Economics for Disaster Prevention and Preparedness

Investment in Disaster Risk Management in Europe Makes Economic Sense

BACKGROUND REPORT

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STATEMENT ON COVID-19 PANDEMIC

The COVID-19 pandemic has led to substantial restrictions on travelling and the organization of workshops and face-to face meetings. Despite these limitations, the World Bank team in collaboration with the European Commission and stakeholders has managed to effectively undertake extensive consultations online to collect data and information as a basis for this work.

Contents

Figures

Tables

Boxes

GLOSSARY OF KEY TERMS

adaptation: Adjustments or changes in economic, social, or environmental approaches in response to the effect of present or future climate change.

avoided losses (first dividend of the triple dividend approach): The short- and long-term damages and losses prevented or reduced by a DRM investment when a disaster occurs.

co-benefits (third dividend of the triple dividend approach): The social, environmental, and economic benefits generated by a DRM investment, which is independent of the occurrence of disasters.

benefit-cost analysis (BCA): Process used to identify, measure, and analyse the benefits of a project, programme, or decision versus the costs associated with it.

benefit-cost ratio (BCR): Ratio used in BCA to summarize the relationship between overall relative benefits and costs of a project. A BCR lower than 1 means that the project's net benefits could be negative, i.e., benefits are lower than costs.

damage: Total or partial destruction of physical assets existing in the affected area. Damage occurs during and after the disasters and is measured in physical units (that is, square meters of housing, kilometres of roads, and so on).

direct and indirect benefits/costs: Benefits/costs either directly or indirectly associated with the impact of the project/program/decision. An example of a direct benefit is the prevention of asset losses or enhancement of environmental value due to a flood prevention measure; a direct cost is the cost of the flood prevention measure. An example of an indirect benefit is the productivity losses prevented given the flood measure, while an indirect cost is the increase in prices in the area leading to displacement and loss of welfare/well-being of certain populations.

disaster risk: The combination of the probability of an event and its negative consequences. The likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

disaster risk management (DRM): Processes for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, all with the explicit purpose of increasing human security, well-being, quality of life, and sustainable development.

disaster risk reduction (DRR): Both a policy goal and the strategic and instrumental measures employed for anticipating future disaster risk. DRR reduces existing exposure, hazard, or vulnerability and improves resilience.

discount rate: Rate of return used to discount future cash flows back to their present value. Financial discount rates are the interest rates used to calculate the present value of future cash flows from a project or investment. Social discount rates indicate a society's average valuation of future versus present impacts of interventions (benefits and costs). A high discount rate indicates a lower valuation of the future and a preference for the present, which particularly in the context of climate change also has implications for intergenerational equity.

early warning system (EWS): An integrated tool of hazard monitoring, forecasting and alert, that enables individuals, communities, governments, businesses and others to take timely actions to reduce disaster risks in advance of and during hazardous events. In terms of flood interventions, EWS refers to interventions that rely on meteorological forecasts of intense or sustained rainfall to identify locations with forecast flooding. EWS comprise technical components to detect rainfall in advance and estimate flood conditions, and to disseminate warnings to affected communities, but also human/behavioural components to take decisions to activate warnings and to respond to warnings.

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

includes the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

green infrastructure: Sustainable, nature-based Infrastructure that makes use of natural processes and ecosystem services for functional purposes, such as disaster risk reduction. Such infrastructure usually yields risk reduction benefits as well as social and environmental effects.

grey infrastructure: Structural, human-engineered infrastructure for flood or other disaster risk management, which includes both static and active elements and which is usually built with materials like steel and concrete.

hazard: The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.

moral hazard: Refers to a situation when rational individuals have incentives to change their exposure to risk when they do not bear the full cost of that risk exposure. For example, a full health insurance coverage may discourage an individual to take care of her physical state since the monetary burden of any healthcare services will be borne by the insurance company.

nature-based solutions (NBS) or natural floodplain management (NFM): A type of flood intervention, which include interventions such as floodplain, dune, or wetland restoration; planting of green infrastructure, for example, hedgerows, woodlands, and natural grasslands; and blue elements such as pools, ponds buffer basins or water courses. Commonly, several elements are combined in a management plan and are often considered as blue-green infrastructure, with the selection determined by the local environment and prevalent flood mechanisms.

net present value (NPV): Difference between the present value of monetary inflows and the present value of cash outflows over a period time. The idea behind the NPV is to project all future monetary inflows and outflows associated with a project/program/decision, discount all these flows to the present day, and add them together. A positive NPV means that, after accounting for the time value of monetary flows, the project/program/decision could yield net benefits.

losses: Quantifiable damages of disasters that can be translated into monetary terms. A distinction can be made between direct disaster losses, which refer to directly quantifiable losses (number of people killed, damages to buildings, infrastructure or natural resources) and indirect losses, which refer to indirectly quantifiable losses (declines in output or revenue, impact on wellbeing, disruptions to flow of goods and services in an economy).

property level protection (PLP): A type of flood intervention, which comprises protection of individual properties through small-scale interventions such as demountable flood walls and gates at doorways, raising the ground floor level or elevation of door thresholds.

resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.

sensitivity analysis: analysis that determines and showcases how results change when assumptions, parameters, or variables of an analysis are changed.

structural protection: A type of flood intervention, which comprises engineered or 'hard' defences with are further classified as permanent engineered structures: levees, dikes, walls, dams flood gates and temporary or de-mountable infrastructure such as temporary barriers.

triple dividend benefit-cost analysis: A systematic approach that evaluate different project alternatives to determine the best option that generates the most welfare for the society by comparing the alternatives' social and economic costs to the benefits, which consist of three dividends: 1) avoided losses and saved lives, 2) unlocked economic potentials, and 3) the social, environmental, and economic co-benefits of the project.

unlocked economic potentials (second dividend of the triple dividend approach): Innovations, entrepreneurship, investments, and other economic activities stimulated due to the reduction in background risks related to disasters through DRM investments. This economic development potential is independent of the occurrence of disasters.

value of a life year: A concept derived from the willingness to pay for increasing life expectancy by one additional year. This measure is considered more appropriate for disasters that mostly displace mortality (i.e., affect certain age groups) rather than mostly causing premature deaths. Theoretically, measurements of actual changes in life expectancy would be the exact measure to consider.

value of statistical life (VSL): The marginal rate of substitution between income (wealth) and mortality risk, i.e., how much individuals are willing to pay on average to reduce the risk of death. It therefore indicates not the value of an actual life but the value of marginal changes in the likelihood of death.

vulnerability: The characteristics and circumstances of the built environment and communities that make them susceptible to damaging impacts (or human vulnerability). Vulnerability factors include building construction type, socio-economic context, and so on.

ACRONYMS AND ABBREVIATIONS

AAL	Average Annual Loss
ADAI	Association for the Development of Industrial Aerodynamics
AEP	Annual Exceedance Probability
AGIF	Agency for the Integrated Management of Wildfires
ARA	Albanian Road Authority
BAP	Biodiversity Action Plan
BASE	Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
C3S	Copernicus Climate Change Service
CCDR-C	Central Regional Coordination and Development Commission
CFA	Country Fire Authority
CTCN	Climate Technology Centre and Network
DACC	Damage Assessment Coordination Centre
DACEA	Danube Cross-border System for Earthquake Alerts
DALY	Disability-adjusted Life Year
DEFRA	Department for Environment, Food, and Rural Affairs
DG	Directorate-General
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DiD	Difference-in-Difference
DPPI	Disaster Preparedness and Prevention Initiative
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSS	Decision Support Systems
EAEE	European Association for Earthquake Engineering
EC	European Commission
EDO	European Drought Observatory
EEA	European Environment Agency
EEWS	Earthquake Early Warning System(s)
EFAS	European Flood Awareness System
EFFIS	European Forest Fire Information System
EMS	Emergency Medical Services
EMSA	European Maritime Safety Agency
EPB	earthquake-prone buildings
ERCC	Emergency Response Coordination Centre
ERDF	European Regional Development Fund

ESHM13	2013 European Seismic Hazard Model
ESPON	European Spatial Planning Observation Network
EU	European Union
EUCPT	European Union Civil Protection Team
EWS	Early Warning System(s)
FEMA	Federal Emergency Management Authority
FEWS	Flood Early Warning System(s)
GDACS	Global Disaster Alert and Coordination System
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHRF Commission	Commission on a Global Health Risk Framework for the Future
GNI	Gross National Income
GPSS	Global Program for Safer Schools
GRP	Gross Regional Product
GRT	Gross Register Tonnage
HEWS	Heat Early Warning System(s)
HWWS	Heatwave Warning Systems
IAEA	International Atomic Energy Agency
ICT	Information and Communication Technology
IMPRESSIONS	Impacts and Risks from High-End Scenarios: Strategies for Innovative Solutions
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISMEP	Istanbul Seismic Risk Mitigation and Emergency Preparedness
JPA	Joint Procurement Agreement
JRC	Joint Research Centre
LCE	Limit Condition for Emergency
LSM	Landslide Susceptibility Mapping
MATRIX	Multi-Hazard and Multi-risk Assessment Methods for Europe
MCA	Multi-criteria Analysis
MCE	Multi-criteria Evaluation
MoNE	Ministry of National Education
MS	Member State(s)
MSP	Multisector Partnership
NBS	Nature-based Solution(s)
NIBS	National Institute of Building Sciences
NIEP	National Institute for Earth Physics
NPV	Net Present Value

OCC	Opportunity Cost of Capital
OECD	Organisation for Economic Co-operation and Development
ONERC	National Observatory for the Impacts of Global Warming (*Observatoire National sur les Effets du Réchauffement Climatique*)
OSD	Office of the Secretary of Defence
PAD	Project Appraisal Document
PBCA	Participatory BCA
PDC	Permanent Drought Commission
PESETA	Projection of Economic Impacts of Climate Change in Sectors of the European Union-based on Bottom-up Analysis
PFAS	Per- and Polyfluoroalkyl Substances
PGA	Peak Ground Acceleration
PLP	Property-level Protection
PML	Probable Maximum Loss
PPE	Personal Protective Equipment
PS	Participating State(s)
PTSD	Post-traumatic Stress Disorder
PWWS	Philadelphia Hot Weather-Health Watch/Warning System
QALY	Quality-adjusted Life Years
R&D	Research and Development
RDNA	Rapid Disaster Needs Assessment
RESIN	Climate Resilient Cities and Infrastructures
RISE	Real-time Earthquake Risk Reduction for a Resilient Europe
ROI	Return on Investment
SDG	Sustainable Development Goal
SEA	System of Earthquakes Alert
SEAP	Sustainable Energy Action Plan
SEPA	Scottish Environment Protection Agency
SERA	Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe
SHARE	Seismic Hazard Harmonization in Europe
SHOPP	Society for Healthcare Organization Procurement Professionals
SoP	Standard of Protection
SuDS	Sustainable Urban Drainage System
TD BCA	Triple Dividend Benefit-Cost Analysis
UCC	USAR Coordination Cell
UCPM	Union Civil Protection Mechanism
UHI	Urban Heat Island
UN	United Nations

UNDAC	UN Disaster Assessment and Coordination
UNFCC	United Nations Framework Convention on Climate Change
USAR	Urban Search and Rescue
USGS	United States Geological Survey
VAT	Value Added Tax
VOLY	Value of Life Year
VOSOCC	Virtual On-site Operations and Coordination Centre
VSL	Value of a Statistical Life
WFD	Water Framework Directive
WTA	Willingness to Accept
WTP	Willingness to Pay
WUI	Wildland-Urban Interface

Note: Currencies have been converted throughout the document to euro values. Wherever the original values were in other currencies, this has been indicated in footnotes. The currency exchange rates used in this document come from the Eurostat database (European Union, 2021). All dollar amounts are US dollars unless otherwise indicated. As the results are based on analysis that is based on inherent uncertainty, results from new analysis under this study or detailed results from external case studies are presented as rounded numbers (i.e., to a maximum of two decimal places) and/or as ranges.

1. About this Background Report

This Background Report accompanies a summary report, which forms part of the World Bank's technical assistance project undertaken with the European Commission's Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) and financed under the Union Civil Protection Mechanism (UCPM) Annual Work Programme 2020. This report is the output produced under Component 1 "Retrospective analysis of the costs and benefits of selected disaster risk management (DRM) investments", with the aim to showcase the benefits of investing in the prevention of disaster risks. This background paper covers (a) methodological approaches for the economic assessment of investments for Disaster Risk Management and Climate Change and (b) summaries of all the case studies featured in this report. It first provides a detailed description of the approaches for the selection of case studies and an overview of all the case studies featured in the report, which can be categorized into three types based on the analysis undertaken: full quantitative analysis, partial quantitative analysis based on the literature, and qualitative analysis. Then it presents selected results from the analysis, focusing on main pieces of analysis and comparing results in light of the literature. Sections start with an introduction to hazard risks worldwide in the EU, include a summary of findings and then present selected detailed analysis for illustration.

2. Overview of Methodologies Applied in the Literature and This Report

This section provides an overview of the methodological approaches and applications to calculate benefits and costs of investments used in this report. The objective is to show the usefulness of using typical BCA procedures and applying the World Bank and Overseas Development Institute (ODI) Triple Dividend of Resilience approach for DRM investments. An overview of important technical terms is defined in *Annex 1*, while alternative methodologies that can be used is included in *Annex 3*.

2.1. The Triple Dividend of Resilience Approach

The 'triple dividend of resilience' approach (Tanner, et al., 2015) is a comprehensive methodology for analysing the net benefits of DRM investments. It identifies three types of benefits (see *Figure 1*): (1) avoiding losses and saving lives during a disaster; (2) unlocking economic potentials as a result of stimulated innovations and bolstered economic activities due to the reduction in background risks related to disasters; and (3) generating social, environmental, and economic co-benefits of DRM investments even in the absence of a disaster.

World Bank-financed projects must include a BCA, which includes a sensitivity analysis and calculation of return on investments (ROIs), among others (Independent Evaluation Group, 2010). Due to the broader benefits that the 'triple dividend of resilience' approach considers, there has been an increase in projects that include this methodology, such as a series of investment projects supported in Romania (World Bank, 2018a; 2019a; 2019c) and Turkey's Disaster Risk Management in Schools Project, as a part of the Global Safe School Program (World Bank, 2019d), for example.

An advantage of the triple dividend approach is that it reconciles perspectives from the humanitarian, environmental, and economic fields. However, estimations of the second dividend have generally been complicated, due to a combination of factors such as missing data, lack of appropriate and feasible methodologies particularly within short analytical time frames for project preparation and appraisal, and lack of expertise to undertake that part of the economic analysis (Mechler & Hochrainer-Stigler, 2019).

Dividend 1, saving lives and reducing losses, relies on quantifying the impact of resilience measures through risk analysis with and without the resilience measures (Mechler, 2016). Risk analysis provides the estimate of severity and frequency of impacts on people, communities, and their structural and infrastructure assets (Ghesquiere, et al., 2006) and the reduction in those impacts due to a particular set of resilience measures being implemented. Disaster risk (or catastrophe) modelling approaches estimate risk in terms of casualties and direct and indirect economic losses by modelling the interaction of hazard, exposure, and vulnerability (World Bank, GFDRR, 2014). For example, they can be used to adjust the vulnerability of building stock to represent the impact on the risk of improved building codes or retrofit programmes. The dividend can be estimated using scenario events or probabilistically to estimate the impact of the intervention on risk metrics such as AAL or extreme events.

In terms of dividend 2, a number of research projects have attempted to estimate in practice the wider economic benefits from DRM investments. Two studies (Erma, et al., 2020) showed the wider economic impacts of investments or policies in DRR from different perspectives. The first report (Madajewicz, et al., 2013) analysed a rural program to provide risk management support to farmers in Ethiopia and showed that risk management tools such as weather-indexed insurance increased farmers' savings (an important reserve in case of floods or droughts) and their investments in productive assets. These reports show that complementary soft investments for preparedness alongside hard infrastructure measures can have a substantial impact on the realization of a

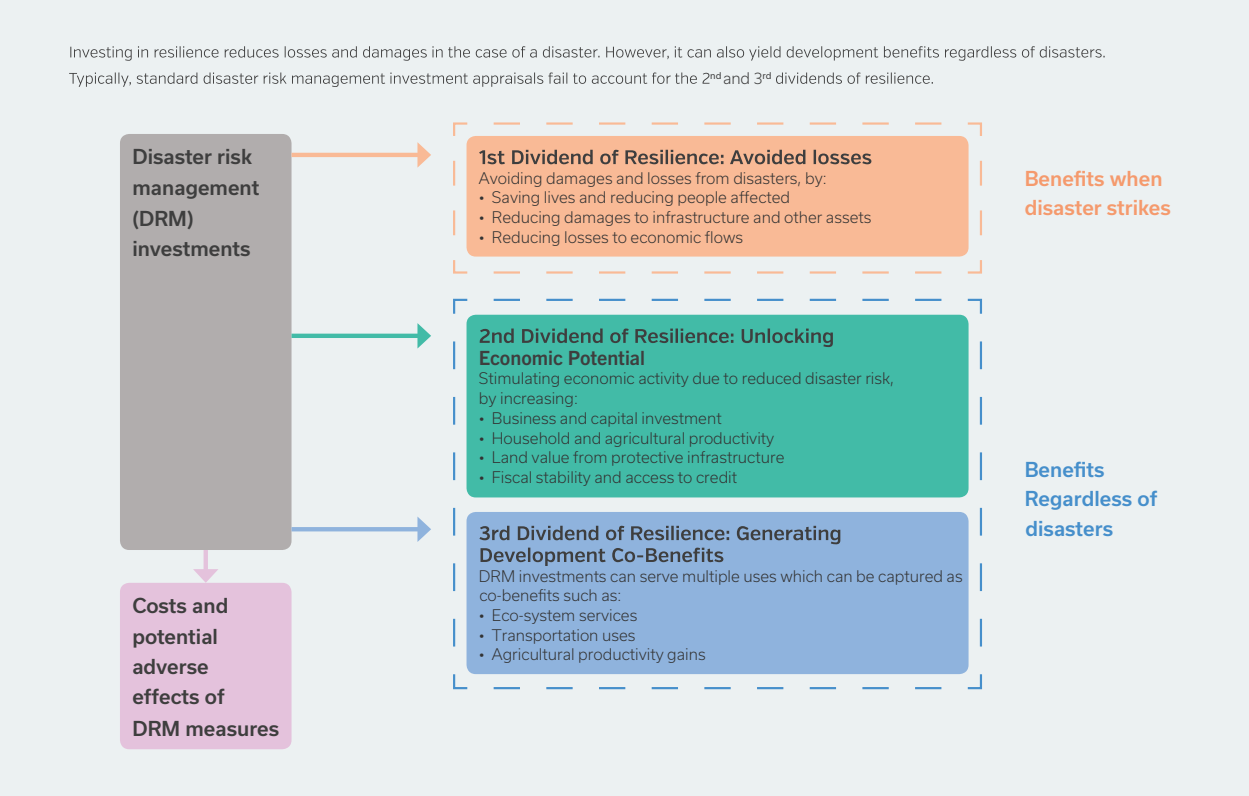
positive second dividend.

