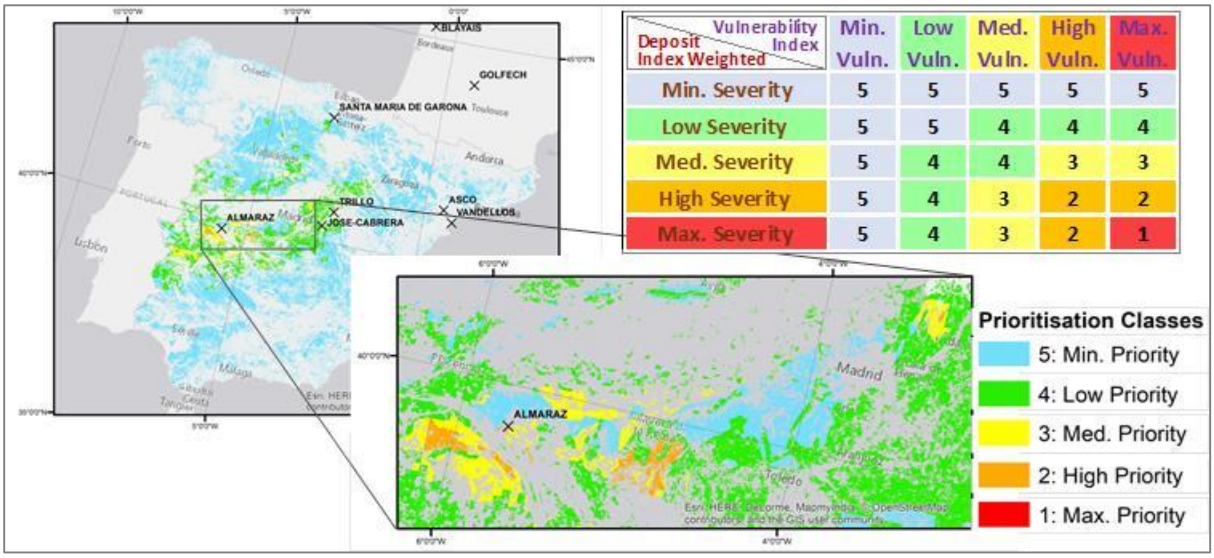
Following the general recommendation for this kind of analysis of working with many hypothetical meteorological scenarios, the base of this case study is the ^{137}Cs ground contamination predicted on a geographical grid spacing by 1387 numerical dispersion calculations (2012-2016 period) for 35 hours of offsite radionuclide release. The simulation were carried out by the Lagrangian mesoscale atmospheric dispersion puff model RIMPUFF of JRODOS System (in the below box is explained the needed steps to carry out a JRodos emergency model chain simulation).

Once performed the set of simulations, the predicted values in each grid cell were grouped into five contamination levels taken as reference the segments predefined in the Nordic Guidelines and Recommendations (NGR, 2014). Once grouped in these five categories, the most frequent ^{137}Cs deposition category for each cell is obtained. The corresponding weighted deposition index for each grid cell is defined as the product between the most frequent deposit category (from 1 to 5) and its associated probability. This new index named "Severity Deposition Index" is, hence, distributed in five classes ranging from 1, which represents the minimum deposition severity, to 5, which represents the maximum deposition severity. The spatial variability of this index identifies those areas largely and continuously affected by high deposits of ^{137}Cs.

Having obtained the severity deposition map, the vulnerability map, which represents the soil capacity to transfer the ^{137}Cs contamination to the cereal crops, is obtained by considering empirical values of soil type distribution and soil properties, the land use and the soil to plant transfer factors, focused on the rainfed cereals. The values of the vulnerability index are grouped in a range from 1 (minimum vulnerability) to 5 (maximum vulnerability).

Finally, the priority index for each grid cell is obtained by multiplying the corresponding severity deposition index and the vulnerability index for cereals (**Figure 41**). The results are grouped in five prioritisation categories, from maximum to minimum priority (range from 1 to 25). The spatial distribution of this priority index, therefore, represents a risk map for prioritising actions, considering the rainfed cereals affected by ^{137}Cs ground contamination from Almaraz NPP releases. This map raises the overall risk categorization and allows identifying priority areas for actions to be undertaken and making decisions on recovery investment. For instance, in areas with high priority index (4-5), remediation actions should be applied with the aim to minimize the root Cs uptake for the next year harvested cereals.

***Figure 41**. Prioritisation map for cereals and ^{137}Cs deposit*



Source: Garcia Puerta et al., 2018

An example application of the JRodos Emergency model chain

The redesigned Java-based version of the EU nuclear emergency response system RODOS (www.rodos.fzk.de) is a decision support system for accident management, in continuous updating. The system is free and open source, and available upon request. JRODOS is a synthesis of many innovative methods and techniques, being suitable for real-time decision-making and for probabilistic analysis, by mean the statistical analysis tool for countermeasure planning available. JRODOS has been developed within several European research projects and is currently being used in more than 20 countries worldwide (Raskob 2010).

JRODOS operates on modern information technology platforms and it is fully supported by the platforms Microsoft Windows and Linux, and partly Mac OS. For straightforward applications, it is sufficient to use a quad core 64 bit laptop with 4 gigabyte RAM and 200 gigabyte hard drive. The system consists of a Server part for computations and system management, a Client part for interactions with the user, and a Data Base (PostgreSQL) (KIT, 2017). JRODOS shows good performance and operational stability and is user friendly in operation and administration. In addition, inherent features and tools allow adapting models, databases, and the user interface to national conditions and user preferences.

In the following, the JRODOS user interface is explained by means of an example application of the so-called EmergencyLite chain (KIT, 2017). To this aim, we assume a hypothetical accident taking place at the Almaraz nuclear power plant, sited in Spain, and the use of re-analysis Grib2 NOMADS data:

1) Create a new project: When the User Interface be open, the operator just need to click on File → "new project" or in the “create a new project” icon. A pop-up window appears to define the project name, project description and model chain. In this case, the EmergencyLite chain project is named "Almaraz". Click [confirm].

