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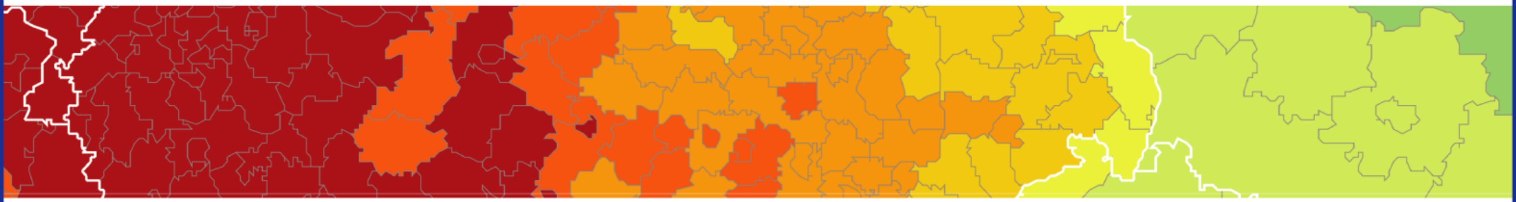

ESPON-TITAN
Territorial Impacts
of Natural Disasters

Applied Research

Final Report – Annex 2
Economic Impacts Analysis

June 2021

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ESPON-TITAN
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Abbreviations

CCA	Climate Change Adaptation
CGE model	Computable General Equilibrium Model
DDM	Damage Distribution Matrix
DRM	Disaster Risk Management
DRMKC	Disaster Risk Management Knowledge Centre
EDO	European Drought Observatory (JRC)
EC	European Commission
ESPON	European Territorial Observatory Network
ESPON EGTC	ESPON European Grouping of Territorial Cooperation
EU	European Union
GDP	Gross Domestic Product
GVA	Gross Value Added
GFCF	Gross Fixed Capital Formation
I/O	Input-Output
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
MRIO	Multi-Regional Input-Output
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne in french, or Statistical Classification of Economic Activities in the European Community
NUTS	Nomenclature of Territorial Units for Statistics
SCGE model	Spatial Computable General Equilibrium Model
SPI	Standardized Precipitation Index
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNISDR	United Nations International Strategy for Disaster Reduction
WISC	Windstorm Information Service

Glossary

- **Capital stock:** In economics, capital stock refers to the assets that are used in the production of goods and services, or in other words, the production assets of an economy. "The total value of the buildings, machines, etc. within a particular economy, which are used to produce goods and services" (Cambridge Business English Dictionary).
- **Damage:** Total or partial destruction of physical assets existing in the affected area[1].
- **Damage function:** Damage functions are used to translate the magnitude of a (natural) hazard into a quantifiable damage on infrastructure, economic assets, ecosystems, etc.
- **Damage distribution matrix (DDM):** DDM is a matrix in which each element (one number in the matrix) represents the distribution (or weight) of the total costs among the affected NUTS3 areas and among the five capital stocks for each NUTS3 region, i.e., it gives you the weight of the cost per capital stock for a specific event level.
- **Direct impacts** consist of the direct damage to assets such as buildings, factories, houses, infrastructure, etc. This concerns the cost of repair or replacement of the assets that were damaged or destroyed (Trinomics et al., 2015).
- **Indirect impacts** refer to the fact that direct loss of capital translates into a loss of production capacity, which affects many parts of the economy, leading to losses of business activity (Trinomics et al., 2015).
- **Economic Loss:** Monetary value of total or partial destruction of physical assets existing in the affected area[1].
- **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." (UNDRR, 2017).
- **Impacts:** The effects on natural and human systems of extreme weather and climate events, generally referred to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructures (IPCC AR5).
- **Impact Pathway:** It is a conceptual model that defines the link between a natural hazard and its direct and indirect economic impacts.
- **Natural hazard:** “process or phenomenon that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" (UNISDR, 2009).
- **NUTS classification:** The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU and the UK. NUTS2 level are the basic regions for the application of regional policies. NUTS3 level are the small regions for specific diagnoses.

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[1] https://www.unisdr.org/files/45462_backgoundpaperonterminologyaugust20.pdf

1 Introduction

One of the aims of the ESPON-TITAN is the here presented development of a global and a local methodology to analyse the direct and indirect economic impact of natural hazards in Europe at global level (applicable across all European countries using available data) as well as at local level (applicable at national, regional and local level for countries where DRM is well advanced and more data is available). To estimate the direct and indirect economic impact of natural hazards across Europe with the global methodology, related disaster economic losses were disaggregated among several capital stocks (inferred from land-use) and among the affected regions to feed into an I/O model for assessing indirect sectoral and regional impacts on a yearly basis between 1995 and 2017. Whereas the global methodology develops a generic damage assessment framework, based on cost estimates from available databases, the local methodology focuses on two specific test regions where impacts are assessed based on more detailed cost estimates. For both levels, the impacts of the four types of natural hazards are analysed at NUTS3 level.

This report follows the following structure:

- Chapter 2 presents the Impact Pathways to establish the link between natural hazards and direct and indirect economic impacts;
- Chapter 3 presents the application of the global methodology. This section starts by discussing the development of the global methodology and then presents the results of the global analysis;
- Chapter 4 presents the application of the local methodology. In this section, the two test regions as well as the local methodology are introduced. In the next sub-sections, the results of the analysis of the two test regions are presented. The section finishes with a short comparison between the outcomes of the global and local analyses to reflect on both methodologies;
- Chapters 5 presents the conclusions and discussion;
- Three annexes were included to this document, which give further details on: reflection on data sources, impact pathways and construction of DDMs.

2 The Impact Pathways

Impact Pathways establish the link between natural hazards and direct and indirect economic impacts. Their description is qualitative, thus not constrained by data availability, and shows the typical direct and indirect economic impacts, how and when they are triggered, the impact category they relate to, mitigation actions typically taken before or during the event, and, lastly, response and recovery actions taken in the aftermath of a disaster. This is based on a detailed literature review and selected cases for desk analysis. The purpose of this analysis is to reveal more information on how different hazards affect the economy, and to provide valuable insights to be used in the global methodology.

The insights gathered through the Impact Pathways drew a comprehensive picture of the total direct and indirect impacts of the investigated natural hazards. Through this essentially mapping exercise, it is possible to determine which of these impacts can be quantified in the global methodology and which remain of a qualitative nature. Moreover, these qualitative impacts, which would remain invisible without the Impact Pathways, are now recognised and further analysed in the context of the selected case studies investigated under the local methodology.

Although each hazard has its own distinct Impact Pathway, which is influenced by different factors (Annex 2.B), when aggregating the impact areas and pathways of the four hazards, they overlap in many ways. The Impact Pathway presented in Figure 2.1 reflects the desk research findings and summarises the direct and indirect impact link for the four hazards.

Floods tend to heavily damage buildings and their contents, followed by transport and infrastructure, resulting in relatively long recovery periods (e.g., for businesses), and agriculture (Jonkman et al. 2008; de Moel, Vliet, and Aerts, 2014; Merz et al., 2010; Rojas et al., 2013; Koks et al., 2019). **Droughts** seem to mainly affect agriculture, together with water and energy supply (Logar and van den Bergh 2013; Stahl et al., 2016). **Windstorm**'s direct impacts are similar to those of floods as buildings and infrastructure are the main damages (Becker, 2015). However, their indirect economic impacts are short lived as most of the power lines are quickly fixed (Seattle office of Emergency Management, 2014). In case a windstorm is accompanied by a coastal flood, it causes significant secondary effects. **Earthquakes** can damage buildings, their contents and critical infrastructure for the production and delivery of goods and services. Earthquakes can also have a negative impact on the availability and the productivity of human capital (Earle, 2015). The reviewed literature (Seville et al., 2014) indicates that the negative economic consequences of earthquakes are partly offset by a subsequent period of increased economic activity, due to higher spending on infrastructure and reconstruction.

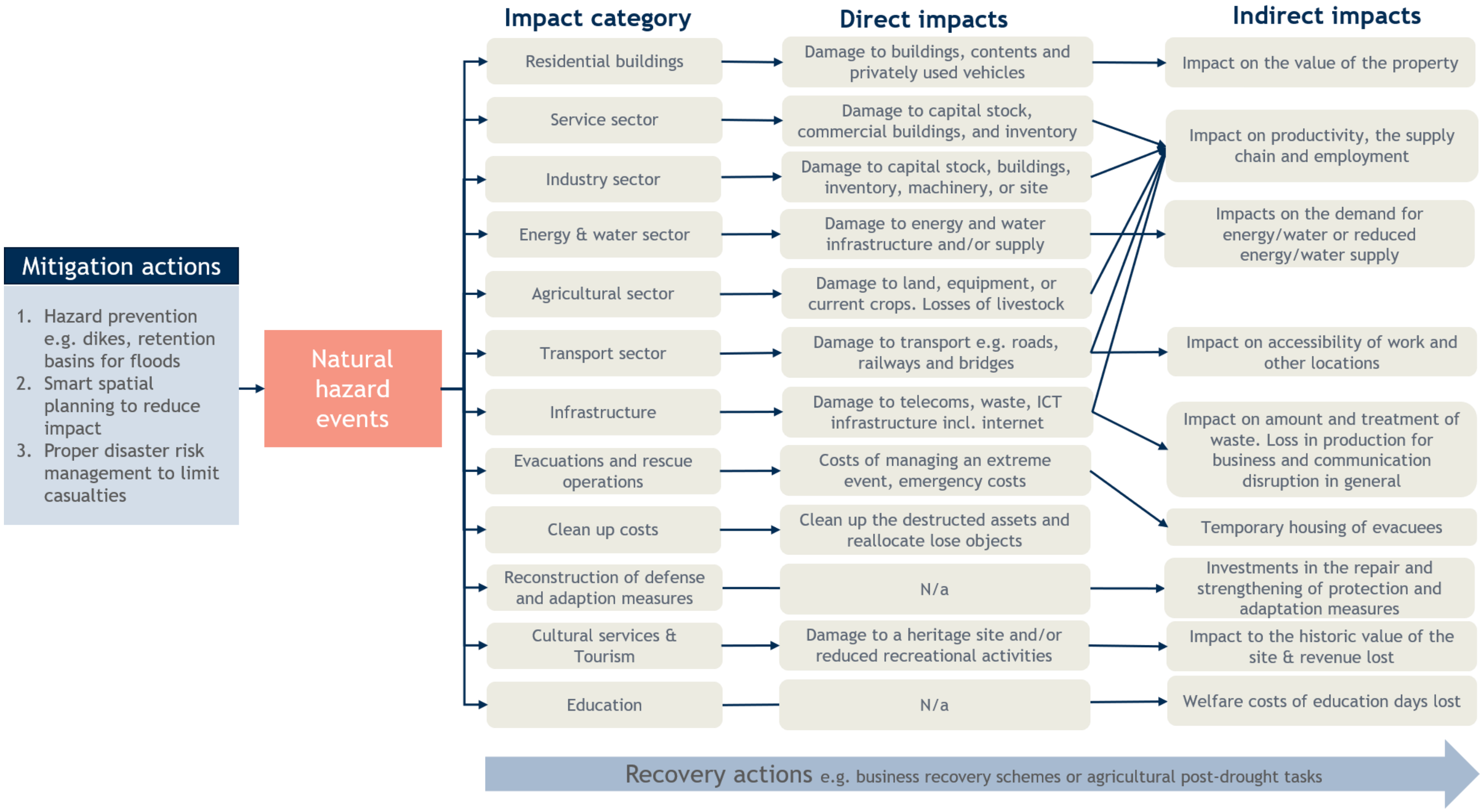


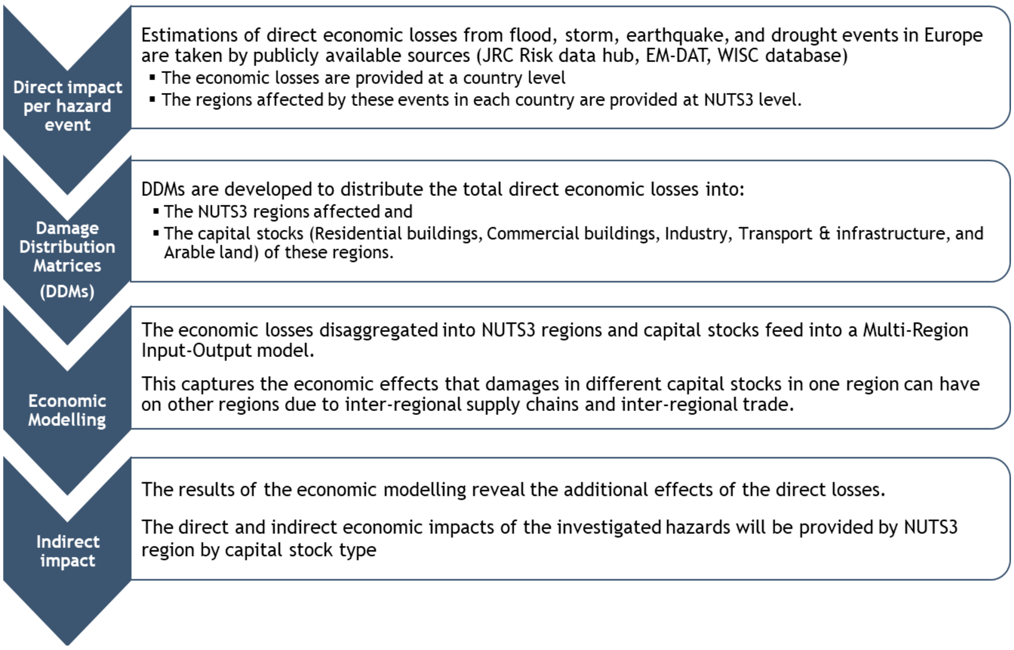
Figure 2.1 Combined Impact pathway for floods, droughts, windstorms and earthquakes

3 Application of the global methodology

3.1 Global direct and indirect economic impacts of natural hazards

For the global methodology, the direct economic damages of the four hazards, as recorded by publicly available databases, are analysed in order to identify their indirect effect on European regional economies. According to our methodology, these indirect impacts emerge due to spill over effects across the supply chain at NUTS3 regions. To estimate these indirect impacts, the global methodological approach stipulates a number of steps.

Figure 3.1 Steps followed for the development of the global methodology



Estimations of direct economic losses from flood, storm, earthquake, and drought events in Europe are taken by publicly available sources (JRC Risk data hub, EM-DAT, WISC database)

- The economic losses are provided at a country level
- The regions affected by these events in each country are provided at NUTS3 level.

DDMs are developed to distribute the total direct economic losses into:

- The NUTS3 regions affected and
- The capital stocks (Residential buildings, Commercial buildings, Industry, Transport & infrastructure, and Arable land) of these regions.

The economic losses disaggregated into NUTS3 regions and capital stocks feed into a Multi-Region Input-Output model.

This captures the economic effects that damages in different capital stocks in one region can have on other regions due to inter-regional supply chains and inter-regional trade.

The results of the economic modelling reveal the additional effects of the direct losses.

The direct and indirect economic impacts of the investigated hazards will be provided by NUTS3 region by capital stock type

The initial step in the global methodology is the collection of data on the direct economic losses caused by natural hazards in Europe. The available sources include the JRC Risk Data Hub for floods, the EM-DAT for droughts and earthquakes, and the WISC database for windstorms (see Annex 2.A Overview and evaluation of validity and reliability of data and *data source*s to be used for the economic impact analysis: Table 7.1 and TextBox 7-1) for more information on the databases). In this sense, two crucial pieces of information are of interest: (i) the total economic losses of hazard events per country, and (ii) the NUTS3 affected regions by each of these events.

The direct economic losses at a national level, as given by the databases, cannot be used directly in the estimation of the indirect impacts. Since the indirect impacts emerge due to changes in inter-regional supply chains and trade flows, the direct economic impacts from national level have to be disaggregated into losses per affected NUTS3 region, and per capital stock.

Capital stocks refer to the assets that are used by different sectors in the production of goods and services; specifically, for this analysis, the five selected are:

- Residential buildings;
- Commercial buildings;
- Industry;
- Infrastructure and transport;
- Arable land.

Using an Input-Output (I/O) framework, the model can translate changes in capital stocks (e.g., damage from floods) into changes in the level of output of economic sectors in other regions.

Damage Distribution Matrices (DDM)[2] were developed to disaggregate national losses into losses per capital stock and per NUTS3 region. As particular NUTS3 regions are affected by events at different levels, and their capital stocks are exposed to a distinct degree, the development of the DDMs varies depending on the examined hazard, as following:

- **Floods:** we use global depth-damage functions by Huizinga et al. (2017), to determine the level of damage per capital stock caused by a flood event. A damage function describes the relation between a hazard intensity parameter and the relative direct damage cost in different sectors of the economy. ‘Flood depth’ is used as an indication of intensity;
- **Windstorms:** we rely on the WISC Revised Tier 3 Loss Indicators[3]. These indicators provide major storms in the EU estimates of economic losses per NUTS3 region, as well as the split among different sectors at country level;
- **Earthquakes:** we look at past earthquake’s events and categorize the proportion of damages on capital stocks according to the impacts of these disasters;
- **Drought:** DDMs are built based on the assumption that capital stocks receive a proportional loss according to their water consumption levels.

The DDMs per hazard is explained in more detail below. However, for a full description, please see Annex 2.B Impact Pathways.

In order for the DDMs to distribute the economic losses among the five capital stocks, the exposure of the NUTS3 regions affected by a disaster is also considered in the case of flood and earthquake DDMs. Exposure refers to the inventory of elements (buildings, infrastructure, and other tangible assets) in an area where hazard events may occur. To determine the exposure of each NUTS3 region affected by a flood or an earthquake event, we looked at land-use data in each of the affected regions. The share of land dedicated to a specific use (e.g. agriculture, manufacturing, etc.) is applied to approximate the composition of capital

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[2] A DDM is a matrix in which each element (one number in the matrix) represents the distribution (or weight) of the total costs among the affected NUTS3 areas and among the five capital stocks for each NUTS3 region. In other words, a DDM gives you the weight of the cost per capital stock for a specific event level.

[3] https://wisc.climate.copernicus.eu/wisc/#/indicators

stocks within each NUTS3 region. Through this, the damage share of each capital stock also depends on how much of this capital stock is present in a given NUTS3 region. Since the DDMs for windstorms are developed based on the WISC database, which already provides disaggregated losses, the exposure of the related affected regions is not required. For the development of the drought DDMs, exposure of the affected regions was also not considered, as the methodology developed did not account for land-use differences.

As mentioned, the economic losses are given by the databases at country level, which does not fit the framework of our analysis, which focus on regional impacts. Therefore, the DDMs are used to also distribute the total country losses to the affected regions. To disaggregate national losses into regional, we look at the levels of capital stocks in each affected NUTS3 region. The share of each region's capital stock value, from the total value of capital stocks in all affected NUTS3 regions, represents the share of economic losses attributed to this NUTS3 from the reported total economic losses. Note that for windstorms, the distribution of total losses among NUTS3 regions is already given by the WISC database. Likewise, earthquake DDMs do not need to consider such distribution because they have a very localised effect, affecting only one region at a time.

The estimated capital stock losses feed into a Multi-Regional Input-Output (MRIO) model, which is able to translate capital stock losses in one region into changes in sectoral output in other regions. Through this, the indirect impacts of disasters are revealed through the spill over effects they cause across the supply chain at NUTS3. The regional and sectoral capital stocks estimations have been developed by Cambridge Econometrics, using various public databases, including EU-KLEMS and Eurostat.

As a result, an overview of economic impacts per natural hazard at NUTS3 is generated, including both direct and indirect effects of all the analysed disasters. An illustration of these results is given by the distribution of those economic damage and losses along the European territory in terms of monetary value and selected related economic indicators.

3.1.1 Database

For the type of analysis followed in this study, and for maximizing the accuracy of the results, the input data used in the economic modelling should cover a sufficient number of events. Therefore, the disasters considered in our methodology should cover a long time period. At the same time, the reliability of the economic loss estimates from disasters tends to decrease in older disaster records. In addition, the older the disaster records, the less possible to satisfy our data needs (e.g. NUTS3 affected regions may not be provided in older disaster records). To ensure a long-term coverage without risking the reliability of the data, this analysis includes disasters from 1995 onwards. In respect to the geographical coverage, the analysis is done at

NUTS3 for all ESPON territory. The multi-regional I/O table, which is a core part of the economic impact analysis, covers 250 European NUTS2 regions[4].

Following ESPON-TITAN rationale, the natural hazards considered in the global methodology include floods (154 events, 25 countries), droughts (11 events, 9 countries), windstorms (31 events, 21 countries) and earthquakes (6 events, 4 countries). The respective damage costs are taken by public databases: for floods and earthquakes, we use JRC's economic losses estimations from the JRC Risk data hub[5]; for windstorms, we rely on the events recorded by the WISC project, which also includes the estimation of their economic losses per sector[6]; drought economic losses are taken by the EM-DAT database[7]. The date of the event, the affected NUTS3, and the reported economic losses per event, were extracted from these databases. For the analysis of the damage costs, estimates of regional and sectoral capital stocks varied by type of stock is needed. The detailed regional capital stock estimates were built using publicly available databases, such as EU-KLEMS, Eurostat, Cambridge Econometrics regional database, which in turn present different systems of recording disaster losses (Annex 2). The construction of these estimates is done by type and NACE economic sector, disaggregating EU-KLEMS 2017 database to NUTS2.

3.1.2 Methodology for economic impact calculations

A Europe-wide methodology was developed in ESPON-TITAN to quantify trends and territorial patterns of economic impacts of natural hazards affecting different NUTS3. The correspondent results offer a wide perspective of the distribution of those economic damages and losses in terms of monetary value and selected related economic indicators (e.g., employment and GDP or GVA). For that, certain assumptions were made, such as the aggregation of NUTS3 capital stock damages to NUTS2, aiming its link to the I/O table structure. Thus, the estimated economic figures should always be viewed as best estimates of hazard events' total actual impacts, at the most detailed territorial level achievable (NUTS3).

There are, of course, limitations to the applied methodology – both with regards to the direct and the indirect economic impact calculation. For the key limitations of our approach to direct and indirect economic impact estimation and our solution to address these limitations, please see TextBox 7-2. Overview of the limitations of the data sources used for the direct impact estimationsTextBox 7-2 and TextBox 7-3 in the Annex 2.A Overview and evaluation of validity and reliability of data and *data sources* to be used for the economic impact analysis.

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[4] https://wisc.climate.copernicus.eu/wisc/#/indicators

[4] https://wisc.climate.copernicus.eu/wisc/#/indicators

to the EU and time coverage of dataset – 2000-2010), and consequently cannot be included in the I/O impact assessment.

[5] Disaster Risk Management Knowledge Centre - DG JRC - Directorate for Space, Security and Migration (2017). DRMKC Risk Data Hub. Available at: https://drmkc.jrc.ec.europa.eu/risk-data-hub/

[6] https://wisc.climate.copernicus.eu/wisc/#/

[7] https://www.emdat.be/

3.1.3 Direct economic impact calculation

The first step in economic impact assessment is to calculate the direct economic impacts of the examined natural hazards on key economic sectors, by deriving impact of events on the five investigated capital stock types (Commercial buildings, Residential buildings, Industry, Infrastructure and Transport, Arable land) and translate the impact on capital stock into impact on economic sectors (the key dimension of interest in our economic impact assessment). For this, three key types of input data are used:

1. **Regional (NUTS2) capital stock estimations:** In order to translate the economic losses/damages attributed to each natural disaster into real economic losses by specific geographical regions and sectors, we need to estimate regional and sectoral capital stocks varied by type of stock. This is done using a number of publicly available databases (EU-KLEMS, Eurostat, Cambridge Econometrics regional database). The construction of the detailed regional capital stock estimates is done by type and NACE economic sector, disaggregating EU-KLEMS 2017 database[8] to the NUTS2[9].
2. **Damage distribution matrices (DDMs):** they provide damages of the natural hazard events per capital stock type, per NUTS3. More specifically, through the established DDMs, the impact of different extreme events in economic terms, in relation to the value of the damage to the different types of capital stock, may be quantified.
3. **Estimation for the distribution of total regional capital stocks across NACE Rev.2 economic sectors, by NUTS2:** It links the capital stock damage to the broader economic sectors of interest (Agriculture, Industry, Construction, Wholesale, Retail, Transport, Accommodation and Food services, Information and Communication, Financial and Business Services, Non-market services). For this calculation, we build capital stock type per economic sector cross-distribution matrices for each country, based on national level (Eurostat data on the cross-classification of fixed assets by industry and by asset types), representing the distribution of each capital stock type across the relevant economic sectors. This gives an indication of what share of the ‘Financial and Business Services’ economic sector accounts for within total ‘Commercial buildings’ type of capital stock of a specific country. This step thus determines the first-order direct impacts of the examined natural hazards on the five investigated capital stock types, by specific geographical regions (NUTS2) and economic sectors.

Our approach of direct economic impact assessment is comprehensive in terms of results and coverage, however, the public databases from which input data was collected are different with regards to their classifications used for economic activities, or their coverage of European regions (for example, the Eurostat dataset for the cross-classification of fixed assets by industry

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[8] http://www.euklems.net/

[9] A similar exercise has been done in PBL-led Horizon2020 MONROE project for a subset of the capital stocks from EU-KLEMS.

and by asset types does not cover Bulgaria, Malta and Sweden – thus, relevant proxy countries were used, selected based on GDP/capita measures and fixed capital formation structure).

3.1.4 Indirect economic impact calculation

The first-order direct impacts of the examined natural hazards on the five capital stocks are used as input to an I/O framework in order to assess additional effects through supply chains. These constitute the indirect economic impacts of the disasters in each NUTS3.

To identify the impact of any given natural hazard on a region's economy, we use a MRIO model, that is a regional-economic model that allows the translation of the previously calculated changes in capital stock types in a specific region (or set of regions) into changes in the levels of output of economic sectors in other regions. It models the economic effects of damages in different capital stocks in one region (e.g., a flood) on other regions due to inter-regional supply chains and inter-regional trade flows.

In this part of the analysis, a linear relation is assumed between changes in the capital stock in a specific economic sector, and output of that specific economic sector (by each NUTS2). The (temporal) loss of the capital stocks leads to the reduction of the sectoral outputs during a certain period of time until the stocks are not recovered to the initial state. Direct damages are translated into the reduction of regional and sectoral capital stocks by type, which results in the loss of output and of regional incomes (wages and capital returns).