Other factors are essential to consider when aiming to measure benefits in terms of reduced flow losses. A significant reduction in flow losses - such as losses in GDP and employment, as opposed to property damage - can be obtained after disaster strikes by various types of resilience tactics related to coping with a disruption of critical inputs such as utility lifelines, critical materials, and workers. Rose (2007) refers to the use of such tactics as "resilience" to distinguish them from ex-ante risk reduction measures, typically referred to as "mitigation". Inherent resilience refers to the capabilities intrinsic to an individual business, household, or institution, or the economy as a whole; it can also refer to the build-up of resilience capacity by pre-positioning this capability for implementation after a disaster strikes. Examples of intrinsic capabilities include resilience "tactics" such as substitution (use of dual-fired boilers for electricity generation, the ability to substitute bottled or trucked water for piped water at the micro level, or the workings of the price system to provide signals of changes in resource values for optimal allocation at the market or macroeconomic level) or the ability to bring excess capacity online when regular capacity is damaged. Examples of pre-positioning include the purchase of portable electricity generators or stockpiling of critical materials.

The concept of adaptive resilience (Rose, 2016) is also essential to consider for estimating dividend 2. Adaptive resilience refers to improvisations after the disaster has struck, such as identifying conservation opportunities not previously thought possible, broadening the range of substitution possibilities, relocating businesses, or effecting technological change. Moreover, all these resilience tactics can have lasting effects through learning or improvements in the functioning of businesses, households, or other institutions to increase the capacity to cope with future disasters. All of these are short-run tactics that differ from long-run climate adaptation. An example of the difference relates to population movements with regard to disasters and climate change: short-run tactics include population evacuation either before or once the disaster has struck, which is typically temporary; for climate adaptation, as in the response to sea-level rise, the tactic would likely be permanent population migration. In short, informing economic actors of the risk may lead to them individually investing in enhanced preparedness, which will have additional positive economic effects regardless of whether a disaster will strike.

In terms of dividend 3, a few studies attempted to quantify some environmental or ecosystem co-benefits. Ideal methodology in such quantification requires adopting a production function method of valuing ecosystem good and services (Barbier, 2009). (Barbier, 2007) considered three broad categories of benefits of ecosystem services: 'goods' (for example, products obtained from ecosystems, such as resource harvests, water, and genetic material); 'services' (for example, recreational and tourism benefits or certain ecological regulatory functions, such as water purification, climate regulation, and erosion control); and cultural benefits (for example, spiritual and religious and heritage). A table in *Annex 3* lists potential economic benefits of ecosystem services.

Figure 1: Triple Dividend of Resilience



Source: (Tanner, et al., 2015)

2.2. Methodology applied to analyse case studies

This report contains quantitative and qualitative analyses of 74 case studies for floods, earthquakes, wildfires, extreme heat, droughts, wildfires, landslides, volcanoes, storms, epidemics, oil spills, nuclear, chemical, and biological hazards. These case studies represent DRM efforts across 24 countries as well as regional and continent-wide efforts. Furthermore, these cases touch on at least one of these important sectors: housing, emergency response and equipment, early warning, health, education, transportation, agriculture and forestry, cultural heritage and recreation, commerce and industry lifeline, and utility systems (for example, water and utility). With the information collected online, through phone interviews with leading experts and practitioners as well as questionnaires sent via email, our team applied the World Bank's triple dividend of resilience approach as much as possible to analyse the well-rounded economic and non-economic costs and benefits of DRM investments and policy implementations.

2.2.1. SUMMARY OF METHODOLOGICAL APPROACH

The World Bank has applied the 'triple dividend of resilience' approach while keeping a certain flexibility. The specific methodologies and modelling approaches were adapted to various types of disaster risk investments and existing results of various BCAs have also been presented.

Although there have been variabilities in analysis of investments, a similar process has generally been undertaken that has the following features:

- Considered the risk profile across UCPM countries. This was undertaken to better understand benefits and costs and the limitation and comparability of available data.

- Collected and summarized data on selected investments. Information was collected on investments in prevention and preparedness as well as DRR, including among others broad figures on national funds and EU programs, intervention type and description, anticipated or actual cost, number of beneficiaries, feasibility studies, any BCA that was undertaken, and how risk is considered (availability of data for future scenarios and so on). Further information was collected through extensive consultations.

- Reviewed case studies related to specific hazards and sectors. These encompassed hazards such as flooding, earthquake, extreme heat, droughts, wildfires, landslides, volcanoes, storms, epidemics, oil spills, nuclear, chemical and biological as well as sectors such as housing, transport, education, health, emergency response, early warning and lifelines, communications, energy and water.

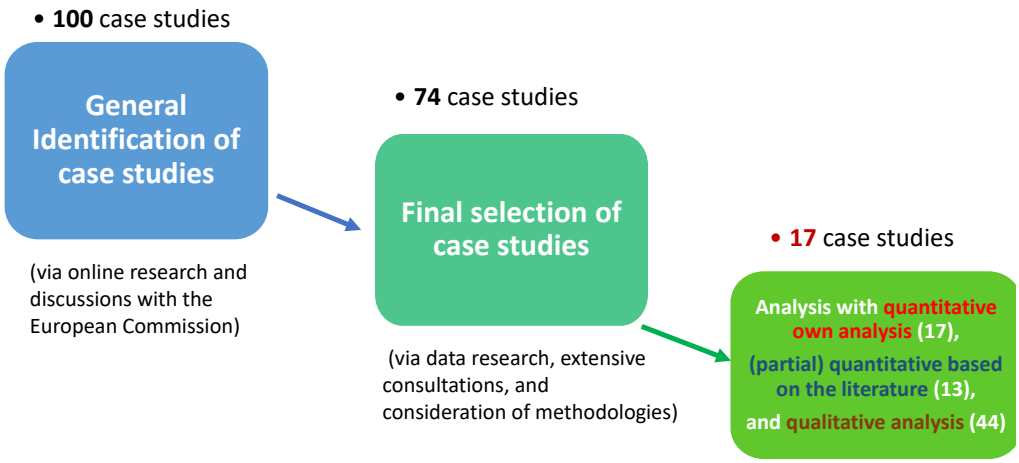
- Applied the triple dividend approach to demonstrate the benefits of DRR investments. The first dividend was estimated by conducting scenario impact models for cases with detailed data being available to simulate the interventions and their impacts. Examples where this might be simulated include the construction of coastal and inland flood protection, relocation of assets and population, restriction of land use, and strengthening/hardening of existing buildings and infrastructure. The calculation of the second and third dividend depended on the availability of data. "The analysis has built on a number of parameters, specific methodologies and assumptions. The process of calculation of the BCAs is described in detail in *Annex 2*.

2.3. Approach for the identification of case studies and overall analysis

2.3.1. APPROACH FOR THE IDENTIFICATION OF CASE STUDIES

The identification and selection of case studies was undertaken through a three-step approach (*Figure 2*). The three steps were (a) identification of case studies for the focus of the analysis, (b) categorization of case studies based on data availability (collected through online research and extensive consultations with stakeholders) and methodological feasibility to undertake at least a partial triple dividend BCA in a quantitative manner or qualitatively describing the benefits and costs, and (c) quantitative analysis with risk modelling for a selected number of case studies and partial or qualitative analysis for the others as well as presenting of results from the literature and World Bank projects.

Figure 2: Process for the selection of case studies



Source: World Bank analysis

Following an initial research and review of existing case studies, approximately 100 case studies from a European context have been selected. These case studies were considered for a preliminary analysis and presented in the inception report delivered in June 2020. The case studies included a mix of relevant sectors (housing, education, transport, health, emergency response, early warning and lifelines, communication/ICT, energy, and water) and hazards that are either natural (floods, droughts, earthquake, wildfires, landslides, and volcanic eruptions) or technological (oil spills, chemical pollution, biological, radiological, or nuclear disasters). The case studies focused on MS/PS of the UCPM; were funded from national funds, at least partly by EU funds or by international financial institutions; and were major projects[1] that were aimed predominantly at reducing disaster risk, increasing prevention and preparedness. These case studies were categorized into thematic areas and hazards and the depth of data and information available for BCA assessed, including through extensive consultations (see *Annex 6*). For all case studies, background information on disaster vulnerability of the country or area, the project funding, achieved or expected impacts as well as cost-effectiveness, and/or triple dividend BCA were presented.

In a second step, case studies were categorized and reviewed according to their suitability for further analysis, and 74 were included in the final selection.[2] These case studies were reorganized by types of investments covering various hazards and sectors and 17 case studies were considered for full quantitative analysis including own risk modelling and/or assessment (3 on floods, 4 on earthquakes, 2 on extreme heat, 7 on wildfires and 1 on chemical; included in those are 3 on early warning). Another 13 case studies were presented based on at least partial quantitative analysis undertaken in the literature, including for World Bank project appraisal or evaluations (5 on floods, 2 on earthquakes, 1 on droughts, 1 on landslides, 2 on epidemics, 1 on oil spills and 1 on multi-hazard). The remaining 44 case studies were described qualitatively as insufficient information and data were found to be able to present results according to triple dividend BCA or at least somehow quantitatively, but these were still considered to be interesting investments that could be suitable for further analysis. An overview of case studies with detailed information and an illustration of coverage by hazards, countries, sectors, and type of methodology is included in *Annex 7*.

In a third step, analysis was undertaken for the case studies and relevant international best practices were presented. A summary of results of the case studies and analysis is included in Part 3 of the report, according to various European Commission priorities, by hazards and types of investments. The international case studies (among others New Zealand, Japan, the United States, and Australia) were mostly selected as per their suitability for transferability of experiences to the EU context and lessons learned from making the economic case for investing in DRR.

Determining an average value on a hazard- or sector-specific BCA was not possible due to non-representative samples of investments and non-uniform methods. An important consideration for the analysis has been the variety of methodologies and levels of modelling or risk assessments applied given the multitude of hazards, sectors and information/data availabilities. For example, some of the case studies are analysed on a scenario basis and others on the basis of AALs. For some of the case studies where a concrete investment could not be found (that is, retrofitting of schools at European scale), a hypothetical scenario was modelled. Moreover, an insufficient number of case studies to have a representative sample undermined the possibility of inferring representative average BCRs for investments.

2.3.2. SUMMARIZED RESULTS FROM ANALYSIS AND CASE STUDIES

A brief summary of the typology, coverage and main information on the case studies is included below (see *Table 1*). A considerable effort has been undertaken to achieve a balanced coverage of hazards, types of investments and countries. However, the lack of data and information, available methodologies to undertake risk assessments and BCA, or possibility to present qualitative information conforming to the Triple Dividend Framework constrained the depth and breadth of coverage. This was expected, as a major

1 Major projects in the programming period 2014–2020 are defined as operations where eligible costs exceed €50 million or €75 million in the case where they contribute to the thematic objective under Article 9(7) (Article 100, Regulation 1303/2013 from the European Commission).
2 The number is higher than just based on the original list of case studies considered, as some case studies were added in the process based on further recommendations from stakeholders.

focus of key EU investments in the past decade has been, for example, on flood risk prevention.

In terms of coverage of countries, a good balance has been achieved in terms of development/income levels[3], geographical locations, and disaster risks commonly faced in subregions. *Figure 3* shows countries in Europe and beyond as well as the coverage of case studies by hazards, sectors, and type of analysis as well as information on countries status of participation to the UCPM. *Figure 4* also shows that the case studies include close to all countries that are expected to suffer from high welfare losses due to climate change (Feyen, et al., 2020).

The following case studies are not included in the map (Figure 3) because they were regional investments across Europe or undertaken in two or more non-neighbouring countries involved.

- 'Mapping landslide hazards': Croatia/Bosnia and Herzegovina/Montenegro - emergency response and equipment - landslide - qualitative.
- 'Early warning and preparedness for droughts': Danube region - emergency response and equipment - drought - qualitative analysis.
- 'Union civil protection knowledge network in earthquake': Albania and Croatia - emergency response and equipment - earthquake - quantitative own analysis.
- 'The case of pandemic preparedness': Across Europe - epidemic - health - partial quantitative/ literature.
- 'Rate of return on health investments': Across Europe - epidemic - health - partial quantitative/ literature.
- 'Schools in seismic countries across Europe': Across Europe - earthquake - education - quantitative own analysis.
- 'European flood awareness system': Across Europe - flood - early warning - qualitative.
- 'URBAN GreenUP': Across Europe - all hazards - housing and public buildings; recreation - qualitative.

Table 1: Overview of Case studies Reviewed as part of Background Research

NATURAL HAZARDS

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
FLOODS	28	United Kingdom, Portugal, Spain, Greece, Cyprus, Poland, Netherlands, Austria, Croatia, Serbia, Malta, Spain, Bulgaria, Denmark, Belgium, Germany, Italy, Europe	Structural protection (8); NBS (14); early warning (5); PLP (1)	Industry, early warning, water, agriculture, housing and public buildings, response and equipment, recreation
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLEMENTATION PERIOD	TYPE OF ANALYSIS
	8.965 billion	EU, World Bank, National	2006 - 2023	Quantitative, own analysis (3); Partial Quantitative / literature (5); Qualitative (20)

3 The case studies cover six upper-middle-income countries and 28 higher-income-countries according to World Bank definition as of 2021. According to the categorization of the World Bank, for FY2021, low-income economies are defined as countries with a gross national income (GNI) per capita of €925 (that is, US$1,035) or less in 2019; lower-middle-income economies are countries with a GNI per capita between €925 and €3,613 (that is, between US$1,036 and US$4,045); upper-middle-income economies are countries with a GNI per capita between €3,614 and €11,197 (US$4,046 and US$12,535); and high-income economies are countries with a GNI per capita of €11,198 (US$12,536) or more.