2) Tab "Site" (Define the scenario – location of the incident): All European operating NPP are already available in JRODOS database. The user can choose the country (e.g. Spain) from the list of countries, and the site/unit (e.g. Almaraz/Amaraz 1) from the list of available reactors. Click [confirm]
3) Tab "Source term" (Define the characteristics of the source term): The first step is to setup the release time (day and hour) (e.g.02.08.2018 09:35). The second one is to define the source term. In an emergency, when the actual emissions may be difficult to obtain quickly and a first assessment of the emergency situation is needed, source terms already stored in JRODOS ("system public" or in "user public"), or previously imported by ourselves ("user defined or imported/loaded run") (e.g. Chernobyl (Waight et al., 1995), Fukushima (Stohl et al., 2012)) are usually used.

- In this case, the user public source term "F6.Tracer_24Hrs_Cs137" is selected. Click [confirm]

4) Tab "Weather" (Specify the meteorological information to run the calculation). In the "Prognosis time setup", the prognosis coverage after the starting release time, and the timestep of the outputs are defined (e.g. 24 hours and 60 min respectively). Meteorological data can be from provider, or defined by the user ("user input"). While the latter can be collected on site or from an existing nearby sites, the prognostic meteorological data needed to perform atmospheric dispersion and deposition calculations, can be obtained from different sources.

   - NOAA National Operational Model Archive and Distribution System (NOMADS) project; JRODOS is usually pre-configured to automatically download NOMADS data, e.g. free global meteorological data from the Global Forecasting System (GFS) of NCEP (GRIB1 and GRIB2 files) (https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs)
   - National meteorological offices or weather services (e.g. HIRLAM (http://hirlam.org/), ALADIN (http://www.umr-cnrm.fr/aladin-old/). They are non-free for most organizations.
   - European Centre for Medium-Range Weather Forecasts (ECMWF) NWP data (https://www.ecmwf.int/)
   - In-house Numerical Weather Prediction data: higher spatial and temporal resolution (e.g. WRF, Andronopoulos et al., 2014). Better spatial and temporal resolution.

- In case of not having files for the simulating period, nothing appears on the data provider label. Click [confirm]

5) Tab "Run" (select the grid type and the distance to which the calculation shall be performed). In this tab, the pre-setting is "Exercise". The spatial coverage of the prognosis is defined in this tab. By default JRODOS used 5 rings of the grids, and JRODOS offers the option of playing with distance and grid type in order to cover the purposes and needs of the calculation (e.g. if the chosen radius of calculation is 800 km, it corresponds to a minimum grid cell size of 2 km. This means that the grid cell size is 2 km around the point of release, and it becomes progressively coarser with the distance). Once selected the grid cell size (e.g. 800 (2)), click [confirm].
6) Tab "Summary". This tab reports a summary of the defined inputs. At this stage, the user can go back to any tab for inspection or corrections, as well as, all input made is saved and can be re-used for future projects. Click [confirm].
7) "Prognostic calculations". By using the defined inputs, JRODOS uses the near range Atmospheric Transport and Deposition Model, the Emergency Action Simulation model and the Terrestrial Food Chain and Dose Module, to carry out the prognosis calculations one after the other, without further user interference. Time consuming depends on the temporal duration of the simulation. In this specific case, the calculation lasts 5 min.
8) "Visualization" (JRodos User Interface). JRODOS illustrates the presentation of map-type results. The central "Map" tab consists of one or more result and map

layers. The list of all layers in the Map tab, the "Map Legend", is visible to the right. The available results are offered in form of a "Result Tree" in the "Projects" section of the user interface to the left of the Map tab. From the "Result Tree", the operator can select the different results provided by the simulation of the specified source term and meteorological data

15.6 Gaps and challenges

In radiation protection, the International Commission on Radiological Protection quantified the risk of stochastic effects of radiation and proposed a system of dose limitation based on three principles, justification, optimisation of protection, and individual dose limitation (Publication 26, ICRP).

Lessons learned from past nuclear events, such as Three Mile Island (1979), Chernobyl (1986), and the most recent of Fukushima have influenced the nuclear industry significantly. The nuclear industry has still to have challenges to maintain and improve the safety regarding nuclear activities. We would like to highlight the importance of the multiform activities conducted to prevent any accident or to limit its consequences should one occur. For instance, the events at Fukushima clearly demonstrate the potential risk significance of accidents involving release of radionuclides from multiple sources. The link between natural hazards and its impact on nuclear facilities is a topic of wide interest for which knowledge should be improved and developed.

PSA results have positive implications for the day-to-day operation of existing nuclear power plants. On top of this, research and development activities should be aimed at improving PSA codes, for instance in order to model all the dependencies between systems and to properly account for human actions. A greater understanding of how to interpret, utilise and communicate probabilistic information is also required. This is particularly important, since future development in forecasting systems, lead to forecast that are inherently probabilistic.

PSA results are complex and it cannot be reduced to a single number. Instead, PSAs provide a wide spectrum of possible outcomes associated with a frequency distribution. It is clear that from the beginning of its use, there have been a change both in quality and in maturity of the PSA technique. The level of detail of PSA has changed considerably. Mosleh 2014 presented a perspective of strengths, current limitations and possible improvements of the PSA methodology. This author reaches several interesting conclusions, as current PSA methods can remain adequate for certain problems, but there is a need for improving stakeholder confidence and engagement in risk-informed decisions through improving and demonstrating credibility of PSAs.