The analysis uses the PBL-JRC EUREGIO database at NUTS2 as the basis for the natural disaster MRIO model. This MRIO database covers 250 European NUTS2 regions from EU26[10], and the UK, as well as 14 industries within each NUTS2. Furthermore, it also covers other non-EU-countries (at national level, not NUTS2) and the 'rest of the world'. For integrity reasons, the analytical approach requires supply chain linkages to be represented globally (thus between European NUTS2 and non-European regions as well). The scope of the current study does not require a detailed representation of non-EU regions, thus all countries not falling under the EU26 and the UK, whereas included in the PBL-JRC MRIO database, are treated as one aggregated group with regards to their I/O relations to the European NUTS2 (included as 'Rest of the World').

While our approach of indirect economic impacts assessment seeks to be comprehensive in terms of results and coverage, the public databases from which input data was collected are different with regards to their coverage of European regions or time coverage.

Our two-step approach implies that while some of the analysed region and industry combinations are only impacted indirectly (through supply chain linkages, calculated in the I/O modelling part), there are region and industry combinations that are subject to both direct impacts (induced by direct damage to capital stock) and indirect impacts (i.e. those induced by

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[10] Excluding Croatia (not included in the I/O dataset).

disruption of economic activities in other linked regions). To tackle the risk of double counting impacts in these regions and industries, we measure the separately calculated economic impacts against each other in the affected regions, and report whichever is larger in a given time period (year), assuming that the other is essentially offset in these cases.

3.1.5 Key results of the global approach

An important insight from total damage data used in the global analysis, applicable for all the analysed years, is that indirect economic impacts, induced in specific regions by a disruption of economic activities in other, linked regions tend to be almost as large as direct impacts. Direct impacts are those damages resulting from a natural disaster hitting a region directly (geographically happening there), while indirect impacts are derived through the use of I/O tables, making use of the observable linkages of economic sectors across regions and countries. The ratio of indirect impacts to direct impacts falls between 60% and 90% in all of the assessed years.

The spatial distribution of the economic impacts indicates that Central, Eastern and Southern European countries tend to be relatively most affected by these types of hazards, in economic terms. This is partly due to the GVA of these regions being relatively lower (compared to, e.g. Northern European countries), thus a certain event may cause a relatively larger damage, compared to their local GVA. This further implies that these countries are highly recommended to derivate their own measures to mitigate the effects of these events (cross-border initiatives cannot be concluded with the used datasets). Besides Central, Eastern and Southern European countries, results of the economic impact assessment indicate that certain NUTS3 areas of the UK and Ireland, Denmark, France and Spain are also highly affected by one or more natural hazard event types across the period 1995-2017.

For two of the investigated hazard types (droughts and windstorms), data availability allows for a comparison of the historical severity of hazards and the average yearly economic impacts the hazards across the same period (1995-2017). The comparison of the hazard’s historical severity and the average economic impact show considerable spatial correlation in case of both droughts and windstorms. The key policy-relevant implication of these findings is that historical data of hazards’ severity and occurrence, combined with a modelling of the economic impacts of the hazards through multi-regional input-output tables can be a powerful tool in estimating future potential economic damages caused by hazard events in specific economic sectors at the NUTS3 level.

4 Application of the local methodology

In this chapter, the local methodology is applied on two test regions. By using the finetuned data inputs, we recalculated the direct and indirect economic impacts. As such, this chapter start by introducing the two test regions, followed by a short summary of the local methodology. In the next section, we discuss the finetuning of the damage distribution matrices and the results of the recalculated direct and indirect impacts. The chapter end with a short conclusion and discussion section.

4.1 Introduction

4.1.1 Prague, Czech Republic

The first test case study is that of Prague, Czech Republic. In 2013, Central Europe was affected by a severe flooding, mainly caused by the heavy rainfall in a number of already saturated river basins (Lorencová et al., 2016). Czech Republic was one of the most heavily affected countries. According to the JRC's Risk Data Hub (2020), the total cost was EUR 623 million including 19 000 people affected and 15 fatalities. Prague has been the municipality worst affected by the flood in economic terms (Daňhelka et al., 2014).

In 2002, a flood with a probability of once in 500 years, hit Czech Republic, causing far larger damages with a total damage cost of EUR 3377 million. Prague took relatively a large share of these damage costs (approximately 1 million Euros) as the city had to be partly rebuilt its historical centre and its transport system was heavily affected (Daňhelka et al., 2014). The authorities came under intense criticism for being unprepared. After this event, the city invested millions in adaptation measures consisting of flood protection measures and disaster response management (Lorencová et al., 2016).

4.1.2 Charente-Maritime, France

The second test case study is that of Charente-Maritime in France. In 2010, several European countries were struck by a major weather depression, the Windstorm Xynthia. Storm Xynthia was not an exceptional storm (maximum wind speeds of 160 km/h), but it was one of the deadliest because it coincided with a phenomenon of high-water spring tide. This resulted in a fairly exceptional rise in water levels, causing a flood that led to the death of 59 people and significant material damage. The windstorm covered a vast area of Europe with rural and urban regions affected in eight EU Members States.

In France, the storm caused almost EUR 2.5 million of damage (French Insurance Association, 2011). Around 500,000 people suffered material damages in France due to the storm (Genovese et al., 2012). The combination of strong winds and high tides resulted in a storm surge which caused major flooding in some coastal regions, mainly in Charente-Maritime, Vendée, and Côtes-d'Armo (Liberato et al., 2013). Failure of coastal flood defences led to widespread flooding along the coast and the death of 47 people in France alone

(Liberato et al., 2013). The region of Charente-Maritime has been selected for this case study as it suffered the highest number of damages (37.6% versus 16.4% in Vendée), including 12 fatalities (French Insurance Association, 2011).

4.2 Methodology for economic impact calculation

Our approach for the local methodology is similar to the global methodology apart from that the former uses detailed information derived from local data sources (bottom-up approach). Moreover, more qualitatively analysis is done in the local methodology to capture impacts, such as environmental and social, for which EU-wide data is not available and cannot be considered by the quantitative global methodology. Subsequently, to assess additional effects through the supply chain, the same I/O framework as in the global methodology is used. As the inputs to the I/O model are finetuned, the results and thus the estimated additional effects through the supply chains are more precise.

4.2.1 Finetuning of the Damage Distribution Matrices

The first step of the local methodology is to finetune the Damage Distribution Matrices (DDMs) for the two test regions. The initial DDMs are calibrated with more sophisticated data inputs, which results in more accurate damages impacts for the test regions, compared to the global methodology.

In order to find precise information about capital stocks for each selected NUTS3 region (same capital stock estimates were used for the global methodology) we analysed local data sources and consulted relevant stakeholder (e.g. via interviews).

4.2.2 Indirect economic impact calculation

The I/O analysis, as applied in the local analysis for the two relevant test years (2010, 2013) essentially uses the same I/O datasets and the same DDMs as the global analysis for all the hazard events happening in these years except for the DDMs of the two case studies, in which cases the new, finetuned (and thus more robust) DDMs are used to capture the direct and indirect damages caused.

In terms of the development of a CGE model relevant for disaster impact analysis, and in order to assess the long-term effects of various type of natural hazard events, we have used the dynamic Spatial Computable General Equilibrium (SCGE) Model that operates at NUTS2 for EU28 and uses the same MRIO database as the I/O analysis for calibration of its main parameters. The model incorporates the representation of regional producers, consumers, governments, inter-regional trade, migration and capital flows. The SCGE model was run for the period of eight years after the extreme event, for each of the chosen two extreme events cases, in order to determine the medium-term direct (in the region itself) and indirect (in other regions via supply chains, migration and capital market) effects of the extreme events. Given that the model is dynamic and runs over time periods we show the recovery paths for each of the cases in time and for each of the economic sectors. We make the SCGE model consistent with the I/O analyses by using the same core MRIO database, same functional forms for the final demand and production functions, as well as the same data for various type of capital stocks.

In order to model the effects of an extreme event in the SCGE model, we use the data on DDMs in combination with the detailed regional capital stocks that are used in the production process. Extreme events result in the loss of various regional capital stocks that can be fully or partially recovered via additional investments. For example, the loss of labour stock cannot be recovered via additional investments whereas the loss of building stock or machinery and equipment can be recovered via extra investments. These recovery process leads to extra expenditures on various capital goods and services and less expenditures on other types of consumption and investments (so-called crowding-out effects). Capital goods and services can be purchased in the same region or in other regions of Europe and countries of the world which leads to indirect effects of the recovery process. The medium-term impacts of an extreme event on regional GDP and sectoral value added, income of the households and regional employment are investigated using the SCGE model. Where possible, the results are compared with the outcomes of the I/O analysis.

4.3 Finetuning of the Damage Distribution Matrices

4.3.1 Prague, Czech Republic

Global DDM

Based on the calculations for the global methodology the following event-specific Damage Distribution Matrix (DMM) and NUTS3 specific DDM were developed for the flood event in 2013 in Czech Republic. As illustrated in Table 4.1, the estimated damage costs for Prague (NUTS CZ010) and its surrounding region is estimated at around EUR 63 million. Moreover, Table 4.2, shows the distribution of the costs for Prague among the 5 capital stocks used in this study. The DDM for Prague is the starting point, and based on an in-depth analysis to be further finetuned.

Table 4.1 Event DDM for flooding of 2013 in Czech Republic (based on global methodology)

NUTS3	Damages (thousands of Euros, 2013)	Share of damages (%)
Prague (CZ010)	63 806	10
Central Bohemian region (CZ020)	240 539	39
South Bohemian Region (CZ031)	71 450	11
Ústí nad Labem Region (CZ042)	210 056	34
Pardubice Region (CZ0530)	37 886	6
Total (2010 price levels)	623 739	100

Table 4.2 NUTS3 DDM for Prague for flooding of 2013 in Czech Republic (based on global methodology)

Prague (CZ010)	Damages in thousands of Euros, 2013	Share of damages
Residential buildings and their contents	€ 5411	8%
Commercial buildings and their contents	€ 16 675	26%
Industrial buildings and their contents	€ 2077	3%
Infrastructure and Transport	€ 39 623	62%
Arable land	€ 19	0%
Total (2010 price levels)	€ 63 806	100%

The DDM is finetuned in two ways:

- The number of capital stock is expanded by the following capital stock/damage categories:
    - Emergency costs: consisting of evacuation costs (evacuation services and shelters provided by the city districts) and cleaning costs and other expenses (costs of cleaning, demolitions, refill of the grit underlying infrastructure and other costs which are not a part of any other category).
    - Cultural costs: damaged works of arts, library collections, teaching aids and leisure facilities for the event in 2002.
- Moreover, we include local sources such as the report by the Czech Hydrometeorological Institute and Ministry of Environment of the Czech Republic (2014) and the reports from the Czech Insurance Association (2013). These sources are complemented with an interview with the head of the Technical Infrastructure Unit of the Institute of Planning and Development of the Capital City of Prague (IPR Prague) as well as informal contact with Czech Hydrometeorological Institute.

Finetuning local DDM

The floods in June 2013 affected a large part of the territory of the capital city of Prague.

The most affected administrative districts include Prague 7 (Troja), Prague 16 (Lipence, Lochkov, Velká Chuchle, Zbraslav) and Prague 10 (see Figure 4.1) (Interview data). In the district of Troja, the Zoo was partly flooded and closed for several months. District 16 is on the outer part of the City and therefore also suffered damages to agricultural land. The central areas (including the historical centre) were not heavily impacted as they were protected by the post-2002 developed flood protection measures. At the same time, in areas prone to flooding, certain activities (e.g. schools, hospitals, industries) were removed (interview data).

The most significant damage was done to Prague's extensive network of sewers and underground pipes (interview data). In the following months, there were complications in the operation of public services, such as sewers, and long-term traffic restrictions due to repair works. In addition, damages were reported to other infrastructure and a large number of properties belonging not only to the city, but also to private owners. Other major damage was caused by the rise of groundwater (flooding of cellars) and the rise water from a damaged sewerage network. The biggest damage occurred in the immediate vicinity of the Vltava and Berounka rivers.

Figure 4.1 Floodplain map of the flood in 2013. Source: Institute for planning and development of Prague (IPR) (2020)

Table 4.3 Description of damages per damage class

Prague (CZ010)	Damages	Source
Residential buildings and their contents	596 houses were damages and 2 were destroyed	Daňhelka et al. (2014)
Commercial buildings and their contents	- Damage to the lower part of Prague Zoo in Troja are estimated at around 6.172 thousand of Euros - In Czech Republic, more than 180 school buildings and facilities, 22 health facilities and 29 social care homes were damaged.	Radio Praha (2013)
Infrastructure and Transport	Parts of all three city metro lines were closed. The transit authority provided alternative transport in the form of buses and special trams.	Radio Praha (2013) & Daňhelka et al. (2014) Stepankova et al. 2013.
Evacuation costs	- 1 280 people were evacuated in Prague - Estimated costs for the Fire Rescue Service of the Czech Republic increased by 2.7 million euros during the floods and immediate response of their effects. The Police of the Czech Republic quantified their costs of dealing with the flood situation to 50 thousand Euros	Daňhelka et al. (2014)
Flood defence	One thousand troops from the Czech Army were called in to help build flood defences	The Sun (2013)
Environmental costs	A total of 187 wastewater treatment plants reported damage, and the wastewater treatment process was affected by the floods at a total of 233 wastewater treatment plants, including 29 large wastewater treatment plants with an operating load of above 10 000 equivalent inhabitants.	Daňhelka et al. (2014)
Cultural costs	Dozens of cultural monuments were damaged.	Daňhelka et al. (2014)

Combing the public costs (Stepankova et al., 2013) and the estimated insured costs[11] by the Czech Insurance Association (2013) results in the following DDM. The Table 4.4 shows that private properties and infrastructure and transport suffered that most damages. Given the large damages to the infrastructure, the share between public spending is 61% versus 39% of insured losses. In addition, the emergency cost (rescue and evacuation service and police work) was EUR 277 392. These costs are not included in the DDM.

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[11] These costs were only presented for the whole Czech Republic. The numbers for Prague are based on the author's own calculations.

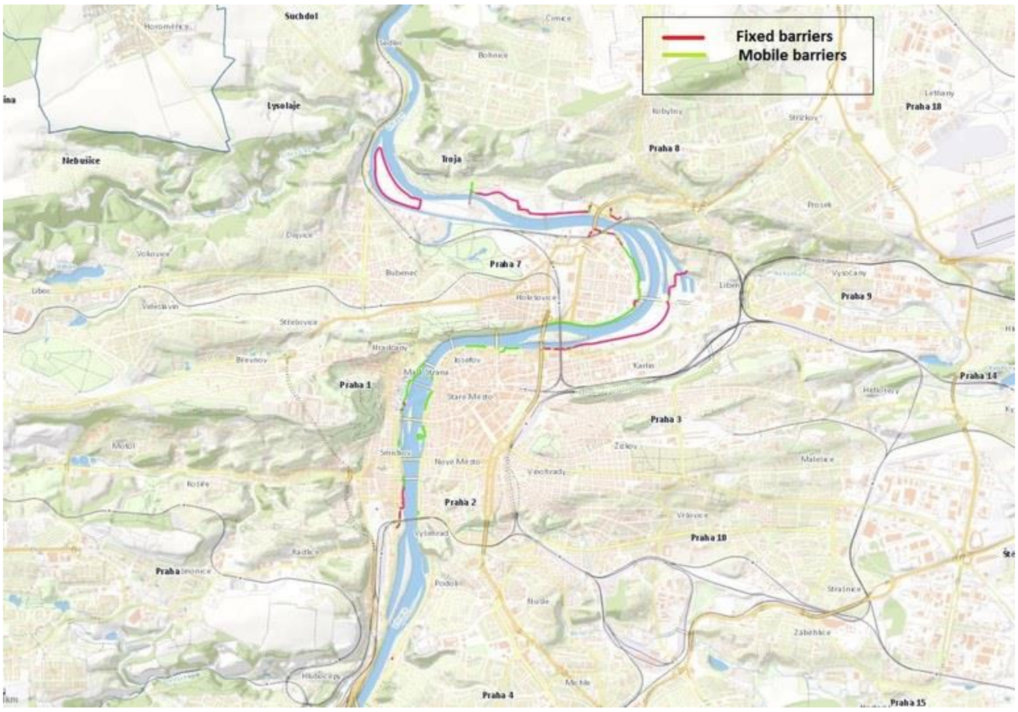
Table 4.4 Final local damage distribution matrix for the flood in 2013. Cost in thousands of Euros

	Private	Industry & commercial	Farming	Transport & infrastructure	Other	Total
Insured losses in euros (2013 price level)	75 808	19 849	877	-	-	96 534
Public losses in euros (2013 price level)	11 178	11 263	2 701	84 502	38 560	148 205
Total in euros (2013 price level)	86 986 1	31 112	3 579	84 502	38 560	244 739
Share of losses	36%	13%	1%	35%	16%	100%

Mitigation measures between 2002-2013

After the severe flood event in 2002, the city council of Prague took several mitigation and adaption measures, consisting of seven stages, which all finalised in 2013. Measures consisted of structural (engineering solution such as water reservoirs and flood defences) and non-structural measures (awareness raising, disaster response management, risk transfer tools, monitoring and management) (Lorencová et al., 2016). In the Figure 4.2, the flood protection measures are illustrated. In detail, the structural measures included linear structures with a total length of 17.5 km, of which almost 6.4 km are formed by mobile flood barriers (Daňhelka et al., 2014). In total, the anti-flood barriers capable should be able to withstand a flow rate of 3 700 m^3/s (Radio Praha, 2013).

Figure 4.2 Overview of the structural flood protection measures for the city of Prague



Source: EEA (2016)

The mitigation and adaptation costs were calculated to be around EUR 154.3 million (see Table 4.5) (Lorencová et al., 2016). Based on a cost-benefit analyses performed by Lorencová et al. (2016) it was concluded that the benefits are greater than costs for a flood with a return period of 50 years or more.

Table 4.5 Mitigation measures

Flood protection measures 2014	Extent in meters	Costs in Thousands of Euros (2013 price level)
Fixed measures	12 460	
Mobile measures	6795	
Heavy mobile measures	130	
Total costs		154 320
Installation costs (per event)		0.65 million
Maintenance + storage (annual)		0.89 million

Source: Lorencová et al., (2016) and interview data

After the flood in 2013, a set of 69 flood protection measures, implemented after 2002 were evaluated. The evaluation included the flood protection measures that were under construction in June 2013 (Daňhelka et al., 2014). Out of the 69 flood protection measures, 45 measures were fully functional. Notably, in Prague the flood protection measures showed to be effective as the areas designated for protection were not flooded. The exceptions were only local problems caused especially by extreme flows in the tributaries of the Vltava River (Botič, Rokytka) or a malfunction of measures relating to the sewerage system (Daňhelka et al., 2014). The local authorities of Prague also learned about the effects of certain crops as for instance the rapeseed plant appeared not to be suited for flooding as it serves as a barrier which prevents the water from flowing. As a result, some areas experienced the same water depth as was measured in 2002 (Interview data).

Discussion and conclusions

The flood in 2013 brought around 245 million euro of damage costs to the city of Prague. The largest share (36%) of the damage costs was directed to private properties such as houses. The underground system of sewage and cables was heavily damaged (35%). Commercial and industry buildings and their contents were damaged to a lesser extent.

Although the data input for the local analysis is more detailed than the data input for the global analysis, there are some limitations to our methodology and data inputs which should be considered when reading our results:

- Especially for the local methodology, we depend heavily on the reporting (and the accessibility and readability) of local authorities and insurance associations. We have included all the available reports on costs and damages. However, as there are different ways of reporting for different institutes (i.e. the Czech Insurance Association and the government), there is a risk that certain costs are double counted for. To avoid these risks, we had informal contacts with authors of certain reports and an interview with the Prague Institute of Planning and Development.

- The insured costs were only presented for the whole of Czech Republic. The numbers for Prague are based on our own calculations. We used, for instance, the share reported damages to residential buildings in Prague to assume the insured costs to residential buildings. We validated our assumptions by looking at historical events.
- For the damage costs for the flood in 2002 we only had information about the total costs of the event. For the distribution of the costs among the capital stocks, we have made our own calculations based on the study by Lorencová et al., (2016).

Comparison of the global and the local DDM

There is a large difference between the global DDM and the local DDM (Table 4.6) for the case study of Prague. The total of the global DDM totals EUR 63 million for the region of Prague whereas the total of the local DDM is EUR 245 million. This can be explained by the high damages to Prague's extensive network of sewers and underground pipes (interview data) which is not considered in our global methodology. Moreover, the house prices are almost three times higher in Prague than the rest of Czech Republic, which results in higher damage costs for residential buildings. This parameter is not included in the global methodology. The DDMs in Table 4.6 show different percentages for the damages per capital stock. There is for instance a large difference between the share for residential buildings and their contents, which can be explained by the high house prices (among others). In the global DDM the share for commercial buildings and their content, together with the industry capital stock, is higher than the share in the local DDM. Both DDMs report high damages for infrastructure and transport and low damages for agricultural land. The comparison for the indirect impacts is discussed below (see results of the I/O analysis).

Table 4.6 Overview of the global and local DDM for the flooding in Prague in 2013

Prague (CZ010)	Global DDM	Global DDM	Local DDM	Local DDM
	Estimated damages in thousands of euros, 2013	**Share of damages**	**Estimated damages in thousands of euros, 2013**	**Share of damages**
Residential buildings and their contents	**5410**	**8%**	**86 986**	**36%**
Commercial buildings and their contents	**16 675**	**26%**	**31 112**	**13%**
Industrial buildings and their contents	**2077**	**3%**	**Included in the number above**	**Included in the number above**
Infrastructure and Transport	**39 623**	**62%**	**84 501**	**35%**
Arable land	**19**	**0%**	**3578**	**1%**
Other	**0**	**0%**	**38 560**	**16%**
Total (2010 price levels)	**63 806**	**100%**	**244 739**	**100%**

4.3.2 Charente-Maritime, France

Global DDM

Based on the calculations for the global methodology the following NUTS3 specific DDM was developed for the windstorm event in 2010 in Charente-Maritime (FR532). As illustrated in Table 4.7 the damage costs for Charente-Maritime is estimated at around EUR 74.5 million. The table also shows the distribution of the costs for Charente Maritime among the 5 capital stocks used in this study.

Table 4.7 DDM for Charente-Maritime (based on global methodology) after the storm in 2010

Charente-Maritime (FR532)	Damages in thousands of Euros, 2010	Share of the damages
Residential buildings and their contents	44 921	60%
Commercial buildings and their contents	3874	5%
Industrial buildings and their contents	3874	5%
Infrastructure and Transport	843	1%
Arable land	20 970	28%
Total (2010 price levels)	74 482	100%

The DDM for Charente-Maritime as developed for the global methodology is the starting point and based on an in-depth analysis to be further finetuned. This is done through three ways:

- **Inclusion of damages due to coastal flooding:** The DDM for the global methodology concerning the Xynthia 2010 event gave an estimate of the damages based on the WISC tier 3 indicators database. The WISC project focused only on damages caused by strong winds and did not take into account the possible flood damages caused by storms (WISC, n.d.).
- **Inclusion of local sources:** The DDM for the local methodology relies on data gathered from local sources to achieve a more precise distribution of damages among capital stocks caused by the wind and the coastal flooding together. The analysis is based mostly on the reports of the French Insurance Association (*Association Française de l'Assurance*) (2011), which analysed the economic damages of Xynthia. The report gives an estimate of the total damages caused by Xynthia for the Charente-Maritime regions as well as the share of damages due to the wind and the flooding. Observation and information reports by the Département de la Charente-Maritime (2012) and the Assemblée Nationale (2010) are also included. In addition, we had informal exchange of information with the Nouvelles Aquitaine Development Durable office, to verify our data sources and findings.
- **Information beyond the 5 capital stocks:** The number of capital stock applied, is expanded by following category: Emergency costs: consisting of evacuation costs and cleaning costs.

Finetune local DDM

The following damages were reported:

- 5000 houses were damaged in Charente-Maritime of which 120 were completely destroyed (French Insurance Association, 2011);
- 4563 car insurance claims were issued (French Insurance Association, 2011);
- The agricultural sector has been severely affected: 350 farms in Charente-Maritime were damaged, covering more than 45 000 hectares, which amounts to 10% of the overall surface area of agricultural lands in this department). Most of the land was flooded during the marine submersion. The land is affected by the salt water and would be infertile for several years (Assemblée Nationale, 2010; HKV lijn water and Rijkswaterstaat, 2010);
- The oyster farms and other aquaculture were heavily damaged along the coastlines. They suffered damage to their installations and equipment on land (buildings and equipment destroyed). It was estimated that nearly 900 aquaculture farms in Charente-Maritime were affected (Sénat, 2010). Some reports even state that oyster and shellfish farmers are, in fact, the occupations that have been hit hardest by Storm Xynthia (Sénat, 2010);
- Salt marshes growers also experienced losses with an estimated total of 420 000 € (Assemblée Nationale, 2010);
- The tourism sector experienced also quite some losses as camping sites were washed away and hotels were damages (HKV lijn water and Rijkswaterstaat, 2010). In La Rochelle, a major touristic seaside town, the area around the old harbour encountered serious problems due to the flood (HKV lijn water and Rijkswaterstaat, 2010);
- Xynthia also caused major power failures. More than 1 million French households had no power, among which were many households in the regions of Charente-Maritime, Pays de la Loire, and the regions of Auvergne, Centre and Limousin (Bersani *et al*., 2011);
- The coastal railway between La Rochelle and Rochefort could not be used for several weeks. The tracks near the coast got undercut by the flood water and became unstable (Bersani *et al*., 2011);
- Many infrastructures were affected. It is estimated that around 200 kilometres of dikes and dunes were damaged by the storm, but also non-insurable goods of local authorities such as roads (Anziani, 2010); and
- In total, the emergency service conducted 16 500 interventions. This is about 45% of the annual number of interventions by emergency services. 900 firefighters were mobilized, as well as civil security units to deal with the risk of interruption of communication routes, psychological help was provided by associations led by the hospital of La Rochelle (Assemblée Nationale, 2010).

Based on the reported damages, it is calculated that the total damage is EUR 795 million. Of this amount, EUR 556 million derive from insured losses and EUR 239 million of losses were covered by public spending (see Table 4.8).