NATURAL HAZARDS

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
DROUGHTS AND EXTREME HEAT	6	United Kingdom, France, Spain, Portugal, Austria	UHI effects (2); early warning (1); irrigation and water provision system (2); early warning and capacity building for droughts preparedness (1)	Housing and public buildings, early warning, water, agriculture
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLEMENTATION PERIOD	TYPE OF ANALYSIS
	100.18 million	EU, National	2013 - 2022	Quantitative, own analysis (2); partial quantitative/literature (1); Qualitative (3)

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
EARTH-QUAKE	7	Italy, Romania, Turkey, Albania, Croatia, Europe	Seismic retrofitting (5); early warning (1); capacity building (2)	Housing and public buildings, education, health, early warning, emergency response, cultural heritage
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLEMENTATION PERIOD	TYPE OF ANALYSIS
	59.22 billion	EIB, National, EU, World Bank	2015 - 2025	Quantitative, own analysis (4); partial quantitative/literature (2); Qualitative (1)

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
WILDFIRES	10	Czech Republic, Poland, Spain, Portugal, Greece	WUIs (2); fuel management for wildfire prevention (1); early warning (3); cross-border support, coordination mechanisms and capacity building (4)	Emergency response, early warning, forestry
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLEMENTATION PERIOD	TYPE OF ANALYSIS
	149.24 million	EU, National	2013 - 2022	Quantitative, own analysis (7); Qualitative (3)

NATURAL HAZARDS

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
MASS MOVEMENT / LANDSLIDES / AVALANCHES	6	Switzerland, Croatia, Bosnia and Herzegovina, Montenegro, France, Spain, Albania, Italy	Information system and cooperation mechanism (3); resilient road (1); landslide prevention and response investments (2)	Agriculture, recreation, Transportation, early warning
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLEMENTATION PERIOD	TYPE OF ANALYSIS
	20.60 million	EU, National, World Bank	2019 - 2020	Partial Quantitative / literature (1); Qualitative (5)

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
VOLCANIC	2	Italy, Spain	Preventive Investment (2)	Transport, early warning
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLEMENTATION PERIOD	TYPE OF ANALYSIS
	55.00 million	EU, National	2013 - 2020	Qualitative (2)

TECHNOLOGICAL HAZARDS AND CROSS-CUTTING

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
OIL SPILLS	1	Estonia	Oil spills prevention (1)	Water, fishery
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLE-MENTATION PERIOD	TYPE OF ANALYSIS
	33.00 million	EU, National	2013	Partial quantitative/literature (1)

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
CHEMICAL	1	Latvia	Cleaning up hazardous waste (1)	Water
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLE-MENTATION PERIOD	TYPE OF ANALYSIS
	29.00 million	EU, National	2013	Quantitative, own analysis (1)

TECHNOLOGICAL HAZARDS AND CROSS-CUTTING

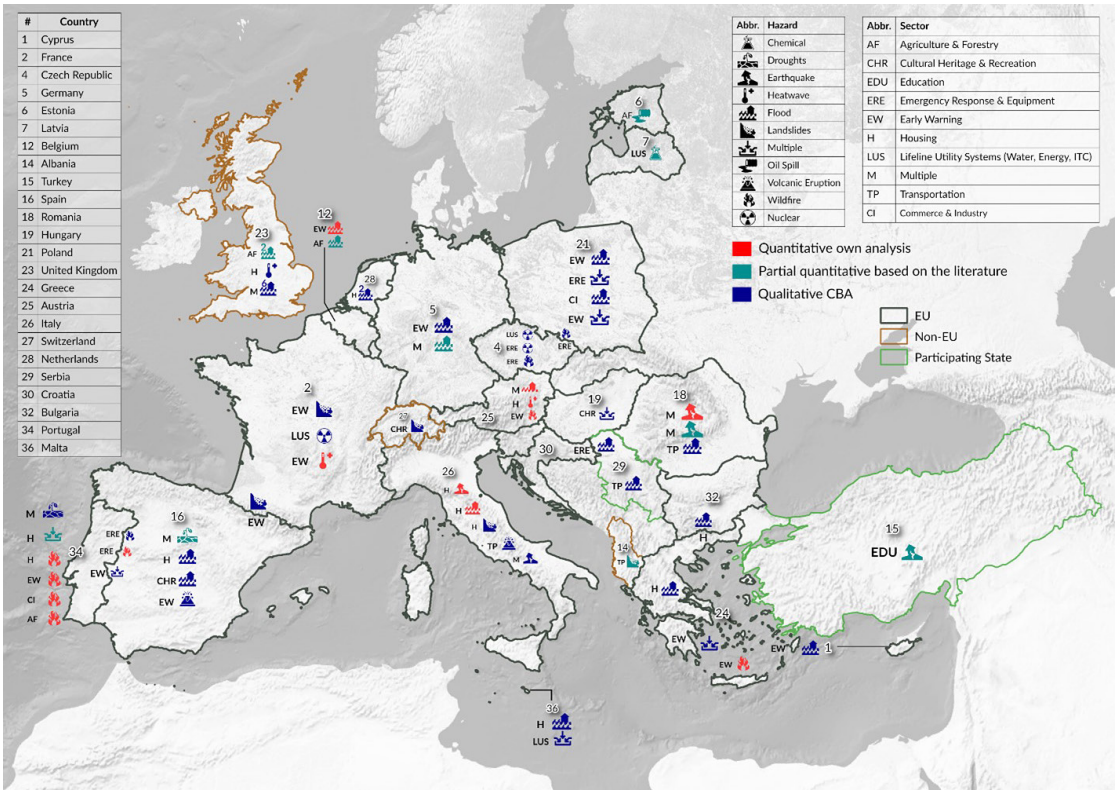
HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
EPIDEMIC	2	Italy, United Kingdom, Sweden, Netherlands, Europe	Return on investment of National Public Health Program (1); equipment for health-related disasters (1)	Health
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLE-MENTATION PERIOD	TYPE OF ANALYSIS
	4.50 billion	EU, National	2021	Partial quantitative/literature (2)

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
NUCLEAR/ RADIO-LOGICAL	3	Czech Republic, France	Security of nuclear power plant (2); cleaning up uranium (1)	Energy, emergency response and equipment, water
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLE-MENTATION PERIOD	TYPE OF ANALYSIS
	24.34 billion	EU, National	2018 and on-going	Qualitive (3)

HAZARD	# CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED
ALL DISASTERS	8	Croatia, Serbia, Romania, Europe and Central Asia, Finland, Poland, Italy, Latvia, France, Europe and Central Asia, Greece, Malta, Switzerland, United Kingdom, Hungary	Rescue and emergency response equipment (1); Early Warning (4); climate change adaptation (3)	Education, transport, emergency response, early warning, communication/ICT, recreation, houses and public buildings
	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLE-MENTATION PERIOD	TYPE OF ANALYSIS
	730.93 million	World Bank, EU, National	2006 - 2020	Partial Quantitative / literature (1); Qualitative (7)

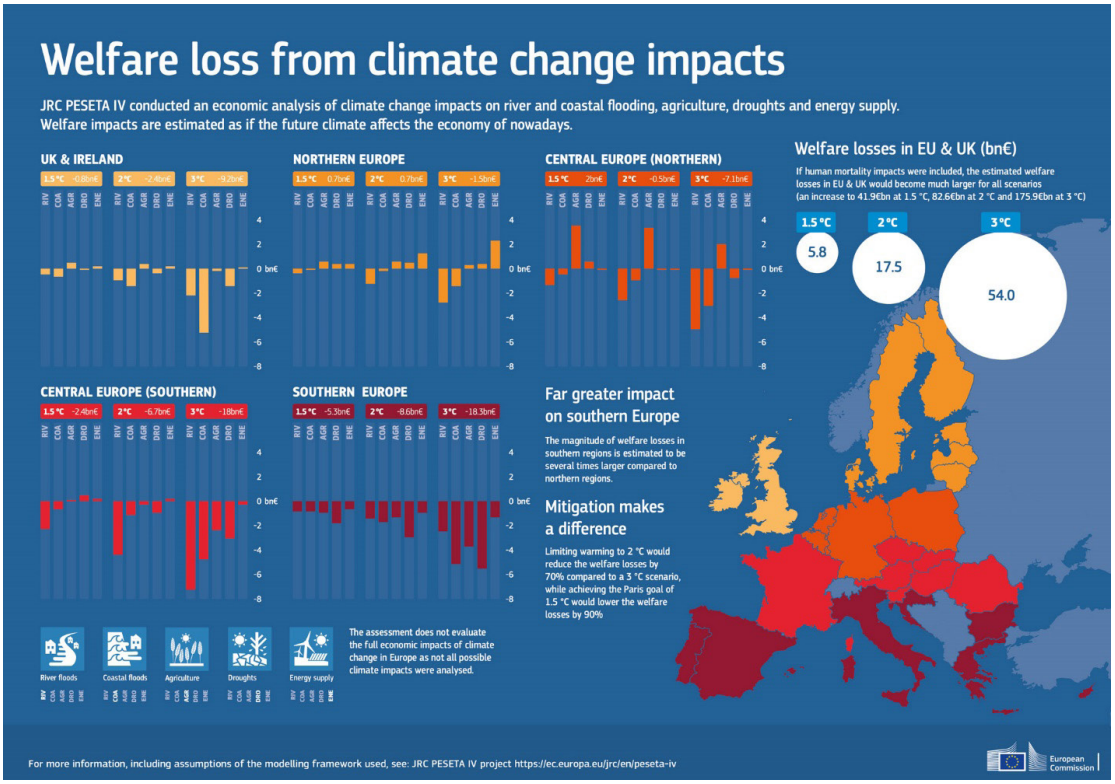
Source: World Bank analysis

Figure 3: Overview of case studies analysed under this report



Source: World Bank analysis

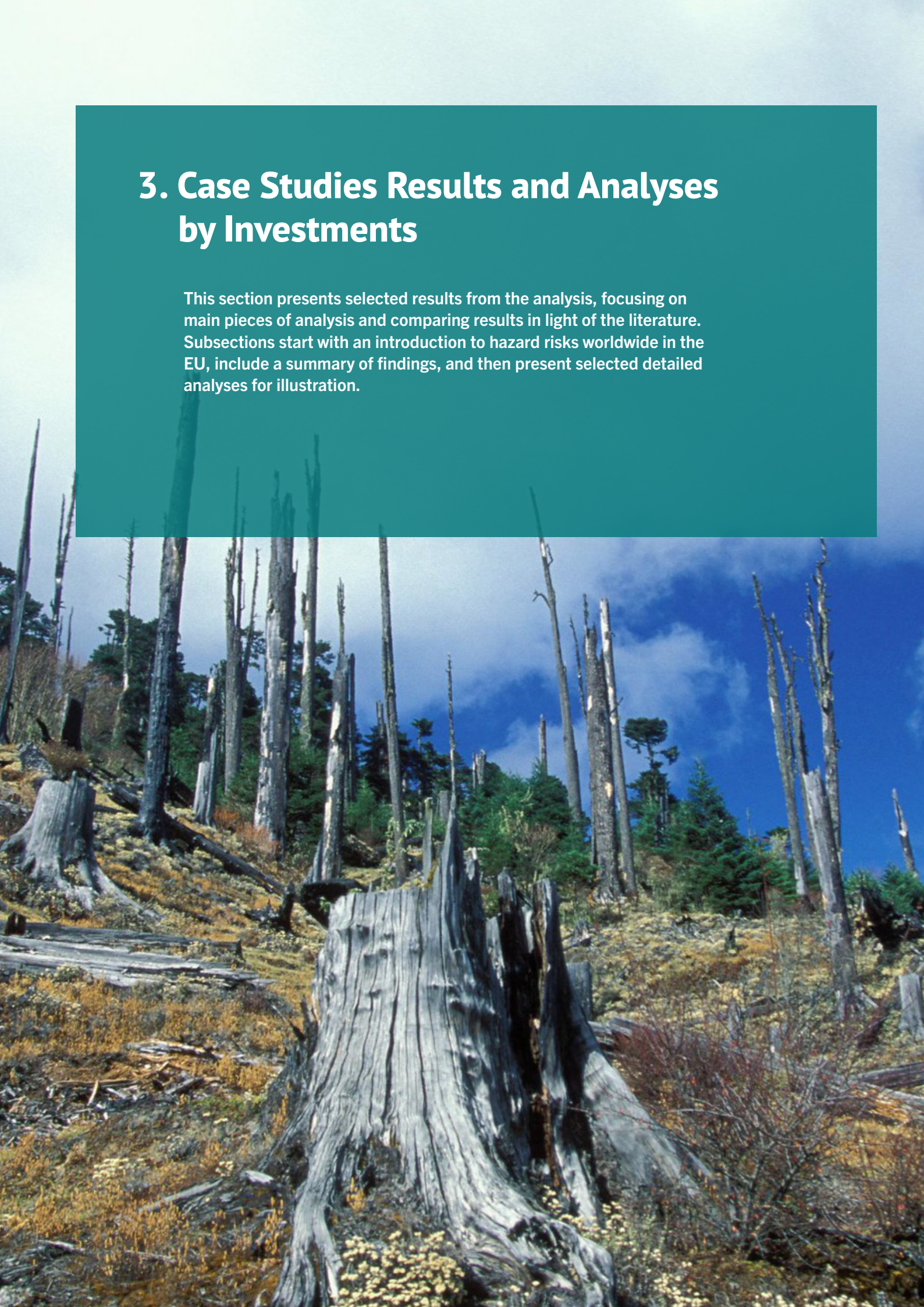
Figure 4: Economic loss (€, billions) from considered hazards and climate impact at warming levels for the EU and the United Kingdom (for macro regions)



Source: Szewczyk, et al. (2020)

3. Case Studies Results and Analyses by Investments

This section presents selected results from the analysis, focusing on main pieces of analysis and comparing results in light of the literature. Subsections start with an introduction to hazard risks worldwide in the EU, include a summary of findings, and then present selected detailed analyses for illustration.



3.1. Flooding

3.1.1. SUMMARY OF FINDINGS FOR FLOODS

Floods are the most frequent natural disasters and the most common disaster regionally, and they can cause widespread devastation that results in loss of life and/or damages to personal property and public infrastructure. More than 2 billion people worldwide were affected by floods between 1998 and 2017 (WHO, 2021). Floods can be classified in three broad categories: (1) pluvial floods, which are caused by rapid and excessive rainfall that quickly cause water to cumulate outside of water bodies; (2) river floods, which are caused when consistent rain or snow melt forces a river to exceed its capacity, causing water to overflow from its course; and (3) coastal floods, which are caused by extreme sea levels associated with storm surge, strong wind, high waves, or exceptional tides.

Over the past 30 years, the number of devastating flood events in Europe has more than doubled, and there has been a proportionally higher increase in the frequency of flooding events caused by surface water flooding due to overwhelmed drainage systems, although investments in flood protection seem to have been effective in reducing flood risk (Paprotny, et al., 2018). JBA Risk Management also cites projections, suggesting that this trend will continue, and the effects of these flooding events will be exacerbated by climate change. A study conducted by Selma Guerreiro and co-authors in 2017 was the first attempt at continental city flooding modelling of European cities, and they found that, generally, cities with a lower percentage of flooding are located in the north and west coastal areas of Europe, while higher percentage areas are seen in continental and Mediterranean Europe (Guerreiro, et al., 2017). Surface water maps, used in conjunction with existing flood data, can provide a fuller picture of these pluvial flooding risks and equip stakeholders with information on areas at risk beyond river floodplains.

A range of interventions designed to deal with inundation triggered by river flooding, flash flooding, and storm-surge coastal flooding are covered in this section. The understanding of hazard and risk distribution is the first step in the development of an appropriate defence strategy. The impacts of river floods, flash floods, and coastal floods can be addressed with different risk reduction strategies.

In this section, we have demonstrated benefit-cost assessments for four types of flood interventions, which can be categorized as (1) structural flood protection (for example, levees and walls), (2) nature-based solutions (for example, NFM and floodplain restoration), (3) property-level protection (for example, small-scale demountable door barriers), and (4) flood early-warning systems. BCRs for the different types of interventions are shown by a combination of conducting detailed case study analysis and reviewing past BCAs, including both prospective and retrospective types of assessments. The flood mechanism in most case studies considered is fluvial flood originating from one or more major rivers. A few other examples consider coastal flood risk from extreme storm surge events, alone or (for delta regions) in combination with river floods. Pluvial flood (flash flood) is also included in some analyses presented. *Table 2* summarizes main data and information sources.

Table 2: Overview of data and information sources for flood analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Structural protection	Machlanddamm	• Total investment information from OECD report on a draft case study of disaster risk prevention and mitigation policies in Austria • Residential buildings exposure data, developed under the Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe (SERA) project
NBS	INTERREG project Eddleston Water	• External economic assessment, published by Tweed Forum (Eddleston Water Project Summary Report and Integrating natural capital into flood risk management appraisal Study Report)
NBS	Sigma Plan	• Costs, risk reduction benefits, and co-benefits obtained from 'Sigma Plan Social-cultural Benefit-Cost Analysis, Synthesis Report (Sigmaplan Maatschappelijke Kosten-Baten Analyse)'
EWS	The Flandres Flood Early Warning System	• FEWS anticipation capacity, warning coverage and losses reduction assumptions based on the national report on flooding published by Flemish Environment Agency • JBA Global Flood Model and residential exposure
PLP	Property Level Protection in Northern Italy	• Implement cost and the simulation of PLP effectiveness based on the ECHO study 'Prevention and Preparedness in Civil Protection: Cost-benefit Analysis of Mitigation Measures to Pilot Firms/Infrastructures in Italy'

Source: World Bank analysis

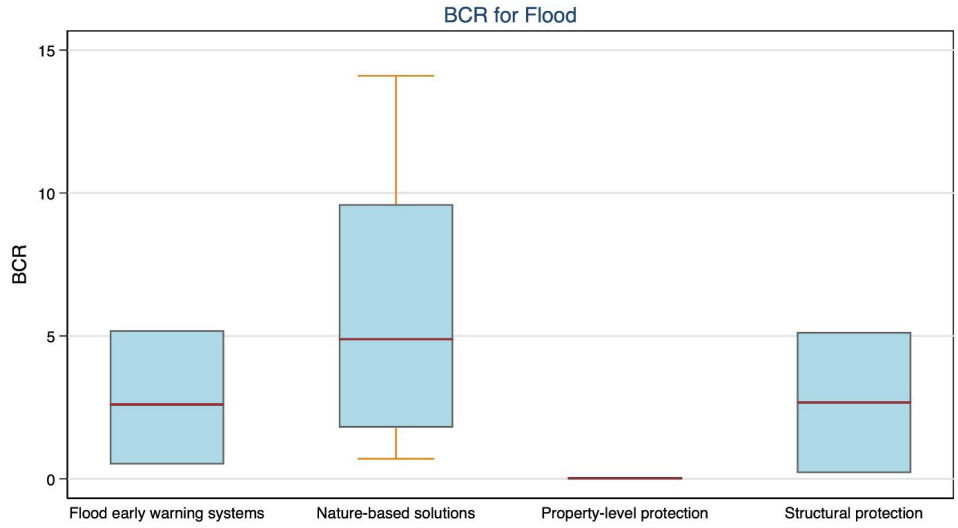
Flood hazard models need to be adapted to test the effect of different investment types analysed on fatalities and economic losses. For the detailed case studies presented, we have applied a global flood model to assess flood impact with and without protection (as a basis to estimate dividend 1), based on stochastic modelling of flood inundation intersected with buildings distribution, construction, and replacement costs. Estimation of dividends 2 and 3 due to flood risk reduction strategies also varies by type of investment and requires data from sources other than the flood inundation model. More details on the methodologies, models, and types of impacts considered are included in the relevant section on floods in the report.

BCRs for flood protection can be extremely variable, as they depend on the scale and type of investment, the intersection of localized hazard and exposed assets, and the factors captured in the analysis. This variability is demonstrated by the specific cases analysed here and broader regional-scale analysis such as conducted under PESETA IV (Dottori, et al., 2020). The Eddleston Water case study, as it includes multiple analyses with different factors, demonstrates the latter. The influence of hazard and exposure intersection is crucial when considering the difference in BCR between case studies and is illustrated in the regional-scale PESETA analysis, which demonstrates the different BCRs possible in each country when common defence assumptions and costs are applied.