PSA applications are becoming more and more important. Due to its own nature, PSA methods have revealed significant differences in results when the same risk problem is analysed by different methods and/or different analysts. The justification of this fact is because most of the factors influencing the PSA results can only be determined with a high level of uncertainty. Seibert et al., 2013 indicates the following major factors of uncertainty to assess the risk in the framework of the FelxRisk project: 1) the accident frequency to different NPP, 2) the risk parameter considered, 3) the release fraction (source term definition), and 4) the dispersion calculations. Among them, the definition of the source term is pointed out as the most important uncertainty factor. Analysts try to reduce uncertainty by a) improving and evaluating their models; b) more precise parameterizations of physical processes; and c) collecting additional data to improve model accuracy.

Level 3 PSA is the least precise level as consequences depend on several factors affecting the transport and impact of the radioactive material. For example, health effects depend on the population in the plant vicinity, evacuation conditions, and the path of the radioactive plume. The plume, in turn, is affected by meteorological conditions, e.g. wind speed and direction, as well as rainfall or snowfall. Similarly, land contamination depends on the characteristics of the radioactivity release and the land use. In this context, an important issue to consider at Level 3 PSA studies is the need to take into account local and specific data to reduce the uncertainties in the assessment of consequences.

15.7 References

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16 Natech accidents

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The impacts of natural hazard events on hazardous industrial facilities, pipelines, offshore platforms and other infrastructure that handles, stores or transports hazardous substances can cause cascading events such as fires, explosions, and toxic or radioactive releases (Showalter and Myers, 1994; Cruz and Krausmann, 2009; Girgin and Krausmann, 2016). These so-called Natech accidents are a recurring but often overlooked feature in many natural disasters and have often had significant human, environmental and economic impacts.

Major Natech accidents may involve multiple and simultaneous releases of hazardous substances over extended areas, damage or destroy safety systems and barriers, and down lifelines often needed for prevention and mitigation of the consequences (Krausmann et al., 2010; Girgin, 2011). Emergency responders are also usually neither equipped nor trained to handle a high number of concurrent hazardous incidents, in particular as they also have to respond to the natural hazard consequences in parallel. The 2002 river floods in Europe that resulted in significant hazardous substance releases, including chlorine and dioxins (Hudec and Lukš, 2004; Gautam and Van der Hoek, 2003), the 2011 Tōhoku earthquake and tsunami that caused a meltdown at a nuclear power plant and raging fires and explosions at oil refineries (Krausmann and Cruz, 2013), and Hurricane Sandy in 2012 that triggered multiple hydrocarbon spills are just a few examples of recent major events that highlight the importance of the possible consequences of Natech accidents. Especially the Tōhoku earthquake is a case-study example of multi-cascading risk, because the earthquake itself caused only limited damage due to the stringent protection measures in place, but the tsunami and its impact on a nuclear power plant resulted in the most severe technological disaster ever recorded in the region whose adverse effects are still persisting (Krausmann and Cruz, 2013).

Natech accidents are events that cascade natural and technological hazards and which feature complex consequences due to synergistic effects between the two different types of hazard. Therefore, targeted prevention, preparedness and response plans are needed to prevent Natech accidents and mitigate their consequences. Unfortunately, natural disaster risk reduction frameworks do mostly not consider technological hazards and technological accident prevention and preparedness programmes often overlook the specific aspects of Natech risk, resulting in a lack of dedicated methodologies and guidance for risk assessment and management both for industries and authorities (Krausmann et al., 2017).

Natech risks exist both in developed and developing countries where hazardous industrial sites are located in natural hazard regions. Natech events are often assumed to be possible only for major natural events, e.g. strong earthquakes or floods. However, it does not necessarily require a major natural disaster to cause a Natech accident; they can be triggered even by more frequent, minor natural hazard events (Necci et al., 2018). Industrial growth, climate change, and the increasing vulnerability of society that is becoming more and more interconnected increases the likelihood of such events in the future. Successfully controlling a Natech accident has often turned out to be a major challenge where no prior risk assessment and proper preparedness planning had taken place. A comprehensive multi-sectoral and multi-hazard national Natech risk assessment is therefore crucial to pinpoint potential risk hotspots and see the overall picture including potential economic and environmental consequences that require special attention. A detailed discussion on how and in which setting Natech risks should be assessed in the NRAs is given by Girgin et al. (2019).

16.1 Risk Assessment Context

Hazardous industrial installations are inherent vulnerabilities for the socio-economic systems in which they are nested. Therefore, Natech risk assessment and management requires a comprehensive understanding of the interdependencies of related natural, technological and societal systems. The risk assessment can be challenging even for the impact of a single natural hazard on a single industrial installation. Consideration of multiple natural hazards and multiple installations at the same time while bearing in mind possible secondary hazardous events that can be triggered by the primary Natech events (i.e. domino events) requires a regional, multi-hazard and multi-vulnerability risk assessment involving a complex chain of risk scenarios with multiple cascading events.

Some hazardous industries with a Natech potential, especially the ones in the energy sector such as refineries, power plants, and oil and gas pipelines, are usually considered as critical infrastructure. It is common practice to analyse critical infrastructure as a separate pillar in national risk assessment (NRA) by focusing on natural-hazard related interdependency and business continuity aspects. However, it is also important to consider Natech scenarios for such critical infrastructure due to the large quantities of hazardous substances that they contain, so that they can be protected effectively to ensure service continuity. Therefore, in some cases national Natech risk assessments should also be multi-sectoral.

Due to these complexities, Natech risk assessment requires a multidisciplinary approach involving stakeholders from both the natural and man-made hazards fields. It concerns on the one hand industry operators and authorities in charge of chemical accident management and on the other hand the public and civil protection. Occasionally, natural hazard conditions may result in hazardous consequences that might be retained in a limited area to reach a wider extent causing cross-boundary problems. Especially flood hazards have a high potential to create cross-boundary Natech accidents (UNEP/OCHA, 2000). When countries share environmental resources or critical infrastructure, commerce and supply chains which might be affected by such accidents, they can face significant economic and social disruptions (Lindell and Perry, 1997). Therefore, in some cases national Natech risk assessments may also need multinational involvement.