According to the French Insurance Association (2011), 88.1% of the insured losses were due to the flooding and 11.9% due to the wind in Charente-Maritime.

Table 4.8 Total costs of the Windstorm Xynthia - in thousands of Euros

	Total insured losses for Charente-Maritime	Total losses covered by public spending	Total
Windstorm	66 221	28 381	94 602
Flooding	490 259	210 118	700 377
Total	556 480	238 500	794 980

DDM for wind

The report of the French Insurance Association (2011) shows the amount of losses for three categories: Private, Automobile, Agriculture, and Professional. The Professional category includes our study's Industry/Commercial capital stock category. Assuming that speed of the wind is the same across one NUTS3 area, we can distribute the Industry/Commercial land losses according to historic (windstorms in 2008-9) distribution of damages among these two capital stocks as can be shown in the Table 4.9.

Table 4.9 Damage Distribution Matrix for the damages caused by the wind - in thousands of Euros

WIND	Private property	Automobile	Industry	Commercial	Farming	Infrastructure & transport	Total
Share of insured	63%	11%	12%	12%	3%	0	100%
Insured losses	41 521	7 549	7 632	7 632	1 887	0	66 221
Share of public spending	0%	0%	1%	1%	70%	28%	100%
Public spending	53	0	207	334	18 995	7 578	27 168

DDM for Flooding

The flooding caused major damages in sixteen municipalities in Charente-Maritime. The flooding was not prevented by the dikes and dunes of the area. In some cases, the dikes were too low (for instance near La Faute-sur-Mer and Aytré) however in other cases the dikes fail (Île d'Oléron). It was also reported that water entered the villages from behind the flood defences. The flood killed at least 8 people. The DDM for the flood is as follow:

Table 4.10 Damage Distribution Matrix for damages caused by the flooding - in thousands of Euros

FLOODING	Private property	Automobile	Industry	Commercial	Farming	Infrastructure & transport	Total
Share of insured losses	56%	8%	4%	17%	15%	0	100%
Insured losses	275 525	40 201	20 420	81 681	72 431	0	490 259
Share of public losses	0%	0%	1%	1%	70%	28%	100%
Non-insured losses	393	0	1 532	2 473	140 629	56 109	201 136

Combined DDM

Combining the insured losses with the reported public costs for both wind and flooding results in the following DDM:

Table 4.11 Final Damage Distribution Matrix for the Windstorm Xynthia - in thousands of Euros

WIND and FLOODING combined	Private	Automobile	Industry	Commercial	Farming	Infrastructure & transport	Total
Share of losses per category	317 493	47 750	29 792	92 120	233 941	63 687	784 784
Losses per category	40%	6%	4%	12%	30%	8%	100%

Other costs

In addition, EUR 10 million for emergency costs has been reported (Bersani et al. 2011; Département de la Charente-Maritime, 2012). These costs are included in the overview of costs in Table 4.8.

Conclusion and discussion

The region of Charente-Maritime suffered substantially from the windstorm of Xynthia. Almost 90% of the damages relate to the coastal flooding damaged private properties, agriculture land and aquaculture equipment, and commercial and industry buildings and their contents. As the region is touristic, the damages between industry and commercial are mostly allocated to commercial. It is interesting to see that a big share of the public spending was directed to the agriculture and shell farming and the rebuilding of infrastructure such as roads and dikes.

Even though the local analysis is more detailed than the global analysis, there are several limitations that need to be considered:

- Reports from public authorities do not make a distinction between damages caused by storm and damages caused by flooding. As such, we used the share identified by the French Insurance Associations.
- The damages to industry and commercial buildings and their contents were reported under one category. To disaggregate this damage class, we used the share that was find for Vendee as this region experienced almost the same type of damages from Xynthia as Charente-Maritime.

- Reports of different government levels discussed the same type of costs. As such, there is a risk that some costs (for instance emergency costs) have been double counted as they were reported by the municipalities and by the Department of Charente-Maritime.
- We were dependent on the documentation of the French Insurance Association and the public authorities. As such, there is risk that not all costs are included in our calculation. In addition, the costs of agriculture and aquaculture was discussed in many public reports which enabled us to find a substantive amount of costs for this category. However, there was less information on the damage to industry and commercial buildings which resulted in a lower share of the costs in our calculations.

Comparison between the global and the local DDM

There are large differences[12] between the global DDM and the local DDM for windstorm Xynthia. However, one should keep in mind that the global DDM only reflects the damages from the storm and omits the damages from the flood. In total there is a difference of around EUR 20 million difference between the global and local DDM for windstorm[13] (Table 4.12). As such, the global DDM deviates here 20% from the local DDM. Zooming in the distribution among the capital stocks, it shows that both DDMs allocate the largest share of damages to residential buildings and their contents (60% versus 45%) and to arable land (28% versus 22%). We only see a large difference for 'infrastructure and transport' as the local DDM distributes 7 percentage points more damages to this capitals stock than the global DDM. Despite their differences, it seems that the two DDMs tell the same story.

Table 4.12 Overview of the global and local DDM for windstorm Xynthia

Charente-Maritime	Global DDM	Global DDM	Local DDM	Local DDM
	Estimated damages in thousands of euros, 2010	**Share of the damages**	**Estimated damages in thousands of euros, 2010**	**Share of the damages**
Residential buildings and their contents	44 921	60%	41 573	45%
Automobile	0	0%	7 549	8%
Commercial buildings and their contents	3 873	5%	7 966	9%
Industrial buildings and their contents	3 873	5%	7 839	8%
Infrastructure and Transport	843	1%	7 578	8%
Arable land	20 970	28%	20 881	22%
Total (2010 price levels)	**74 481**	**100%**	**93 389**	**100%**

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[12] The difference between to global and the local DDM totals 720.497 thousands of Euros.
[13] The emergency costs are not included in the final numbers

4.4 Calculation of the direct and indirect impacts at local level

4.4.1 Prague, Czech Republic

Results of the I/O analysis

The results of the economic impact assessment, when applying the local approach and using its finetuned data, clearly show an increase in the calculated economic damages (in terms of drop in economic output) compared to the global methodology for the 2013 flooding event in Prague. While the change is rather marginal at the total ESPON area NUTS3 level (2% increase in total damages for the year 2013), the finetuned damage calculations of the local approach resulted in a 157% increase for the relevant NUTS2 region CZ01, compared to the initially calculated economic damages under the global approach.

Results of medium-term analysis with SCGE model

Direct and indirect impacts on GDP

This section of the report describes the results of simulation runs with the SCGE model in case of the flooding event in 2013 in Prague.

We model this extreme event through the loss of the sectoral of capital stocks in the year 2013 and gradual recovery through additional capital investments in the five years that follow the extreme event. Besides the loss of capital, we also model additional governmental expenditures associated with handling the extreme event where both the investments needed for recovery of capital stocks as well as the additional governmental expenditure are financed through a decrease in the households' consumption budget.

We calculate the impacts on GDP of the region directly affected by the extreme event, rest of the European country where the region is located, the rest of EU28 and the rest of the world. The impacts are calculated compared to the baseline projection where the economic growth of various regions follows the long-term growth projections of the latest EU Aging Report of DG ECFIN[14].

Figure 4.3 shows that the negative effect of the extreme event is not being fully recovered in the medium-run and it looks like the region is ending up in a different lower growth path because part of the global investments is being relocated towards other regions and countries that were not hit by the extreme event and did not lose their productivity and productive capacity for a number of years. Rest of EU28 and rest of the world (ROW) experience slight positive effects because they have become more productive and competitive due to the inflow of additional investments and hence have higher levels of production as compared to the baseline. The rest of the country on the other hand has slight negative effects because it has been affected negatively by the decline in the production capacity of the affected region through the supply

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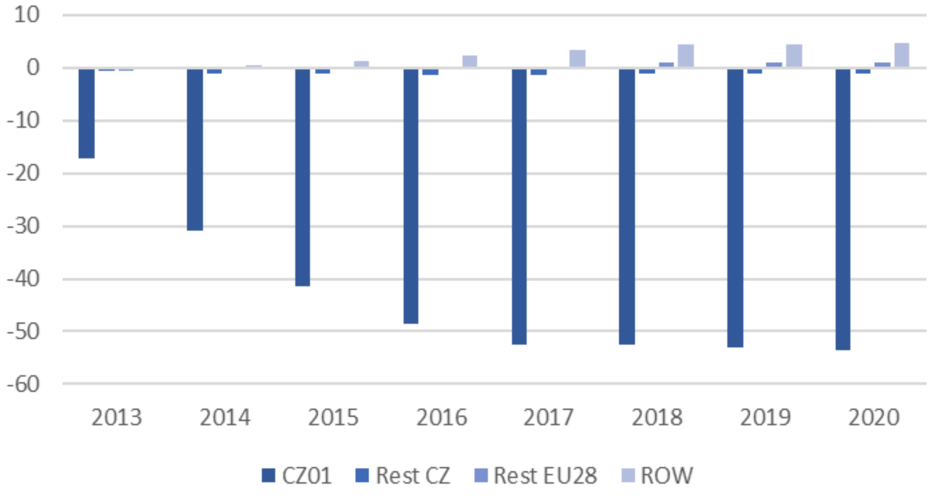
[14] https://ec.europa.eu/info/sites/info/files/economy-finance/ip079_en.pdf

chains. In case of the rest of the country the positive impact of the inflow of extra investments does not compensate for the negative impacts via the supply-chains.

The magnitude of the indirect effects is relatively small which is explained by the fact that the economy of Prague is dominated by the services which do not have as large supply chain effects as the industry. The indirect effects are related to the additional purchases of goods and services for reconstruction of the lost capital stock, this involves a lot of construction services that are local and do not lead to large indirect effects in other regions and countries.

Initially in the year 2013 the GDP of the affected region falls with about 0.05% and other the period of the following five year the level of the capital stock is recovered and the GDP growth between 2013 and 2020 is about 3.4%. However, despite the economic growth in this period the level of GDP remains lower than in the baseline scenario.

Figure 4.3 Medium-term direct and direct impacts on GDP in millions of Euros



Source: SCGE model

Sector-specific impacts

Flood in Prague in 2013 has destroyed the capital stocks of different sectors of the economy that has led to reduction of their output levels as compared to the baseline. The most affected sector is the Agriculture followed by Industry and Other services sector that includes transportation that has been affected by the event (see Table 4.13). The levels of production for all the sectors increase during the recovery process but they remain lower as compared to the baseline levels, meaning that the extreme event has put the region on another slightly lower growth path.

The sector which output is positively affected by the extreme event in the years of the recovery process is the construction sector. This is due to an increased demand for construction services that are needed to reconstruct buildings, plants and infrastructure damaged by the extreme event. Despite the temporarily positive effect even this sector ends up with the level of production lower as compared to the baseline due to indirect negative effects via the supply chain since the other sectors of economy have lower production levels. The only sector that is positively affected by the extreme event is the sector of non-market services. This could be explained by the fact that this sector provides services for households not only in Prague but also outside of this region.

Table 4.13 Sectoral development as compared to the baseline scenario, where baseline values are 100

	2015	2016	2017	2018	2019	2020	2021	2022
Agriculture	98.98	98.18	97.57	97.17	96.97	96.98	96.98	96.98
Industry	99.91	99.85	99.80	99.76	99.75	99.75	99.75	99.75
Construction	100.11	100.11	100.11	100.10	100.10	99.99	99.99	99.98
Other market services	99.92	99.85	99.80	99.76	99.75	99.75	99.75	99.75
Financial, business services	99.96	99.94	99.92	99.90	99.89	99.90	99.90	99.90
Non-Market Services	99.98	100.00	100.02	100.03	100.04	100.09	100.09	100.09

Source: SCGE model

4.4.2 Charente-Maritime, France

Results of the I/O analysis

Similarly to the Czech case study, the results of the economic impact assessment also increase largely when applying the local methodology’s more detailed data. The calculated economic damages (in terms of drop in economic output) due to the Xynthia windstorm are almost eight times higher under the local methodology than under the global approach for the total NUTS2 region FR53 – however, it is important to note that in the case of the Xynthia hazard event, the global methodology only accounted for the windstorm damages induced by the event, while the more sophisticated local methodology included both the windstorm damages and damages induced by the related flood event. The Xynthia event clearly had an impact on other regions and countries (other than NUTS3 region FR532) as well, and the impact on these other regions / countries is captured through the I/O table’s supply chain impacts, as indirect impacts.

Results of medium-term analysis with SCGE model

Direct and indirect impacts on GDP

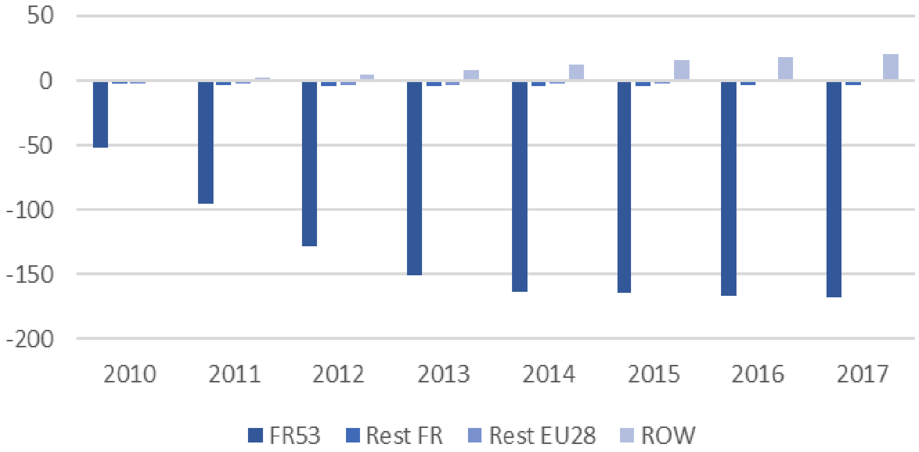
This section of the report describes the results of simulation runs with the SCGE model for the world in case of the storm event in 2010 in the region Charente-Maritime in France (see Figure 4.4).

We model this extreme event in the same way as the previous one, but using other data related to the sectoral damages, which means that the results are also different. We calculate the impacts on GDP of the region directly affected by the extreme event, rest of the European country where the region is located, the rest of EU28 and the rest of the world. The impacts are calculated compared to the baseline scenario. The negative magnitude of this extreme event is higher as compared to the flood in Prague due to higher damages.

Figure 4.4 shows that the negative effect of the extreme event is not being fully recovered in the medium-run and it looks like the region is ending up in a different lower growth path because part of the global investments is being relocated towards other regions and countries that were not hit by the extreme event and did not lose their productivity and productive capacity for a number of years. In case of this extreme event only the rest of the world experience slight positive effects because they have become more productive and competitive due to the inflow of additional investments and hence have higher levels of production as compared to the baseline. The rest of the country as well as the rest of EU28 on the other hand has slight negative effects because it has been affected negatively by the decline in the production capacity of the affected region through the supply chains. In this case the positive impact of the inflow of extra investments does not compensate for the negative impacts via the supply-chains.

The magnitude of the indirect effects is again relatively small but somewhat larger as compared to the previous extreme event in Prague. Initially in the year 2013 the GDP of the affected region falls with about 0.2% and other the period of the following five year the level of the capital stock is recovered and the GDP growth between 2013 and 2020 is about 3.2%. However, despite the economic growth in this period the level of GDP remains lower than in the baseline scenario.

Figure 4.4 Medium-term direct and direct impacts on GDP in millions of Euros



Source: SCGE model

Sector-specific impacts

The storm event in 2010 in the region Charente-Maritime in France has destroyed the capital stocks of different sectors of the economy that has led to reduction of their output levels as compared to the baseline. The most affected sector is the Agriculture followed by Industry and Other services sector that includes transportation that has been affected by the event (see Table 4.14). The levels of production for all the sectors increase during the recovery process but they remain lower as compared to the baseline levels, meaning that the extreme event has put the region on another slightly lower growth path.

The sector which output is positively affected by the extreme event in the years of the recovery process is the construction sector. This is due to an increased demand for construction services that are needed to reconstruct buildings, plants and infrastructure damaged by the extreme event. The only sector that is positively affected by the extreme event is the sector of non-market services.

Table 4.14 Sectoral development as compared to the baseline scenario, were baseline values are 100

	2015	2016	2017	2018	2019	2020	2021	2022
Agriculture	97.03	94.67	92.89	91.70	91.11	91.13	91.14	91.15
Industry	99.91	99.83	99.77	99.73	99.71	99.70	99.70	99.70
Construction	100.30	100.30	100.30	100.30	100.29	100.00	100.00	99.99
Other market services	99.64	99.34	99.11	98.96	98.88	98.87	98.87	98.87
Financial, business services	100.01	100.01	100.00	100.00	100.00	99.99	99.98	99.98
Non-Market Services	100.01	100.08	100.13	100.16	100.18	100.24	100.24	100.24

Source: SCGE model

5 Conclusion and discussion

5.1 Comparison between the economic models

The Cambridge Econometrics' I/O framework and SGCE model are applied for the assessment of short and medium-run effects of the two chosen extreme events in Prague (Czech Republic) and Charente-Maritime (France). These two modelling frameworks capture both direct and indirect effects of the extreme events. Direct effects captured in the models are related to the loss of production capacity and hence reduction in production volumes due to the loss of various types of capital stocks coursed by the extreme events. Indirect effects captured by the two modelling frameworks include in case of I/O model inter-sectoral and inter-regional linkages through the supply chains and in case of SCGE model also the impacts via the relocation of capital investments and migration. The indirect effects in SCGE model are expected to be lower as compared to the I/O model since SCGE model allows for adjustments along the supply chains which could partially mitigate the negative impacts of the extreme events.

Difference of the effects between the economic sectors are explained by the magnitude of the loss in sector-specific capital stocks due to the extreme event as well as whether the sector supplies goods and services needed during the recovery process. Construction sector may experience temporary positive effects (as compared to the baseline) since its services are needed for reconstruction activities. Other sectors that have lost their capital stocks are affected negatively and even after the recovery of their capital stocks to the original levels their growth path remains lower as compared to the baseline.

5.2 Comparison between the local and global outcomes

Comparing the local outcomes with the global outcomes for the two case study regions of Prague and Charente-Maritime, shows that the local methodology results in higher reported direct damages due to the inclusion of detailed data on the damage costs.

Moreover, the local outcomes show that the direct damages increase to a relatively larger extent than indirect damages in the case of the flooding in Prague. For the test region of Charente-Maritime, the change to direct and indirect impact is similar with the I/O framework for the local methodology. However, cross analyses with the SCGE[15] model shows a different trend as the magnitude of the indirect effects is relatively small but somewhat larger as compared to the previous extreme event in Prague.

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[15] Spatial Computable General Equilibrium.

6 References

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7 Annex 2.A Overview and evaluation of validity and reliability of data and *data source*s to be used for the economic impact analysis

Table 7.1. Overview of the databases and their attributes

Hazard type	**Database**	**Year**	**Economic losses**	**Secondary sources for economic damages**
Floods (River floods)	Risk Data Hub by JRC's Disaster Risk Management Knowledge Centre (2017)	1871-2018	Millions of Euros, 2011	E.g. Hanze, Dartmouth Flood Observatory (DFO), EM-DAT, COPERNICUS, WIKIPEDIA
Windstorms	Windstorm Information Service (WISC) by Copernicus Climate Change Service (2017)	1979-2017	USD, indexed to 2012	Vendor models
Earthquakes	Risk Data Hub by JRC's Disaster Risk Management Knowledge Centre (2017)	1992-2018	Millions of Euros, 2012	National Oceanic and Atmospheric Administration (NOAA), EM-DAT, WIKIPEDIA
Droughts	EM-DAT by The Centre for Research on the Epidemiology of Disasters (CRED) (2009)	1900-present	Damages given in current dollars	United Nations, Food and Agriculture Organization (FAO)

TextBox 7-1. Limitations of the databases used for the analysis of the economic impacts of disasters

In our study we use the databases for their information on economic damages per event. However, ideally these databases would include more information in relation to hazards (e.g. intensity data, specific spatial information, vulnerability of the affected area etc.). While it is now too early to wish for such a comprehensive database, several institutions are making progress on the harmonization of the reporting of hazards, so that in the future research can rely on comprehensive damage and loss data collection.

Limitations of the Risk Data Hub

This database includes different databases (e.g. EM-DAT, Hanze, DFO) and consequently finds challenges in the following difference between databases (Faiella et al., 2020):

1. Differences in the reported time of occurrence and the spatial extent.
2. Differences in classifying the type of disaster and the definitions of the indicators.
3. Differences in currencies and prices of economic losses (e.g. EM-DAT reports economic losses in American dollars, while HANZE reports economic losses in the currency used at the time of the event and then the same amount converted in euro in 2011 prices).
4. In addition, the secondary databases do not always specify if the value of some attributes was not recorded or it was null.

The differences between the databases makes the comparisons less reliable and statistics inconsistent and highlights the need for a more systematic and comprehensive data collection (Faiella et al., 2020).

Limitations of WISC

The WISC database applies vendor models to estimate the economic losses. It was found that there is a wide range in the loss estimations of the different vendor models (in some cases a factor four difference between their estimates) (Koks, et al. 2017). This can be explained by the different model behaviour and vulnerability curves and the differences in calibrating.

Limitations of EM-DAT

The estimated damages reported by EM-DAT includes “the amount of damage to property, crops, and livestock. The value of estimated damage is given in US$ (‘000). For each disaster, the registered figure corresponds to the damage value at the moment of the event, i.e. the figures are shown true to the year of the event.” (EM-DAT, Explanatory notes).

For droughts, EM-DAT seldom includes the end date of an event. In addition, according to the literature EM-DAT records the day it was declared as humanitarian emergency (GFDRR, 2002), while other sources usually record a period for the disaster itself (start/end).

Moreover, EM-DAT only includes events for which either ≥ 10 people killed, and/or ≥ 100 people reported affected, and/or a declaration of a state of emergency, and/or a call for international assistance. As such, it only reports on significant droughts, while smaller droughts are that could also have a considerable impact are not take into account (CRED, 2009).

TextBox 7-2. Overview of the limitations of the data sources used for the direct impact estimations

Limitations of the Regional capital stock estimates

Availability: the regional capital stock estimate series are available for NUTS2 regions for the years 1995-2016. For the years 2017 and 2018, regional capital stock estimates of the year 2016 are considered, and the relevant damage distribution matrices (DDMs) of these two years are applied as negative ‘shocks’ to the initial 2016 regional capital stocks.

Limitations of the Eurostat dataset on the cross-classification of fixed assets by industry and by asset types

Cross-classification of fixed assets by industry and by asset (stocks) collected by Eurostat is available at the country level only. Thus, the same constructed converter tables across fixed asset types and industries is used for all NUTS2 regions of a specific country (e.g. the converter table constructed for Finland is used for all five NUTS2 regions of Finland).

Data not available (or insufficient) for some of the investigated countries: Bulgaria, Malta, Sweden. For these, converter table of a relevant proxy country is used, based on data on GDP/capita (Eurostat, 2020a) and structure of GFCF (Eurostat, 2020b) (gross fixed capital formation) from Eurostat. Based on these two data sources, cross-classification of the following countries are used as proxies for the missing countries:

- For the case of Bulgaria: Romania
- For the case of Malta: Italy
- For the case of Sweden: Finland

TextBox 7-3. Overview of the limitations of the data sources used for indirect impact estimation

The regional-economic analysis of economic direct and indirect impacts of the natural disasters is carried out using a hybrid MRIO model at NUTS2 level for EU26* (excl. Croatia) and the UK, although the damage costs of each hazard events are calculated at the NUTS3 level. In order to be able to have an estimate of the economic direct and indirect impacts of the natural disasters at the NUTS3 level, estimates at the NUTS2 level need to be disaggregated to NUTS3 based on a number of indicators that are available at this regional level of detail, such as direct impacts and sectoral structure (value added and employment for NACE 1-digit sectors).

Given the lack of data on the capital stocks at the NUTS3 level and little sectoral detail, the disaggregated NUTS3 level economic effects are a best estimate of hazard events' impact at this territorial level. The results of NUTS3 and NUTS2 level are as consistent with each other as possible by design.

Limitations stemming from the time coverage of the multi-regional input-output tables

The detailed multi-regional input-output tables from the PBL-JRC database (used for indirect economic impact calculations) are not available for all the investigated years of the study (1995-2017), but are available as open data for each years between 2000 and 2010. The scope of the I/O and CGE modelling can be extrapolated to cover the whole investigated time period (1995 onwards) and so providing a robust representation of economic impacts on a year-specific basis.

As the scope of the current study requires more years than those covered by the PBL-JRC MRIO database, the I/O tables for the years between 1995-1999 and 2011-2017 need to be estimated based on three key data sources:

- Data on **total GVA** from the World Input-Output Tables (World Input-Output Database, n.d.) for the years 1995-1999 and 2011-2014, and from World Bank (World Bank, n.d.) for the years 2015-2017;
- Data **on total gross output** from the World Input-Output Tables (World Input-Output Database, n.d.) for the years 1995-1999 and 2011-2014; for the years 2015-2017, the same split of GVA / total gross output are assumed as in the year 2014 (due to gross output data unavailability);
- The existing **multi-regional input-output table (expressed in monetary terms) transformed to percentage terms**, to reflect demand of a specific NUTS2 region & industry combination, from each supplying NUTS2 region & industry combinations. Structurally, this represents how total yearly intermediate demand of a specific region & industry combination is distributed across all the supplying sectors (which can also take a value of zero, i.e. total intermediate consumption of an industry of a specific region from another industry of another region equals zero). Practically and given the structure of the I/O table, these values are calculated by deriving the shares that supplying region & industry combinations (on the supply-side of the I/O table) mean within total intermediate demand of each individual region & industry combinations (on the demand-side of the I/O table). The same is done for GVA, separately from intermediate consumption – allowing for the exogenously collected intermediate consumption and GVA data to reflect changes in global productivity over time. Shares are thus split out on a demand-side basis, with shares within total intermediate demand adding up to 100%, and shares within total GVA adding up to 100%.

The so-derived shares of the first (2000) available year are used to calculate absolute values of the I/O table for the preceding years (for the years 1995-1999), while the shares calculated for the last year available from original source (2010) are used to calculate absolute values of the MRIO table for the years following 2010.