Results of the analysis of investments are generally positive in terms of net benefits (BCRs higher than 1, positive NPVs and IRRs higher than defined thresholds), although consistent with research findings (Dottori, et al., 2020) some hard infrastructure investments, in some contexts, tend to have BCRs close or lower than 1. Complementary investments and comprehensive analysis to inform designs (including considering climate change scenarios) could therefore be highly beneficial for investments to maximize benefits across sustainability goals. More details are included in *Figure 5*, *Figure 6* and *Figure 7*.

Figure 5 shows the distribution of benefit-cost ratios (BCRs) for flood investments, based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange).

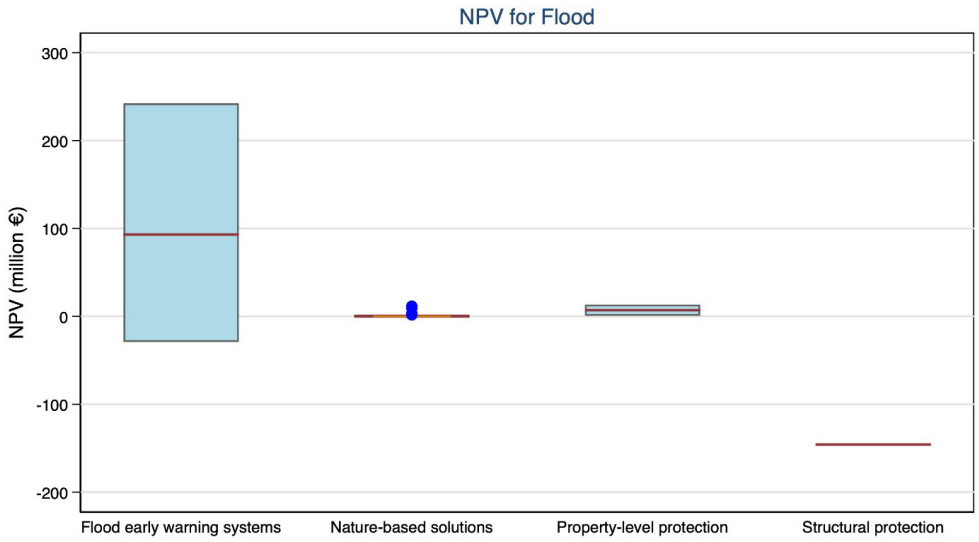
Figure 5: Findings of BCA for floods (BCRs)

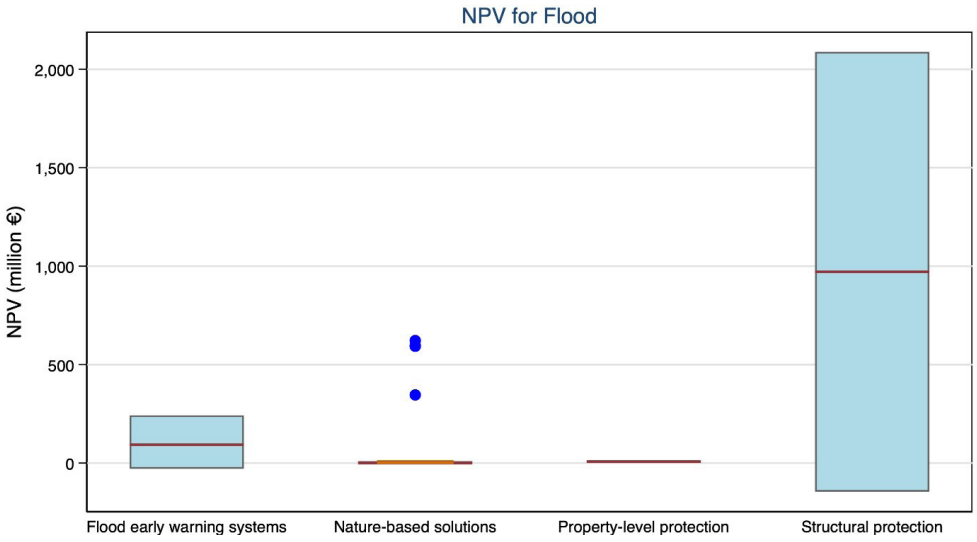


Source: World Bank analysis; based on external data and information; presenting in part results from literature based on World Bank & external reports (1 structural protection result from World Bank (2007), 3 nature-based solution results from Spray (2016), Hölzinger & Haysom (2017) and Gauderis, et al. (2005))

Figure 6 presents boxplots that display the distribution of NPVs (in millions of euro) for different types of investments in flood prevention based on a five-number summary: minimum (shown in yellow), first quartile, median (shown in red), third quartile, and maximum (shown in yellow). The outliers are shown as dots. Extreme values are excluded from the first graph and included in the second one.

Figure 6: Findings of BCA for floods (NPVs)

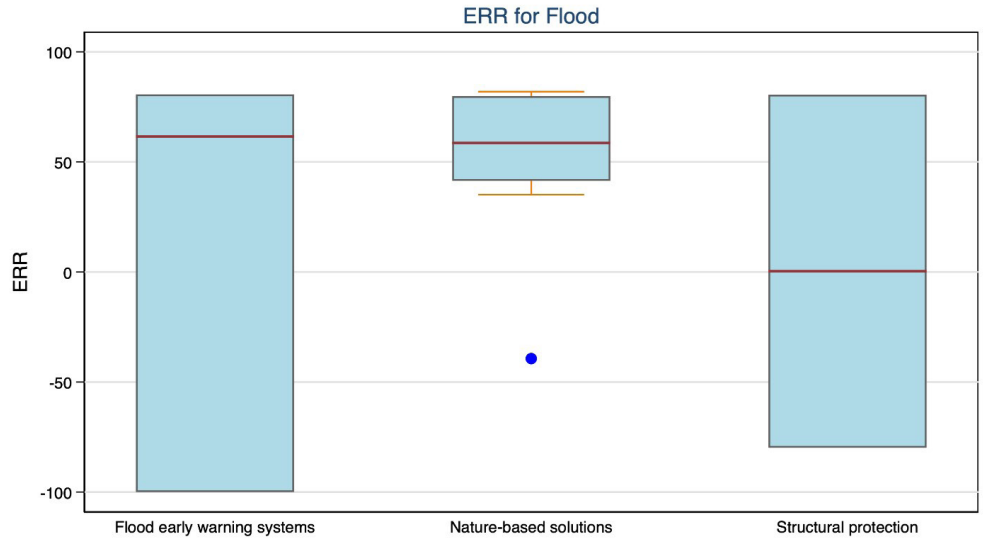




Source: World Bank analysis; based on external data and information; presenting in part results from literature based on World Bank & external reports (1 structural protection result from World Bank (2007), 4 nature-based solution results from Spray (2016), Grossmann & Hartje (2012), Hölzinger & Haysom (2017) and Gauderis, et al. (2005))

Figure 7 below shows the distribution of ERRs for different types of investments in flood based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). The outliers are shown as dots.

Figure 7: Findings of BCA for floods (ERRs)



Source: World Bank analysis; based on external data and information; presenting in part results from literature based on World Bank & external reports (1 structural protection result from World Bank (2007), 3 nature-based solution results from Spray (2016), Hölzinger & Haysom (2017) and Gauderis, et al. (2005))

Overall, the results and qualitative research on structural protection showed that hard infrastructure solutions are not necessarily always an option that has a BCR higher than 1. However, the BCR is dependent on the modelling assumptions and the availability of data to enable the quantification of all dividends (particularly intangible impacts over health and environment), which were not included in some case study analyses. Given increasing multi-hazard risks and the need for integrated investments, it is imperative to collect sufficient baseline information across all dividends when designing investments, to assess hard infrastructure solutions with the Triple Dividend Framework; this would promote designing investments that maximize co-benefits alongside reducing losses and saving lives. Evaluating the costs and benefits of complementary or other investments (soft investments, NBS) with the Triple Dividend Framework when considering hard infrastructure can reveal added ecosystem benefits and any impact (positive or negative) in terms of cost or protecting lives and assets. Another result emerging from qualitative case studies is that citizen and stakeholder engagement and extensive consultations and cooperation mechanisms can support an enhanced decision-making of designs informed by evaluation (the Netherlands, Malta) as well as implementation (Greece/Bulgaria cross-border and Greece). More details on the utilization of BCA and participatory decision making in the Netherlands for flood risk management are highlighted in *Table 89*, *Table 90* and *Table 91* in *Annex 5*. Moreover, prioritization models and methodologies such as criticality analysis (Vukanovic, 2018; Rozenberg, et al., 2019), can support the better targeting of specific assets and infrastructure considering the asset-specific vulnerability and cost-effectiveness, which have been applied in countries such as Serbia or Romania (European Commission, 2018).

- **Case study 1 (new analysis under this project (Heidrich, 2016; JBA Risk Management, 2021), ex post):** Analysis of Central Europe's largest flood control protection project, the Machlanddamm in Austria, showed that the protective structures had variable effects on reducing risk in each of the protected communities. On average, the reduction of risk in residential properties was 12 percent compared to the undefended scenario. BCR of <1, NPV of about –€146 million, and IRR/ERR of –80 percent was estimated, which is considered to be low but considers only benefits of avoided damage. The lack of flood-related fatalities in any case in Austria meant they were not considered, land/property values were not expected to be affected (due to additional regional development restrictions), and dividends 2 and 3 could not be estimated due to a lack of data on additional amenities and even official information on the exact number of protected houses.

- **Case study 2 (World Bank Project Appraisal Document [PAD] analysis (World Bank, 2007), ex ante and ex post):** The analysis of a major river flood protection project in Poland derived a high BCR (5.14, NPV of about €2 million, IRR/ERR of 81 percent), which was mainly due to the consideration of intangible benefits (that is, reduced mental health and health impacts) and the consideration of economic benefits from future gravel production in the reservoir area, which became available due to the flood strategy including construction in a gravel-rich area. The case study estimated substantial physical and mental health benefits from the risk reduction investments.

- NBS make use of natural processes to decrease flood risk while also providing ecosystem services, they can be implemented alone or in combination with traditional engineering approaches. The EU has been building evidence of the cost-effectiveness of NBS through various programs. While NBS can be more cost-effective than structural (grey) infrastructure, they can provide lower safety benefits in some cases compared to hard infrastructure (although costs generally also decrease). It can be most beneficial to consider NBS as complementary solutions, forming hybrid green-grey infrastructures, and they can maximize a range of benefits including improving water storage/absorption capacity, ecosystem services, recreational use, protection around coastal risks, and so on. They can also allow for longer-term flexibility under projected climatic changes, whereas a firm standard of protection (SoP) of hard defences may not easily be adapted to address more extreme risks. NBS can provide educational opportunity (Eddleston Water, United Kingdom), create habitat networks (Ijsselpoort, the Netherlands), and have co-benefits in terms of climate and erosion regulation (Yorkshire, the United Kingdom). Landscape preservation such as

dunes has also been shown to support the restoration of habitats and protect from flood and storm risks (Barcelona, Spain) and flood risk reduction in coastal/tidal areas seems to generally work well with integrated ecosystem presentation/ upgrading measures (Sandwich, the United Kingdom, and Alkborough, the United Kingdom). In urban settings, measures combining natural building materials and shaping park and recreation areas as well as neighbourhoods with green solutions can have positive impacts on flood risk reduction and liveability of the areas (Benicassim, Spain; Mayes Brook River, the United Kingdom; and Malmö, Sweden).

→ **Natural Floodplain Management:**

- **Case study 3 (External analysis by Scottish Environment Protection Agency [SEPA] and contractors (Spray, 2016), ex ante and ex post):** The analysis of the Eddleston Water project that involved landscape restoration yielded high BCRs at economic appraisal (BCR of 9–17). A second estimation of ecosystem services, which applied a different set of services and valuations, showed that BCRs are lower and only higher than 1 when a 100-year timescale is considered. Depending on the assessment and combination of options, the BCR was estimated at 1.71-2.42 (NPV up to €9,512 and IRR/ERR of 41–59 percent). This indicates that these interventions tend to take longer to yield economically valuable benefits and that longer time horizons for policy recommendations should be considered and even potentially lower discount rates. Moreover, in such wide-ranging analyses, the selection and valuation of benefits can lead to different outcomes.

- **Case study 4 (external analysis (EEA, 2017; Grossmann & Hartje, 2012), ex post):** The analysis of the green, hybrid, and grey infrastructure solutions implemented along the Elbe River in Germany showed highest net benefits for an integrated floodplain management investment with green infrastructure compared to hybrid or grey investments (NPV of €429,746 compared to 196,337 and 72,707, respectively) while showing negative NPV for grey infrastructure where only avoided loss benefits are included. This case study is specific as it looks at options of replacing old flood protection infrastructure and used a cost-effectiveness methodology.

- **Case study 5 (external analysis (Hölzinger & Haysom, 2017) ex post):** The analysis of the floodplain restoration project in Chimney Meadows, the United Kingdom, demonstrates the high value (BCR of 1.5–4.8, NPV €1,665–€11,528, IRR/ERR 35.1–79.18 percent) that restoration from intensive farmland can have on flood risk as well as co-benefits. The study measured many ecosystem benefits affecting the second and third dividend and could be improved by exploring the effects on agricultural supply chains and impact on broader communities.

→ **Nature-based coastal and tidal protection:**

- **Case study 6 (external analysis by Sigma Plan contractors (Gauderis, et al., 2005), ex ante):** The analysis of the Sigma Plan, an integrated flood protection plan combining grey and green infrastructure, yielded BCRs higher than 1 for all solutions including just implementing a storm surge barrier. The BCR increases from an estimated 1.87 to 4.97 (NPV until 2100 of €346–593 million, IRR/ERR of 46.57–79.89 percent), and the relative cost-effectiveness increases when integrating grey measures with NBS or using a work-with-nature approach. Although safety benefits tend to decrease slightly, costs also decrease while co-benefits (especially environmental ones) tend to increase.

Flood Early Warning Systems (FEWS): provide integrated hazard monitoring, forecasting, and alerts that enable various stakeholders to take timely actions to reduce disaster risks in advance and during hazardous events. Economic assessments of EWS impacts in quantitative terms are prone to several uncertainties, relying on many assumptions and generalizations and the results should be considered with caution as they may capture impacts from other investments as well. The literature reviewed for this report shows that FEWS tend to have positive benefits (for example, European Flood Awareness System [EFAS] (Pappenberger, et al., 2015) and Grimma, Germany). Moreover, risk information systems related to EWS can also have numerous benefits (Greece/ Cyprus Environmental Risk Management Information Service, Poland PANDA).

- **Case study 7 (new analysis under this project, ex post) (JBA Risk Management 2021, Perera et al., 2019):** The analysis of the advanced FEWS in

Flandres, Belgium, yielded a range of BCRs for various scenarios to test sensitivity of losses to uptake of the warnings issued (5 percent, 25 percent, and 50 percent assumed loss reduction). BCRs ranged from 0.5 to 5.2 (NPV of -€1.5 million to €12.5 million, IRR/ERR of –100 to 80.65 percent) suggesting that the strategy requires a minimum level of uptake to provide a BCR greater than 1. Benefits may have been underestimated given the difficulties to capture dividend 2 and 3 benefits, which may include actions of households after flood warning and reductions in emissions and were not quantified due to unavailable data.

PLP involves the installation and deployment of flood resistance measures (retrofitting or by design) to prevent water from entering individual properties and resilience measures to limit the damage caused once it has entered. There is limited information available on examples of PLP being applied in EU MS, but benefits can be substantial given potential increases in property values as well as energy efficiency when substantial PLP measures are implemented. A prospective analysis of PLP was conducted to explore the levels of benefits, but there were great difficulties in quantifying uptake or buy-in of PLP strategies and co-benefits at the individual property level.

- **Case study 8 (new analysis under this project, ex ante/hypothetical):** The analysis of a hypothetical comprehensive PLP program over two towns in Northern Italy based on previous research on PLP cost estimates (ECHO, 2014) yields BCRs of less than 1, lower than examples found in the literature. This can be explained by three factors: (a) the difficulty in estimating a realistic PLP investment in relation to the hazard probability and standard of defence; (b) the transferring of assumptions from different contexts (for example, rural settlements exposed to intense river floods compared to high-density urban areas exposed to moderate pluvial floods); and (c) the uncertainty in risk modelling for specific locations (building level), affecting the scale of risks to be taken into account and thus the scale of costs.

3.1.2. STRUCTURAL PROTECTION AGAINST FLOODS

Risk reduction strategies using structural protection focus on the control of floodwaters that result from intense rainfall and/or overflow of river channels. Most flood risk management involved engineering measures to control flooding, avoiding as much as possible the change of hazard where vulnerable elements are located. These are also known as 'grey' or 'hard' measures and can include both static elements (such as embankments, dams, levees, and channels) and active elements (such as water gates, pumps, and mobile barriers).

The design of protection measures relies on the assessment of risk probabilities to elaborate appropriate protection standards. A design flood is defined by its probability of occurrence, for example, '1 percent annual exceedance probability (AEP) or 1 in 100 return period' defines a flood which has 1 chance in 100 of occurring in any one year. Structural protection measures are designed and built to meet with a certain SoP. It is important to note that protection standards need to be updated over time, in line with the changes in hazard frequency brought by climate change.