Although they are recognised and even highlighted as an important emerging issue, Natech risk is currently not considered in a systematic way in NRAs. Usually Natech scenarios are only accounted for some of the hazards, but not for the others. This heterogeneity becomes a problem in the national risk evaluation when hazards that include the Natech risk in their assessment are ranked alongside the hazards that do not include the Natech risk. The key point for a proper Natech NRA is to consider all natural hazards and their interactions when assessing the potential for Natech accidents due to the presence of technological hazards. For this purpose, Natech risk can be calculated as part of the risks assessment for each natural hazard separately, or they can be considered as part of the risk due to technological hazards. In the first case, Natech contribution to the overall natural-hazard risk is better presented which is useful for hazard ranking purposes, whereas in the second case the importance of different Natech scenarios can be better spotted. In fact, consideration of both aspects can be beneficial, but it is important not to count the overall Natech risk contribution both under natural and technological hazards, as this leads to double-counting of the same risk and the related impacts that could mislead the final evaluation. Good documentation and bookkeeping practices would allow Natech-related contributions to be recorded properly, so that they can be easily separated from the overall analysis if necessary.

As many natural hazards have regional extent, the EU NRA guidelines suggest localised risk assessment only for advanced risk assessment. However, industrial installations are usually point assets at national or regional level. They are also not uniformly distributed but concentrated at certain regions for operational or logistic purposes. Therefore, technological hazards are usually localised and this aspect needs to be considered in the NRA. It is therefore necessary that Natech-related assessments are performed at local or regional level, and then subsequently combined at higher levels.

In order to assess Natech risk, industrial installations located in natural hazard zones should be identified and the expected on-site severity and impact potential of each natural hazard should be determined separately. This requires not only natural-hazard specific information, but also detailed technical data on the installations. Information (e.g. natural hazard risk maps, industrial equipment data) that is already gathered through related regulations, but more specifically in the other sections of the NRA framework, should be utilized as much as possible in a time- and cost-effective manner. Considering Natech aspects during hazard-specific data collection and effective coordination of data collection and analysis activities may prevent repetition and duplicate work for Natech-specific needs. For this reason, the authority designated to manage the NRA should open communication channels with each actor and involve them effectively in the Natech risk assessment process.

Natech risk assessment methodologies are mainly based on industrial risk assessment methodologies that vary from qualitative to fully quantitative approaches. For Natech risk assessment purposes, these methodologies need to consider equipment damage models for natural-hazard impacts, the possibility of multiple events at several equipment or installations simultaneously, release and consequence scenarios considering natural hazard conditions, and the unavailability or malfunctioning of accident control and mitigation measures including lifelines due to natural hazard impact. Some technological risk control regulations (e.g. the EU Seveso III Directive) requires that hazardous installations assess accident scenarios triggered by natural hazards and document the results in safety reports. Besides their original purposes, such information can also be utilized for NRA purposes. Frequently, however, the industries carry out the assessment of natural hazards autonomously for these studies and although providing valuable information for the Natech hazard at the facility level, some of the natural-hazard related assumptions and scenarios may not be compatible with those used in the NRA. A better approach for assessing the Natech hazard in the NRA is one in which the authority provides the information about the risk scenarios used in the framework of the NRA for each natural hazard to the industry. In turn, the industry can identify and build relevant Natech risk scenarios that are coherent with all the other risk scenarios chosen for the NRA. Following a systematic selection approach, possible Natech scenarios can be reduced into a manageable set of reasonably-to-be-expected or worst-case scenarios which should be analysed in detail for each installation separately. For consistency at the regional or national level, the Natech scenario building and analysis methods should be standardized throughout the NRA study and use of significantly different methods for different installations should be avoided.

The systematic evaluation of Natech risks in the NRA framework will not only result in informed decision making, but also in a better identification and prioritization of protection measures which can be implemented to reduce and control Natech risks in a cost- and time-effective manner.

16.2 Risk Identification

The first step in national Natech risk assessment should be identification of the industrial installations which might be affected by natural hazards. Major natural disasters can impact large areas and Natechs can occur at any hazardous installation in the affected area, meaning that potentially multiple and simultaneous releases of hazardous substances can be triggered at various locations. Natural hazards having such an impact potential are normally covered in their own hazard-specific sections under the NRA. Therefore, the available natural hazard and natural risk information including maps can be utilized for Natech risk assessment purposes. However, not only extreme natural disasters but also high frequency-low impact hazards can result in cascading effects at individual installations if vulnerabilities exist and risks are not handled property (Pescaroli and Alexander, 2015). Therefore, such hazards should also be considered wherever possible.

Industrial risk control and prevention regulations usually focus on industrial production and storage facilities that are located onshore. In addition to these facilities, other industrial installations such as offshore platforms, onshore and offshore pipeline systems, and onshore transportation systems handling or storing hazardous substances should also be included in national Natech risk assessment. Consideration of hazardous military installations, mining activities, and polluted sites which are usually excluded from the conventional industrial risk management process, is also recommended for the sake of completeness of the assessment.

Because each natural hazard has the potential to affect different geographic areas with different intensities, some industrial installations are not vulnerable to certain natural hazards simply because they are not located within the impact area. Hence, they are not required to be assessed for possible Natech scenarios. However, the national Natech risk assessment should always start with the complete inventory and exclude installations on a case-by-case basis depending on location. Linear and networked infrastructure, such as pipeline and transportation systems, which usually cross long distances through a wide-range of climatic and geographical zones, require special consideration. Especially pipelines are usually located in the countryside where the detection of releases can be delayed, leading to major spills and significant economic damage particularly at special locations such as river crossings (Girgin and Krausmann, 2016). Time-variant operational characteristics should be further assessed for transportation systems.