Limitations stemming from the regional coverage of multi-regional input-output table

Multi-regional input-output (MRIO) tables from PBL-JRC EUREGIO database (to be used for the indirect economic impact calculations), are publicly available from the PBL EUREGIO website (PBL, 2019). A related paper (Thissen et al. 2018) describes the methodological background of the dataset construction in detail.

- The initial dataset available from to download follows the NUTS2 regional classification for the EU, and distinguishes 250 European NUTS2 regions.
- As no (comparable) supply and use tables were available for Romania and Bulgaria at the development of the MRIO database, data on input-output flows for these two countries are available as country-total; thus indirect economic impacts are calculated at the country-level, and final results are disaggregated to the NUTS3-level.
- Due to the year of entry and the time coverage of the dataset (2000-2010), Croatia is not included in the multi-regional I/O tables and thus is not included in the I/O impact assessment.

Limitations stemming from the regional detail of multi-regional input-output table

Linking NUTS2 MRIO analysis to NUTS3 economic effects: Both multi-regional input-output tables and Cambridge Econometrics' own dataset on regional capital stock estimations present data at the NUTS2 territorial level, which means that the economic impacts of hazards, in the first round, can be derived at the NUTS2 level and need to be disaggregated afterwards to the NUTS3 level to arrive to final results.

8 Annex 2.B Impact Pathways

The ‘impact pathways’ which represent the link between the four hazards and their direct and indirect economic impacts. The links’ description also shows how these impacts were triggered and the impact category they relate to. As such, they form the basis of the economic modelling. The impact pathways are developed by means of a detailed literature review and one case study desk analysis per hazard.

Aside of the direct and indirect impacts, the literature review analyses response and recovery actions typically taken in aftermath of a disaster and their typical costs (e.g. infrastructure rehabilitation). We follow the definition of the United Nations Office’s for Disaster Risk Reduction (UNDDRR). According to the UNDDRR’s Terminology of Recovery, recovery should aim at “restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and “build -back- better”, to avoid or reduce future disaster risk.” In this analysis we only focus only on the recovery of economic assets and activities.

Lastly, the mitigating impacts related to prevention and risk management are reviewed in the literature. We take the definition of Botzen et al. (2019) who classify mitigation action as *pre-disaster* actions (e.g., public information campaigns, individual insurance and defensive investments, public defensive investments).

In addition, it is important to further explain what we mean with direct and indirect impacts. We follow the description of our previous study (Trinomics et al., 2015):

- **Direct impacts** consist of the direct damage to assets such as buildings, factories, houses, infrastructure, etc. This concerns the cost of repair or replacement of the assets that were damaged or destroyed. Direct costs are routinely estimated by insurance companies, specialized agencies, etc. This means that these costs often are reasonably well-documented.
- **Indirect impacts** refer to the fact that this loss of capital translates into a loss of production capacity, which affects many parts of the economy, leading to losses of business activity. For example, firms that are dependent on products from the affected area do not receive the quantities they had asked for. Also, firms that produce articles for damaged or lost factories cannot deliver their products anymore. In both cases, damage and costs are involved beyond the immediately affected entities. Indirect costs are usually far more difficult to measure than direct costs, and we need a model to estimate size and composition of the losses.

Hazards - in general - have a negative effect on economic growth both the direct and indirect economic effects (Klomp and Valckx, 2014). However, its impact on economic growth depends on several factors. One of these factors is a country’s level of development as developed countries have possibly better developed health care systems and information systems and more resilient economies which are better able to cope with shocks (Kousky at al., 2014; Hoeppe 2016). This differences per country are taken in consideration in the Territorial Vulnerability Assessment discussed later. Impacts also vary greatly between sectors and hazard types, with some sectors being severely affected and some coming out neutral or improved. For instance, for the agriculture sectors storms and droughts result in negative impacts whereas short floods can be beneficial for the production (Loayza et al. 2009). Overall, you see that sectors which are more exposed to weather experience larger damages and those who are involved in reconstruction see temporary booms (Kousky at al., 2014). Notably, even if changes in the macroeconomy are small, hazards can result in large distributional consequences, depending on the recovery actions (Kousky at al., 2014). As such, it is important to learn how each hazard affects different sectors and assets.

In following sections, the impacts pathways are discussed for floods, windstorms, earthquakes and droughts. The social effects such as affected people and fatalities as well as environmental effects are not within the scope of global methodology. As such, these impacts are not including in this review but are further discussed with the local methodology.

B.1. Floods

Floods are among the most frequent and costliest natural hazards (Botzen et al. 2017). It is therefore that floods have been well studied in the literature. There are different kinds of floods such as flash, river, and coastal floods. The different types of floods result in different effects. For instance, coastal flooding generally brings strong wave action, and urban drainage floods are likely to be heavily polluted (Paprotny et al., 2018). In this study river floods are mainly studied as this type of flood occurs throughout all of Europe. However, we do see that this type of flood occurs mostly in central and western Europe, with flood losses concentrated between June and August (Paprotny et al., 2018). The level of the flood damage costs depends among others on physical characteristics of a flood (e.g. level of inundation depth, duration of the flood, degree of contamination in the water, velocity) but also the level of warnings prior to the flooding (Olesen et al. 2017). In addition, the exposure (assets available in the flooded area) determines the level of damage costs. The flood’s (in)direct impacts on assets and sectors are explored in this section.

Literature review

Direct and indirect impacts

A summary of the most common (in)direct impacts is presented in the Table 8.1. Here, the study on climate extremes by Trinomics et al. (2015) serves as the basis as it already lays out the different impacts of floods. The study is complemented with insights from other literature (Jonkman et al. 2008; de Moel, Vliet, and Aerts, 2014; Merz et al., 2010; Deloitte, 2016; Koks et al., 2019).

Table 8.1. Overview of the direct and indirect impacts of river floods

Impact category	**Direct Impact**	**Indirect Impact**
Residential Buildings	Direct damage to buildings, contents and privately used vehicles. Level of damage can differ per type of building (e.g. a bungalow or a 3-story building) and per material type (e.g. wood versus concrete).	Indirect impact on the value of the property.
Service sector	Direct damage to capital stock, commercial buildings, and inventory.	Indirect impact on the supply chain and employment. In addition, indirect impact on productivity as the ability of the workforce to deliver a normal amount of economic output (economic outputs related to hours worked/full time equivalent output) is hampered. These impacts are also felt outside the flooded area. Lost production because of redirection of resources towards reconstruction.
Industry sector	Direct damage to capital stock, buildings, inventory, machinery, or site. For instance, mining, metal processes, car and mechanical, engineering industry, chemical industry, construction industry, installers workshop, carpentry, etc.	
Energy & water sector	Direct damage to energy and water infrastructure.	Indirect impacts on the demand for energy/water or energy/water supply.
Agricultural sector	Direct damage to land, farming equipment, or current crops. Losses of or harm to cattle.	Indirect impact on the long-term productivity of the land.
Transport Sector	Direct damage to transport such as roads, railways, etc.	Indirect impact on accessibility of work locations which may result in reduced productivity and potentially lost wages. If the transport of goods is disrupted or delayed, this could have indirect impacts on the business supply chain. Residents have difficulty travelling to reach relatives, schools, or hospitals due to flooded transport infrastructure.
Infrastructure (waste, telecommunication, ICT infrastructure, etc.).	Direct damage to telecoms, waste, ICT infrastructure incl. internet, etc.	Indirect impact on amount of waste and knock-on effects on disposal and treatment of waste. Damage to telecom infrastructure to result in loss in production for business and communication disruption in general.
Evacuation and rescue operations	Costs of managing an extreme event, emergency costs – we are considering this a direct economic impact of the event.	Temporary housing of evacuees.
Reconstruction of flood defences	N/a	Investments in the repair and strengthening of flood defences.
Clean up costs	Clean up the destructed assets and reallocate lose objects. With some floods, sewage water or contaminated water has flooded the area.	N/a
Cultural services (e.g. heritage sites, landscape character and access) & tourism	Direct damage to a heritage site.	Indirect/intangible (unpriced) impact to the historic value of the site and revenue losses.
Education lost	N/a	Welfare costs of education days lost.

In this study, the global methodology aims to find the distribution of the total costs among the 5 capital stocks. The literature indicates different numbers for the distribution of the total damage. In general, a large share of the costs (19% to 30%) goes to residential and commercial buildings (Environment Agency, 2018). In case an industry area is affected, a large share of the damage costs (30% to 80%) would come from this sector. Transport asset damage costs may range from 8% to 60% of the total damage costs (Koks et al., 2019). Lastly, agriculture costs are relatively low compare to the other damage classes with a range from 0% to 4% (de Moel, Vliet, and Aerts, 2014; Deloitte, 2016).

Recovery actions

There are many recovery actions taken after a flood event to restore the damage to the capital stocks and to reduce negative indirect impacts such as reduced productivity and increased unemployment rates. One of the most significant damages is often done to residential, commercial, and industrial buildings and their contents. Therefore, the recovery action consists of drying and repairing these assets. In addition, roads and bridges can be swept away or weakened which need to be restored in order to revive transport for households and workers. Recovery of infrastructure (such as electricity, gas, and tele-communications) is also essential as it disrupts businesses and households in their restoration. Lastly, farmers need to reallocate their cattle, repair broken buildings and fences as well as replanting or mending their crops. Below these recovery actions are discussed in more detail by zooming in on the different recovery periods of the different capital stocks. The recovery periods are important for the modelling of the economic indirect effects.

Recovery period

The recovery of the affected capital stocks after the end of a disaster is not instantaneous. It can actually take up to several years for the capital stocks to recover a disturbance. This recovery period varies significantly depending on the capital stock and the type of disaster. This section presents evidence from the literature on the length of the recovery periods of each of the five capital stocks after a flood event has occurred.

Koks et al. (2015) applied a recovery time-period of 10 years in the direct and indirect flood risk modeling, where the model iterates over each day. However, other studies point out that the intensity of the flood, and particularly the duration determine the recovery period. Reconstruction of the area can only begin once the water has receded and the area is accessible again. For this reason, Koks and Thissen (2016) relate the recovery period to the return period of a flood: a flood with a 100-year return period has a recovery period of 6 months whereas a flood with return period of 10 000 years had a recovery period of 2 years. Carrera et al. (2015) applied a recovery period of one year in their study. In addition, the authors used one week as the recovery period for non-agricultural sectors and 3 months for the agricultural sector. Below the differences between the recovery periods of the capital stocks is discussed.

Residential buildings

The recovery rate for residential buildings depends on the household's own resources, kinship of family's and friends' resources and institutional support (governmental) (Lindell, 2013). Notably, households are in many cases not insured against floods.

In a study by Kienzler et al. (2013), households were interviewed about their building status 8-9 months after a large flood in Germany. They found that after 9 months, the progress of the restoration depended on flood type, flood experience and socio-economic structure. For instance, out of the 449 households interviewed in the 'most resistant' group, 269 (60%) indicated that their house was restored, including content. However, from the weakest group, both in preparedness and flood intensity, only 35% of the buildings was restored. Kienzler et al (2013) also found that the buildings' content is faster recovered then the buildings itself.

In an earlier study by Trinomics et al. (2015) residential damage and the number of affected households (or population) was used to estimate the amount of labour which would be either unavailable or delay the travel to work (as a production constraint during economic recovery period). As there is a lack of studies in determining the relationship between residential capital damage and labour delays, they assumed that as a result of a major flood in Central Europe, a drop of 0.6% in labour force, with an initial delay of 3 hours due to transport and reads disruptions, and a 9% of labour force affected by this delay. The recovery path was linearly modelled with fully recovery in 10 months.

In addition, an assumption was made in a drop in household consumption of 'non-basic' (luxury) goods, with an exogenous recovery path. For the Central European Flood, a reduction of 50% with an s-shape recovery path was taken. The shape assumes a low recovery in the first periods after the disaster, with a more than proportional increase once the process of recovery is more advanced, to finally reduce the marginal increase at the end of the process.

Industry and commerce

There is variation among business sectors and between large and small business in their patterns of recovery. In general, wholesale and retail businesses experience significant sales losses, whereas manufacturing and construction companies often show gains following a disaster (Lindell, 2013). Moreover, large businesses tend to recover more quickly. In addition, Hallegatte (2014) assumes in his study that the inventories in the construction sector are economically not indirectly affected due to substitution possibilities and assistance from nonaffected regions. In a study by Alharbi and Coates (2017) the recovery of manufacturing SME's was modelled based on a 21-day period simulation. However, Wedawatta and Ingirige (2012) report SME's that are out of business of 3 to 6 months.

Transport and infrastructure

Recovery of infrastructure (such as electricity, gas, and tele-communications) is essential as it disrupts businesses and households in their restoration (Koks et al. 2019).

In a study by Kemp (2016) the electricity impacts are discussed for the Lancaster District in England. During a flood event with a 100-year return period, a 132 kV substation failure affected 61 000 properties whose power was progressively restored over 2 days, an outage that impacted over 100 000 people (Kemp 2016). The study of Kemp shows the importance of fast recovery of infrastructure is. The doubling of the recovery time may even result in almost three times higher losses (Koks and Thissen, 2016). There was no information found for the recovery period of transport.

Arable land

Based on a study by Brémond et al. (2013), it can be concluded that agriculture is affected in the first year after the flood due to reseeding of replanting of crops. Moreover, the authors mention that the impacts of floods may continue for several years by changing crop rotation. For instance, due to the impossibility of preparing the soil, it may be difficult to sow the next crop in time.

Mitigation actions

The occurrence of a disaster has been shown in some cases to increase investments in reducing risks (Kousky et al. 2014). There are several measures which a country or region can take to protect themselves from floods such as (1) flood prevention e.g. dikes, retention basins (2) smart spatial planning to reduce flood damage and (3) proper disaster risk management to limit casualties.

In Austria, flood protection measures were put in place after the 2002 floods helped to prevent more extensive damage (Habersack et al., 2009). It was estimated that around 40 municipalities were spared from greater damage by means of retention basins (Habersack et al., 2009). More specifically, in the municipality of Gabersdorf in Styria the retention basin was built at a cost of € 1.2 million and opened in 2008. For that area, the damage potential of a flood is around € 1.1 million. In the summer of 2009, the municipality's retention basin was fully filled 3 times (of which it was overflowing once), so it is estimated that prevented damages were at least € 3 million in 2009 (Habersack et al., 2009).

In a study by de Moel et al., (2014) it was found that damage-reducing measures can substantially reduce flood risks for regions in Rotterdam (the Netherlands) that are outside the primary flood defence system. One of these measures is dry proofing.[16] With dry proofing up to 1 m they estimate that the total flood risk of the region was reduced by 56%. In addition,

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[16] Dry floodproofing lowers the potential for flood damage by reducing the probability that the building content is flooded.

elevating buildings by more than 100 cm would virtually remove the entire risk, indicating that inundation levels of buildings in the unembanked region rarely exceed 1 m (de Moel et al. 2014).

In addition, Botzen et al. (2017) examined whether private measures can be helpful in flood-proofing and whether these measures are economically attractive for certain categories of commercial buildings such as shops and mechanic workshops. In their study in Umbria, Italy, they found that in case an area has a high probability (1/10 years), flood-proofing measures are economically attractive. However, they conclude that while flood-proofing measures are desirable, the majority of Umbria's companies have neither taken measures to protect themselves nor purchased flood insurance (Botzen et al. 2017).

Case study desk analysis

For floods the case study of the flood in Cumbria, in North West England is studied to learn more about the direct and indirect impacts and their links.

Cumbria is a county in North West England which is known for its floods. Notably, between Wednesday 18th November and Friday 20th November in 2009 as record of daily rainfall was fallen which caused rivers to burst their banks, flooding towns and villages (Cumbria.Gov., 2010).

Indirect impacts

According to HANZE database (2017), the total reported damage of this flood event is: 1 fatality, 8900 persons affected[17] and 371 million losses in euros[18] (Paprotny, 2018; HANZE, 2019).

The Cumbrian government reported a total cost of over EUR 317.8 million of which EUR 142.5 million was cost to commercial property and business infrastructure, EUR 104.5 million to residential buildings and other buildings, and EUR 39 million to infrastructure, including damaged and destroyed bridges, roads and the Port of Workington (see Figure 8.1). Other major costs include € 148.5 million cost to business and economy. An estimated € 8 million went to the health service (part of welfare) as two GP surgeries in Cockermouth were flooded and forced to relocate to the town's community hospital. In addition, temporary clinics were established in communities cut off by the flood. The cost of supporting local businesses affected by the floods, both through specialist grants and advice and support, is estimated to be around € 5.7 million. The cost to the environment is around € 9.1 million and includes waste, historic environment, Natural environment, rural recovery and Public Rights of Way (Cumbia.Gov.UK, 2011). When zooming in on the impacts on the study's 5 capital stocks we see that two third the damage costs went to industry and commerce, a quarter to residential areas and one-tenth to transport (see Figure 8.2).

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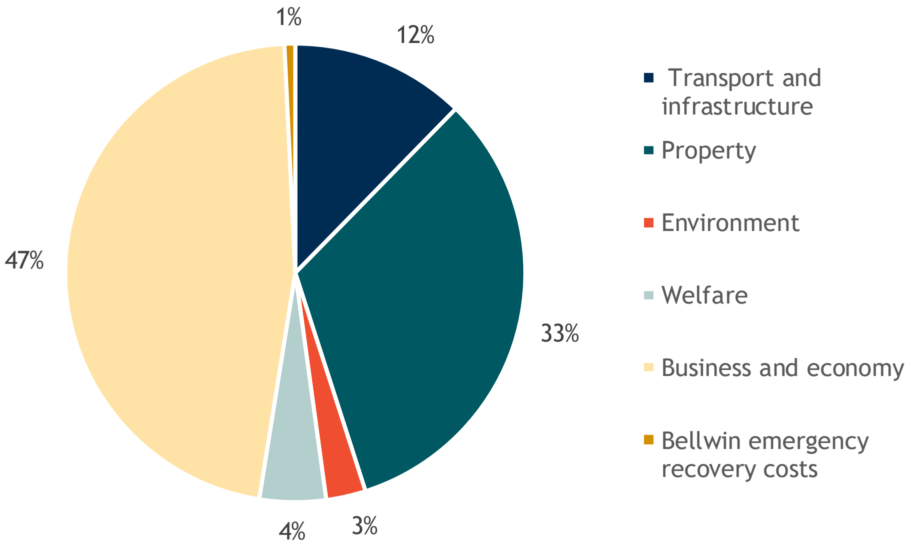
[17] The number persons affected was estimated by multiplying the number of houses by 4 (Paprotny et al. 2018).

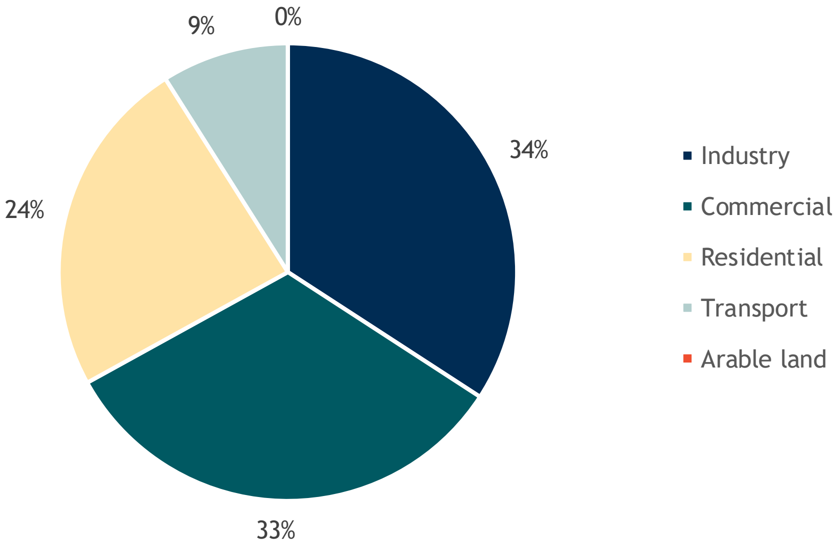
[18] Damages in monetary terms converted to euro, correcting for price inflation relative to 2011.

Figure 8.1. Split of damage costs among the different impact areas.[19]



Source: Cumbria.gov.uk (2011)

Figure 8.2. Split of damage costs among the 5 capital stocks



Data based on Source: Cumbria.gov.uk (2011)

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[19] The Bellwin recovery scheme is a governmental emergency financial assistance which reimburses local authorities for costs incurred on their immediate actions to safeguard life and property or to prevent suffering or severe inconvenience as a result of a disaster or emergency in their area.

Description of the direct effects

In total, 1% of the properties[20] were reported as flooded, of which mainly residential buildings (80.1%) and to a lesser extent commercial building (19.9%) (Cumbria.Gov.UK., 2010; VOA.Gov.UK, 2015). Mainly residential buildings were affected (Cumbria.Gov.UK., 2010).

The agriculture sector experienced relatively small damages. In total 225 farms were recorded to suffer from severe effects of the flooding e.g. fallen stock with carcasses deposited on neighbouring farms or washed out to sea (Cumbria.Gov.UK., 2010).

The infrastructure of Cumbria was impacted heavily with the most significant effects seen in the destruction or severe damage to the county's road and public bridges (Smyth, n.d.). Other impact on infrastructure was the damage to power lines and telecommunications (including contact with the emergency services) (Cumbria.Gov.UK., 2010).

Description of the indirect effects

Businesses were heavily affected. Notably, in the Allerdale, 3057 of the 4100 businesses were affected (Allerdale, 2009).[21] In an annual monitoring report, the local government of Allerdale (2009) stated: "At the time of writing, not a single shop is functioning normally in Cockermouth Main Street. Travel and shopping patterns will be severely affected for at least 6 months. During this period the accessibility of Workington town centre from the north will be severely curtailed and Cockermouth town centre will not be functioning normally. It is to be hoped that the longer-term impacts will not be severe" (Allerdale, 2009: 44).

Especially, small and medium-sized enterprises (SMEs) were affected (Wedawatta et al. 2014). By means of a survey Wedawatta et al. (2014) found that businesses not directly affected by the flood event experienced a range of impacts and that short-term impacts were given a higher significance. Impacts related to transport and access that were identified showed to have correlation to 'reduced sales' and 'additional cost'. These impacts also affected businesses that did not experience any direct damages of the flooding (Wedawatta et al., 2014).

For most of SME's, the significant costs were related to arranging alternative premises and structural repairs to buildings (Cumbria.Gov.UK., 2010). In many cases, the insurance covered only part of the damage cost to buildings and most businesses received no compensation for interruption to normal trade. In the study of Wedawatta et al. (2015), 324 business provided an estimate of their cost which was gave an average of € 49 812 per business. A long-term impact is the significant increase in costs of property insurance and excesses, meaning that SMEs would be exposed to increased losses in the event of a future flood event (Wedawatta et al., 2014).

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[20] Excluded from this count are properties that were cut off by the waters but not flooded themselves.

[21] 2012 data from NOMIS official labour market statistics.

Cumbria has a strong reliance on tourism. It was estimated that 72% of the tourism businesses have suffered directly or indirectly from cancellations (Cumbria.gov.UK, 2010). Additionally, concerns were raised about the impact on the image of Cumbria. Moreover, the port of Workington experienced economic losses (estimated to be in excess of EUR 7.75 million) as it was forced to close as the result of sediment deposition. Dredging companies were paid to clear the waters (Smyth, n.d.). In total 23 bridges were (temporarily) closed, affecting economic and recovery activities. For instance, due to the closed bridges in Workington, the citizens had to make a 65 km instead of 3 km, round trip to reach work, school, healthcare and shopping.

Recovery actions

The recovery phase was evaluated in the impact assessment done by the Cumbria government (2010). The recovery planning started early (during the event), which allowed key partners to get together and set up working groups on welfare, business, environment, communications, finance and infrastructure.

Cumbria has taken many actions to ensure a fast recovery, among them, the Business Recovery Grant Scheme established by Cumbria Chamber of Commerce and County Council, and a winter campaign to announce they were open for tourists and businesses again. After six months, the intermediate priorities were addressed (temporary road bridge and increased public transport); however, it took another year to be fully recovered (Cumbria.gov.UK, 2010).

Mitigation actions

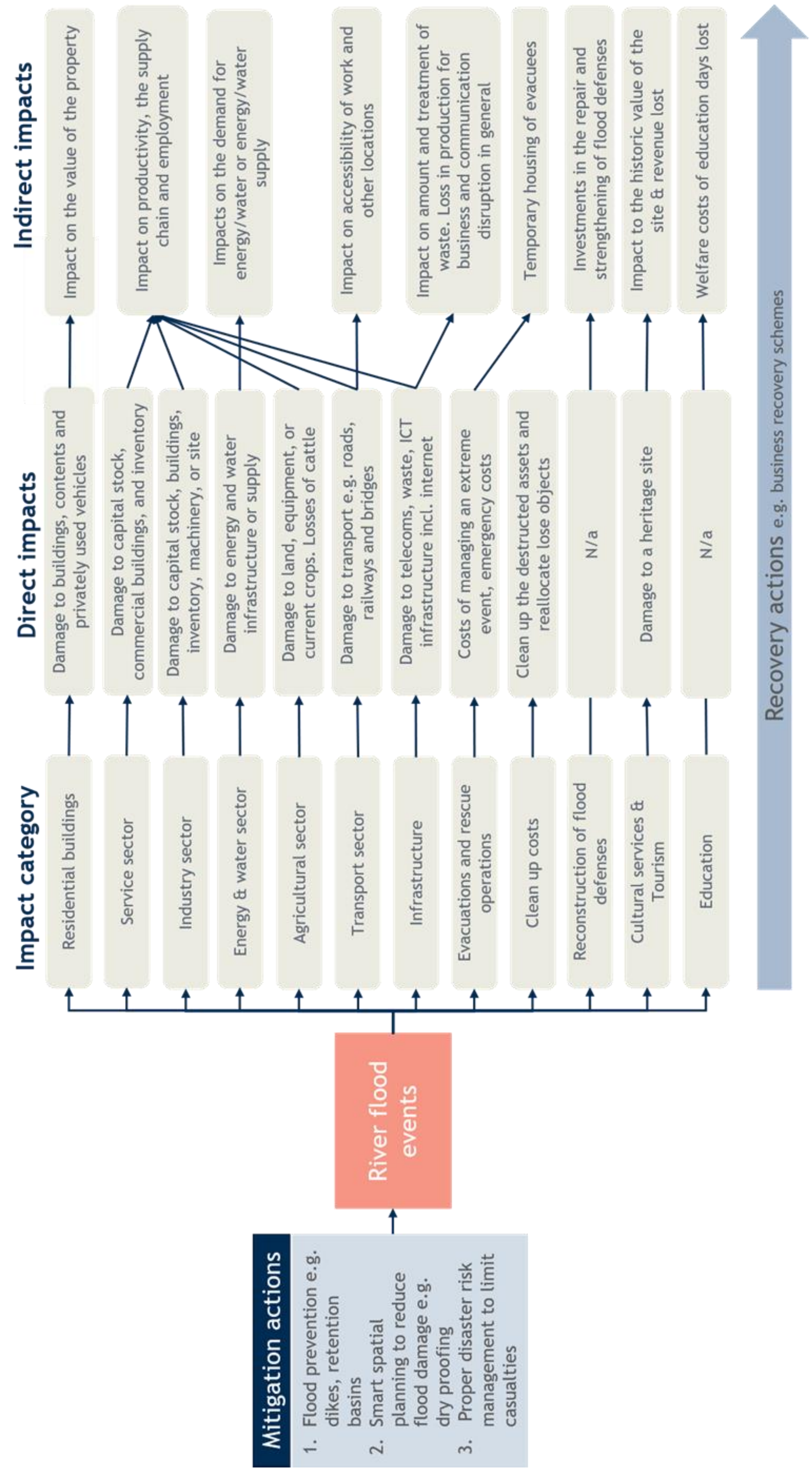
The reason for the large impact is the scale of the unexpected flood, and unprepared businesses. In order to be better protected and prepared for the next flood, the Flood and Water Management Act 2010 (the Act or FWMA) was adopted (Cumbria.gov.UK, 2014). Based on this Act the Local Flood Strategy was developed, which (1) coordinates the resources available during the flood; (2) promotes a wider understanding and awareness of flooding in Cumbria; and (3) explains how citizens can play a part in reducing flood risk (Cumbria.gov.UK, 2014). In addition, the flood defences had increased.