Models can account for the risk reduction due to flood protection by explicitly modelling protective structures of by delineating area protected by those structures. Site-specific models built for a particular location can explicitly include the structure in the model and estimate the chance of the protection being overtopped or breached, resulting in a flood. Probabilistic models over a large area tend to assume a level of flood protection in terms of the return period (that is, a defence designed to protect up to a 1-in-50-year event) and floods are assumed to not cause loss below that return period. A hybrid approach - defining the areas protected, as informed by the locations of the protection system, and applying the design level of protection in only those areas - can also be applied and assumes that those protected areas only experience flooding when an event is above the design-level return period. These approaches can be applied to a scenario-based analysis of probabilistic analysis and can simulate the benefit for a single protective structure or commonly a series or combination of multiple structures and types of structure.

RIVER FLOOD PROTECTION: THE MACHLANDAMM, OBERÖSTERREICH, AUSTRIA

This case study is a new ex-post analysis under this project that involved modelling of hazards.

→ Description

The Machlandamm is Central Europe's largest flood control protection project and the largest one in the history of the Oberösterreich region. Construction began in 2008 and was completed in 2012. It consists of about 30 km of earth dams, 4 km of mobile flood protection elements, and a few hundred meters of flood protection walls, in addition to pumping stations, gate valves, and an 8.4 km flood basin running parallel to the Danube River (Heidrich, 2016). The project includes eight project units on the left bank of the Danube and protects seven municipalities (Ecker & Hrebik, 2012). Each unit is protected by earthen dams with an SoP of 1-in-100-year return period, except for one area with 1-in-30-year SoP (Weingraber, 2020), as indicated in *Figure 8*. The dam has been designed with spillways such that they cannot protect against larger floods; else the flood risk of other communities would be increased. The total cost of the project was €182.6 million (€150,000 per house protected) (GOV/PGC/HLRF, 2015). The project was supported financially by the Oberösterreich region and by other institutions. In 2013, a severe flood hit the region (IBS, 2013), but available estimates of impact are subject to significant uncertainties about what they include and are only available at much broader geographic scales than this case study's domain. Therefore, we estimate damage to the case study areas using a proprietary flood model.

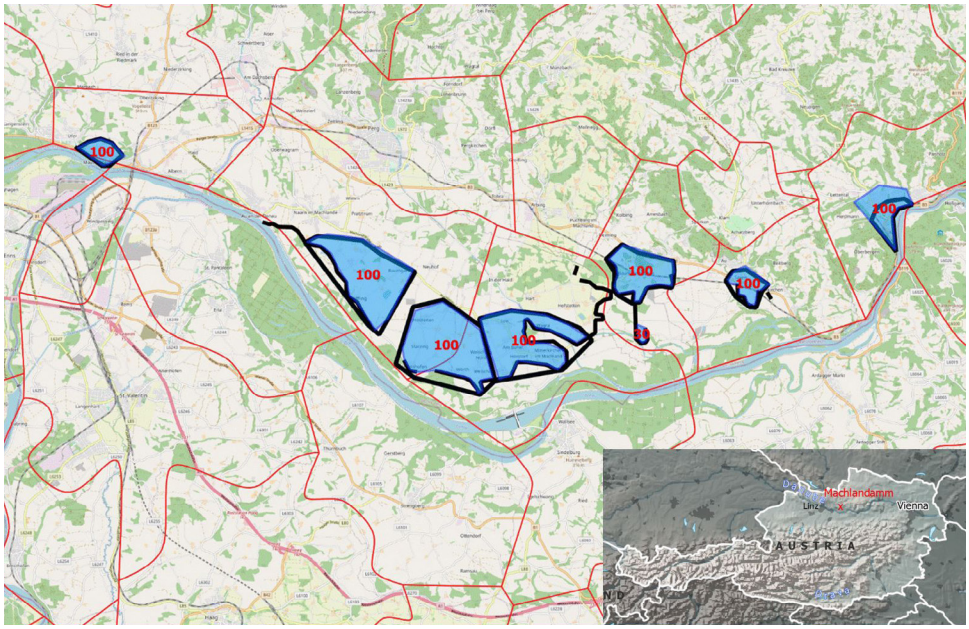
→ Methodology

Dividend 1 (avoided fatalities and economic damage) is estimated by applying the JBA probabilistic global flood model to estimate the frequency and severity of river flooding on the relevant section of the Danube without and with the effect of flood protection by the Machlandamm. The simulated difference in number of buildings flooded and resulting economic damage, represented as AAL and return period losses, is the expected benefit of protection. The analysis uses exposure data.

The analysis of this case study uses a methodology and data consistent with the accompanying EU regional flood analysis. The exposure data applied are a disaggregated version of residential buildings data developed under the SERA project (Crowley, et al., 2020). The communities in the study area are largely residential buildings; damage to these buildings is modelled with a residential property and contents vulnerability curve developed by JBA. The accompanying project report on Component 2 (regional analysis) contains more details on all aspects of the risk analysis method.

Flood protection is accounted for in the model by identifying the communities protected by the protective structure in each of the eight project units (*Figure 8*). Only the effect of the earth dam is included; no demountable barrier defences have been modelled due to a lack of information on their operation and location. Where the return period of a simulated flood event in the model is below the SoP, the defence is modelled as being fully effective and no flooding occurs in the delineated area (JBA Risk Management , 2021). Where the severity of a simulated flood event exceeds the capacity of the defence, a defence overtopping calculation is applied to reduce the impact of the flooding based on the volume of water overtopping the defence. The change in flood return period is applied to all exposure points located within a defended area, thus reducing the risk estimate (AAL) and return period losses in that area.

Figure 8: Location of case study and areas estimated to be protected by each project unit of the Machlandamm, with SoP denoted for each unit



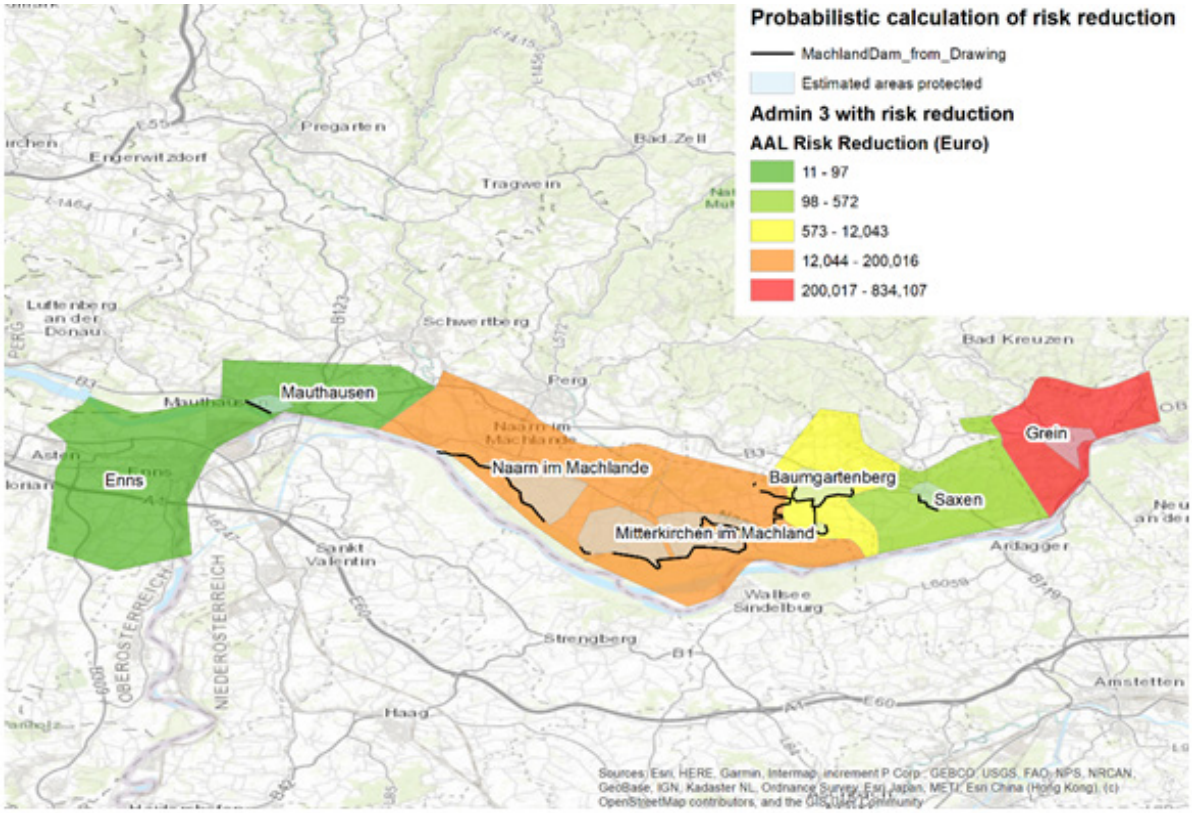
Source: World Bank analysis; elaboration based on information from interview and reports

In attempting to quantify the effects of protection on Dividends 2 and 3 of the Triple Dividend Framework, we encountered an absence of data. This prevented the quantification of some potential benefits, which for an investment of this size would be expected to include stimulus of the local or regional economy due to the construction project, and change in land value or property prices due to enhanced flood protection. In Oberösterreich there is a law prohibiting new development in high-risk flood zones, so we assume no broad change in land value due to new development potential (since none can be constructed). However, property values and domestic land value could be expected to increase due to higher level of flood protection afforded by the dam. No analysis on this aspect had been previously conducted for the Machlandamm and the age of the project prevented thorough analysis of these aspects here.

→ **Results of the analysis, by dividends and overall**

The analysis showed variable influence of the protective structures on reducing risk in the protected communities. *Figure 9* shows the estimated risk reduction (AAL in euros) per level 3 administrative unit, with Grein showing the greatest potential reduction. The risk reduction is a factor of flood inundation with and without the protection and the concentration and value of exposure within the protected area. The overall reduction in risk to residential properties due to Machlandamm protection is 12 percent compared to the undefended scenario.

Figure 9: Simulated reduction in risk per level 3 Administrative unit (AAL) due to protection by the Machlandamm flood protection



Source: World Bank analysis; elaboration based on the results from the analysis

Table 3: Risk reduction represented by change in AAL due to the Machlandamm flood protection at key settlements in the case study area

ADM2	ADM3	BASELINE LOSS	DEFENDED LOSS	REDUCTION %
Perg	Baumgartenberg	100,244	88,201	–12
Perg	Saxen	355,017	354,445	–0
Perg	Naarn im Machlande	1,385,847	1,185,831	–14
Perg	Mitterkirchen im Machland	799,441	619,618	–22
Perg	Mauthausen	1,757,207	1,757,110	–0
LinzLand	Enns	4,707,258	4,707,247	–0
Amstetten	Grein	891,294	57,187	–94
Total		9,996,308	8,769,639	–12
Risk reduction (reduction in AAL)			–1,226,669	

Source: World Bank analysis; based on external data and information

Table 4: BCR for Machlandamm per dividend, assuming a 30-year period of operation

	BENEFITS (€, MILLIONS)	COSTS (€, MILLIONS)
Dividend 1	36.8	
Dividend 2	Not quantified	
Dividend 3	Not quantified	
Total	36.8	182.6
BCR = 0.2		

Source: World Bank analysis; based on external data and information

Table 5: Detailed breakdown of benefits for Machlanddamm by dividend

FIRST DIVIDEND	BENEFIT/COST
Lives saved	Not quantified (no evidence of fatalities without the protection)
Injuries avoided	Not quantified (as above)
Property damage avoided (reduction in AAL for each year of 30 years of the assumed operation period)	€36.8 M
Total first dividend	€36.8 M
SECOND DIVIDEND	
Change in property value	€0
Value added to broader economy from construction sector	Not quantified (lack of available evidence)
Total second dividend	*€0*
THIRD DIVIDEND	
Transportation uses	Not quantified (lack of available evidence)
Total third dividend	n.a.
Cost of construction	€182.6 M
Second cost item	
Maintenance costs	Not known
TOTAL DIVIDEND	€36.8 M
BCR	0.2
NPV	–€145.8 M
IRR/ERR	–79.85%

Source: World Bank analysis; based on external data and information

→ Challenges faced and lessons learned

This case study demonstrates that the impact of some structural protection infrastructure can be simulated with relatively little detailed information on the structure. No official data were available to describe the location, length or height of the earth dam or delineate the areas protected. Publicly available satellite imagery was used to digitize the dam position in GIS software and to estimate the areas protected by each section of the dam. Official information describing the prescribed level of protection was then sufficient to estimate the frequency of flooding, up to which the dam is effective. However, uncertainty around the protected area and protected number of houses may underestimate the overall reduction in AAL.

The case study also demonstrates the need to assess prospective large risk reduction investments according to the Triple Dividend of Resilience Framework in the project appraisal stage. Despite the size of investment and potential benefits under dividends 2 and 3, there was little information available so long after the investment was implemented, with which to confirm or quantify those benefits, including after extensive consultations and additional research.[4] The main challenge for analysing this case study was the lack of information on the co-benefits of the dam construction, primarily benefits to the construction sector and impact of increased flood protection on property values in the protected areas. This has hampered the full evaluation of such a significant investment and potentially underestimates the BCR. With more comprehensive analysis, a possible distributional effect is that this structure can prevent risk or harm to those who are near rivers, including people with low incomes or who are homeless. Moreover, it is uncertain who benefits from the increased job opportunities in the locality since large construction firms normally have their own workers who may not be locally hired. In addition, if there are any locally hired workers involved in dam construction, it is uncertain where they find their next employment once the dam construction has been completed. Consequently, local realization of economic benefits becomes difficult to quantify.

In fact, other studies have found positive net benefits of investments through ex ante economic analysis as well as ex post when considering increases in property values in upgraded areas, among others. Analysis has been undertaken for a major infrastructural investment in Poland in the Odra river basin. Moreover, other analysis showed some of the challenges for large-scale structural protection programs in terms of costs incurred as well as interesting solutions that can support better decision-making, development, and implementation of these projects to achieve higher net benefits. These include risk-based prioritization of investments such as strengthening road infrastructure, soft measures enhancing capacity, management of water resources and participatory decision making. Examples are projects implemented in Serbia, the Netherlands, Bulgaria, Greece and Malta that provided some useful lessons learned.

Possible avenues for further research could be considered. Considering some of the factors below could potentially be expected to increase the assessed net benefits of this investment:

- Benefits of reduced stress (mental health)
- Reduction of traffic and economic activity disruption
- Property value increases linked to the enhanced liveability of the area

RIVER FLOOD PROTECTION ON THE ODRA RIVER BASIN, POLAND

→ Description of the case study

Major infrastructural investments in a dam and improved conductivity of Odra river (World Bank, 2007) in the area of Wroclaw, Poland, were undertaken in a World Bank project in 2006, which included a prospective economic analysis for Wroclaw. The economic analyses comprised a comparison between the incremental capital and operating costs of the project scenarios with the incremental economic benefits resulting from their implementation. The parameters for the economic evaluation include a 30-year period of operation and a 90 percent economic conversion factor. The economic analysis considered

4 For example, information about prices would have been costly to retrieve as the extraction is complex and therefore undertaken by private companies.

both tangible and intangible benefits, making the methodology closer to the triple dividend approach.

→ Methodology

The BCA of this project estimated annual average damages with and without flood protection, considering multiple flood probabilities and severity. Avoided damages, that is, the difference between damages with and without the project, were the main benefits considered with the specific components of: property and contents flood damage; damage to public infrastructure and facilities; agricultural production losses; damage to trees; and damage to environment, land and livestock. Secondary benefits included the benefits from the exploitation of gravel in the Raciborz reservoir area. While many intangible benefits were considered in the project appraisal, the ERR was based on these quantified primary and secondary benefits.

→ Results of the analysis by Dividends and overall

The estimated ERR for the project was 17.4 percent. That is, the Polish economy would realize a 17.4 percent rate of return from implementing the project. This is above the 10 percent opportunity cost of capital (OCC); before the 2008 financial crisis 10 percent was a threshold above which projects were considered worthwhile (today this threshold is lower).

Total direct flood damage was estimated €4.01 billion (PLN 12.035 billion), and intangible damages at €0.5 billion (PLN 1.965 billion), with the project projected to reduce damages to 72 percent of these estimates (€2,166.3 billion and €353.7 billion, or PLN 8665.2 billion and PLN 1414.8 billion, respectively). In addition, the project was expected to generate €5 million (PLN 20 million) equivalent annual extraction of gravel from the Raciborz reservoir area. Gravel stock can last for a total duration of 20 years. At a discount rate of 3.5 percent, present value of this 20-year stream of future incomes is calculated at €73.55 million (PLN 294.2 million).

The following tables list these benefits according to the triple dividend framework and results from analysis (*Table 6* and *Table 7*). Reduction in the direct flood damages forms the first dividend, economic benefits of the project are included as the second dividend, and finally the intangible benefits are included as the third dividend.

Table 6: BCR for river flood protection for Poland's Odra river basin per dividend (all values in 2006 Euro values at the exchange rate of 1€ = 4 PLN).