If the number of industrial installations that should be analysed is numerous, a hazard ranking of the installations by using a preliminary but systematic methodology that considers Natech-specific constraints is suggested to select the most critical installations. For major natural hazards, which have a potential of multiple and simultaneous Natech events, not only major but also medium-sized installations should be included in the ranking, as they may result in a significant overall impact although their individual impacts may not be considerable. The list of upper and lower-tier industrial establishments covered by the Seveso III Directive (2012/18/EC) can be utilized as a baseline industrial facility inventory, which should be complemented with other industrial installations (e.g. pipelines, offshore platforms). As the tiers are determined according to the hazard characteristics and qualifying quantities of substances potentially present at the installations, the list can also be used for ranking purposes. In order to simplify the analysis, industrial parks or industrial zones where multiple installations are located in close proximity can be handled as single entities.

Following the identification of the Natech-prone installations, potential Natech scenarios should be developed for each installation. The main hazard scenarios in case of Natech accidents are fires, explosions and toxic releases. These hazards are obviously linked with the hazardous properties of the substances involved, but also with other factors such as, the substance inventory, the energy factor, the time factor, the intensity-distance relations, exposure and intensity-damage/injury relationships (Lees, 2012). All the methods available for hazard identification for conventional industrial accidents (e.g. checklists, hazard surveys, hazard and operability studies, and safety reviews) can be used for building Natech scenarios, provided that they take into account Natech-specific conditions:

— For a complete Natech analysis all the release events resulting from each possible damage mode should be addressed.

— Performance variations due to natural hazard impact should be introduced in the hazard identification and each release event should be fully developed

— Experts should carefully assess the potential unavailability or malfunctioning of industrial items, in particular barriers and protection layers

— Scenarios should consider not only the Natech-related release events but also their evolution given the potential contemporary unavailability of protection barriers and resources.

A damaged item is very likely to produce uncontrolled variations, but impacts on performance can be expected in undamaged items, as well. Examples of such scenarios are explosions of chemical reactors due to loss of reaction control or the release of substances into the environment, instead of being captured or thermally degraded.

Complex industrial processes may result in a large number of hazardous situations given the same operational deviations. Therefore, such scenarios should be carefully analysed when considering natural hazard conditions.

Natural-hazard specific mitigation measures (e.g. flexible connections, anchorage) may increase the resilience of equipment to certain natural hazards. It should be noted, however, that there is the misconception that structural and organizational protection measures in place to prevent and mitigate conventional industrial accidents would be sufficient to protect against Natech events (Krausmann et al., 2017). In contrast, the natural event that damages or destroys industrial buildings and equipment can also render unavailable safety instrumentation (e.g. sensors, alarms), engineered safety barriers (e.g. containment dikes, deluge systems) and lifelines (e.g. power, water, communication) needed for preventing an accident, mitigating its consequences and avoiding its further escalation. Generally, for conventional technological accidents, emergency management systems consider that all safety systems are available, while for Natech events many of these could actually be unavailable at the same time. Assumptions on the availability of safety measures and personnel drastically affect the Natech scenarios. Therefore, care should be taken in scenario development when considering Natech-specific conditions.

Electricity is critical for the proper operation of an industrial installation and it is a lifeline that might be unavailable due to natural hazard conditions. This includes the primary power grid, but also back-up generators. Cable snapping, short circuits and floods are frequent causes of onsite power loss at industrial installations. As documented in past events, power loss alone can trigger a Natech accident (ARIA, 2009). In addition, safety systems and barriers implemented to prevent or mitigate accidents may be unserviceable due to lack of electricity. Water supply, both external and internal, might also be unavailable in case of a major natural disaster. Underground pipes and connections, as well as water reservoirs, tanks, and pumping systems, are frequently damaged in earthquake, tsunami and flood events (Girgin, 2011). The natural disaster may either damage the equipment directly or cut the power supply required for its operation. Besides acting as the primary firefighting agent, water also serves for cooling purposes to control dangerous exothermic reactions. Therefore, a lack of water may not only hamper effective response activities, but may also result in adverse cascading events. Safety barriers play an important role in the prevention and mitigation of accidents. Due to natural hazard impacts, some or all of these systems may become unavailable or unserviceable. Affected barriers can be structural (e.g. containment dikes, deluge systems) or organizational (e.g. communication). For example, containment bunds lose their capacity to retain accidental spills during flood events. Similarly, firefighting equipment, such as sprinkler systems, can fail to activate after being damaged in earthquakes.

With respect to crisis response, onsite response teams may be hampered by natural hazard conditions. For instance, the industrial site may be flooded and may hence only be accessible by boat. In some cases, response personnel may be adversely affected by hazardous substance releases, rendering them incapable of combatting the consequences of the Natech accident. Fear and worry for their own lives and the lives of their families possibly affected by the natural hazard, can result in underperformance, as well. Offsite response teams may not always be available as they might be overwhelmed by having to respond to requests related to natural-disaster impacts on the population. In some cases, although they are available they may not be able to reach the accident site as access routes can be blocked or otherwise rendered unusable (Necci et al., 2018).

16.3 Risk analysis

Once the risk scenarios have been determined, the impacts of each scenario can be analysed by using available conventional methods that calculate the relations between natural hazard impact, physical or operational damage, release of hazardous substance, consequences of the incident, and the impact area. Analysis priority can be given to the scenarios which are expected to result in the highest impact. Natech risks should be considered in all impact categories, i.e. human, economic and socio political impacts. A Natech accident may not only result in short-term harm to public health and the environment, but also cause significant business interruption.