However, in 2015 and 2016 severe floods hit Cumbria again. In a study by the Environmental Agency (2016) it was concluded that the impacts, for instance, in Cockermouth were significantly less during the floods of 2015 than those caused by the floods of 2009. It was also stated that in the previous month of November, the flood defences had proved their effectiveness in protecting Cockermouth from flooding numerous times. To increase flood protection and resilience, EUR 87 million was invested in flood defences across Cumbria in 2016 (Environmental Agency, 2016). Additionally, better catchment management was installed.

Impact pathways

The impact pathways, reflecting the findings from both the literature review and the case study, are presented in the Figure below. As you can see in the Figure is that the direct impacts lead often to same kind of indirect impacts i.e. reduced value of buildings, lower productivity, disturbed value chains and increased unemployment rates.

Figure 8.3. Impact pathways for flood events



B.2. Windstorms

Windstorms concern a large part of Europe. Although significantly less devastating than phenomena in inter-tropical areas, storms in temperate regions can cause significant losses of property and human life. Most of the severe windstorms affecting Europe form on the Atlantic Ocean during the autumn and winter months (known as "winter storms"), progressing at an average speed of around 50 km/h and can be up to 2,000 km wide (Georisques).

In Europe between 1950 and 2006, there have been 70 severe windstorm events resulting in total insured losses of approximately USD 50 million (Schwierz et al., 2009). This is a direct result of the geographical position of our continent, located in the axis of the path taken by a large proportion of winter storms (their preferential south-west/north-eastern spread explains why the northern part of European territory is most frequently affected).

Literature review

Direct impacts

The direct impacts of windstorms are mostly structural as buildings and infrastructure are the most affected. To identify the different impacts of windstorms, a literature review was undertaken. The Table 8.2 presents a list of the most common direct economic impact of windstorms (Becker, 2015).

Table 8.2 Economic direct impacts of windstorms in Europe

Impact category	Impact type
Agriculture sector	Damage to crop lands Damage to livestock shelter
Residential buildings	Damage to buildings (mainly due to internal pressure) (Ginger, 2018) Trees falling on buildings
Energy & industry sector	Damage to buildings (mainly due to internal pressure) Trees falling on power lines Damages to lines and pylons
Transport	Trees falls on rails Derailing of trains Damages to catenary wires Blocking of roads by falling trees Toppling of trucks
Infrastructure (e.g. telecommunication)	Damages to antennas or over ground telecommunications lines
Clean up costs	Debris removal can place a strain on budgets
Service sector	Many businesses close during the storm Damage to buildings (mainly due to internal pressure)
Evacuations and rescue operations	Costs of managing an extreme event, emergency costs

Indirect impacts

Windstorms have indirect economic impacts, but they are usually short lived as most of the power lines are quickly fixed (Seattle office of Emergency Management, 2014). The biggest indirect impact is caused by power outages. Only if a windstorm is accompanied by a coastal flood it does cause any significant secondary effects.

Table 8.3 Economic indirect impacts of windstorms in Europe

Impact category	Impact type
Agriculture sector	Short term impact on the productivity of the land
Energy and industry sector	Blackout can affect large areas
Transport	Blackouts affect train service Short-term disruptions of transport lines
Infrastructure (e.g. telecommunication)	Disruption of power supply can lead to breakdown of telecommunication lines
Service sector	Indirect impact on the supply chain
Evacuations and rescue operations	Temporary housing of evacuees

Recovery actions

Windstorms can cause important economic losses as their effects can be felt across several countries. However, as there are no significant damages, the recovery would be fast.

The literature on recovery from windstorms is rather limited. From the available sources it is revealed that there are various elements that affect the length of the recovery period after a windstorm. Such elements include not only intensity-related factors, such as the severity and duration of the event, but also disaster aid policies and activities, such as clean-up activities and economic reparations to those who suffered the damages. One other major factor is whether the windstorm was accompanied by a coastal flood or not.

The recovery of the industry, residential, and commercial capital stocks to pre-disaster levels depends on the type of damages windstorms cause on these capital stocks. According to several sources, these damages refer to mainly damages in buildings. Although these are often significant, very rarely the damages include complete building demolition. Therefore, it is assumed that the recovery of these capital stocks to pre-disaster levels is achieved by the end of the first year after the event occurred.

Windstorms have a more extensive effect on transport and infrastructure, with often vehicles and energy transmission networks completely destroyed. Power lines woould be repaired in most cases after one week leading to the main cause of disruptions to disappear (Seattle Office of Emergency Management, 2014). As such, the period required for the reparation of such damages is considered again to not exceed one year.

Lastly, windstorms have a very significant effect on agriculture, forestry and aquaculture. Trees can break to a degree that the plant cannot recover, and crop and vegetable production can be permanently lost due to strong winds, hail, cold, and rainfall. Losses in agriculture also include damages in greenhouses and agricultural infrastructure. The recovery of the crops and seasonal vegetables takes only until the next harvest to recover. However, dead trees may imply that the recovery of such fields can take up to several years. To deal with the discrepancy of the different recovery period durations, we assume that the arable land recovers at the pre-storm levels in one year.

Mitigation actions

As the duration and the severity of a windstorm can be predicted, it is possible for local authorities to take preventive measures prior to the event to reduce the amount of losses. Mitigation actions on the longer term are still needed to reduce the structural vulnerability of buildings and infrastructure to strong winds. These short-term and long-term mitigation actions (FEMA, 2013. and Becker, 2015) are presented in Table 8.4.

Table 8.4 Windstorm mitigation actions

Mitigation actions
Short-term
Disconnect endangered power lines Start-up of additional power plants Shut down of wind turbines Reduction of speed limits and closing of tracks for railways Speed reduction or closing of motorway bridges Batteries or generators provide power supply for a limited time period for telecommunications infrastructure
Long-term
Adopt regulations governing residential construction to prevent wind damage Promote or Require Site and Building Design Standards to Minimize Wind Damage Protect Power Lines and Infrastructure. The regular maintenance and upkeep of utilities can help prevent wind damage. Retrofit Residential, Public Buildings and Critical Facilities
Proper design of the gas networks

Case study desk analysis

For windstorms the case study of windstorm Xynthia is studied to learn more about the direct and indirect impacts and their links. Windstorm Xynthia is a major weather depression that struck several European countries between February 26 and March 1, 2010. The system, which originated in subtropical regions, mainly affected Southern and Western Europe. Storm Xynthia was not an exceptional storm (maximum wind speeds of 160 km/h), but it was one of the deadliest because the coincidence of this phenomenon with a high-water spring tide. This resulted in a fairly exceptional rise in water levels, causing the death of 59 people and significant material damage. The windstorm covered a vast area of Europe with rural and urban regions affected in eight Members States.

In France, the storm caused almost two billion euros of damage. The combination of strong winds and high tides resulted in a storm surge which caused major flooding in some coastal regions, mainly in Charente-Maritime, Vendée and Côtes-d'Armor. Failure of coastal flood defences led to widespread flooding along the coast and the death of 47 people (Liberato et al., 2013). Around 500,000 French people suffered material damages due to the storm

(Genovese et al., 2012). Whilst France bore the brunt of the storm, impacts of the storm were also felt in other European countries. Seven people died as a result of the storm in Germany, mostly as a result of falling trees. Building damage was caused in a number of major German cities (Maurer, 2012).

Xynthia reached Portugal and Spain, two countries that rarely suffer from such winter storms (Aon Benfield 2011). Four people died as a result of the storm in Spain. Portugal was also hit by powerful winds and heavy rain as a falling tree killed a person in Paredes and the northern cities of Porto and Vile Nova de Gaia issued river flood warnings (GC Capital, 2010).

One person was killed in Belgium. Some electricity cuts and falling trees were also reported in several parts of the country, notably in Liege, Verviers, Herstal and Brussels. In Switzerland falling trees caused disruption to rail services and secondary roads (Liberato et al., 2013).

Direct impacts

The estimated overall losses from the 2010 Xynthia storm are € 2.250 million (Munich RE, 2010). As the impacts were the biggest in France, we focus on this country. The most significant impact categories for the Xynthia storm were damages to residential buildings, industry and businesses and arable land.

Table 8.5 Overall losses Winter Storm Xynthia 2010

	Overall losses (€ m)	**Insured losses (€ m)**
Germany	750	500
France	3.100	1.500
Spain	250.00	100.00
Europe as a whole	**4.500.00**	**2.250.00**

Source: NatCatSERVICE, Munich RE, 2010

Damages to residential buildings

There were significant damages to buildings due to high wind speeds and to the storm surge. The regions of Vendée and Charente-Maritime were the most affected by the storm (Liberato et al., 2013), although reports of property damage are found in most of the affected countries (GC Capital, 2010; Maurer et al., 2012). Insurers estimated the damages to residential buildings to € 157.7 million (Lumbroso and Vinet, 2012).

In France, 707 residential properties were condemned following the floods. In response to the coastal flooding the French Government announced in April 2010 that it had decided to destroy 1,510 houses in the affected areas of which 823 were in the Vendée and 595 were in Charente-Maritime. The government promised to fully compensate all homeowners, based on the value of the real estate prior to the storm, with the ministry of finance stating that they would pay € 250,000 per house (Lumbroso and Vinet, 2012). This was not a universally popular policy and is likely to have resulted in significant societal disruption. Since May 2010, these areas are called solidarity zones and, since June 2010, properties are no longer compulsorily expropriated.

Damages to industry and businesses

Business was impacted by the Xynthia storm, both in terms of damage to capital stock and inventory. The cost of insurance compensation paid to business was estimated at € 208.9 million (Cour des Comptes, 2012). The sectors impacted included tourism (hotels, campsites etc.), river fishing (and shipbuilding (Genovese et.al, 2012; Maurer et al., 2012).

Damages to arable land

The consequences of storm Xynthia on agriculture were also significant. More than 52 000 hectares of agricultural land were flooded in Vendée and Charente Maritime after seawalls and embankments ruptured[22]. This led to the destruction of crops, equipment, livestock in the affected areas. In Charente-Maritime, the most affected region, the total damage estimated by the farming community is close to € 50 million (Maurer et al., 2012). In the Vendée 500 sheep drowned (The Connexion, 2010). In the Ré Island, 150 hectares of potatoes as well as 600 hectares of vineyard suffered heavy damage (Maurer et al., 2012).

Direct damage to shellfish beds was less than caused by a previous storm in 1999, which occurred at low tide. Xynthia enriched coastal waters with nutrients by suspending sediments through agitation and by flow-back of water after having swept the land. This appears to have contributed to the appearance of the alga Pseudonitzschia australis, which increases the toxicity of organic nitrogen and has been coincident with Amnesia Shellfish Poisoning (ASP) within oysters and mussels.

Forests and wooded areas were also damaged in France and Germany due to the high winds (Forest Europe, et al., 2011).

Indirect impacts

The indirect impacts were mostly felt by the agriculture sector as the fields were burned by the salt and are expected to be infertile for several years (Maurer et al., 2012). There were also knock-on effects to cattle farmers who could not put animals out to pasture due to damaged ditches and draining canals. The salinized pasture lands also reduced farmers’ ability to make hay in the summer months (The Connexion, 2010).

The indirect impacts felt by the agricultural sector are on worker and capital productivity, and the knock-on effects to the wider supply chain

The storm destroyed a number of sewage treatment plants close to many shellfish farms leading to potential indirect impacts through viral contamination. However, although up to 9%

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of oysters and mussels were found to have low-level contamination 2 days after the storm, one month later the number of positive samples was greatly reduced, even for norovirus.

Table 8.6 Crop losses and shortfalls in Charente-Maritime[23]

	Crop losses and loss of earnings			**Lost funds**	**Total**
EUR	2010	2011	2012		
Field crops	7 366 800	2 629 100	1 479 000	16 728 500	28 203 400
Fodder areas	5 231 200	1 068 700	575 100	2 370 000	11 885 000
Fines and potato	1 148 000	776 000	162 500	211 500	2 298 000
Salt farming	700 000			400 000	1 100 000
Other Productions	2 000 000			No data available	2 000 000
Agricultural services enterprises	1 000 000				1 000 000
Total	17 446 000	4 473 800	2 216 600	22 350 000	46 486 400

Recovery actions

Immediately after the storm, emergency work was carried out to ensure protection against the next tides. 190 projects were concerned in France in 2010 (Jacquet et al., 2013). Repairs to all types of defence (masonry dams, earth, sand dunes) were carried out. In the areas at risk from sea floods, amicable purchase boundaries were marked out to enable the people in these areas to re-localise elsewhere (Jacquet et al., 2013). 1162 properties in France were purchased by the National Major Risks Prevention Fund (FPRNM).

Mitigation actions

The west of France was unprepared for a strong windstorm combined with a high spring tide which resulted in significant coastal flooding. Risk zoning policy and building legislation in areas subject to floods were put in the spotlight. In France, dikes and flood defences gave a false sense of safety, and thus contributed to the urbanization of areas at risk. This led to increased exposure and reduced active management of risk (Lumbroso, 2011). Historically, the purpose of the sea walls was to protect agricultural land, not urban areas. Dike failure due to flooding was also aggravated by the lack of monitoring of the dikes some of which were then in a defective state.

Impact pathways

The impact pathways, reflecting the findings from both the literature review and the case study, are presented in the Figure 8.4.

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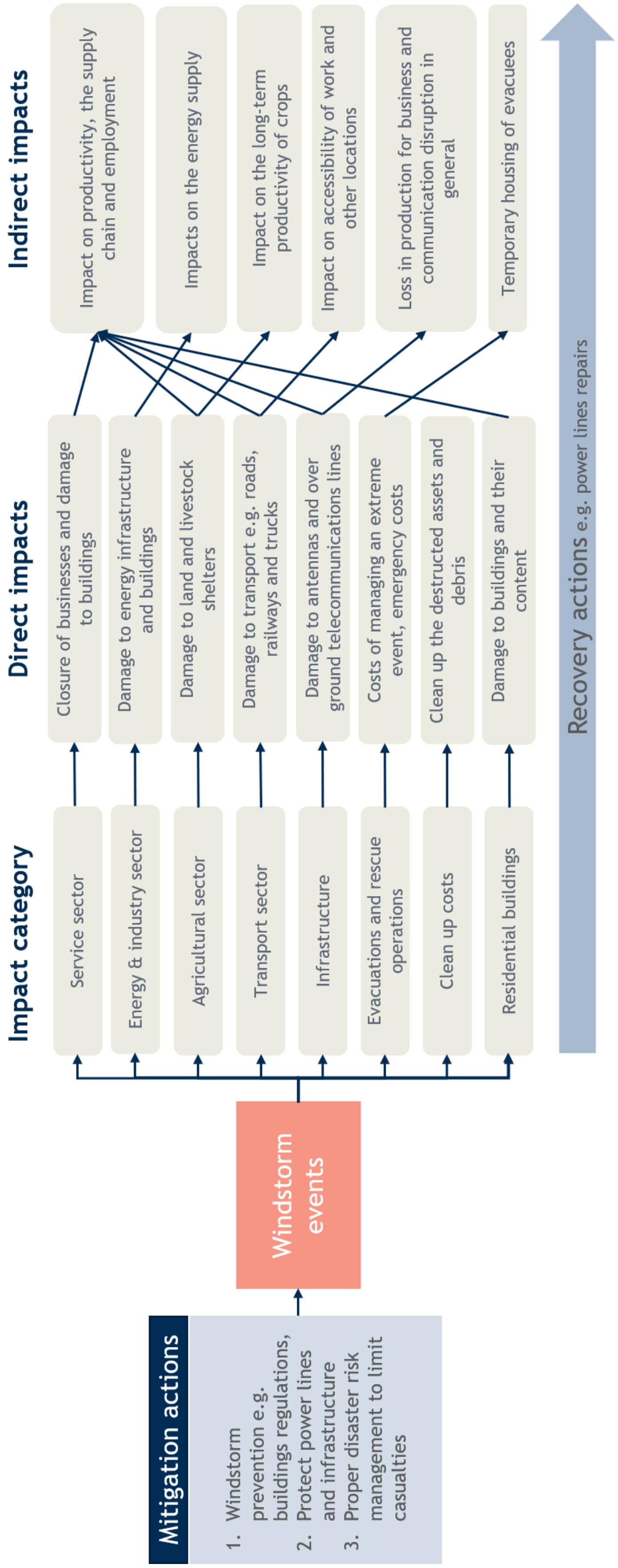
[23] Chambre d'agriculture de Charente-Maritime, 2011. Note de la Direction Départementale des territoires et de la mer, février 2011, http://www.charente-maritime.chambagri.fr/fileadmin/publication/CA17/Xynthia/Flashs/Xynthia_bilan_1_an.pdf

Figure 8.4. Impact pathways for windstorms



B.3. Earthquakes

An earthquake is a sudden shaking movement of the earth caused by waves moving on and below the earth's surface. The shaking ranges from quite gentle in small earthquakes to incredibly violent in large earthquakes. Earthquakes occur most often along geologic fault. The most exposed regions of the continent can be found in Italy, the Balkans, Greece, Bulgaria and Romania.

Literature review

Direct impacts

To identify the impacts that earthquakes events in Europe could have, a literature review was undertaken**.** Table 8.7 presents a list of the most common direct economic impact of earthquakes (BCcampus and University of California, 1997).

Table 8.7 Economic direct impacts of earthquakes in Europe

Impact category	**Impact type**
Residential buildings	Buildings damage Subsidence and tilting due to liquefaction Fire damage due to gas pipe explosions (University of California San Diego)
Agriculture sector	Damage to livestock shelter and farming equipment
Energy and industry sector	Fuel pipelines rupture and damaged electrical lines Buildings damage
Cultural services and tourism	Damage to a heritage site
Transportation & infrastructure	Damage to railroad lines Damage to roads and bridges
Service sector	Shops and business may be destroyed
Evacuations and rescue operations	Cost of managing an extreme event, emergency costs

Indirect impacts

The indirect impacts of earthquakes on the economy can in many cases be felt on the longer term. Earthquakes can have an effect on recovery times in a number of ways. Earthquake can damage critical infrastructure for the production and delivery of goods and services. Earthquakes can also have a negative impact on the availability and the productivity of human capital. Table 8.8 presents a list of the most common indirect economic impact of earthquakes (BCcampus).

Table 8.8 Economic indirect impacts of earthquakes in Europe

Impact category	Impact type
Private buildings	Depreciation of the value Loss of capital
Agriculture sector	Impact on the long-term productivity
Energy and Industry sector	Indirect impact of the supply chain and employment Business disruption due to power supply problems Depreciation of the value
Cultural services and tourism sector	Lost revenues
Transportation & infrastructure	Indirect impact on accessibility of work locations which may result in reduced productivity and potentially lost wages.
Service sector	Indirect impact of the supply chain and employment Depreciation of the value
Evacuation and rescue operations	Temporary housing of evacuees
Clean up costs	Debris removal can place a strain on budgets

Recovery actions

The reviewed literature (Seville et al., 2014) assumes that these negative economic consequences are in part offset by a subsequent period of increased economic activity, due to higher spending on infrastructure and reconstruction. The magnitude of this effect depends on the amount of additional spending, how it is financed as well as the scale of the multiplier effect. According to Skidmore and Toya (2002), natural disasters, such as earthquakes, could present an opportunity to update capital stocks and in turn facilitate the development of early technologies.

The estimated time to recovery can be seen in different ways. One way is to estimate the time it would take to replace all the damaged buildings. In this case, it may take 10 years or more. As an example, L'Aquila city centre reconstruction should end by 2023, 14 years after being struck by the earthquake (Contreras et al., 2018). For the Canterbury earthquake in 2010, it could take up to 20 years for damaged roads to return to their prior state (Stuff, 2018).

Recovery also involves the return of production output of the affected area to pre-earthquake levels. This varies greatly according the location, the magnitude of the earthquake as well as the concentration of certain capital stocks in the area.

Mitigation actions

Earthquakes damages can be reduced, as the main cause of damage is the inadequate seismic resistance of the building stock, lifelines and industry. Therefore, adequate prevention and preparedness strategies on the built environment are needed to mitigate the adverse consequences of earthquakes disasters that we see today (JRC, 2013).

EU countries supported the Eurocodes, the European Standards for Construction and pushed for the coordination and promotion of Civil Protection as well as for related research program. However, these actions, while needed, do not address the critical issue in areas vulnerable to moderate and strong earthquakes in Europe: most of the buildings and infrastructure built prior to the adoption of the current standard are highly vulnerable and many perform vital functions in the cities (JRC, 2013).

In a study by the JRC (2013) several actions are summarised to reduce the severity of an earthquake's consequences. These are presented in Table 8.9.

Table 8.9 Earthquake mitigation actions

Effect type	**Mitigation actions**
Ground motion / shaking	Evaluate the seismic performance of existing buildings and strengthen those with insufficient seismic resistance Ensure the quality of construction Evaluate the seismic resistance of lifelines, transportation networks and industrial facilities, and strengthen where necessary Strengthen monuments and buildings of high cultural value
Fault rupture	Not building across potential active faults
Landslides	Avoid building in these zones or build taking adequate precautions, for instance by stabilizing the soil.
Fires	Seismic design standard for the gas networks

Case study desk analysis

For earthquakes the case study of the Emilia earthquakes is studied to learn more about the direct and indirect impacts and their links.

In 2012 two major earthquakes struck Northern Italy, causing 27 fatalities and widespread damage. The overall coverage of the affected area is estimated to be around 9000 km^2 (Andreini, 2014).

The region of Emilia-Romagna was mostly damaged (nearly 92% of the total recorded damages), particularly in the provinces of Modena, Ferrara, Bologna and Reggio Emilia. Lombardy and Veneto were affected to a lesser extent with nearly 8% and 0.4% of total damage respectively (EC, 2012). The earthquakes became known as the Emilia earthquakes.

The Emilia-Romagna region is a densely populated with 550 000 inhabitants. The region is relatively wealthy region as it represents one of the country's most productive areas (more than 120 thousand businesses (of various sizes) and 420 thousand workers), producing almost 2% of the national GDP and significantly contributing to regional (and national) export (Pagliacc & Russo, 2016).

Direct impacts

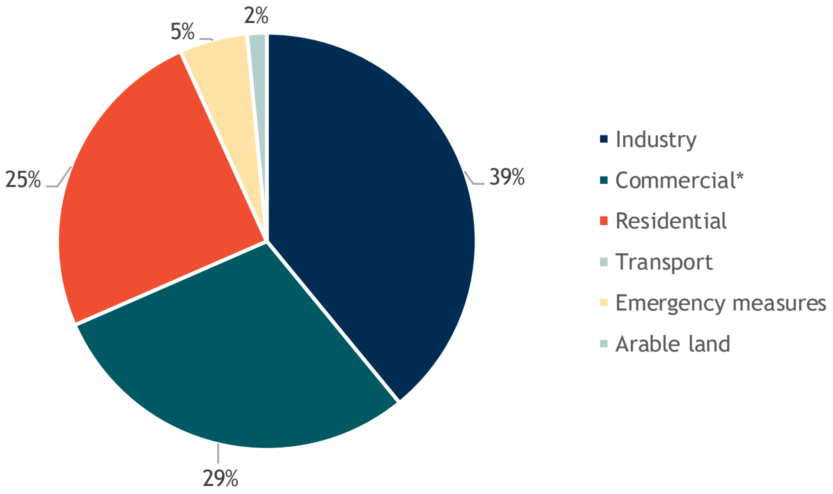
The earthquake struck a large area, with sizable socioeconomic differences within the affected area itself (Pagliacc & Russo, 2016). The earthquakes resulted in at least 50 injured people in the first earthquake and 350 in the second, as well as a total of 45 000 homeless (Reuters, 2012).

The National Council of Engineers (2014) estimated a way higher loss of about EUR 13.3 million[24] which represents about 0.86% of 2012's GDP (Codogno, 2016).[25]

Overall, this event has a large economic loss compared to the intensity of the earthquakes. This can be partly explained by the fact that two earthquakes followed each other within a short time period. However, the high losses are also caused by the exposure of this areas as the area has a high percentage of industrial precast buildings and overall high vulnerability of public and residential buildings (Magliulo et al. 2014).

The damage costs consist mainly of damage costs to residential building, (EUR 3.3 million), infrastructure, historical and artistic heritage (damage costs not found), industrial activities (EUR 5.2 million), agriculture (EUR 0.2 million) and costs of emergency measures (EUR 0.7 million) (Codogna, 2016). The distribution of the damage costs is illustrated in the Figure 8.5 below.