BCR: 5.14		
	BENEFITS	COSTS
Dividend 1	2.17 B	
Dividend 2	73.6 M	
Dividend 3	353.7 M	
Total	2.59 B	505 M

Source: World Bank compilation based on extracted data from the World Bank documents

Table 7: Detailed breakdown of Odra River benefits by dividend

FIRST DIVIDEND	BENEFIT / COST
Lives saved	Not quantified (no evidence of fatalities without the protection)
Injuries avoided	Not quantified (as above)
Avoided direct damages	€2.17 B
Total first dividend	€2.17 B

SECOND DIVIDEND	
Change in property value, productivity, capital investment	Not quantified
Value added to broader economy from construction sector	Not quantified
Present value of all future gravel production, assuming duration of 20 years and discount rate 3.5% (EURO)	€73.6 M
Total second dividend	€73.6 M
THIRD DIVIDEND	
Transportation Uses, agricultural productivity, ecosystem benefits	Not quantified
Reduction in intangible losses due to project (reduced stress, alcoholism, suicide rates, fear of floods, loss of control over situation, loss of memorabilia, and health problems)	€353.7 M
Total third dividend	€353.7 M
First cost item	
Cost of construction	€505 M
Second cost item	
Maintenance costs	Not quantified
TOTAL DIVIDEND	€2.59 B
Total cost	€505 M
COST-BENEFIT RATIO (RATIO)	5.14
NPV	€2.1 B
IRR/ERR (%)	80.53

Source: World Bank analysis; based on results from World Bank Odra River PAD

→ Challenges faced and lessons learned

In addition to quantifying many tangible benefits, this appraisal used robust methods to quantify many intangible benefits with considerable longer-term impacts. This includes increasing stress, fear of further floods, loss of control over the situation, loss of memorabilia and health problems. Inclusion of these additional benefits is important to justify the overall economic viability of the project. However, several potential benefits and costs have not been quantified, which would likely adjust the BCR presented above from the project documents. A distributional impact that we should be wary of is the ability for this development to displace local residents who may no longer be able to afford living in the area. An increase in property value could lead to real estate price increases, and this may catalyse gentrification in the area.

ADDITIONAL EXAMPLES OF STRUCTURAL PROTECTION INVESTMENTS AGAINST FLOOD RISK

Several additional investments in structural flood protection were found that could provide lessons learned and inspirations. These investments cover technical solutions such as barriers (dams, sluices and dykes) and reclaiming land from the sea in the Netherlands; enhanced capacity for response across borders of Bulgaria and Greece; construction of a network of storm water management infrastructure in Malta; and building of flood prevention structures in Greece. Highlights and main lessons learned of these investments are presented in *Box 1* below.

Box 1: Overview of other investments in structural flood protection across Europe

A review of investments in structural flood protection across Europe provided several lessons learned and inspiring achievements outlined below. A common theme is that a combination of structural protection and soft factors such as improvements of water management or support of citizen engagement in the design and evaluation of programs contributed to the success and net positive benefits of the projects.

A large-scale program implemented in the Netherlands showcases some of the challenges faced with massive projects in terms of costs, but also solutions that can be found in collaboration with civil society. The battle of the Dutch in reclaiming land from the sea provides one of the most ambitious and successful examples of flood protection engineering. The Zuiderzee Works and the Delta Works are two massive flood protection works, which required consistent public investments (6–7 percent of Dutch annual GDP at that time) and were a challenge for political decision-making. After a storm in 1953 where 1836 people lost their lives, a large-scale project ("Delta works") was implemented that consisted of a series of dams, sluices and dike reinforcement that was completed 1958-1997, including the Maeslant storm surge barrier in the port of Rotterdam (Bos & Zwaneveld, 2017). Overall costs for the Delta works were €5 billion and €450 million for the Maeslant barrier (Dutch Water Management, 2020)(Maeslantkering). This compares to around €5.5 billion investments for the Venice lagoon barrier (see *Table 8* below that shows the cost of eight different storm surge barriers built in Europe since 1958). The final design of the Maeslant barrier was selected based on a cost-effectiveness analysis and standards for flood protection according to land use and assets (Kind, 2014). The ex-ante cost-effectiveness analysis showed that the solution was best compared to alternatives such as raising dikes in the whole area of Dordrecht, representing savings of around 200 million EUR.

A cross-border program in a common area of Bulgaria and Greece has achieved successes in terms of reducing negative impacts of floods (Interreg Greece-Bulgaria, 2021). The cross-border area of Greece and Bulgaria, especially the areas across the two international river basins of Struma/Strymon and Evros/Maritsa, is highly vulnerable to floods. "Cross Border Planning and Infrastructure Measures for Flood Protection" is an EU-financed €11.5 million (€9.8 million ERDF-funded) INTERREG project implemented from 2017 to 2020 that protects the area from floods. The main objective of the project is to reduce the risk of floods by improving existing flood protection infrastructure along the river flow and reducing obstructions in the narrow areas of the river basin. It also invests in early response equipment, which can reduce negative social and economic impacts on the surrounding area and raise public awareness. The project is expected to reduce flood risk for residents and increase safety for business owners to locate and operate in this area.

A flash floods resilience project in Malta has achieved some benefits in terms of protecting residents. Between September and January in Malta, severe flash floods occur frequently resulting in economic loss and disruption. The €62.5 million (€44.9 million EU-funded) project "National Flood Relief Project" supported by EU funds 2007-2013 aimed to build an effective storm water management system through the construction of a network of underground tunnels, canals and bridges (European Commission, 2013a). The project aimed for Malta to meet the requirements of the European Floods Directive, while helping to reduce the negative impacts of flood on human health, the environment, cultural heritage and economic activity, and improve sustainability by reusing storm water from both urban and rural areas. The project was expected to benefit an estimation of 165,000 Maltese residents directly and indirectly. Subsequent EU funding (€54 million 2013-2015) under the second River Basin Management Plan of the country supported continued works on the storm water management system and the collection and reuse of rainwater via reservoirs (European Commission, 2019). As water management systems and impacts from floods are still massively impacting the country and criticisms were made for the effectiveness of the programs implemented, the Energy and Water Agency of Malta undertook extensive consultations and developed a menu of measures for the third RBMP (The Energy and Water Agency, 2020) comprehensively addressing the water sector and its management.

In Athens, Greece, flood protection has been combined with efforts to enhance the liveability of the city while promoting economic activity (European Commission, 2013b; EPRS, 2020). The most damaging recent floods in Greece, in 1994 and in 2003, caused over €623 Million (US$700, 1994 ROE) and €707 Million (US$800, 2003 ROE) of damage, respectively. The €84 million project "Stopping Athens floods" (€71.4 million funded by the EU) 2007-2013 was launched to reduce the impacts of flood while encouraging employment and city rejuvenation. The project invested in new flood prevention structures, which was aimed to protect about 116,000 residents flood. In addition, the implementation of the project itself was expected to create 712 jobs and thus generate co-benefits for Greece's economy. Moreover, recent continued investments in the region of Attica north of Athens included ambitious aims to enhance the flood prevention network across municipalities where over 500,000 people live and commute every day combined with a €150 million loan from the EIB for disaster risk prevention and climate change adaptation programs

across Greece (The National Herald, 2019). Given general challenges of procurement, land management and planning of such complex investments, the project was selected by Transparency International Greece and the European Commission to be part of an Integrity Pact to monitor specific commitments connected to procurement (Transparency International EU, 2017). Moreover, a Horizon 2020 program supported the engagement of citizens in environmental monitoring, particularly flood and water management issues (Alice Accelerate Innovation, 2018).

Table 8: Comparison of costs for major investment projects in storm surge barriers in Europe

NAME	TYPE	LOCATION	COST (M €)
Maeslant barrier	Sector gate – y axis	Hoek van Holland (NL)	450
Hollandse IJssel barrier	Vertical lift gate	Capelle aan den IJssel (NL)	20
Eastern Scheldt barrier	Vertical lift gate	Vrouwenpolder (NL)	2400
Haringvliet sluices	Sector gate – x axis	Hellevoetsluis (NL)	600
Ramspol barrier	Inflatable tube	Kampen (NL)	48
Hartel barrier	Vertical lift gate	Spijkenisse (NL)	98
Venice barrier	Flap gate	Venice (IT)	5500
Thames barrier	Rotary segment and gate (x axis)	London (UK)	600

Source: Noguiera & Walvaren (2018)

The structural flood protection projects described above focus on protecting multiple properties/infrastructure and areas of land from a source of flood hazard. This can explain the somewhat broad estimated number of beneficiaries and is related to substantial potential benefits but also costs.

Structural protection may also be implemented for asset-specific protection, such as sections of road or railway including bridges and tunnels, to improve the resilience of the transport infrastructure. A method used to prioritize the protection of transport infrastructure is criticality assessment. Modelling multiple individual segments as inactive (representing a damaged or blocked segment), the impact on disruption across the network can be measured to assess the criticality of each segment and to measure overall redundancy in the transport network. Analysis of the vulnerability of segments against risk of damage should enable a prioritization of DRM interventions including protective structures and inform BCA or cost-effectiveness analysis of the potential interventions. *Box 2* below outlines a few examples of projects implemented for protecting specific assets mainly in the transport sector.

Box 2: Structural protection for specific assets in the transport sector

Two projects have showcased theoretically and in practice the application of cost-effectiveness analysis for the prioritization of targeted structural protection interventions. Undertaken by the World Bank, a modelling exercise ranked roads in different countries including Serbia according to their criticality (Vukanovic, 2018; Rozenberg, et al., 2019). The criticality was assessed based on vulnerability (therefore priority for intervention) and the cost-effectiveness of interventions based on the impact costs avoided and implementation costs. Though based on limited information, the model undertook an economic analysis that examined the cost-effectiveness of the roads, which can help to inform more proactive and resilient investments in Serbia.

The CFR-SA railway project at Simeria, Romania, is one EC-funded project that focused on specific assets. Costing €2 billion and financed through the Large Infrastructure Operational Programme (LIOP) 2014-2020, the project comprises rehabilitation and modernization works to develop a high-speed rail link at the town and railway junction of Simeria. Crucially, the project considered climate change adaptations and protection of the rail and bridge infrastructure due to extreme flows and extreme storms. It also developed structures to protect the infrastructure from rockfalls (European Commission, 2018).

3.1.3. NATURE-BASED SOLUTIONS FOR FLOOD PROTECTION

The concept of 'nature-based solutions', 'ecosystem-based adaptation', 'eco-DRR', or 'green infrastructure' has emerged as a good alternative or complement to traditional engineering approaches. NBS make use of natural processes and ecosystem services for functional purposes, such as decreasing flood risk. These interventions can be implemented alone or in combination with "hard" engineering approaches (grey infrastructure). They can help mitigate flood and decrease vulnerability to climate change while also creating multiple other benefits to the environment and local communities. These include sustaining livelihoods, improving food production and in turn food security, sequestering carbon, and providing recreation.[5] Such solutions can be applied to river basins (for example, reforestation and natural flood control areas), coastal zones (dunes and wetlands), and cities (urban parks).

NBS for risk management were supported by the EU agenda first by FP7 projects and more recently by the H2020 programme and several Interreg projects, aimed at providing evidence of NBS cost-effectiveness, covering risk reduction benefits as well as social and environmental effects. As with conventional engineering solutions, the effective application of NBS requires a comprehensive risk assessment comparing the risk under baseline and defended scenario.

Although traditional risk assessment methods can be applied to evaluate NBS, they hardly incorporate the full range of benefits generated by nature-based projects (European Union, 2019). NBS are emerging approaches that still need to develop standards and guidance to facilitate a common understanding of their effectiveness and the risk reduction outcomes. It is also difficult to apply the concept of 'protection standard' to NBS, because they do not protect from flooding to a particular level, yet they can reduce flood risk potential to a large degree. The EEA (2017) analysed the cost-effectiveness of green and grey infrastructure investments for flood protection in Germany, finding that the green measures can be superior to grey solutions and cost-efficient even when their indirect benefits were not considered.

While green infrastructure can take various forms and, in principle, can be applied to address fluvial, pluvial, and coastal flood in isolation or in combination, the local environment and risk context dictates which solutions are applicable. For instance, floodplain restoration can only occur where there is a fluvial floodplain, not in steep-sided catchments, and dune restoration/stabilization is only possible in coastal areas with sand dunes. The following sections all present short examples of NBS risk-reduction initiatives. Due to the multi-faceted approaches typical of NBS, some components of these cases are applicable to more than a single section, but they are broadly presented here according to their primary focus. Smart green solutions can be particularly important in urban contexts, as shown for investments in Spain, the UK or Sweden to reduce flood risks and maximize co-benefits.

3.1.3.1. Natural floodplain management

This section highlights cases which aim to improve the condition of the floodplain to enhance ecosystem services and reduce flood risk by increasing capacity of the floodplain or wetland areas to retain runoff and reduce peak flows in the river. We present BCA performed in NFM projects in the catchment of Eddleston Water, Scotland, which demonstrate the myriad ecosystem services benefits of NBS. Further examples such as a comparison of green versus grey versus hybrid solutions for flood protection on the Elbe River, Germany, and other investments from England and the Netherlands.

5 For ecosystem services associated with floodplains, see EEA (2019)

INTERREG PROJECT EDDLESTON WATER (SCOTLAND)

This case study is an external analysis that was undertaken with ex-ante and ex-post analysis that involved partially modelling of hazards.

→ Description

The Eddleston Water project, ongoing since 2009, aims to reduce flood risk and restore the Eddleston Water for the benefit of the local community and wildlife. It is funded by the Scottish government, Interreg, and the SEPA. The project involves river re-meandering, the planting of over 200,000 trees and the creation of new wetlands within the catchment (70 km2). This should slow the speed and impact of floodwaters affecting the village of Eddleston (population 550) and town of Peebles (about 8,400) as well as creating new wildlife habitat, such as improved spawning for salmon. The project partnership, led by the Tweed Forum, is closely monitoring the project results, including any reduction in flood risk for downstream communities. The study was undertaken by the project consortium (see below) rather than in this project; it is included here as it is a rare case that demonstrates the high level of detail considered in a study of costs and benefits of NBS over several years.

→ Methodology

Spray (2016) analysed the Eddleston project including flood regulation to assess wider ecosystem benefits as well as costs of afforestation and riparian woodland planting. By far the greatest benefit of afforestation was in climate regulation—using a value transfer approach this yielded up to four times the cost of afforestation. Flood regulation in the catchment contributed a minor proportion of the benefits, as did biodiversity, education, aesthetics, water quality, and recreation.

Another study (MacDonald, 2020) of this catchment tested the application of combining avoided damages and natural capital in an economic appraisal of options, using the B£ST model (Horton, et al., 2019), which was selected after a review of available models in the same study. This study uses a slightly different benefit estimation framework and returns different results compared to the previous BCA. It considers the results from previous reports and adds the actual outturn cost data for the implementation of NFM in the Eddleston catchment. Benefits in terms of avoided flood damage are compared for the NFM already implemented (Tweed Forum, 2020) additional NFM investment (increasing the area changed from improved grassland to native woodland and wet reed beds, and increasing the number of flow restrictors and ponds), and traditional in-town engineered flood defences (Burgess-Gamble, et al., 2018) and PLP. In addition, it estimates the impact of a range of hybrid options. Four options for in-town defences and three sub-options for different levels of NFM were tested; for clarity here the report presents only two options: current NFM measures and the application of two different in-town standards of protection. The report used updated definition of costs and took flood and ES benefits from analysis. The breadth of components included in the study was made possible by the availability of GIS data on the location and characteristics of the different interventions, project reporting of cost data, detailed simulation of avoided damages from traditional structural protection in the settlements and for NFM measures. The reduction in flood peak by slowing the catchment response is demonstrated, although it is noted that the potential impacts of climate change by 2050 would more than counteract the considerable improvement.

→ Results of the analysis, by dividends and overall

The impact of re-meandering, creation of ponds, introduction of woody flow restrictors and forest planting each have shown flood reduction and ecological benefits, according to the SEPA study. The study focused on the benefits delivered from planting riparian woodland, which returns a positive NPV and average BCR of 12.5 across low, central and high scenarios (*Table 9*) - primarily from improvements to ecosystems in this catchment, with benefits of flood regulation in Eddleston village still positive under most current floods and under all climate scenarios. Benefit transfer values for ecosystem studies were applied from other studies.

Table 9: Estimated costs and benefits from the first economic appraisal of Eddleston Water NFM (lower and upper bound results in parenthesis)

ALL VALUES GIVEN IN 2012 THOUSAND EURO PER YEAR	2016	2040	2080
Total cost	7.81 (6.36 –9)	7.81 (6.36 –9)	7.81 (6.36 –9)
Total benefits (flood reduction and ecosystem benefits)	110.37 (60.94–157.96)	106.9 (58.32–156.35)	106.82 (58.03–158.15)
Net benefits (total benefits minus total cost)	102.56 (54.58–148.94)	99.1 (51.96–147.32)	99.01 (51.66–149.13)
BCR	14.1 (9.6–17.5)	13.7 (9.2–17.3)	13.7 (9.1–17.5)

Source: Spray (2016); Original values in pound converted using 2012 currency rate £1 =€1.26

According to the analysis, the total NPV of ecosystem benefits scaled over 100 years was reported at €1.25 million (with lower and upper bounds of €1 million and €1.3 million). This is additional to the benefit of avoided property damages of €680,000. The summary of total costs and benefits in the Triple Dividend Framework, based on central estimates for a 30-year timescale (and accounting only for the contribution of NFM not associated activities), the triple dividend BCR is presented in *Table 11*. The original project reports provide longer timescales and value ranges. The reduction in property damage in Eddleston and Peebles is shown in *Table 10*, with the annual reduction in damage estimated at €35,473, equating to the NPV of €680,000 over 30 years.[6]

Table 10: Impact of NFM measures in the Eddleston Water catchment, on property damage in Eddleston village and Peebles town

RETURN PERIOD	PRE-NFM DAMAGES	POST-NFM DAMAGES	AVOIDED DAMAGE	PRE-NFM NO. OF HOUSES AFFECTED	POST-NFM NO. OF HOUSES AFFECTED	SPARED HOUSES
	(€, thousands)					
AAL	1.05	1.01	35	n.a.	n.a.	n.a.
10	2.96	2.88	87	75	73	2
50	3.4	3.2	207	98	86	12
100	3.7	3.48	228	109	100	9
200	4.06	3.79	267	115	109	6

Note: MacDonald (2020); Original values in pound converted using 2020 currency rate £1 = €1.12.