The severity of the hazardous consequences (i.e. fire, explosion, toxic dispersion) following the physical damage depends on several factors. The quantity of hazardous material and the rate at which it is released are probably the two most important factors. In conventional industrial risk assessment, different top events are often grouped into release categories having certain scenarios. This is because different top events, even though they originate from different mechanisms, could indeed release a similar amount of substance. This principle is at the basis of the bow-tie approach for industrial risk analysis and Natech incidents are no exception. Christou (1998) provides a generic but concise overview of the most common consequence phenomena and the associated models used in the analysis. TNO (2005) give a more detailed description of available models and the conditions under which they should be used.

The nature and the extent of the consequences also highly depend on the environmental conditions. For this reason, conventional industrial accident scenarios are generally built on assumptions regarding the typical conditions at the facility and its surroundings. For Natech scenarios, environmental conditions might be significantly different from such typical conditions. For example, in case of weather-related events (e.g. storm, hurricane) the atmospheric conditions are usually close to extreme and unstable conditions rather than typical stable conditions. Similarly, the release environment might be different from the normal environment (e.g. release into water instead of ground in case of flooding). For accurate results, such hazard-specific environmental conditions should be property considered in the analysis. For a coherent analysis, environmental data should be provided by the natural-hazard related authorities of the NRA to the experts performing the Natech risk analysis.

Natech accidents may result in exposed areas in all environmental compartments (i.e. air, soil, groundwater, and surface waters) that are much greater than for conventional industrial accidents. For example, if a flood causes an overflow of containment dikes at an installation, any released substance that would normally be captured within the containment dikes can easily be dispersed by the flood waters and contaminate the environment up to hundreds of kilometres through a river system (UNEP/OCHA, 2000). In the case of earthquakes, cracks that occur in containment dike floors due to ground movement may leak liquid substances that can eventually lead to significant groundwater pollution (Girgin, 2011). When the vulnerabilities due to the natural hazard are manifold, potential multiple releases from different parts of an installation and also from multiple installations simultaneously should be taken into account when assessing exposure. The possibility of on- and off-site secondary cascading events (i.e. domino effects) should be considered as well. In case of multiple simultaneous or cascading toxic releases, the overall extent of the toxic cloud can be significantly larger compared to a conventional chemical accident with a release from a single source.

The exposure and vulnerability of the population may also significantly vary during Natech conditions. For instance, when there is toxic atmospheric dispersion caused by an earthquake, shelter in-place might not be possible because of structural damage to buildings. Also, evacuation from the location of a Natech accident might not be feasible because of the blockage of escape routes by debris or flooding. In addition, people might be reluctant to evacuate a hazardous area if relatives are still trapped under the debris (Girgin, 2011). Such factors should be considered in undertaking exposure and vulnerability analysis.

In order to identify the Natech likelihood, the entire ensemble of industrial equipment at risk of damage (i.e. targets) should be assessed. Targets may sustain physical damage if the intensity of the natural hazard is sufficiently high or simply malfunction in case of lower impact severities. Damaged targets may directly release hazardous substances or trigger events that lead to loss of containment, while others can create an uncontrolled deviation in the system that can eventually result in a release. Some targets may have the responsibility to control or mitigate undesirable events; hence, their failure can contribute to a release or amplify the consequences.

Natech likelihood depends strongly on the vulnerability of equipment to the natural hazards at each site. Vulnerability to different natural hazards varies for a given equipment type. Atmospheric storage tanks, especially those with floating roofs, appear to be particularly vulnerable to natural hazards. This is critical from risk point of view, as these units usually contain largest amount of hazardous substances. In addition, in case of flammable releases the likelihood of ignition is high in earthquake and lightning triggered Natech accidents, which may escalate into major fires or explosions and result in cascading (domino) accidents (Krausmann et al., 2011). Physical damage is usually caused by buckling of the tank shell, displacement of the tank (e.g. by floating or shifting), external impact (e.g. collision with other equipment items), or collapse of tanks supports (e.g. foundation or legs) (GDL Natech, 2016). Other equipment (e.g. reactors, columns, separators, pumps, heat exchangers) also retain significant amounts of hazardous substances and can be affected by natural hazards similar to storage tanks. Onsite pipes and pipework are also frequently damaged by the displacement of equipment or by external impact such as collision with moving (e.g. floating, falling) objects usually launched by the natural hazard. In detailed Natech risk assessment, besides direct physical damage, indirect effects such as uncontrolled operational variations can also be assessed.

Unless detailed numerical methods are used, the conventional approach for the damage assessment is based on damage states (DS) which group different and possibly numerous damage conditions under a set of qualitative damage categories ranging from no damage (DS1) to total collapse (DS5). For most of the industrial equipment, historical Natech accident and near-miss data is used to deduce reliable damage probabilities for each damage state. Simplified fragility functions in the form of fragility curves are available for storage tanks for earthquakes (Fabbrocino et al., 2005), floods (Landucci et al., 2012), and lightning (Necci et al., 2013). However, these curves cover only specific conditions (e.g. equipment characteristics, operational conditions) and for other conditions and also for other equipment some expert judgement is usually necessary in the assessment process. Among all possible damage states, the actual damage state that may happen in case of a certain natural hazard impact depends on a number of factors such as construction characteristics (e.g. design criteria, material), current physical state (e.g. corrosion, aging, fatigue), and operative conditions (e.g. filling level, pressure). For this reason, it is hard to establish what damage state is to be expected for a given equipment for a given natural hazard scenario. Therefore, in most cases all plausible damage states should be analysed. Because the damage states are usually defined in qualitative terms (e.g. minor, moderate, extensive), it is difficult to associate a damage state to a well defined release event and the current practice is limited to the use of very generic scenarios that are based on expert judgement.