Figure 8.5. Damage distribution



Source: Based on Codogno, 2016 & Rossi et al. 2019a.[26]

These costs are discussed in more detail below. Except for agriculture damages as there was no additional information found.

Damage to residential buildings

There were large damages to the residential buildings as most of the buildings were not designed according to any seismic resistance standard (Andreini, 2014). An explanation for this is that only in 2003 the region was seismically classified (Nosengo, 2012). In 2006, a law was

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[24] Number based on funding allocated to deal with emergencies and processes of reconstruction following the earthquake

[25] The JRC's Risk Data Hub, reported a total of 200 million euro of economic damages.

[26] Note that for commercial buildings the number is estimated based on the large damage costs for cultural heritage buildings

introduced to impose building standards appropriate for the seismic hazard classification. However, the transition period was long, and administrators did not enforce the adoption of appropriate technical standards. In a study by Moreni (2017) it was found that in in 66 municipalities assessed, the percentage of buildings designed for seismic resistance is approximately 4% of the total number of existing residential buildings.

The area is also rich of cultural heritages, holding many churches, bell towers, towers, palaces and fortresses. The Emilia Romagna Regional Office of Cultural Heritage and Landscape estimated that a total 2500 cultural heritage buildings were damaged (Parisi and Augenti, 2013).

Damage to industry and businesses

Businesses within the region reported 32 direct economic losses reflecting EUR 2.41 million damage costs. The industrial sector alone suffered 33 losses for EUR 1.46 million (Rossi et al., 2019).

Below some of the largest damages are discussed:

- The Production of Grana Padano and Parmigiano-Reggiano was badly affected as the earthquakes resulted in a collapse of it ageing racks (see Figure 8.5). Approximately 300.000 wheels, with an estimated value of € 200 million, were destroyed (UNDRR, 2012).
- In total, 500 factories were damages and 3.000 other factories were not accessible (Meroni et al., 2017).
- In total, five of the deaths occurred in small, recently built factories that completely collapsed, killing workers on night shifts. The timing of the earthquakes (at night) saved many workers as during the day those factories would have been filled with workers, and the death toll would be much higher (Nosengo, 2012).
- A number of medium-size companies in the region were an important part of the global production chain for the automotive industry (Codongo, 2016).

Damage to transport and infrastructure

The main roads connecting the affected towns were not damaged by the earthquake. Several roads were closed to prevent injury from the collapse of unstable or damaged building (UCL EPICentre, 2012). In addition, bridges and railroads were temporarily closed as they were inspected (Cimellaro et al., 2013).

Indirect impacts

Due to the disaster, at least 15 000 workers were laid off or lost their jobs. Of these, 5000 were from the engineering sector, 4000 from food production, 4000 from biomedical production, and 2000 in ceramics (UCL EPICentre, 2012).

In the study by Pagliacci and Russo (2016) the long-term impacts (2012-2014) are calculated. They included two population variables (total population and foreigners) and two employment variables (in total manufacturing and in manufacturing SMEs). The study differentiates its results for affected area and non-affected area in the Amelia-Romagna region. They found that there was a population reduction in the affected area and foreign population moved outside the affected area, which signals a weakening of the demand of labour in that area. A little reduction in employment in manufacturing was found in the affected area. And lastly, employment in manufacturing SMEs has decreased less than in the non-affected area.

Recovery actions

The affected region was supported by immediate reconstruction funds. In the first year, 11.6% was allocated while by the following year almost 27% were already allocated. Especially a large amount was spent on the reconstruction of buildings (reflecting 81.2% of the budget).

Also, the European Union contributed; the region received a record number of EUR 670 million from the European Union Solidarity Fund (EUSF) (EC, 2012). This fund aims to cover the huge costs of restoring essential infrastructure, providing shelter and rescue services as well as protecting the cultural heritage of the region. Of this fund, the largest share is spent on the cost of emergency operations (over EUR 465 million) which relates to the provision of temporary accommodation for some 43 000 people for up to 3 years. In total, EUR 90 million relates to repairs of basic infrastructure and over EUR 60 million to the cost of the rescue services. In 2017, it was calculated that the Emilia-Romagna Region has already granted about € 2 000 million for the reconstruction of residential buildings and commercial areas (Meroni et al. 2017).

Overall, it was said that the recovery period for industry and business took several months (Fioravante et al., 2013). Some industries built a smart campus to start again to operate in less of one month.

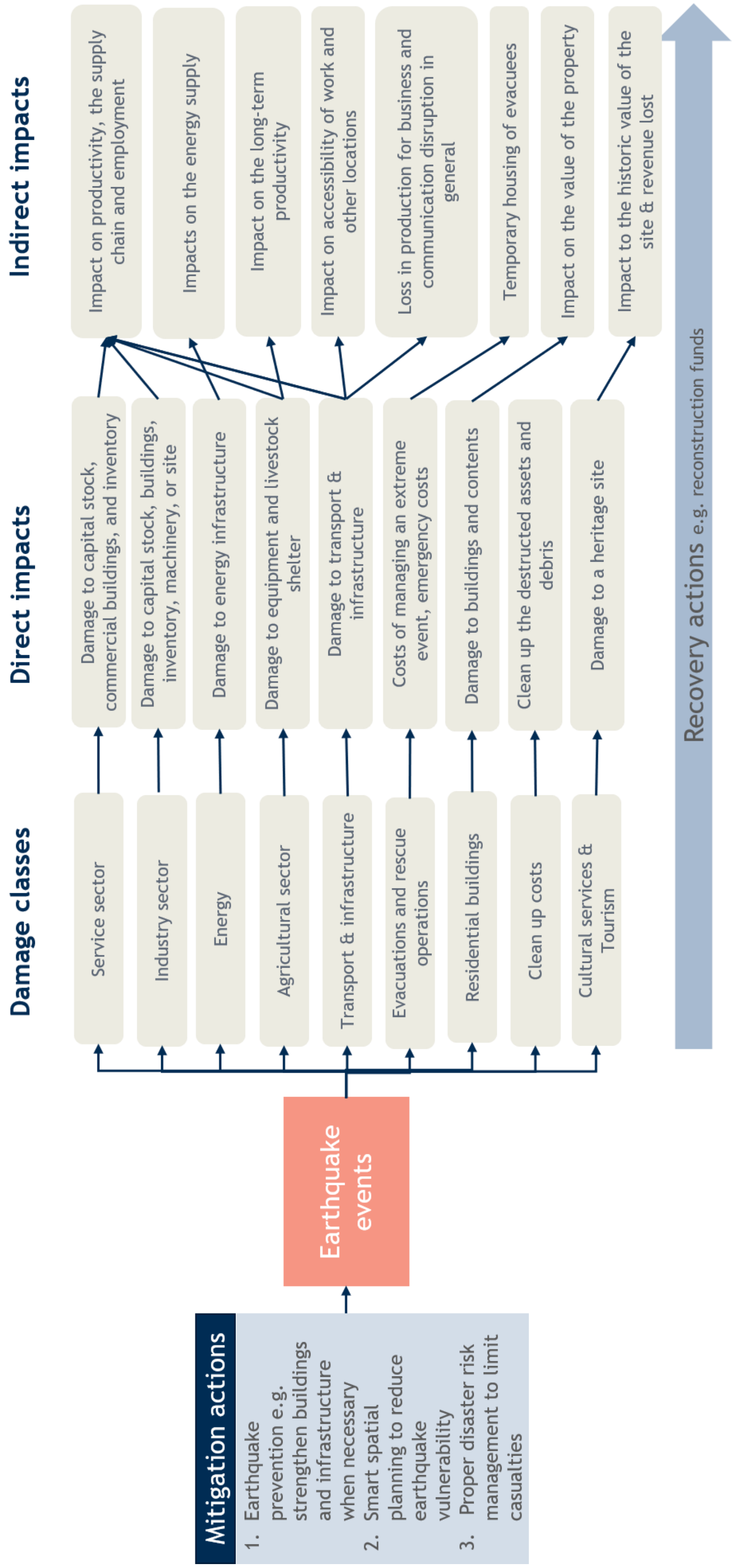
Mitigation actions

Even though Italy is the most earthquake prone country, it was unprepared for seismic risks (Nosengo, 2012). This is mainly due to the fact the region was only declared seismic area in 2003. It is important to stress that the industrial buildings built after that the Region was declared seismic area in 2003, practically did not suffer any damage. This shows that criteria for the seismic improvement of foundations as well as the seismic assessment and improvement of industrial building pay offs (Fioravante et al., 2013). The way forward is a better integration of seismic aspects in the laws and codes for building design and reinforcement.

Impact pathways

The impact pathways, reflecting the findings from both the literature review and the case study, are presented in the Figure 8.6.

Figure 8.6. Impact pathways for Earthquakes



B.4. Droughts

In general terms, drought is an event of unusual and temporary deficit in water availability. However, there are multiple more specific definitions, which depend on several factors, such as the region, its needs, and disciplinary lenses through which it is examined. According to the definitions used in European Drought Observatory,[27] droughts can be grouped into four main categories:

- *Meteorological* – It is defined on the basis of precipitation shortages (how much drier than normally and for how long)
- *Soil moisture (or agricultural)* – This type of drought is a result of a meteorological drought that caused soil moisture deficit that limited the water availability for plants.
- *Hydrological (including river flow)* – This type is associated with precipitation shortfalls on surface and subsurface water supply. All droughts originate from precipitation deficiency, but this type of droughts is concerned with how this deficiency affects hydrologic systems.
- *Socio-economic* – It occurs when the demand for a good or service (e.g. water, crop production, hydropower, etc.) exceeds its available supply due to weather-related shortfall in water availability.

The first three types of droughts perceive droughts as a physical phenomenon, while the fourth one approaches it in terms of supply and demand.

Literature review

Direct impacts

The direct impacts of droughts are usually non-structural and spread spatially and temporarily over larger areas and periods than the damages resulting from other natural hazards (Naumann et al., 2015). To identify the impacts that drought events in Europe could have, a literature review was undertaken. Table 8.10 presents a list of the most common direct economic impacts of droughts and the type of these impacts as were identified by the European Drought Impact report Inventory (EDII).[28] The Table is a synthesis of direct economic impacts based on Stahl et al. (2016).

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[27] European Drought Observative (EDO) (n.d.). European Commission website on the European Drought Observative. (website) Available at: https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000

[28] European Drought Centre (EDC) (n.d.) Search the European Drought Impact Report Inventory (EDII) database. (website). Available at: http://www.geo.uio.no/edc/droughtdb/edr/impactdatabase.php

Table 8.10 Economic direct impacts of droughts in Europe

Impact category	Direct impact type
Agriculture sector	• Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc. • Reduced productivity of permanent crop cultivation • Agricultural yield losses of normal production • Reduced availability of irrigation water • Reduced productivity of livestock farming (e.g., reduced yields or quality of milk, reduced stock weights) • Forced reduction of stock (early selling/slaughtering) • Regional shortage of feed/water for livestock
Forestry sector	• Reduced tree growth and vitality • Decrease in annual non-timber products from forest trees (e.g., cork, pine nuts, etc.) • Increased occurrence of water stress indicators and damage symptoms (e.g., premature ripening, seasoning checks, defoliation, worsened crown conditions etc.) • Increase of pest/disease attacks on trees • Increased dieback of trees • Damage to short rotation forestry plantations (energy forestry)
Fishery sector	• Reduced (freshwater) fishery production • Reduced aquaculture production
Energy sector	• Reduced hydropower production • Impaired production/shut down of thermal/nuclear powerplants (due to a lack of cooling water and/or environmental legislation for discharges into streams)
Industry sector	• Restriction/disruption of industrial production process (due to a lack of process water and/or environmental legislation/restrictions for discharges into streams)
(Waterborne) transportation	• Impaired navigability of streams (reduction of load, increased need of interim storage of goods at ports) • Stream closed for navigation
Cultural services and tourism	• Sport/recreation facilities affected by a lack of water or snow • Impaired use/navigability of surface waters for water sport activities (including bans)
Water sector	• Local and regional water supply shortage / problems (drying up of springs/wells, reservoirs, streams) • Bans on domestic and public water use (e.g., car washing, watering the lawn/garden, irrigation of sport fields, filling of swimming pools) • Limitations in water supply to households in rural and urban areas (supply cuts, need to ensure water supply by emergency actions)
Buildings and infrastructure	• Structural damage due to soil subsistence due to groundwater abstraction • Structural damage due to soil shrinkage due to soil moisture reduction

To identify how a drought event affects different sectors, we perform a small literature review in the Global methodology section to learn about the distribution of the costs among the different capital stock.

Indirect impacts

Indirect costs occur as a result of biophysical impact on the economy as a whole, meaning changes in resource-based activities of the rest of the economy (Logar and van den Bergh, 2013). As indirect impacts are results of direct damages, they usually occur at a later point in time than the direct costs. The table below presents per impact category indicative indirect costs, which may or may not emerge during a drought event. The table is a synthesis of indirect economic impacts based on own elaboration and Stahl et al. (2016) and Logar and van den Bergh (2013).

Table 8.11 Overview of indirect economic impacts of droughts

Impact category	Indirect impact type
Agriculture sector	• Increased prices of agricultural products • Reduced agricultural employment • Business interruption in sectors using agricultural products as an input (e.g. food industry) • Changes in crop choices • Reduced tax revenues from farmers
Forestry sector	• Increased prices of timber and timber products • Reduced employment in forestry and related sectors • Business disruption in related industries (e.g. carpentry) • Assets and sectors impacted by wildfires which are a result of droughts
Energy sector	• Increased electricity prices • Business disruption due to power supply problems • Increased reparation costs
Industry sector	• Disruption of supply chains
(Waterborne) transportation	• Disruption of trade • Disruption of supply chains
Cultural services and tourism	• Reduced tourism due to reduced water-related activities
Water sector	• Non-market welfare losses due to water restrictions in households
Buildings and infrastructure	• Business disruption due to damages on buildings and infrastructure

Recovery actions

Most of the times, droughts do not cause structural damages, but rather reduce the supply of water to humans, economies, and ecosystems. Therefore, the recovery actions after a drought refer to the actions undertaken to restore losses caused by the water deficit. Once the drought is over and the water flow is back to normal, most of the disrupted economic activities can return to their pre-hazard processes without any additional effort. However, this is not the case for agriculture, where farmers should undertake recovery actions regardless of how well they have been prepared for such an event (WMO and GWP, 2017). These actions include measures for enhancing plant health and soil water conditions.

Recovery periods

With regard to the duration of the recovery period, meaning how much time is required for the affected capital stocks to recover to their pre-hazard state, it is a matter of the mitigation actions undertaken before and during the drought event and the recovery actions implemented afterwards. As it is subsequently explained arable land and manufacturing, water supply, and energy generation can return to their pre-hazard conditions within a year after the end of drought, provided that successful recovery actions have been undertaken.

Droughts do not usually cause the destruction of productive capital, but rather a temporary retirement of productive capital as production capacity declines.[29] Therefore, the recovery of the arable land and manufacturing, water supply, and energy generation does not require any reconstruction effort or additional investments. If adequate recover actions are implemented, the Arable land should return to the previous state already in the next harvest period after the drought event has ended. For energy production, water supply, and manufacturing, a short delay between the end date of the drought event and the availability of water is expected, so as the water reservoirs to be refilled. This delay, however, it is assumed to be in the order of months.

Finally, in case there are structural damages in buildings and infrastructure, due to soil shrinkage or subsistence, recovery would require reparation measures or even reconstruction. However, Corti et al. (2009), who examined the link between drought events and damages in building in France, concluded that although there is a connection, damages occur in the long-term and thus there is no reconstruction process following a drought like after other disasters.

Mitigation actions

Mitigation refers to the short- and long-term actions, policies, or programmes implemented during and in advance of a drought event that aim at reducing social, economic, and environmental vulnerability to droughts. Since the main impacts of droughts are on water supply for humans, agriculture, industry, and electricity generation, mitigation actions include permanent planning and sound integrated management of water supply and demand and identification of sustainable sources of energy production (FAO, 2019). Additional preparatory measures that can mitigate the effects of droughts are the establishment of early warning systems, the development of proactive drought management strategies, and other institutional and governance measures that can improve drought management plans (WMO and GWP, 2017).

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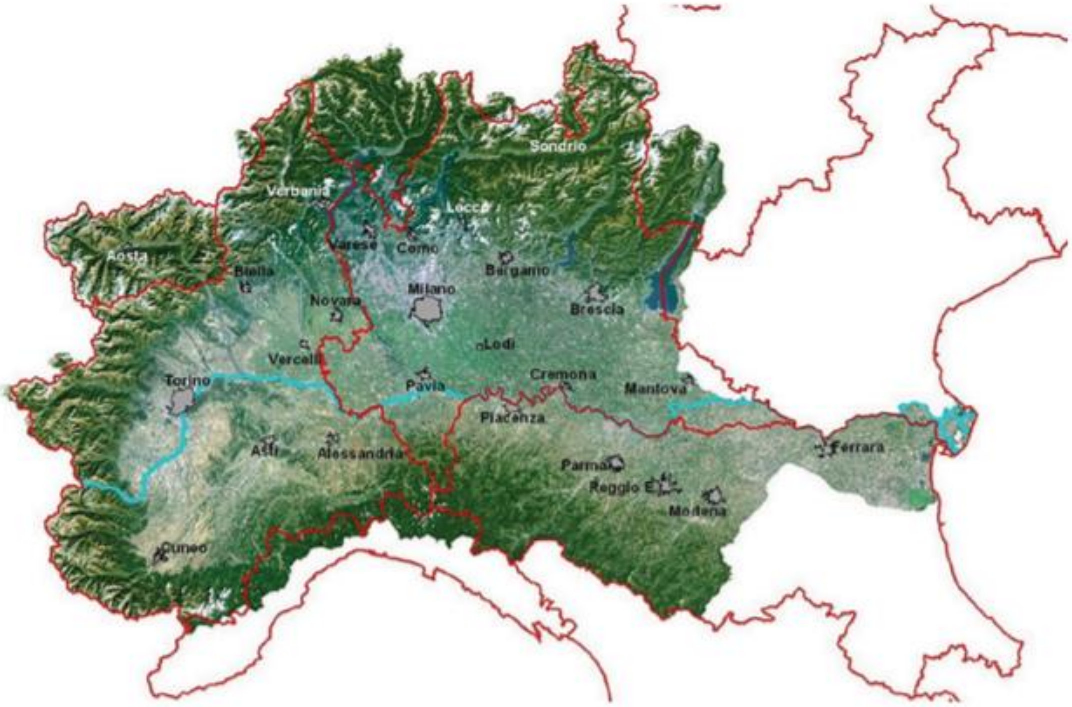
[29] Droughts indirectly might cause damage to buildings due to soil subsidence resulting from excessive groundwater extraction, however, this is assumed that it has a minor effect in Agriculture and manufacturing, water supply, and energy generation.

Case study desk analysis

The Po River Basin in Italy has experienced significant droughts in the past, concentrating a relatively high interest in the literature, which allows for an in-depth analysis of drought economic impacts in the region. The Po River Basin is found in the northern part of Italy, extending from the Alps in the west to the Adriatic Sea in the east, covering nearly one-fourth of the Italian territory, with a total population of about 17 million. The basin spans across more than 70 thousand km^2 covering 8 NUTS2 Italian regions[30] and a small part of French territory.

Figure 8.7. Po River Basin



Source: Musolino et al. 2019

The basin constitutes a significant centre of socio-economic development, as 34% of the value added created in Italy comes from this area (Musolino et al. 2019). This is a result of both the rich natural resources present in the area and the economic activities taking place in the region. According to Musolino et al. (2019), the basin is an important agricultural area, with 35% of national agricultural production and 55% of national livestock coming from this region. It is also a centre of industrial production as it concentrates 29% of Italian industrial and services firms. About 890 hydropower plants are in the basin, with an installed hydropower capacity that reaches 48% of the total power production in Italy. In addition, the 400 thermal power plants located in the basin correspond to 32% of the total Italian power production. The basin also contributes substantially to the public water supply in Italy, as in 2018, the largest amount of

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[30] Piedmont (ITC1), Aosta Valley (ITC2), Liguria (ITC3), Lombardy (ITC4), Veneto (ITH3), Emilia-Romagna (ITH5), Tuscany (ITI1), and Provincia di Trento (ITH2)

water abstracted for drinking use across all Italy was abstracted by the Po river district (2.8 million m^3) (Istat, 2020).

The presence of these economic activities in the Po river basin increases the exposure of the region to drought events. According to Istat (2020), from 2001 to 2017, the annual average precipitation in Po river basin decreased by 2% compared to the 1971-2000 period. A significant drought event took place in the region in 2003. After a winter characterized by low snowfall a low-precipitation spring led to a major reduction of water flows ranging between 50-75% of average flow (Musolino et al., 2019). A description of the direct and indirect economic impacts of this drought event is presented below.

Direct impacts

According to Carrera et al. (2013), the 2003 drought event in the Po River Basin affected agriculture, hydro- and thermoelectricity production, and water supply and sanitation services. The crop yield per hectare in 2003 dropped by a double-digit percentage compared to the average crop production between 2000-2010. The production loss varied substantially across areas and crops. In terms of the affected areas, the drought caused a higher agricultural loss in the higher-altitude areas than the lower-altitude areas. With regard to the crop type, according to an econometric analysis performed by the Italian Farm Accounting Data Network (FADN) wheat production decreased by 10% and maize by almost 5%. The average farm income declined by 6%, however, the labour demand increased by 28%. FADN's econometric analysis has indicated that water stress has a different effect on agricultural production, income, and labour, depending on the season and drought intensity. According to Mysiak et al. (2013), the gross production losses for wheat, barley, oats, rice, maize, and sorghum were EUR 156 million (in 2003 prices). However, the gross yield gains (namely in the higher altitudes) were estimated in the same study to be around EUR 44 million, coming mainly from gains in rice production. Therefore, the net loss of the drought of 2003 for the examined crops is estimated at around EUR 113 million.

The energy sector was also one of the most impacted sectors of the drought of 2003. The cost of forgone energy production was estimated at around EUR 280 million (Carrera et al., 2013). The prolonged droughts in the region indicated that there is an insufficient amount of water available for cooling of thermoelectric power plants.

Although damages in the industrial sector did occur, these were considered as significantly lower than the costs of the agriculture and energy sector. This is also a result of the progressive lower hydro-demanding manufacturing technologies that are used in the industry (Musolino et al., 2013).

Indirect impacts

The indirect impacts of the drought event of 2003 have been analysed by few studies. Musolino et al. (2017), who examined the socio-economic impact of this drought, estimated the welfare loss of different social groups, using consumer surplus theory. According to their results, farmers resulted to be the “winners” of the event, as the negative effect of reduced production was largely counterbalanced by the positive economic effect of the price increase. Their results indicated that farmers gained EUR 700 million from this. On the other hand, consumers were found to be the “losers” of the event, losing welfare of about EUR 820 million, due to the reduced water quantity and the price increase.

Similar results were reported by Mysiak et al. (2013), who estimated that the increased maize prices compensated the yield losses, resulting from increased crop profitability. However, similar compensation was not observed for other crops – such as soft wheat for which the drought of 2003 resulted in net economic loss.

Carrera et al. (2013) examined how this drought affected several social indicators. Their analysis showed that the drought was quite short to have an effect on the structure of the population or give rise to health issues.

Recovery actions

To cope with the drought event, the River Basin Authority together with the Civil Protection Agency initiated the so-called Drought Steering Committee (Cabina di Regia) and the Protocol of Intent (Protocollo d’intesa). The agreement allowed the additional release of 3.7 million m^3 per day from the Alpine reservoirs in order to address the water deficit in the downstream areas (Mysiak et al., 2013). It also restricted the water abstraction from the agriculture sector.

Recovery actions in the agricultural sector focused on auto-adaptation strategies – such as alternative production techniques, crop choices, technological change, and reduction of production in certain areas (Carrera et al. 2013). The reasons that these auto-adaptation strategies increased the resilient of the sector to droughts are described by Mysiak et al. (2013):

- Farming technologies improved efficiently, increasing the agriculture total surface and decreasing working intensity per hectare
- Irrigation intensity increased, together with the development of alternative sources of water (groundwater)
- energy production (biomasses) was introduced in the farming business, providing and alternative source of income.

The recovery measures in urban areas mainly referred to local and regional administrations declaring water use restrictions to allow for the sectors in most need to have access to adequate water and for the reservoirs to be gradually refilled. Mild restrictions were in place in the Parma town and in Ferrara. Moreover, the water abstraction devices in Ferrara had to change as the low river flow hampered their abstraction capacity (Carrera et al. 2013).