The Mott Macdonald study assessed 12 options for managing flood risk in Eddleston Water catchment to assess value for money and BCR of each – this is a combination of retrospective and prospective analysis using the B£ST model. A matrix of costs and benefits was created showing the variation in BCR of three NFM options (no catchment NFM versus NFM already implemented versus additional NFM) and four in-town protection options (legal minimum versus defences with 75-year return period SoP versus defences with 200–year return period SoP versus PLP) over an appraisal period of 100 years. The flood damages avoided and ecosystem benefits of NFM already implemented and additional NFM are shown in *Table 12*.

Comparing the in-town defence options also showed the various BCRs of changing the SoP of defences, and

6 Converted from Pounds using £1 = €1.12 (2020).

applying PLP. The baseline of NFM and no change to in-town defences yielded damages avoided of €1,064,000 at a BCR of 0.45, when ecosystem services are not considered. The addition of 75-year SoP defences increased the damages avoided to €5,497,000, 200-year SoP defences to €6,485,000 and PLP to €6,124,000. However, the BCR remained at 0.48 for 75-year defences, 0.45 for 200-year SoP defences, and only increased significantly for PLP, returning a BCR of 1.34. Corresponding estimates were also developed in that study for a case with no NFM, and with the additional NFM options.

Table 11: Estimated benefits and costs for INTERREG project in Eddleston, Scotland per dividend, based on a 30-year timescale

(€, THOUSANDS AT PRESENT VALUE)	
FIRST DIVIDEND	
Property damage avoided	680
Total first dividend	680
SECOND DIVIDEND	
Total second dividend	0
THIRD DIVIDEND	
Recreational benefits	391.2
Carbon benefits	897.9
Non-use biodiversity benefits	71.7
Benefits to anglers (NFM contribution), assuming ecological condition change 'bad' to 'moderate' (change to 'good' may result in three times this value)	45.7
Ecological status change (NFM contribution; 'bad' to 'moderate' (change to 'good' may result in two to four times this value)	0.7–1.9
Timber	452.8
Agricultural income foregone (lost income)	–340.5
Health benefits	95.1
Education	160
Total third dividend (central estimate, for NFM contribution only)	1,253.3
Costs - NFM	
Enabling costs	779
Capital costs	1,072
Operation and maintenance costs	831
Other costs	13
TOTAL DIVIDEND	
Total benefits	1,933.3
Total cost	2,694
BCR	0.7
IRR/ERR (%)	–39.35

Source: World Bank compilation; based on extracted data from the sources mentioned above; Original values in pounds and converted using 2020 currency rate £1 = €1.12.

Table 12: Estimated benefits and costs for INTERREG project in Eddleston, Scotland per dividend, based on a 100-year timescale

	NFM ALREADY IMPLEMENTED (€, THOUSANDS AT PRESENT VALUE)	ADDITIONAL NFM (€, THOUSANDS AT PRESENT VALUE)
FIRST DIVIDEND		
Property damage avoided	1.1	3.2
Total first dividend	1.1	3.2
SECOND DIVIDEND		
Total second dividend	0	0
THIRD DIVIDEND		
Amenity		
Carbon benefits	1.67	8.65
Non-use biodiversity benefits	0.8	5.44
Education	0.7	5.15
Flows in watercourse	0.43	0.43
Water quality and pollution	0.41	3
Agricultural income foregone (lost income)	Not assessed	Not assessed
Timber production	Not assessed	Not assessed
Total third dividend (central estimate, for NFM contribution only)	4.7	19.78
Costs - NFM		
Total cost	2.34	13.46
TOTAL DIVIDEND		
Total benefits	5.77	22.97
Total cost	2.34	13.46
BCR	2.42	1.71
NPV	3.38	9.51
IRR/ERR (%)	58.62%	41.41%

Source: Macdonald (2020) assessment of current NFM measures and prospective analysis of additional measures; original values in pounds and converted using 2020 currency rate £1 = €1.12

→ Challenges faced and lessons learned

This case study demonstrates the value in undertaking a multi-year study of benefits from flood interventions, being able to incorporate ecosystem benefits that are realized over time. This particularly concerns ecological responses to modifying the channel and habitat (Spray, 2016), which can result in multiple ecosystem services benefits from water quality to amenity value. It also demonstrates the different BCRs that are possible when ecosystem services are valued differently, or different services are included (here differences include addition/omission of amenity, timber, and agricultural production foregone). Potential distributional effects could include maintaining the area's biodiversity, preventing damage and injury to households living along the river, and ensuring that the river continues to be a source for clean water for the rest of the community.

Other studies have shown the comparative benefits of NFM. Green infrastructure solutions appear to have the highest net benefits and be most cost-efficient when these are compared to structural protection

measures such as on the Elbe River in Germany, even without consideration of indirect benefits. Moreover, indirect benefits can be substantial, as shown in the Chimney Meadows or other case studies in the United Kingdom and the Netherlands. It would therefore be interesting to undertake more such multiyear case studies with high-quality, site-specific information, to compare various infrastructure solutions to analyse the advantages of combining grey and green infrastructure.

The various analyses on this NFM project demonstrate the potential range and magnitude of benefits of NFM investments but that prospective appraisals can demonstrate optimal additions to NFM options. Here, with a fourfold increase in benefit but over 5.5 times the original cost, the BCR reduces with the potential addition of NFM measures. The analysis also demonstrated the multidimensional appraisal required to consider the optimal in-town structural defences and optimal level of NFM in the catchment, but note that the negative impact of structural options on some ecosystem services such as amenity benefits are not included here.

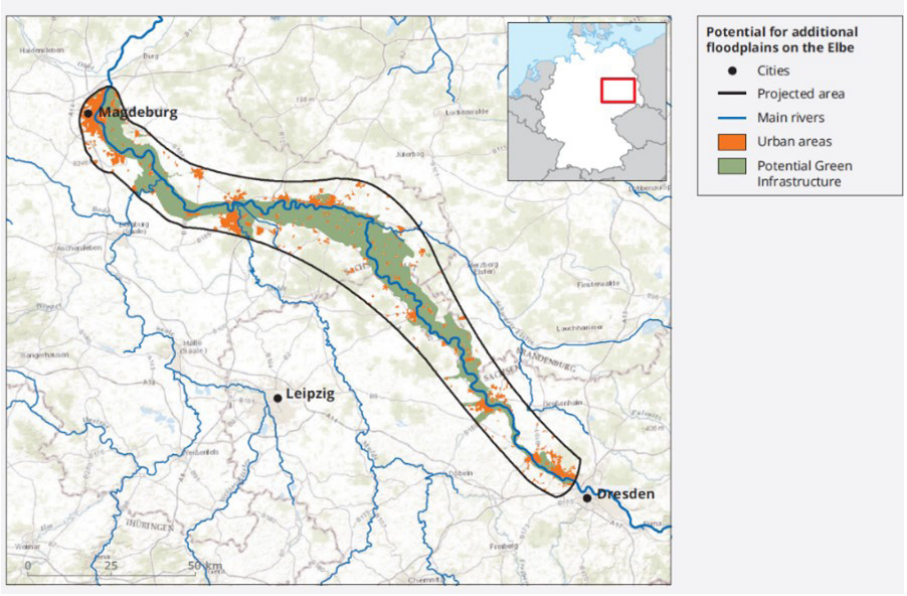
GREEN, HYBRID, AND GREY INFRASTRUCTURE SOLUTIONS ON THE ELBE RIVER, GERMANY

This case study is an external analysis that was undertaken with ex-post analysis. Introduction and background

→ Introduction and background

A high-probability flood scenario in the Mittlere Elbe/Elde region of Germany on the Elbe River would be expected to impact 3,500 residents and four industrial facilities in the region, while an extreme catastrophe would affect 210,000 residents and up to 289 industrial facilities (EEA, 2017). Starting in the Czech Republic, the Elbe is a 1,100 km waterway that crosses 10 states and many important cities in Germany ‚Mittlere Elbe/Elde is in the middle of the Elbe river basin region and is at high risk of flooding. Magdeburg is the most vulnerable region and was frequently hit by floods in 2002, 2003, 2006, and 2013. In order to reduce flood risk for the region, dikes were built in the 19th and 20th centuries, which effectively protect about 85 percent of the floodplains and decrease losses due to flooding. In recent years, proposals that suggest a shift from traditional grey infrastructures to nature-based green measures have been made, as the green measures are expected to be more adaptable to climate changes, support ecosystems and unlock social and environmental benefits beyond flood risk reduction (see *Figure 10*).

Figure 10: Elbe River basin districts and potentials for green infrastructures



Source: EEA (2017)

→ Description

In order to examine the effectiveness and efficiency of grey and green solutions and find the optimal solution, seven approaches are considered, including a green solution, several grey solutions, and a mix of the two (see *Table 13*). The green solution refers to the restoration and preservation of floodplain wetland, while the traditional grey solution aims at the relocation or enclosure of dikes and dam.

Table 13: Green, Grey and Hybrid measures for flood prevention in Elbe, Germany

TYPE	NAME OF MEASURES	SHORT DESCRIPTION
Green	Controlled retention polders with ecological flooding	Restoring a wetland in a floodplain (3.2 K ha) and preserving it. This will increase the area for the river to flood.
Hybrid	Combination of polders with ecological flooding and dike relocation	Restoring a wetland in a floodplain (4.1 K ha), preserve it and relocate a dike (3.4 K ha).
Grey	Large scale dike relocation	Relocate a dike in large parts of the river (35 K ha)
	Small scale dike relocation	Relocate a dike in chosen parts of the river (9.4 K ha)
	Large scale controlled retention polder	Enclose areas (25.6 K ha) with a dike and a dam, flooding during overcharge.
	Small scale controlled retention polder	Enclose areas (3.2 K ha) with a dike and a dam, flooding during overcharge.
	Combination of polders and dike relocation	Enclose an area (4.1 K ha) and relocate a dike (3.4 K ha).

Source: World Bank compilation; based on information extracted from external documents, notably Grossmann & Hartje (2012)

→ Methodology

Grossman & Hartje (2012) calculated the BCA and notably the NPVs of the seven measures and determined the effectiveness of the solutions based on the expected lifetime of a dike of 100 years and a social discount rate of 3 percent. The costs of the measures included construction and maintenance costs as well as the economic losses from activities in agriculture and forestry due to wetland restoration or dike enclosure. The benefits are considered under two scenarios: the first scenario only considers the direct benefit of flood risk reduction, while the second scenario includes indirect benefits from nutrition retention and biodiversity conservation.

→ Results of the analysis by Dividends and overall

The study finds that the green infrastructure solution provides the highest net benefit and is the most cost-efficient measure, even without the consideration of the indirect benefits. The NPV of the green solution is around €108 thousand per ha in the scenario when only taking into consideration flood risk management benefits. If the indirect benefits are included, the number will rise to around €430 thousand per ha, which is significantly higher than the NPVs of the alternative solutions (see *Table 14*). This indicates that green solution yields substantial co-benefits in terms of nutrition and biodiversity preservation.

Table 14: Cost-effectiveness of infrastructure options for the Elbe: NPV of options

		DIRECT EFFECTS	INDIRECT EFFECTS		NPV (IN 2012 PRICES)	
		Flood-risk reduction Benefits [EUR/ha/y]	Nutrient retention	Biodiversity conservation	Only flood risk management — Scenario 1	Integrated floodplain management — Scenario 2
Green	Controlled retention polders with ecologicalFlooding	4.12	+++	+++	108.26	429.75
Hybrid	Combination of polders with ecological flooding and dike relocation	1.83	++	++	43.23	196.34
Grey	Large scale dike relocation	0.165	+	+	-3.71	72.71
	Small scale dike relocation	0.07	+	+	-7.37	155.34
	Large scale controlled retention polder	1.02			13.84	13.84
	Small scale controlled retention polder	4.12			101.99	101.99
	Combination of polders and dike relocation	1.83	+	+	43.23	182.2

Source: Grossmann & Hartje (2012)

→ Challenges faced and lessons learned

This is an example of replacing old flood protection infrastructures. Alternatives considered include both traditional and eco-friendly options, with the green or eco-friendly restoration producing the highest net benefits allowing for environmental/ecological sustainability. While this is not a conventional case of building new flood protection infrastructures, wider range of alternatives made this case study an interesting one for future references – both in the cases of restoration or new constructions.

This study had to use a cost-effectiveness methodology as it was aimed to assess the replacing of traditional protections (that were reducing the flood damages by 85 percent) by green protections, we should only be accounting for environmental/ecological benefits. It could benefit from providing an analysis of different alternatives. By investing in green infrastructure options for integrated floodplain management, the communities near the Elbe can used the saved money to invest in other climate-resilient projects. Moreover, members of local communities will also be able to increase their private allocations on other important things. For example, reduced private burden of flood due to public investment in DRM projects will allow them to invest more on their children's human capital development. Such longer term indirect benefits may be regressive to income, that is, poorer households may benefit more through their increased allocations to daily essentials.

CHIMNEY MEADOWS, OXFORD, ENGLAND, FLOODPLAIN RESTORATION

This case study is an external analysis that was undertaken with ex-post analysis.

→ Description of the case study

The Chimney Meadows case study demonstrates the effect that restoration of floodplains from intensive farmland can have on flood risk. Chimney Meadows is a 260-hectare farm with 50 hectares protected as natural reserve to 2003, and the rest as farmland in intensive management. In 2003 the land was purchased by a wildlife trust, with the goal to covert the agricultural production land into nature reserves so that the entire land is protected. The goal was achieved by extending the area of floodplain hay meadows and reinstating wetland features, which not only protect wading birds, but also reduce the danger of flooding.

→ Methodology

An ecosystem services assessment (Hölzinger & Haysom, 2017) for the site lists benefits as flood protection, food, health (walking), recreation and aesthetics, water quality regulation, and wild species diversity. The assessment considered a business-as-usual scenario (intensive farming continues) and aspirational scenario which comprises the 'reversion of arable land to species-rich grassland, restoration of wet grassland and swamp, extension of woodland and planting and restoration of hedgerows'. Benefits of ecosystem services and costs of site maintenance were quantified as far as possible to a monetary benefit using the benefit transfer approach, over a 30-year timescale and discount rate of 1.5 percent, though limitations on scientific evidence prevented full quantification of all services. Outside of the change in land management, all other conditions are assumed to remain unchanged over the 30-year period.

The assessment report details the approach to quantify each benefit; in summary health benefits are estimated using the WHO Health Economic Assessment Tool (HEAT) for cycling and walking; Global Climate Regulation benefits by estimating the change in greenhouse gas emissions due to land use change; wild species benefits using the WTP method; food production based on agricultural statistics and previous yield records; and flood regulation based on avoided damages.

→ Results of the analysis by Dividends and overall

A BCR greater than 1 was determined under both a business-as-usual scenario (BCR 1.5; total net benefits of €1.7 million) and an aspirational scenario (BCR 4.8; total net benefits of €11.5 million) over a 30-year period *Table 15* below. If we interpreted the results in terms of Triple Dividend, we could notice the following benefits:

- **Dividend 1:** Avoided losses through conversion of agricultural land into wetlands reducing flood potential; the resulting reduction in food production due to land reversion is reflected in the aspirational assessment. Social benefits for flood regulation were estimated under the project to be €3.2 million compared to €1.2 million in the 'business as usual' (BAU) scenario (although food production private value decreased by half).

- **Dividend 2:** The health benefits (walking) as well as recreation & aesthetics have substantial economic benefits in terms of attracting tourism. Recreation & aesthetics alone was estimated to increase from a social value of around €134 thousand to €1.9 million and health (walking) benefits from around €192 thousand to €987 thousand.

- **Dividend 3:** The wild species diversity, water quality regulation and global climate regulation can be considered as co-benefits as they would occur regardless of the disaster occurring (or not influenced by reduced perceptions of risks). The global climate and water quality regulation are major benefits items, as they respectively increase the social value from 0 to €2.8 million and from €15 thousand to €1.5 million. Wild species diversity also increases from €1.9 million to €3.4 million of social value.

- The costs only increase slightly, as the capital and equipment costs are considerably reduced and labour or site management costs increase slightly.

Table 15: Benefits and costs from Chimney Meadows floodplain restoration over a 30 years period (2023-2052) applying a discount rate of 1.5%

	BENEFIT SPLIT (PRIVATE VS SOCIAL)	TOTAL CAPITALISED VALUE	
		BAU -THOUSAND € 2015 (THOUSAND £ 2015)	ASPIRATIONAL (ASP) -THOUSAND € 2015 (THOUSAND £ 2015)
FIRST DIVIDEND			
Flood Regulation	100% social	1.18 (0.84)	3.23 (2.29)
Food	100% private	1.16 (0.82)	0.63 (0.45)
SECOND DIVIDEND			
Global Climate Regulation (only AMB)	100% social		2.84 (2.02)
Health (Walking)	100% social	0.19 (0.14)	0.99 (0.7)
Recreation & Aesthetics	BAU: 47% private, 53% social Aspirational: 1% private, 99% social	0.25 (0.18)	1.94 (1.38)
Water Quality Regulation	100% social	0.015 (0.010)	1,477 (1,049)
Wild Species Diversity	100% social	1.94 (1.38)	3.44 (2.44)
Total Benefits		4.74 (3.37)	14.56 (10.34)
COSTS			
Capital & Equipment	100% private	1.59 (1.13)	1.04 (0.74)
Labour	100% social	1.39 (0.99)	1.54 (1.09)
Site & Livestock Management	100% social	0.097 (0.069)	0.46 (0.32)
TOTAL DIVIDEND			
Total Costs		3.08 (2.19)	3.03 (2.15)
Total Net Benefits		1.67 (1.18)	11.53 (8.18)
BCR		1.5 (RATIO)	4.8 (RATIO)
NPV		1.67 (1.18)	11.53 (8.18)
IRR/ERR		35.10%	79.18%

Source: Hölzinger & Haysom (2017). Original values in GBP shown in brackets, converted using the currency rate 2015: £1 = €1.41

→ Challenges faced and lessons learned

Full valuation of the ecosystem services is presented in the assessment report, but these depend on the site's environment and climate, so while assessments such as this one can be taken as a guide, specific assessments must be conducted for each project. Such a dedicated assessment would require collecting and analysing primary data, which is not possible in this study. Given the opportunity for further analysis, exploring the effects on agricultural supply chains could help to quantify the impact to food supply for the broader community to account for distributional effects.