Each Natech scenario has a conditional probability of occurrence given a natural hazard trigger. The overall Natech event probability can be calculated by summing a set of conditional event probabilities including damage, release, and consequence-related events (e.g. ignition, explosion), which can be calculated by various methods (Lees, 2012). For estimating the conditional probability of release following a damage, the most simplified assumption is to select a single release scenario for each damage state. In reality, multiple release scenarios can be associated with each damage state by varying conditional probabilities. Unfortunately, there is no established method to determine conditional release probabilities in case of Natech accidents. Therefore, in case of multiple release scenarios for each damage state, conditional release probabilities are either taken as equal to one or assigned by expert judgment. It is usually recognised that the vulnerability of an asset changes if two independent hazards occur in a short time lapse. However, intermittent natural hazards, even if they are not major events may also affect the vulnerability of industrial equipment. For example, high flow conditions during medium-sized floods may increase riverbed scouring which reduces the cover on pipelines at river crossings, eventually leading to pipe breaks due to excess external forces or debris impacts (Girgin and Krausmann, 2016). Whenever it is feasible, such factors should be considered while estimating the probability of possible damage.

16.4 Risk evaluation

Being an inherent cascading multi-risk, the adequate evaluation of Natech risk requires proper handling and ranking of cascading risks in the NRA process. Natech risk can be evaluated:

- as a part of the risk assessment of a natural hazard in the so called multi-hazard risk analysis;
- as part of the risk assessment of technological hazards;
- as a separate dedicated risk assessment.

In the process of ranking the risks, it should be clearly stated if Natech risks are included for each risk, and how they are assessed. As a general rule, risks that include Natech risk assessment should not be directly compared with risks that do not include this assessment. Comparison could still be carried out, provided that the contribution of Natech risk was fully explicated. Keeping track of Natech risk contributions also allows the comparison of the level of Natech risk with the risk of the other natural and man-made hazards.

Consequences beyond the local extent are quite common especially if critical infrastructure is directly involved or affected by the Natech events, or if the impacts areas are extended, e.g. during floods. This results in amplified economic impacts, which can sometimes be as big as or much bigger that the impact of the natural hazard itself. For example, the March 5, 1987 earthquake in Ecuador (Ms 6.9) caused the destruction of more than 40 km of the Trans Ecuadorian Oil Pipeline due to massive debris flows following the earthquake. Approximately 100,000 bbl of oil spilled into the environment and the loss of revenue during the five months required for repair was 800 million USD, equal to 80% of the total earthquake losses (NRC, 1991). Therefore, it is important to quantify Natech damage not only considering the cost of direct physical damage, but also considering all cascading consequences. Similar to industrial and nuclear risks, the long-term adverse effects of released environmentally persistent and carcinogenic substances on human health and the environment should be evaluated for Natech risk while evaluating socio-economic impacts.

Besides ecological damage, large areas may become unfit for human use (e.g. agriculture, drinking water, living), and comprehensive clean-up and restoration may be needed. Especially groundwater and surface water clean-up operations are very costly and may require long time periods. Similar to other hazards, the socio-economic implications of Natech accidents are difficult to quantify. Nevertheless, historically all major Natech accidents have had a strong impact on both EU's and member states' policies. Therefore this aspect is important for overall evaluation.

The potential impacts of Natech accidents are numerous and target-specific. On top of this, the perception and tolerance of decision makers and the public to different types of technological consequence scenarios are usually very different. This makes difficult the quantification and evaluation of consequences, especially if they are originating from multi-cascading events. Usually a shared decision making by all stakeholders is required similar to the other hazards considered by the NRA. Specific to Natech risk, the stakeholder group should include both natural and man-made hazard related actors. The following guidelines may be useful for evaluation of the impacts:

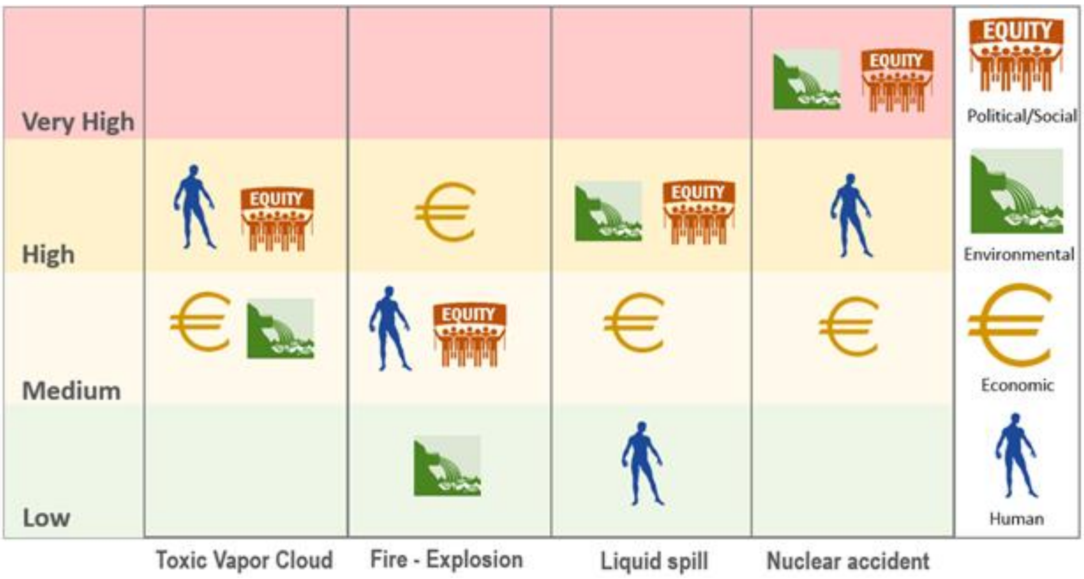
- Toxic vapour clouds may have the largest impact on the population, but lower impact on the environment and almost no impact on the asset.
- Fires and explosions may have the largest impact on the asset, but lower impact on the people and very low impact on the environment.

— Liquid spills of chemicals, solvents or fuels may have the largest impact on the environment, but lower impact on the asset and almost no impact on the population.