Mitigation actions

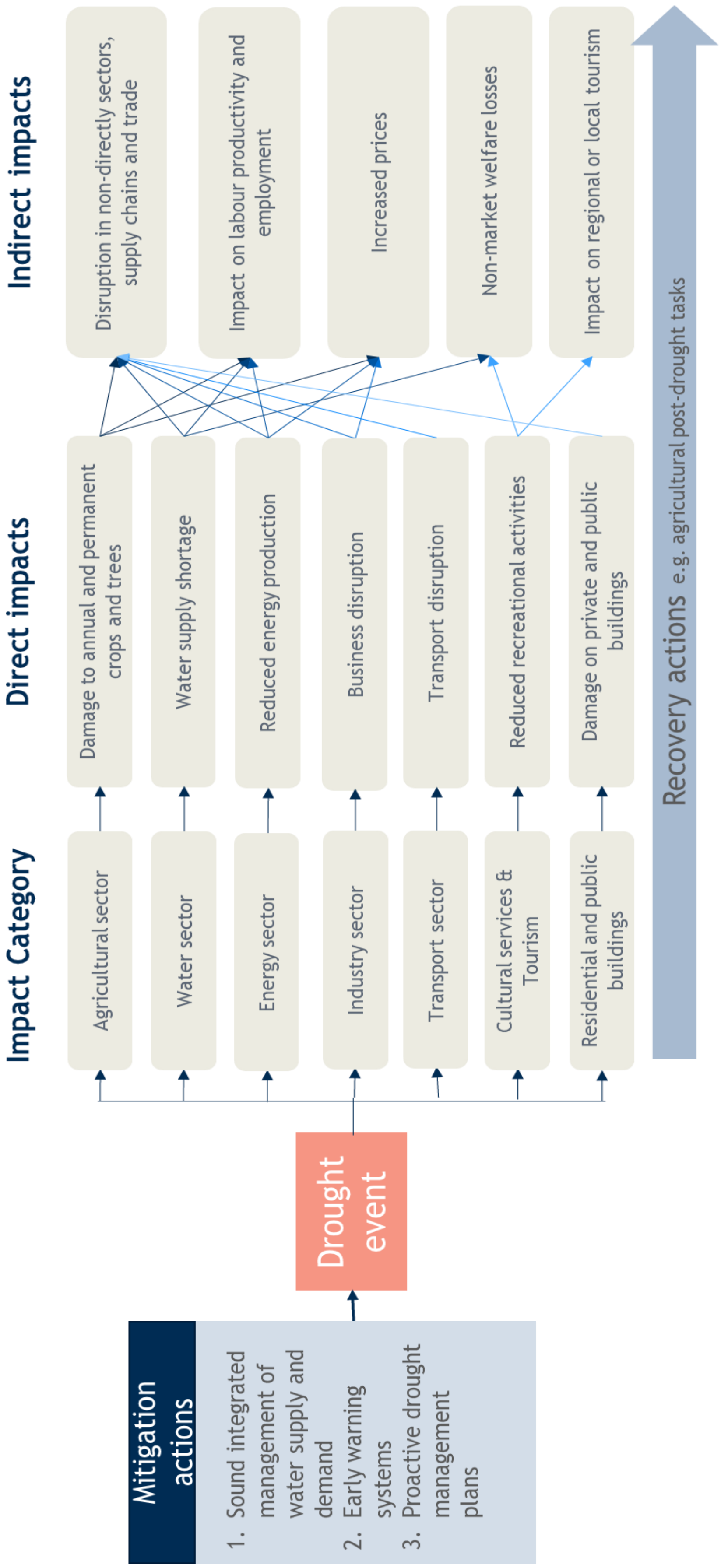
As for the mitigation actions taken in the aftermath of the 2003 drought event, the Po River Basin Authority initiated the Water Balance Plan (Piano di Bilancio Idrico), which is a permanent tool for the management of emergency situations, such as droughts. The plan also describes the Po River Drought Early Warning System, which aims at forecasting, simulating, and controlling entire Po river basin and provide useful data for coping with emergency drought events (Carrera et al., 2013).

In addition, Italian authorities increased their efforts to achieve efficient water use. One of the measures taken by the central government is the investment in water infrastructures both for irrigation and other uses (Carrera et al., 2013). Moreover, the National Irrigation Plan was developed by central and local authorities together. For the 2007-2010 period, the Plan provided a series of interventions amounting to EUR 1.1 million. These interventions included restoration and efficiency measures of the reservoirs and water storage systems, water infrastructure repair and renovation, measures that tackle unauthorised withdrawals, renovation of monitoring systems, and use of grey water for certain uses (Carrera et al. 2013).

Impact pathways

The impact pathways, reflecting the findings from both the literature review and the case study, are presented in the Figure 8.8.

Figure 8.8. Impact pathways for a drought event



9 Annex 2.C Methodology for the development of the Damage Distribution Matrices

C.1. Floods

Floods and their monetary direct and indirect damages are well studied in the literature (see Impact Pathways - Annex A). This literature has shown that the sectoral distribution of economic losses of a flooding event is not always the same, but is rather affected by multiple factors, such as intensity variables (water depth, velocity, duration, extent of flooding etc.) and exposure (number and value of assets in an affected area). This suggests that the distribution of the damage costs among the study's five capital stocks differs per flooding event.

Various methods have been developed to assess flood damages at various scales (e.g. Jonkman et al., (2008), Jongman et al., (2014) and Carrera et al., (2015)). An extensively used method in the analysis of sectoral damages from flood events is the use of flood damage functions. Damage functions combine intensity variables with exposure variables to find damage factors for each affected capital stock. Most damage functions are developed for the local or national level such as the Dutch standard-method (HIS-SSM) which is used to calculate flood damages by the use of damage curves (De Bruijn, et al., 2015). A few studies have performed continental flood damage assessments, such as Rojas et al. (2013).

For this study we use the "Global flood dept-damage functions" by Huizinga et al. (2017) which is appropriate to both fluvial and marine floods. Huizinga et al. (2017) provide one of the first comprehensive global database of flood damage functions that can translate flood water levels into direct economic damages. Consequently, it can be used for our global approach as it includes damage functions for all the ESPON country members.

In the section below we describe how the damage functions are used to develop the DDMs for floods. In doing so, the data needs to include intensity variables and exposure variables are discussed. To illustrate how the DDMs are developed, an example of a flood event in Poland in 2010 is presented in detail. Lastly, the limitations of our approach for the economic assessment of floods are discussed.

Development of DDMs

For each recorded flood event in the JRC's Risk Data Hub, a DDM is developed based on the intensity on the one hand, and on the exposure on the other.

The intensity of a flood is given in meters of water depth. By means of the damage functions, the water depth is associated with a certain damage factor for each capital stock. Exposure data gives us the information about the flooded area, the land-use (e.g. the buildings, roads, arable land etc.) of this area and the related maximum damage value in euros of each land-use. With the damage factor (determined by water depth) it is calculated to what extent the buildings, roads and other land-use are affected by the flood. For example, with a flood of 1.5

meters, 50% of residential buildings are damaged, resulting in a 50% damage value of the maximum damage value for residential buildings.

The final step for the development of the DDMs is to estimate damages for each capital stock and through this deduce the distribution of the total economic losses among the five capital stocks. In the table below an overview of the different data components is given. Each input is discussed in detail in the section below.

Table 9.1. Overview of data inputs to develop the event specific DDM

Variable	Sub-variable	Source	Unit	Time	Level
Intensity	Water depth	ESPON-TITAN river flood hazard map with a return period of 100 years	Meters	100-year return period, based on NUTS 2013	NUTS3
	Damage factor	Global depth-damage functions by Huizinga et al. 2017	Percentages	2007	NUTS3
Exposure	Flooded area without waterbodies	JRC's flood simulation map based on floods with a return period of 100 years	Square meters	100-year return period, based on NUTS 2013	NUTS3
	Land-use of flooded area	Eurostat's land-use data	Square meters	2009, exemptions for NO, RO, BG (2011) and HR (2015)	NUTS2, exemptions for NO (NUTS3) and CH (NUTS0)
	Maximum damage value	Global depth-damage functions by Huizinga et al. 2017 & Eurostat's Standard Output data for agriculture	Euro per square meter	Price levels of 2010	NUTS0

Damage functions

The Global depth-damage functions by Huizinga et al. (2017), is based on six damage classes, namely residential, commercial and industrial buildings, transport, infrastructure and agriculture. The residential, commercial and industrial buildings, all include the content of the building.

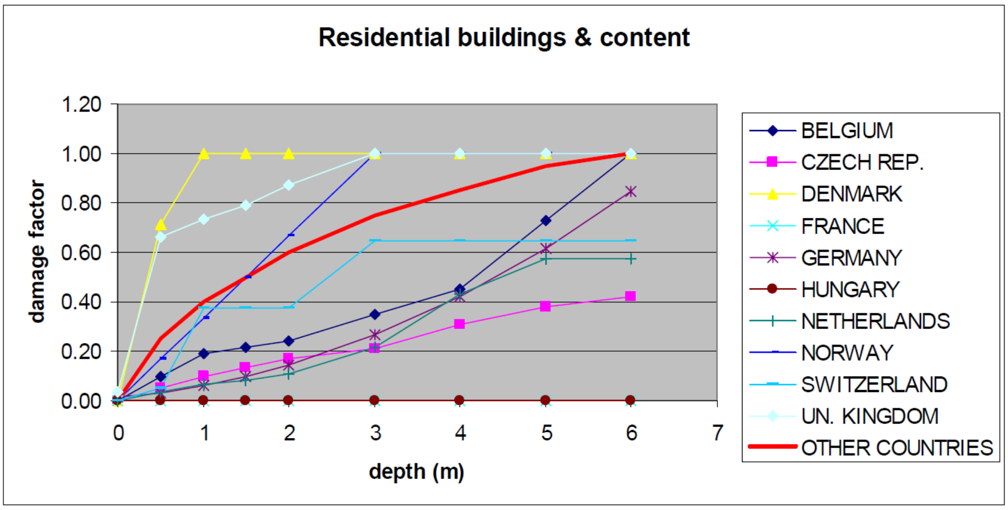
The damage classes are aligned with the five capital stocks considered in this study as shown in Table 9.2.

Table 9.2. Damage class description. Source: Huizinga et al. (2017)

Damage class	**Description**	**Study's 5 capital stock**
1. Residential buildings	Refers to residential buildings such as houses and apartments and their contents	Residential
2. Commercial buildings	Refers to commercial buildings and their contents such as offices, schools, hospitals, hotels, shops, etc.	Commerce
3. Industrial buildings	Refers to industrial buildings and their contents such as warehouses, distribution centres, factories, laboratories, etc.	Industry
4. Transport	Transport facilities	Transport & infrastructure
5. Infrastructure	Roads and railroads	
6. Agriculture	Based on damage resulting from flooded agricultural lands only (i.e. does not include farms, sheds, farming material, etc.)	Arable land

The damage functions for Europe are mainly based on the unpublished article by Huizinga (2007) in which the author developed flood-damage functions for EU member states. The damage factors in the damage curves are intended to span from zero (no damage) to one (maximum damage). Below, an example is given for residential buildings in the EU.

Figure 9.1. Damage factor for residential buildings including inventory



Source: Huizinga (2007)

Depth estimation

The flood extent refers to the number of assets at risk in an affected area. The intensity indicators determine the magnitude of the damage to these assets. Intensity can be indicated by water depth, velocity, duration, rise rate, period, water quality and water salinity. The most common used indicator to determine intensity is the water depth. This indicator is also used in the Global Depth-damage Functions by Huizinga et al. (2017) and thus is used in this study as well. However, the JRC's Risk Data Hub provides no information about the water depth nor the flood extent. Therefore, this information is derived from the ESPON-TITAN river flood hazard map.

The ESPON-TITAN river flood hazard map applies the European Flood Awareness System (EFAS) Lisflood hydrological model, while combining hydrological and hydraulic models, long-term streamflow simulation from meteorological data and floodplain hydraulic simulations for flood depth (Alfieri et al., 2014). As a result, this map provides information about the median water depth and the potential maximum flood extent in a particular location caused by the simulated 100-year flood event at NUTS3 level (EXIMAP, 2007).

In general, higher return periods have lower inundation depths, and lower return periods have higher inundation depths (Koks et al., 2012). We therefore take the map with the return period of 100 years as these floods would have more significant damages and therefore are more likely to be in line with the reported flood damaged in the JRC’s Risk Data Hub.

Land-use in affected area

After the flood extent is calculated for each NUTS3 area, it is important to know what type of assets are exposed in the affected areas. To do so, we need spatial information containing information about the five capital stocks. Currently, common datasets, such a Corine land cover dataset, do not differentiate between residential, commercial, industrial and transport classes as they all fall under the category of urban fabric class. Although the most detailed approach would be to further disaggregate this one class into the capital stocks of this study, this level of detail is not necessary for the global methodology. Instead, Eurostat’s land-use data at NUTS2 for the year 2009 level gives us the necessary spatial information for the five capital stocks of this study. Since, however, the analysis is being done at NUTS3 level, it is assumed that the NUTS2 land-use data can be disaggregated to NUTS3 level. In practice, NUTS3 areas are much smaller than the NUTS2 areas they relate to, and they therefore not always reflect the land-use division of the linked NUTS2 area.

For several countries the Eurostat database does not provide land-use information as the countries do not report on this type of information or countries are not members of the European Union. For these countries, national reports are consulted.

National maximum damage values

The study by Huizinga et al. (2017) provides not only the damage functions, but also the national maximal damage value for residential buildings, commercial buildings, industry, and infrastructure & transport in euro per meter.[31] The development of the maximum damage value differs for each capital stock. In addition, maximum damage values may vary strongly between countries due to different assumptions and definitions in reported cases. A short description of the methods behind the national maximum damage values is given below. However, for a detailed explanation we would like to refer to the study by Huizinga et al. (2017).

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[31] The damage values are harmonized to 2010 price level and to Euros

Residential, Commercial and industrial buildings

To derive the maximum damage estimates for residential, commercial and industrial buildings, Huizinga et al. (2017) identified the construction costs per country, then estimated the total construction costs for typical residential, commercial, and industrial buildings, and adjusted their estimates for each country based on socio-economic parameters.

Transport and infrastructure

The literature is very limited about the maximum damage value for transport. Huizinga et al. (2017) applies an average maximum damage value of EUR 751,2/m^2. To calculate a country's specific maximum damage value, the maximum damage is recalculated according to the GDP per capita (2015) – ratio of the national maximum damage value.

Huizinga et al. (2017) applied the values for infrastructure from the European study (Huizinga, 2007) as the European average are well known. The average value in Europe is EUR 24/m^2 for five countries with a long-established track-record on damage assessment, namely United Kingdom, Germany, the Netherlands, Belgium and France. To calculate a country's specific maximum damage value, the maximum damage is recalculated in the same way as transport. Here, transport and infrastructure are combined to align with the Eurostat's land-use definitions.

Arable land

For arable land a different approach is taken to estimate the maximum damage value per euro square meter. Agricultural crop damage is related to a loss in output when crops are destroyed by the flood. It is assumed that the maximum damage in agriculture is equal to the value of the agricultural production in the flooded area. Therefore, the methodology is based on the Eurostat's Standard Output (SO) of arable land per country.

Table 9.3 Average maximum damage value for Europe

Capital stock	**Value (EUR/m^2 – 2010)**[32]
Residential	750
Commerce	621
Industry	534
Transport	751
Infrastructure	24
Arable land	0.22

This data set differs from that of Huizinga et al. (2017) because Eurostat's data is more appropriate for the European maximum damage values. However, non-EU member countries,

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[32] Each collected maximum damage value is representative for the price-level of the selected recent year for all data available, set to year 2010, except for arable for which the year is 2013.

such as Norway, Switzerland and Iceland, are not included. To complement the Eurostat database, national reports on maximum damage value for arable land are studied. Below an overview is given of the average maximum damage in Europe for the five capital stocks.

The use of DDMs

For the floods there is a total of 154 events recorded across Europe in the JRC's Risk Hub Database. In this study, the damage costs for each event are distributed among the 5 capital stocks. In many cases a flood event covers multiple NUTS3 areas. We therefore develop a DDM per event, which includes all the affected NUTS3 regions. This DDM includes 1) the distribution of the total costs among the affected NUTS3 areas and 2) the distribution among the five capital stocks for each NUTS3 area.

The application of the different elements explained above are demonstrated in the example with a flood event in Poland.

Example of flood event in Poland

The JRC's database reports a flood event in Poland in 2010. The flood affected 17 NUTS3 areas and had a total damage cost of EUR 2.3 million. Based on the JRC's Flood Simulation Map and Eurostat's land-use data we calculate the land-use of the affected areas in square meters for the five capital stocks (Table 9.4). For instance, in PL115, 430 thousand m^2 are indicated as residential area.

Table 9.4 Overview of the first step for the development of DDM. Only 5 out of the 17 affected NUTS areas are showed for simplicity purposes

NUTS 3	**Land-use of affected area (m^2)**				
	Residential	**Commercial**	**Industry**	**Transport / Infrastructure**	**Arable land**
PL115	4 303 809	1 578 063	860 761	3 586 507	91 527 673
PL12C	2 042 351	748 862	272 313	1 770 037	39 962 006
PL129	12 384 81	4 541 126	1.651 318	10 733 572	242 331 045
PL213	3 027 595	1 159 504	515 335	1 932 507	32 079 626
PL219	716 743	274 497	121 998	457 495	7 594 428

Poland's maximum damage value for each capital stock is given in the Table 9.5. The national maximum damage value is calculated based on the information provided in the study of Huizinga et al. (2017), except for the maximum damage value for arable land.

Table 9.5 Overview of Maximum damage value (€/m2) per capital stock

Maximum national damage values				
Residential	**Commercial**	**Industry**	**Transport / Infrastructure**	**Arable land**
€/m^2, 2010	€/m^2, 2010	€/m^2, 2010	€/m^2, 2010	€/m^2, 2013
€ 98.	€ 211	€ 178	€ 116	€ 0.14

As mentioned, different flood depths cause different level of damages. Therefore, the NUTS3 areas should be linked to the depth estimations given by the ESPON-TITAN river flood hazard map. With the depth estimation we can find the right damage factor per capital stock, which determines the extent to which the capital stock is damaged. The table below shows, for instance, that with a depth of 3 meters in NUTS3 area PL219, 90% of transport and infrastructure would be damaged.

Table 9.6 Depth estimation and the related damage factors

NUTS3	Flood depth (m)	Damage factor				
		Residential	**Commercial**	**Industry**	**Transport / Infrastructure**	**Arable land**
PL115	1.5	50%	45%	40%	63%	65%
PL12C	1	40%	30%	27%	48%	55%
PL129	1.5	50%	45%	40%	63%	65%
PL213	2	60%	55%	52%	74%	75%
PL219	3	75%	75%	70%	90%	85%

To arrive to the DDM for each affected NUTS3 area, we multiple the damage factor for each capital stock with its maximum damage value, which is in turn multiplied with the land-use of that capital stock. For example, the formula below gives the total loss received by the Residential capital stock in each affected NUTS3 region. The same formula is used for all capital stocks. It relates the share of a capital stock damaged in a NUTS3 region with the exposure of this capital stock in this region:

$$DDM\ per\ NUTS = (damage\ factor\ residential * maximum\ damage\ value\ residential) \\ * residential\ land\ use$$

To derive at the distribution for one NUTS3 area, the total absolute of the five capital stocks is added up so that the total absolute value in euros is known. Each capital stock within this one NUTS3 area is divided by this total to calculate the percentage of damage costs per capital stock. This is done for all the affected NUTS3 areas of one flood event. Together these distributions represent (partly) the DDM of that event.

As mentioned, the DDM distributes the total losses among capital stocks and among NUTS3 regions. For the latter – we need to distribute the total costs (EUR 2.3 million) as reported in the JRC's Risk Data Hub among the seventeen NUTS3 areas. This distribution is found by taking the sum of the five capital stocks for each NUTS3 region after which the sum of each NUTS3 area is added to total sum of the seventeen NUTS3 areas all together. Then, the sum of each NUTS3 areas is dived by the sum of the seventeen NUTS3 areas. As such, we calculated that 3% of the JRC's reported costs belongs to NUTS3 area PL115 (see Table below). After which, we find that EUR 73 million of the JRC's total damage cost is dedicated to PL115. Lastly, the DDM of PL115 is used to distribute the EUR 73 million among the capital stocks. For instance, the total damage to Residential buildings in PL115 is around EUR 22 million.

The distribution of the reported costs among the NUTS3 areas and their DDMs are presented in percentages as illustrated in the Table 9.7.

Table 9.7 Overview of Damage Distribution Matrix for a flood in Poland

NUTS3	**Distribution of the reported damage cost**	**Damage distribution matrix**				
		Residential	**Commercial**	**Industry**	**Transport / Infrastructure**	**Arable land**
PL115	3%	30%	22%	9%	37%	2%
PL12C	1%	34%	19%	5%	40%	2%
PL129	9%	30%	22%	6%	40%	2%
PL213	2%	34%	25%	9%	31%	1%
PL219	1%	33%	27%	9%	30%	1%

The final DDMs are a result of the combination of two datasets, namely the JRC's Risk Data Hub and the study's own calculations. The damage functions by Huizinga et al. (2017) are used to determine 1) distribution among the affected NUTS3 areas within one flood event and 2) the distribution among the five capital stocks for each affected NUTS3 area. The JRC's Risk Data Hub is used to find the floods events and their related reported damage costs. Based on the DDMs, the reported damage costs are distributed so that they can be applied for the calculations of the direct and indirect impacts.

Discussion & limitations

JRC's reported damage costs versus study's calculated damage costs

In the example of the flood in Poland, we find that the total absolute value of the 17 affected NUTS3 areas is EUR 22 million, which is around 10 times higher than the recoded damage costs reported by the JRC (€ 2.3 million). In most cases, the JRC damage costs are rather low but we prefer to work with the JRC's Risk Data Hub to find the damage costs as it is a standardized database compared to the alternative (fragmented information per event) although the damage costs could be underestimated. The distribution of these costs is based on our own calculations. Below we discuss the factors that limit a precise calculation of the costs are discussed.

The DDMs developed for floods provide a precise distribution as they consider bottom-up information such a land-use, depth and flood extent. As such, the DDM is location specific and does not apply to other locations or countries. This is of importance as it allows for the inclusion of details to a global approach which increase the internal validation of the direct and indirect costs calculated in the next steps.

Moreover, it is important to note that the JRC's database has several limitations as well, as it is for instance hard to trace back the compilation of the different sources reporting on the total amount of damage costs for a certain event. It is therefore difficult to validate the JRC's total costs with our calculated total costs.

However, by combining the two databases, the methodology for calculating the damage costs per capital stock is the most robust.

The methodology for flood damage estimations has several limitations which can explain the overestimation of damage costs. Below we elaborate on the limitations.

Uncertainty in the flood extent and flood depth

There are a few limitations with the use of the ESPON-TITAN river flood hazard map. Not all floods recorded in the JRC’s Risk Data Hub are characterised with a 100-year return period. Some floods even have a return period of 500 to 1000 years which could imply that the simulation map underestimates the depth and the flood extent in some cases. At the same time, for floods with a 20- or 50-year return period, the water depth and flood extent estimation would be overestimated.

Importantly, the ESPON-TITAN river flood hazard map refers to conditions of no flood defences which means that for instance for the Netherlands, known for its water defences, the flood depth and extent would be overestimated (Alfieri et al., 2014).

Moreover, the flood depth estimations for the minimum flood depth are very small as in many cases around the edge of the flooded area, the water depths are naturally very small. At the same time, the maximum flood depth, reflecting the deepest point of the flood, can be very high. To correct for these large differences between the minimum and maximum flood depth, we take the median of the depth as this is relatively unaffected by extreme scores at either end of the distribution. As a result, each NUTS3 area is characterised with a median depth. In the case of the occurrence of multiple events in one NUTS3 area in the time period of 1995 to 2018, the median stays the same. In practice, it is unlikely that different events in one NUTS3 area has the same depth and flood extent estimation. However, as real indication of flood depths and extent are often not reported, the ESPON-TITAN river flood hazard map is the best way forward in building the DDMs.

Overestimation in land-use data

The Global Depth-Damage Functions approach by Huizinga et al. (2017) is designed to match Corine land-use data or other detailed spatial data at cell level. However, in our study we apply NUTS2 level land-use data. As a result, the square meters for e.g. residential areas would be higher, as Eurostat does not make a distinction between for instance gardens and the actual house or the distance between houses. Huizinga et al. (2017) already corrects for this by assuming that for residential, commercial and industry the density is respectively 20%, 30% and 30%. However, it is the questions whether this is correction is applicable for all European countries and for the difference between rural and urban areas. In addition, there is no correction for other land-use types (arable land and transport and infrastructure). The overestimation of maximum damage value per square meter leads to an overestimation of the total damage costs.

Damage functions and maximum damage values are not country or location specific

The damage functions used in this study apply for all the countries in Europe. This leads to uncertainty as the damage functions in practice differ per country. Moreover, the damage functions are developed for urban environments as the underlying data on maximum damages is derived from construction cost surveys which mainly concern costs of urban types of buildings (Huizinga et al., 2017). For the maximum damage value, it is also important to note there is a difference between urban and rural house prices. In general, house prices are more expensive in urban areas assuming houses are the same size (Huizinga et al., 2017).

No inclusion of mitigation measures

Based on the available data, we have tried to include data for the reference year of 2010 and closely related years. However, not for all data points we succeeded in this. It is therefore better to refer to a reference period 2009 to 2017.

However, even more important is that we assess floods event from 1995 to 2018. The data points such as land-use would not stay the same in this time period due to population growth and urbanisation. Notably, mitigation measures taken after a flood event are not considered. This means that all the events before reference period have an under estimation as mitigation measures are included whereas, in practice, they were not in place. The events after the reference period lead to overestimations, as mitigation are not considered.

C.2. Windstorms

Windstorms are winds that are strong enough to cause substantial damages to trees and buildings (Sharkey et al., 2019). Extreme winds affecting Europe are typically generated by extratropical cyclones (ETC) systems originating in the North Atlantic. ETC are cyclonic-scale (~1000 km) storms[33] that are not tropical cyclones. As most of the damaging windstorms in Europe are ETC[34], the Windstorm Information Service (WISC) project focused its analysis on ETC. Results of the project are used for the analysis of windstorms in Europe.

WISC has developed a high-quality dataset of windstorm information, including estimation of economic losses, for historic windstorms in Europe. The resulting DDMs are event specific and present:

1. the share of total losses attributed to each NUTS3 region affected by the windstorm;
2. the share of losses of each capital stock per NUTS3 region.

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[33] American Meteorology Society website. Glossary of meteorology. Available at: http://glossary.ametsoc.org/wiki/Extratropical_cyclone

[34] WISC website. WISC products. Available at: https://wisc.climate.copernicus.eu/wisc/#/help/products#tier3_section

Windstorms impacts

The impacts of windstorms are mostly structural and can range from fallen trees to structural building damages in extreme cases. To identify the impacts that windstorms events in Europe could have, a literature review was undertaken. Table 9.8 summarises the most common impact categories and the type of these impacts. A more detailed description is presented in the Windstorm Impact Pathways (Annex 2.B.).

Table 9.8 Windstorms impacts

Impact category	**Impact type**
Agriculture	• Damage to crop lands • Damage to livestock shelter
Energy and industry	• Power outages due to damaged electrical lines
Buildings and infrastructure	• Damage to buildings (mainly due to internal pressure) (Ginger, 2018)
Transport	• Trees falls on rails • Damages to catenary wires • Blocking of roads by falling trees
Telecommunication	• Damages to antennas or telecommunications lines

WISC project

The Windstorm Information Service (WISC) project focuses on monitoring windstorms that have hit Europe in the past and constitutes part of the Copernicus Climate Change Service project.[35] WISC provides an extended database of historical windstorm tracks, high-resolution footprints, windstorm occurrence and severity as well as Tier 3 indicators [36](Total Sectoral Insured Losses per year, Total Windstorm Loss) of historical windstorm losses. The estimation of the economic losses is based on the windstorm's footprint and detailed exposure and vulnerability datasets. The core input data for WISC is various reanalysis datasets used by the University of Reading and the UK's MET Office (UKMO). The economic losses of the analysed windstorm events are presented in total losses per country and can be disaggregated into 5 sectors (Industrial/commercial, Residential, Agricultural, Transport, and Other) per event. The database also includes losses per NUTS3 region for each event.