— Nuclear accidents with loss of radioactive material may have high impact on both the population and the environment and lower impact on the asset.

Figure 42 summarizes the expected maximum impact of some of the most common major accident typologies in case of Natech accidents.

Figure 42. *The maximum potential levels of socio-economic impacts as ranked for different types of consequences.*



The EU NRA guidelines emphasise the importance of a periodic review of NRAs to keep them updated as risks emerge and evolve. For Natech risks, such reviews should not only consider the changes in the natural hazard risks (e.g. due to factors such as climate change or availability of new information), but also changes in the industrial installations due to process or capacity modifications and upgrades, which are quite common during the operational lifetime of the installations.

Risk analysis methodologies for both natural and technological hazards have inherent uncertainties that need to be stated explicitly in the analysis phase and considered in the decision-making process. Because Natech risk assessment unites methods from both fields, it also compounds and amplifies uncertainties. Therefore the results should be evaluated with care. Documentation of the Natech scenarios and the analysis methods utilized to estimate the probable extent and impact of hazardous consequences is important not only for keeping track of uncertainties, but also for being able to merge and compare the results properly, especially if local or regional assessments are conducted as part of national assessment.

16.5 Good Practices

Being an emerging risk even in developed countries, Natech risk is hardly assessed by national competent authorities in a comprehensive manner. Although there are no detailed NRAs, there are national and international programs and regulations that require the assessment of Natechs in safety documents of hazardous installations and adoption of measures necessary to reduce the related risks. Usually these rules have been implemented in the aftermath of one or several major Natech accidents (Lindell and Perry, 1997).

In the European Union, Directive 2012/18/EC on the control of major-accident hazards involving dangerous substances (Seveso III Directive) that regulates chemical accident risks at fixed industrial installations explicitly addresses Natech risks and requires the installations to routinely identify environmental hazards, such as floods and earthquakes, and to evaluate them in safety reports. With its latest implementation, the directive also demands an assessment of accident scenarios triggered by natural hazard impact. In France, the new zoning regulation for industrial installations in seismic areas divides industrial establishments into two risk groups to identify Natechs risks and to facilitate emergency planning: normal risk and special risk (Decrees 210-1254[165] and 2010-1255[166]). Installations in the second category have to guarantee the containment of hazardous materials under seismic loading by complying with specific mechanical resistance requirements to ensure a structure's capability to withstand a given value of ground acceleration, chosen in accordance with the seismic zone it is in (Planseisme, 2016). In Germany, the rule TRAS 310 requires industrial establishments with major chemical accident potential to assess the risk of flood-triggered accidents at their installations, to take necessary risk reduction measures, and to consider the possibility of an increase of flood risk due to climate change (TRAS 310, 2012). They also introduce the innovative concept of "accident despite precautions", which requires the inclusion of Natech scenarios into emergency plans, even if their risk has been mitigated.

The Natech Addendum to the OECD Guiding Principles on Chemical Accident Prevention, Preparedness and Response contains amendments to the guiding principles for guidance on Natech accidents (OECD, 2015). In Japan, the Law on the Prevention of Disasters in Petroleum Industrial Complexes and Other Petroleum Facilities was updated after the Tokaichi-oki earthquake triggered several fires at a refinery in 2003 (CAO, 2012). Moreover, the amended Japanese High Pressure Gas Safety (HPGS) Law requires companies to take any additional measure necessary to reduce the risk of accidents, to protect its workers and the public from any accidental releases caused by earthquake and tsunami (Cruz and Okada, 2008). In the US, the state of California released the Accidental Release Prevention (CalARP) program, which calls for a risk assessment of potential hazardous materials releases due to an earthquake (CalARP, 2014).

No risk assessment tool that is currently available can capture all aspects of Natech risk. However, recently, risk assessment tools and methodologies capable of estimating regional Natech risk have become available. The JRC's Rapid Natech Risk Assessment and Mapping System (RAPID-N), which is publicly available at http://rapidn.jrc.ec.europa.eu, allows quick local, regional and national Natech risk assessment including natural hazard damage assessment and accident consequence analysis with minimum data requirement (Girgin and Krausmann, 2012; Girgin and Krausmann, 2013). Other available tools are ARIPAR for a quantitative treatment of the problem (Antonioni et al., 2009), and PANR for a qualitative assessment methodology (Cruz and Okada, 2008). Although currently limited to selected natural hazards and certain types of installations, the tools are in active development to cover additional hazards and industries, and they can significantly facilitate NRA studies.

16.6 Gaps and Challenges

A number of research and policy challenges and gaps exist that can prevent effective Natech risk management. These include a lack of data on equipment vulnerability against natural hazards, and the unavailability of a consolidated methodology and guidance for Natech risk assessment, which has, for instance, resulted in a lack of Natech risk maps. The few existing Natech risk maps are usually only overlays of natural hazards with industrial site locations and are therefore only Natech hazards maps. Proper Natech risk maps must also include an estimate of the potential consequences, which may differ significantly from site to site. Attention should be paid to the inherent limitations of existing equipment vulnerability models originating from non-Natech applications if these are used to substitute for Natech-specific models.

By analysing past Natech accidents, conclusions can be drawn concerning the vulnerability of industrial equipment to different natural hazards, common damage and

[165] https://www.legifrance.gouv.fr/eli/decret/2010/10/22/2010-1254/jo/texte
[166] https://www.legifrance.gouv.fr/eli/decret/2010/10/22/2010-1255/jo/texte

failure modes, and the hazardous substances mostly involved in the accidents. Incident databases are important tools for this purpose. The JRC's Natech accident database (eNatech) is such a database specifically designed for the systematic collection, analysis, and dissemination of worldwide Natech accident data. It is publicly available at http://enatech.jrc.ec.europa.eu.

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