The method in the WISC loss modelling framework is calibrated on very limited data, whereas models from insurers such as Swiss Re are calibrated on a larger set of observed loss claims. This increase the chances of suboptimal loss curves (Copernicus, 2017). The estimated losses in WISC might not be as accurate as other vendor models but are the best ones available in an open access format.

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[35] Copernicus Website. Windstorm Information Service. Available at: https://climate.copernicus.eu/windstorm-information-service

[36] id.

Development of DDMs

The analysis of the windstorm disasters is done at event level. There are three pieces of input data required for the development of the DDMs for each windstorm event:

- The total economics losses of the windstorm,
- The distribution of the total losses among the NUTS3 regions affected, and
- The distribution of the total losses among the capital stocks affected by the windstorm.

For each of the 31 extreme windstorms, which are analysed here, all the data mentioned above are taken by the WISC databases. To distribute the total economic losses of each windstorm event among the five capital stocks of our study, we look at the sectoral economic losses provided by WISC. The WISC dataset disaggregates the total economic losses per windstorm per country into five sectors, i.e. Industrial/commercial, Residential, Agriculture, Transport, and Other. Using the distribution of the economic losses among these sectors, we can infer the distribution of losses among the five capital stocks Residential, Commercial, Industry, Infrastructure & Transport, and Arable land. For this, each WISC sector is matched with one of our capital stocks, and the share of the total losses received by each sector corresponds to the share of losses suffered by the matching capital stock.

Although the match of some sectors with some capital stocks is straightforward, there are two issues with the WISC database that pose a challenge. The first is that in the WISC database, losses are presented together for the Industry and the Commercial Sectors. The second is that an “Other” sector category is included in order to capture sectoral losses that do not fit into any of the rest of the sector categories. In order to convert losses among sectors in the WISC database to losses among capital stocks, two assumptions were made:

1. The share of losses of the Industry/Commercial sector in WISC is split equally between the Industry and Commercial capital stock;
2. The losses of the “Other” sector in the WISC database are divided equally among the capital stocks.

The Table 9.9 shows which WISC sectors correspond to each capital stock:

Table 9.9 Matching the WISC sectors to the study's capital stocks

WISC sectors	Capital stocks
Industry / Commercial	Industry (50%)
	Commercial (50%)
Residential	Residential
Transport	Infrastructure & Transport
Agriculture	Arable land
Other	20% of “other” losses to each stock

The Table above is used to match the WISC sectors to the five capital stocks. For example, if the Residential sector in a country suffered 40% of the total losses from a windstorm, the Residential capital stock it is assumed to receive 40% of the total losses as well. If, on the other hand, the Industry/Commercial WISC sector suffered 10% of the total windstorm losses, the Industry and the Commercial capital stocks would receive 5% of the total losses each. The distribution of capital stock losses that is estimated for each affected country is assumed to be the same in all NUTS3 regions of this country.

The DDM should also distribute the total national economic loss from a windstorm to the NUTS3 regions affected. Since the WISC database provides euro value estimates of economic losses incurred by each affected NUTS3 region for each windstorm event, the share of losses for each NUTS3 region can be easily calculated.

The final DDM is a combination of the two shares described above. For each windstorm examined, the total country-level losses are distributed among the NUTS3 regions affected and among the capital stocks of each region.

The development of the Austrian DDM for the Kyrill windstorm is presented below, to illustrate our approach in more detail.

Austrian DDM for the Kyrill windstorm

According to WISC's estimation, the Kyrill windstorm in 2007 caused losses of around € 82 million in Austria. Using the euro values of economic losses per WISC sector, the share of losses per sector are estimated and presented in the table below.

Table 9.10 Distribution of total losses per WISC sector in Austria from the Kyrill storm in 2007

WISC sectors	Share of total losses
Industry / Commercial	6.6%
Residential	47.8%
Transport	0.7%
Agriculture	44.3%
Other	0.6%

Using Table 9.11, the share of losses per capital stock in Austria is presented below.

Table 9.11 Distribution of total losses per capital stock in Austria from the Kyrill storm in 2007

Capital stocks	Share of total losses
Industry	3.4%
Commercial	3.4%
Residential	47.9%
Infrastructure & Transport	0.9%
Arable land	44.4%

To identify how the national economic losses were distributed among the affected NUTS3 regions, we look at WISC's euro estimates on losses per NUTS3. According to WISC the storm affected 24 (out of 35 in total) NUTS3 regions in Austria, each suffering a different amount of losses. The table below summarises the share of losses incurred by the 'significantly' affected NUTS3 regions. Note that only the NUTS3 regions that incurred more than 0.5% of total losses are presented in this example due to space limitations. The formal analysis of this windstorm event covers all the NUTS3 regions affected.

Table 9.12 Distribution of total losses per NUTS3 region affected in Austria from the Kyrill storm in 2007

Austrian NUTS3 regions affected	Share of total losses per region
AT121	5%
AT123	2%
AT124	12%
AT311	32%
AT312	23%
AT313	20%
AT314	1%
AT315	5%

**Note that the Austrian NUTS3 regions that incurred very low losses are excluded from the table.*

From the combination of the two tables above, we derive the Austrian DDM for the Kyrill storm, which can be used to distribute the total losses recorded for Austria. Note that the same storm impacted 10 countries in total, and thus the same procedure is followed for the rest of the countries.

Table 9.13. Overview of Damage Distribution Matrix for Kyrill storm in Austria

Affected NUTS3	Distribution of the reported damage cost	Damage distribution matrix				
		Residen-tial	Commer-cial	Industry	Transport / Infrastructure	Arable land
AT121	5%	47.9%	3.4%	3.4%	0.9%	44.4%
AT123	2%	47.9%	3.4%	3.4%	0.9%	44.4%
AT124	12%	47.9%	3.4%	3.4%	0.9%	44.4%
AT311	32%	47.9%	3.4%	3.4%	0.9%	44.4%
AT312	23%	47.9%	3.4%	3.4%	0.9%	44.4%
AT313	20%	47.9%	3.4%	3.4%	0.9%	44.4%
AT314	1%	47.9%	3.4%	3.4%	0.9%	44.4%
AT315	5%	47.9%	3.4%	3.4%	0.9%	44.4%

C.3. Earthquakes

According to Cassidy (2016), an earthquake is “a tectonic or volcanic phenomenon that represents the movement of rock and generates shaking or trembling of the Earth”. The literature that analyses the economic impacts of earthquakes often deploys earthquake damage functions, however, these mainly focus on the impact of earthquakes on different types of residential buildings or on specific parts of infrastructure, such as electricity distribution circuits (Breiding, 2012). As our literature review did not reveal damage functions for other capital stocks, the analysis of the distribution of the total economic losses of an earthquake follows a different approach. For the development of the earthquake DDMs, we look at past earthquake’s events and categorize the proportion of damages on capital stocks according to the impacts of these disasters.

Earthquake impacts

As illustrated in the earthquake Impact Pathway (see Section 1.1), earthquakes can be very destructive, with significant economic impact. The table below presents the most common economic impact categories of earthquakes and the type of these impacts.

Table 9.14 Earthquakes impacts

Impact category	**Impact type**[37]
Agriculture	Damage to livestock shelter
Energy and industry	Fuel pipelines rupture and damaged electrical lines
Tourism and recreation	Lost revenues
Buildings and infrastructure	Buildings damage Subsidence and tilting due to liquefaction

Development of DDMs

In order to identify how the total damages of earthquake events were distributed among the different sectors of the economy; we review the effects of several earthquakes in different geographical locations (Daniell et al., 2012).

In their paper, Daniell et al. (2012) analysed the economic losses of past earthquakes and their distribution among 47 economic sectors. Data was retrieved by the Earthquake Report (Daniell et al., 2012) in order to analyse the split of damages for earthquakes that took place in Europe. One of these earthquakes, for which the split was given, is the earthquake in l'Aquila (Italy), which is shown in Table 9.15.

Table 9.15 Distribution of total damages of earthquake events into capital stocks

L'Aquila (2009)	
Sector	**%**
Agriculture, aquaculture, forestry	10
Commercial	4
Industry	36
Infrastructure	6
Buildings/Housing/Private property	44
Total	**100**

The Table 9.16 shows that the buildings sector is clearly the one most severely affected by earthquakes.

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[37] BCcampus website. The Impacts of Earthquakes. Available at: https://opentextbc.ca/geology/chapter/11-4-the-impacts-of-earthquakes/

Table 9.16 Mapping of economic sectors

Economic sectors from Earthquake Report (Daniell et al., 2012)	**Capitol stocks in this study**
Buildings/Housing	Residential
Private	Residential
Public	Commercial
Industrial and commercial	Industry
Industrial	N/A
Commercial	Commercial
Health	N/A
Education	Commercial
Culture & Religion	Commercial
Food security	N/A
Household goods	N/A
Private property	Residential
Inventory	N/A
Infrastructure	Transport/ Infrastructure
Economic sectors from Earthquake Report (Daniell et al., 2012)	**Capitol stocks in this study**
Agriculture	Arable land
Irrigation	Arable land
Fishery	Arable land
Forestry	Arable land
Trade	Industry
Recreation	Industry
Manufacture	Industry
Tourism	Industry
Goods & Services	Industry
Banking	Industry
Public administration	Industry
Environment	Industry
Cost of Relief	Industry
Demolition & Rubble removal	Industry

From the analysis of major earthquakes that occurred in Europe; namely the earthquake in L'Aquila (2009), in Athens (1999) and in Roermond (1992), we estimate the split of economic damages among different sectors. To develop the earthquake DDMs, these economic sectors are converted into the capital stocks considered by this study, using the Mapping table below.

The analysis of these three diverse earthquakes in Europe revealed that there were some differences in the split of losses between the sectors. Therefore, the average share of losses per capital stock is estimated from which a unique DDM for all the earthquake events of our analysis is developed.

Table 9.17 Earthquake specific distribution

Earthquakes specific distribution (% damage)			
Sector	**Roermond (1992)**	**Athens (1999))**	**L'Aquila (2009)**
Arable land	0	0	10
Commercial	47	11	4
Industry	22	9	36
Transport/Infrastructure	5	5	6
Residential	26	75	44
Total	**100**	**100**	**100**

It is important to note that earthquakes (unlike floods, windstorms and droughts) have very localized impact. To take into account the exposure of the NUTS3 region affected by the earthquake, we look at the land-use of the NUTS2 region affected. Through this, the exposure of each region in earthquake events is shown by the composition of regional economies affected, which shows whether the affected region is mostly urban, industrial, or agricultural.

The table below shows the average distribution of losses for the 3 earthquakes analysed (Roermond, Athens and l'Aquila) as well the average land-use share for the corresponding NUTS2 area.

Table 9.18 Earthquake general distribution

EU DDM		
Sector	**Average share of damage (%)**	**Average land-use (%)**
Arable land	3.3	76
Commercial	20.7	5
Industry	24	2
Transport/Infrastructure	5.3	7
Residential	48.3	10
Total	100	100

The development of the DDM for the earthquake that hit Emilia-Romagna in Italy (ITH5) in 2012 to illustrate in detail our approach.

Earthquake DDM for the earthquake of 2012 in Italy

The following formula is used to calibrate, for each type of capital stock, the EU losses DDM for one particular NUTS2 region.

$$A_{ER} = A_{EU} + \frac{LU_{ER}}{LU_{EU}}$$

A_ER represents the split of losses going to Arable land in the Emilia-Romagna region

A_EU represents the average split of losses going to Arable land in the EU

LU_ER represents the percentage of land-use being attributed to arable lands in Emilia-Romagna

LU_EU represents the average percentage of land-use being attributed to arable lands in the NUTS2 regions of the earthquakes for which the distribution of losses is already given (L'Aquila, Athens and Roermond).

This calculation is done for every type of capital stock (Residential, Commercial, Industry, Transport/Infrastructure, Arable land). This results in one DDM per NUTS2 region affected by an earthquake in our dataset.

Table 9.19 Earthquake DDM for the earthquake in Italy in 2012

Affected NUTS3	**Distribution of the reported damage cost**	**Damage distribution matrix**				
		Residential	**Commercial**	**Industry**	**Transport / Infrastructure**	**Arable land**
ITH5	100%	40%	22%	25%	5%	8%

All earthquakes analysed in our study have affected only one NUTS2 region each, apart from the 2016 central Italy earthquake, which occurred in 3 NUTS2 regions. The development of the DDM for this event also involves the distribution of total losses to the NUTS2 regions. This is done by analysing the earthquake effects based on local sources. According to EC (2012), the 2016 central Italy earthquake affected mostly the region of Emilia-Romagna (91.6%), followed by Lombardy (8%) and Veneto (0.4%).

C.4. Droughts

As mentioned before, he classification of droughts broadly used in the literature categorizes droughts into four types: Meteorological drought, Agricultural, Hydrological, and Socio-economic. The drought events considered in our methodology are the events recorded in the EM-DAT database, which takes a more socio-economic approach. More specifically, EM-DAT defines droughts as "an extended period of unusually low precipitation that produces a shortage of water for people, animals and plants" and adds that "drought is not solely a physical phenomenon because its impacts can be exacerbated by human activities and water supply demands."[38]

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[38] EM-DAT (website). EM-DAT Glossary. Available at: https://www.emdat.be/Glossary

Drought impacts

A summary of the main direct impacts identified in the literature used for the development of the Impact Pathways is given in the table below.

Table 9.20 Summary of main direct economic drought impacts identified in the impact pathways

Impact category	Impact type
Agriculture and farming, aquaculture, and forestry	• Reduced productivity of annual and permanent crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc. • Agricultural yield losses • Reduced productivity of livestock farming (e.g., reduced yields or quality of milk, reduced stock weights) • Reduced tree growth and vitality • Increased dieback of trees • Reduced (freshwater) fishery and aquaculture production
Energy and industry	• Reduced hydropower production • Impaired production/shut down of thermal/nuclear powerplants • Restriction/disruption of industrial production process
Public water supply	• Regional and local water supply shortage / problems (drying up of springs/wells, reservoirs, streams)
Waterborne transportation	• Stream closed for navigation • Reduced navigability of streams (reduction of load, increased need of interim storage of goods at ports)

Drought disaster impacts can be measured in losses (negative economic impacts measured in monetary units) or damages (destruction of physical assets in the affected area measured in physical units). The monetary value of these damages (their related loss) is expressed in terms of replacement costs (Naumann et al., 2015).

Split of drought damages

Damage functions for droughts are not so common. The literature review revealed only a very limited number of damage functions related mainly to agriculture and energy generation. To use the existing damage functions, we would need to make a series of assumptions that would hamper the reliability of our results. Therefore, the approach we have taken to develop the DDMs for droughts follows a similar logic as Jenkins (2013). More specifically, Jenkins (2013) disaggregates the direct economic losses of each drought event in Spain into sectoral losses, based on the share of each economic sector's water abstraction from surface water bodies. For example, according to Jenkins (2013), the water use in Spain is shared among agriculture, forestry, fishing and hunting (65%); utilities (31%); and manufacturing (4%). Using these shares, Jenkins (2013) distributed the total economic losses of several drought events recorded for Spain to sectoral losses.

Therefore, to distribute the total economic losses (as reported by EM-DAT) into capital stock losses, we look at the water use of several sectors in each of the affected countries. To identify the share of sectoral water use for the countries affected by the droughts, we use Eurostat's database, which reports for all ESPON countries on country-level water abstraction levels from surface water bodies for four industries, namely agriculture, manufacturing, water supply, and electricity (cooling).[39]

Eurostat dataset includes only four out of the eight impact categories of droughts as presented in Table 9.21. To identify whether the sectors not included in the Eurostat database incur significant economic losses, we reviewed three diverse drought events of different duration and geographical locations in Europe to identify the predominantly affected sectors. The results from this review are presented in Table 9.21, where the left-hand side column for each drought event shows the real economic losses for each industry in million Euros as recorded in EC (2007) and the right-hand side column shows the estimated share of the total losses.

Table 9.21 Distribution of total damages of past drought events into various industries adapted from EC (2007)

	Portugal 2004-5		**Finland 2002-3**		**Hungary 1961-90**	
Sectors	**Million €**	**%**	**Million €**	**%**	**Million €**	**%**
Manufacturing	€ 32	4%	€ 1	1%	€ 300	7%
Infrastructure	0	0%	0	0%	0	0%
Buildings	0	0%	0	0%	0	0%
Agriculture	€ 519	61%	€ 17	22%	€ 4000	87%
Energy	€ 261	31%	€ 50	64%	€ 200	4%
Water supply	€ 32	4%	€ 10	13%	€ 50	1%
Navigation	0	0%	€ 0.1	~0%	€ 50	1%
Total	**€ 844**	**100%**	**€ 78**	**100%**	**€ 4 600**	**100%**

From the table, it can be confirmed that the impacts of these past drought events mainly involve agriculture, energy production, water supply, and manufacturing, all of which are covered by Eurostat's database on water abstraction. Navigation has incurred in some cases economic losses due to lower water levels in rivers, but these losses represent less than 1% of the total economic loss, if any. As the incurred losses from the waterborne transport is expected to be low or non-existent in most cases, we do not estimate losses for transportation.

To ensure minimization of bias when determining the sectoral losses of drought events, we look at the distribution of water abstraction for two different years and estimate the average share for each sector to ensure that potential distortions due to exceptional temporary factors are phased out.

Development of DDMs

As already explained, the DDMs are used to distribute the reported total economic losses of drought events into five capital stocks (i.e. Residential buildings, Commercial buildings, Industry, Arable land, Transport & Infrastructure). The impact categories of drought events in

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[39] Eurostat (2020). Water abstracted by sector of use. Available at: https://ec.europa.eu/eurostat/databrowser/view/ten00006/default/table?lang=en

Europe identified previously involve only agriculture, manufacturing, water supply, and energy production. These impacts can be translated into losses in two capital stocks, namely *Arable land* to account for the agricultural impacts of drought events and *Industry*, which receives the share of total losses that corresponds to manufacturing, water supply, and energy production. The rest of the capital stocks (i.e. Commercial buildings, Residential buildings, Infrastructure & Transport), it is assumed, that are unaffected by drought hazards.

Since the distribution of the total economic losses of drought events follows the share of water use by agriculture, energy, water supply, and manufacturing per country, it logically follows that the resulted shares are country specific. Therefore, for the analysis of droughts we have to develop country specific DDMs for all countries analysed affected by drought events.

In addition, the DDMs should not only distribute the total economic losses of each drought event to capital stocks, but also to the different NUTS2 regions affected by each event. Since the indirect impacts of these disasters are analysed at a regional level, the economic losses incurred by each NUTS2 region has to be known. We cannot assume an even distribution of the total loss among the NUTS2 regions affected, as some regions differ in size, economic activities, etc. To account for these differences, we look at the size of each NUTS2 region's agriculture and industry capital stocks and distribute the total losses proportionally. Through this we match the share of the total losses attributed to a NUTS2 region to an indication of their economic activity. Note that only the agriculture and industry capital stocks are considered since these are the only impact categories by droughts. The detailed regional capital stock estimates of the affected NUTS2 regions are taken by Cambridge Econometrics' database (see Sub-section 1-4).

The demonstration of the development of the Spanish DDM follows as an example. The development of the DDMs for the rest of the countries affected by the drought events of our database is not presented in this report.

Drought DDM for Spain

The table below presents the water abstractions from surface water bodies of Spain per sector that can be affected by a drought event as identified in the previous section. We chose two different years in order to account for possible year-specific anomalies of water distribution among different sectors.

Table 9.22 Water abstraction from surface water sources by main water-dependent sectors in Spain

Sectors	**Water abstraction 2009 (Mio m^3)**	**Share 2009 (%)**	**Water abstraction 2014 (Mio m^3)**	**Share 2014 (%)**	**Average**
Agriculture	18 970	64%	17 331	65%	**65%**
Manufacturing	386	1%	359	1%	**1%**
Energy	6100	21%	5870	22%	**21%**
Water supply	4208	14%	3055	12%	**13%**
Total	**29 664**	**100**	**26 615**	**100**	**100**

According to the share of the water abstraction from different sectors, we can infer the share of total economic losses on each capital stock affected by the drought event in Spain. The share of losses attributed to the Arable land capital stock corresponds to the share of water abstraction from agriculture, while the share of losses attributed to the Industry capital stock corresponds to the share of water abstraction from manufacturing, energy, and water supply. This is shown in the table below.

Table 9.23 Share of total losses attributed to capital stocks in Spain

Impact categories	**Capital stock**	**Share of tot. losses**
Agriculture	Arable land	65%
Manufacturing	Industry	35%
Energy		
Water supply		

The total losses of all drought events in our database are given at a national level. As discussed in the previous section, since the analysis is at a regional level, the national losses have to be distributed among the NUTS2 regions affected by the disaster. To do that, the total losses are distributed to each NUTS2 region affected in the Spanish drought in 1999 based on their relative size of their Arable land and Industry capital stocks against the total amount of these capital stocks in all the affected NUTS2 regions together. The exact share of total losses for each NUTS2 region affected by the drought is given by the following formula:

$$Share\ of\ loss\ in\ NUTS2_i = \frac{Arable\ land_i + Industry_i}{\sum_{i=1}^{n} Arable\ land_i + Industry_i}$$

Where, the *Share of loss in NUTS2* represents the share of the total economic losses incurred by the NUTS2 region i, $Arable\ land_i$ represents this region's agriculture capital stock and $Industry_i$ the region's industry capital stock, while $\sum_{i=1}^{n} Arable\ land_i + Industry_i$ represents the total Arable land and Industry capital stocks in all the affected NUTS2 regions, and n represents the set on NUTS2 regions affected.

The total losses of the Spanish drought in 1999 were estimated by EM-DAT at DUS 3.2 million. The losses occurred in the following NUTS2 regions: Andalucía (ES61), Extremadura (ES43), Castilla (ES41 and ES42), Región de Murcia (ES62), Comunitat Valenciana (ES52), Cataluña (ES51), Aragón (ES24). The table below presents how the total losses (converted in Euro 2010 constant prices) are distributed among the affected NUTS2 regions.

Table 9.24 Distribution of total losses among the affected NUTS2 regions

Affected NUTS2	Share of total losses (%)	Losses per NUTS2 (€)
ES24	6%	200 163 317
ES41	11%	327 684 426
ES42	8%	253 237 209
ES43	2%	51 820 136
ES51	36%	1 141 944 209
ES52	17%	541 066 980
ES61	16%	491 075 863
ES62	4%	134 269 860
Total	**100%**	**3 141 262 000**

The synthesis of the two tables above gives the DDM for the Spanish drought in 1999. The DDM is presented in Table 9.25. The DDM shows the percentage of the total economic losses recorded by EM-DAT incurred by the capital stocks Arable land and Industry in each NUTS2 region affected by the drought. The last column presents the share of total

Table 9.25 DDM for the drought in 1999 in Spain

Affected NUTS2	Distribution of the reported damage cost	Damage distribution matrix				
		Residential	Commercial	Industry	Transport / Infrastructure	Arable land
ES24	6%	0%	0%	35%	0%	65%
ES41	11%	0%	0%	35%	0%	65%
ES42	8%	0%	0%	35%	0%	65%
ES43	2%	0%	0%	35%	0%	65%
ES51	36%	0%	0%	35%	0%	65%
ES52	17%	0%	0%	35%	0%	65%
ES61	16%	0%	0%	35%	0%	65%
ES62	4%	0%	0%	35%	0%	65%

Occurrence of drought damages

There are two issues associated with use of the DDMs in the modelling part of the methodology. The first is related with the occurrence of the estimated direct economic losses and the second involves the recovery period of the damaged capital stocks.

Occurrence of the direct economic losses

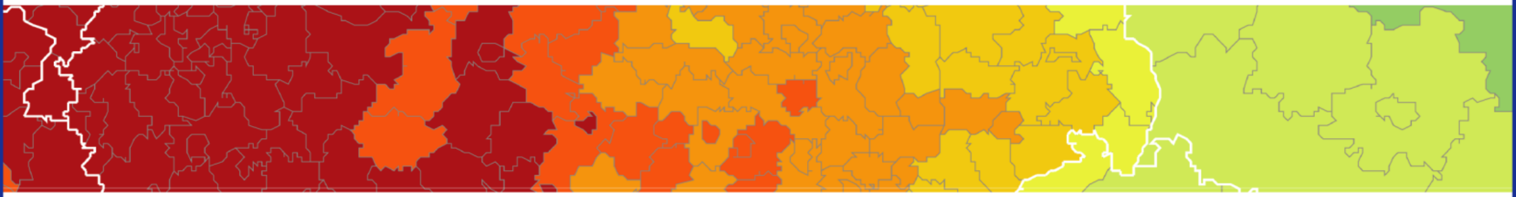
The time of occurrence of the drought economic losses in the capital stocks needs to be determined prior to the analysis of the indirect economic losses. In other words, it needs to be determined if the direct losses occur instantaneously in one point in time or over the duration of each drought event.

Agriculture

As agricultural production becomes a marketable commodity only upon its harvest, the occurrence of the drought economic losses is estimated according to the duration of the drought in comparison to the harvest period (it is assumed to be September in this study). More specifically, for the drought events that their duration covers the month September, the drought losses occur the year of that September. For example, the drought in Hungary in 2003 lasted between April and October, therefore, the economic losses of this drought, it is assumed to occur in 2003. For the droughts that their duration did not include a September, it is assumed that the economic losses occur in the year of the subsequent September. For example, the drought in Lithuania lasted between November 2005 and July 2006, therefore, the economic losses of this drought, it is assumed to occur in 2006. The exact estimations of the start and end date of all drought events in our database where provided by GTK, based on their own estimations using Standard Precipitation Index with three-month accumulation period (SPI-3) data of the affected countries.

Industry

Losses in energy generation, water supply, and manufacturing represent economic losses in the Industry capital stock. There is usually a lag between the beginning of the drought event and the occurrence of the direct economic impacts in these activities, due to the use of water reserves. There is also a lag between the end of the event and the termination of the adverse economic impacts, as the water availability increases gradually. The economic losses of the drought events accumulate gradually over the duration of the event. Therefore, the direct economic losses in Industry, it is assumed to occur the year of the end date of the drought event.



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