ADDITIONAL EXAMPLES OF INVESTMENTS IN FLOODPLAIN AND WETLAND RESTORATION FOR FLOOD RISK REDUCTION

Additional investments in floodplain and wetland restoration have been made in Europe, which provide effective ways to reduce flood risk while unlocking ecological and environmental benefits. Such investments include two British flood prevention schemes that created new wetland habitats or natural river systems, a floodplain development and habitat restoration project in the Netherlands, and the establishment of woody barriers and woodlands in Yorkshire, UK. Outcomes and main lessons learned of these investments are presented in *Box 3* below.

Box 3: Additional examples of investments in Floodplain and Wetland restoration

A review of investments in floodplain and wetland restoration across Europe provided inspiring outcomes and lessons learned outlined below. A common theme is that these investments reduce the negative impact of floods and climate change and also generate substantial benefits in terms of ecosystem and biodiversity conservation.

The village of Tattenhall in Yorkshire, UK is a community at flood risk with 14 properties flooded during the 2000 flooding season (JBA, 2013). In this context, the Mill Brook Scheme (RRC, 2013) was established, which aims at reducing flood risk for the village through creation of wetland habitats. When the project was completed in 2016, 1.5ha of reedbed and wet grassland habitats were created, which increase floodwater storage and reduces flood peaks. It is estimated that the project will benefit a main road and 22 properties in terms of flood risk reduction. The benefit of the creation of the habitat outweighs the project's overall cost of €19 thousand, with an outcome Measure of 4a: €21 thousand per ha. (Revell, 2018). In addition, the habitat also generates environmental benefits by reducing agricultural pollution, improving water quality, and enhancing biodiversity and wildlife protection.

As part of the Warrington Flood Risk Management Scheme, the Padgate Brook River Restoration project (McIlwrath, 2018) reduces flood risks through the creation of a natural river system and the restoration of a 5 ha reedbed. Aiming at sustainability and climate change adaptation, the project was completed without using heavy engineering and provides access to a green space. The project was completed in 2015 with a total cost of £0.25 million, and it includes a self-cleansing channel that hugely decreases its maintenance costs. The project is expected to protect 226 properties from flood during its design life of 100 years. At the same time, it also increases water quality and quantity and generates aesthetic value. The benefit-cost ratio for the project is 18.

The floodplain development project of the Ijsselpoort area, Netherlands supported the enhancing of the habitats for species, reduced flood risks and water storage capacity (Natuurmonumenten, 2020). Formed by the upper floodplains of the river Ijssel, the Ijsselpoort area is included in the Natura 2000 network of protected sites due to the presence of large areas of threatened habitats and endangered species. The LIFE Floodplain development project was launched to tackle the negative impacts of climate change on the safety of the river and its surrounding area, including increasing the floodplain water storage capacity to reduce flood risk.

Investment in constructing woody barriers and land management for flood risk reduction in Pickering, Yorkshire, UK, aimed to reduce flood risk for the town. The project (Nisbet, 2018) was established in 2009 by the Forest Research and the Environment Agency with a total funding of €4.5 million. The goal was accomplished through the construction of low-level bunds and woody dams and the planting of 29 ha of riparian and 15 ha of farm woodlands. The project is effective in terms of flood protection as it reduces the chance of flooding in a year from 25 percent to 4 percent for the town of Pickering. During the 2015 Boxing Day storm event, the project protected properties in the local community from being impacted by the flood through a 15-20 percent reduction in the flood peak. At the same time, it also yields benefits in terms of climate and erosion regulation. The benefit-cost ratio for the project ranges from 5.6 (for the woodland measures), 3.8 (for the combination of woodland, moorland and farm measures), to 1.5 (for the combination measures plus the large flood storage bund).

3.1.3.2. Nature-based coastal and tidal protection

Considering sea level rise projections, extreme sea levels in Europe could rise by as much as 1 m or more by the end of this century. According to the last PESETA IV report (Vousdoukas, et al., 2020), around one-third of the EU population lives within 50 km of the coast. In the absence of further investments in coastal adaptation, annual coastal flood losses for the EU and UK are projected to grow from €1.4 billion per year (0.01 percent EU + UK GDP) to €10.9 billion (0.05 percent EU + UK GDP of 2050) and €14.1 billion (0.06 percent GDP) by mid-century for a moderate-mitigation and high-emission scenario, respectively. In the second half of this century, the rise in coastal flood risk further accelerates and by 2100 annual coastal flood losses are projected to reach €110.6 billion (0.24 percent EU + UK GDP in 2100) and €239.4 billion (0.52 percent GDP), respectively. The total number of people exposed to coastal flooding in Europe is projected to rise from €0.1 million to €0.47 million and €0.58 per year by 2050 under a moderate-mitigation and high-emission scenario, respectively, which further climbs to 1.4 and 2.2 million people per year by the end of the century.

Around 95 percent of these impacts could be avoided through moderate mitigation and by raising dikes where human settlements and economically important areas exist along the coastline. The report includes a BCA. The costs and benefits of raising dikes show high spatial variability between different coastal locations, but overall, benefits exceed costs for about 20 percent of the European coastline segments under a moderate-mitigation and high-emission scenario, respectively. Thus, the present natural or hard shoreline protection is economically optimal for about 80 percent of the European coastline, under a moderate-mitigation and high-emission scenario, respectively. In urbanized and economically important areas, the benefits tend to surpass the costs several times.

The examples below showcase several BCAs including combinations of grey and green infrastructure to protect against coastal floods in isolation at the coast, and combined risk of coastal and fluvial flood in the tidal reaches of rivers. In the absence of ecosystems such as mangroves and coral reefs in Europe, restoration and stabilization of dune systems represent the main option for nature-based coastal risk reduction at European shorelines. However, coastal protection also considers the effect of extreme water levels from high tides or storm surges on the tidal zone or in estuaries where coastal waters can interact with high fluvial flows from inland; in such cases restoration of wetlands and the floodplain can also be applied. The section comprises a detailed case study from Belgium and other examples from England or Spain (see *Box 4*). The examples also show that coastal measures can in some cases apply to major urban areas, as well as rural coastal settings.

SIGMA PLAN - COASTAL PROTECTION OF THE SCHELDT ESTUARY, BELGIUM

This case study is an external analysis that was undertaken with ex-ante analysis that involved modelling of hazards and consideration of climate change scenarios.

→ **Description**

The Sigma Plan is an integrated flood protection plan that was first established in 1977 after a major storm surge in the previous year. The Sigma Plan (inspired by the Dutch Delta Plan) offers protection against coastal storm surges as well as floods caused by excessive rainfall, protecting 20,000 ha of land bordering the Scheldt River and its tributaries such as the Rupel, the Nete, and the Durme Rivers. To achieve adequate protection, the plan combines engineered or 'grey' infrastructure measures (mainly strengthened dike protection and a storm surge barrier) and 'green' measures in the form of a network of controlled flood areas (Sigmaplan.be, 2021). The Sigma Plan has not been fully implemented yet and some components remain to be realized. In 2015, 1,200 ha of controlled flood areas were operational and ongoing work was expected to continue this area. In a recent report, the alternatives for the update of the Sigma Plan from the current situation have been compared through BCA - providing a case of retrospective analysis of an existing project while also being a prospective analysis for changes to that project. The baseline alternative is represented by the measures already implemented

plus the completion of the original Sigma Plan, except for the storm surge barriers. In the plan alternatives, a higher safety level (lower flood risk) is aimed for by implementing additional measures: storm surge barriers at Oosterweel and in the Rupel basin, dike raising, flood control areas and a retention basin.

→ **Methodology**

All proposed protection measures are evaluated with ex ante BCA including discount rates and climate change scenarios up to 2100 (Gauderis, et al., 2005) Complete ex-post evaluation is done on those areas where measures are already completed. Simulations of hazard scenarios were produced in 2005. The BCA is carried out in two phases. First, 10 basic alternatives are evaluated and compared with each other. They include all types of possible measures (storm surge barrier, dike raising, room for the river), including plausible combinations of different solution types in relation to a range of security levels achieved. The solution with the best BCR represents the best basic alternative. A sensitivity analysis is also carried out. In the second phase, the best solution direction is optimized by fine-tuning all the variables within that solution. The study area is subdivided into five zones and an optimal solution is sought for each zone. The optimal Sigma Plan is equal to the combination of optimal solutions of the five separate zones. Costs and benefits accounted in the analysis include the following:

- **Implementation costs of initial investments plus the maintenance and management costs.** A surcharge of 15 percent was charged for 'unforeseen' costs. Value added tax (VAT) is not included. It assumes an annual investment amount of €50 million starting in 2010. Costs for land expropriation are accounted separately (see agriculture).

- **Risk reduction benefits that consist of avoided risks and avoided costs.** The avoided risks are the difference in damage during flooding between the plant alternative and the zero alternative. Customary hydraulic modelling approach is used to estimate flood areas with a certain probability of occurrence. Both overtopping and dike breach scenarios are accounted. The damage for all these floods is estimated as function of the flood extent and depth over the total number of flooded houses, businesses, infrastructure, and agricultural land. In addition to economic damage, the number of victims is also estimated and valued.

- **Effects for agriculture.** In some cases, agricultural activities may remain in the flood zone but are subject to restrictions and damage when used as flood control areas; in other cases, they are not compatible with the function of the inundation area and thus are permanently lost.

- **Costs for forestry.** The potential flooding areas contain more than 2,000 ha of poplar forests. If these areas are designed as flood control areas, there is no significant impact. Poplars like wet soils and can withstand occasional flooding.

- **Costs for shipping.** Possible nuisance to shipping can be expected during the construction of a storm surge barrier at Oosterweel. The effects of the small storm surge barriers on the Rupel, Nete, and Dijle are smaller and not accounted.

- **Ecosystem benefits.** NBS generate natural benefits, split as effects on uses (production functions, regulation functions, and recreation) and non-use value (including option value, inheritance value, and existence value).

- **Recreational value** estimated on the basis of an estimate of the number of expected holiday-makers on the dikes and their experiential value.

- **Visual nuisance** for local residents estimated on the basis of a key figure for the potential loss of value of houses and included as a one-off cost in the construction of the flood zone.

The alternatives are compared according to three evaluation criteria: the net current benefits in the base scenario, the payback period in the baseline scenario, and the payback period in the 'worst case' scenario. The base scenario assumes a discount rate of 4 percent and a sea level rise of 60 cm over the next 100 years. In the worst-case scenario, future benefits are discounted more strongly and therefore less valued (discount rate of 7 percent) and the expected sea level rise is 30 cm. In this scenario, the benefits of the Sigma Plan will be lower. In both scenarios, average economic growth is assumed.

→ **Results of the analysis by dividends and overall**

The analysis includes a set of measures for the short term (always profitable in the short term) as well as additional measures for the longer term (will likely become profitable by 2050). The measures that best meet the various criteria discussed above were included in the definition of an optimal Sigma Plan with measures for both the short term (construction 2010) and longer term (for example, 2050). From four possible plans meeting the criteria, one was selected as the optimal solution, subjected to a more detailed analysis, such as the evaluation of design variants, the search for additional measures for the long term and sensitivity analyses.

The optimal Sigma Plan consists of a combination of flooding areas and local dike elevations. The solution found to have the highest NPV and the shortest payback period consists of a combination of flooding areas and local dike elevations ('Optimal A', see *Table 16*). In 'Optimal B', those flooding areas are set up as 'controlled reduced tidal areas', rather than simple flood control zones, while 'Optimal C' includes additional measures to be built in 2050, including various configurations of additional flood areas. Full engineering details of each solution are given in the full report (Gauderis, et al., 2005).

Table 16: Overview of costs and benefits of all plan alternatives (€, millions in 2004 prices) for optimal Sigma Plan up to 2100

	STORM SURGE BARRIER	OPTIMAL A	OPTIMAL B	OPTIMAL C
FIRST DIVIDEND				
Risk reduction benefits until 2100 (€, millions)	748	737	730	752
SECOND DIVIDEND				
Net benefits until 2100 (agriculture, forestry, shipping, ecosystem services, recreational) (€, millions)	–5	–8	33	–11
Costs				
Implementation costs (€, millions)	397	132	139	149
TOTAL DIVIDEND				
Total dividend (€, millions)	743	729	763	741
NPV until 2100 (€, millions)	346	596	622	593
BCR	1.87	5.52	5.49	4.97
Payback period baseline (years)	40	16	13	16/51
Payback period worst case (years)	No payback	45	33	N.A.
IRR/ERR (%)	46.57	81.89	81.78	79.89

Source: World Bank compilation; based on data and information from external sources mentioned above; Baseline scenario: discount rate of 4%, average economic growth, sea level rises 60 cm in 100 years. Worst case: discount rate of 7%, average economic growth, sea level rises 30 cm in 100 years.

Compared to the Oosterweel storm surge barrier alternative (complemented with control flooding areas), Optimal A has lower safety benefit; however, the storm surge barrier has also much higher implementation costs, realisation time, and no effect on risk upstream. The NPV until 2100 is therefore much lower. Sub-alternative B is similar to A but emphasises the use of natural measures to create flood control areas where possible, instead of structural ones. It has slightly higher costs but also generates additional natural benefits, so the NPV is higher and the payback period is lower. Sub-alternative C accounts for additional flood control areas built in 2050 and shows better BCR than the storm surge barrier. The investments in the first period pay for themselves in 16 years, and the investments in the second period in 51 years.

→ Challenges faced and lessons learned

The analysis shows that a combination of grey and green measures represents the optimal alternative in terms of realisation costs over avoided flood damage and natural ecosystem services benefits. This is especially true when considering the costs of updating the defence solutions to cope with the effects of climate change in the long-term. As exemplified through the analysis, the Sigma Plan project symbolizes the future of integrating green and grey solutions to create environmentally conscious infrastructure and therefore enhance conditions for future generations. Considering maintenance or improvement costs can be important as well as to carefully consider options to enhance co-benefits, as shown in other cases in the United Kingdom or Spain.

ADDITIONAL EXAMPLES OF NBS FOR COASTAL AND TIDAL PROTECTION

Additional investments were made in the coastal and tidal areas of Europe to reduce flood risk. These investments include improvement of tidal river defences and creation of tidal flood relief area in Sandwich, UK; creation of flood storage area and Biodiversity Action Plan (BAP) habitat in Alkborough, UK; and construction of dunes that protected the beaches and coastline of Barcelona, Spain. Highlights of the investments and the main lessons learned are showcased in *Box 4* below.

Box 4: NBS for flood risk reduction in coastal and tidal areas

A review of NBS that reduce risks in coastal or tidal flooding provides insightful results outline below. A common theme is that the investments all include maintenance or improvements over the existing measures and yield substantial co-benefits in recreational value and ecosystem preservation.

Located on the right bank of the River Stour, Sandwich is a historical town with upstream urban areas vulnerable to extensive flooding. To reduce flood risk for the local community, the Sandwich Tidal Defence Scheme (Bishop & Burgess-Gamble, 2018) was established in 2015, with the goal to improve the existing tidal river defences and create a 240ha tidal flood relief area. It is estimated that 486 residential and 94 commercial properties are protected by the scheme, with a sea level rise of 50 years included in the design. At the same time, the scheme also yields social and ecological benefits, as 20 ha of new wetland habitats were created for recreational uses and bird protection. With a total cost of 21.7 million pounds, the scheme yields a BCR of 10.5.

The Alkborough Flats Managed Realignment scheme (Manson, 2018) is one of the largest managed realignment sites and flood storage scheme in Europe, completed in 2006. Though greatly valued for commerce, industry, agriculture and wildfire, Alkborough Flats and the area surrounding it often face flood under high tides, with increasing intensity due to sea level rise and sediment movements. In this context, a massive flood storage area was constructed, which reduced tidal flooding risk for over 600 properties. It is estimated that without the Alkborough Flats Scheme, the volume of the flood would be 7 percent more during the 2013 tidal surge. The scheme also created 370 ha of a BAP habitat, which provides various ecosystem services benefits. The total cost of the project is €16.3 million (£11.1 million), while its benefits in flood defence and ecosystem protection is estimated to be €34.6 million (£23.6 million). The BCR of the project is 2.72.

In Barcelona, Spain, coastal dunes are disappearing due to erosion and rapid urbanization, which increases the beaches' vulnerability to storms, tidal floods, and sea level rise. The five-year EU project OPERAs (OPERAs, 2020) addresses the issue by constructing and maintaining semi-fixed dunes along Barcelona's coastline. The project enhances the coastal area's resilience to storms and floods, which reduce the hazards' negative economic impacts on the real-estate and tourism. The construction of the dunes is also crucial in terms of preserving the beach and the coast's ecosystem, which yields substantial ecological co-benefits.

3.1.3.3. NBS for urban flood risk reduction

In Europe, many cities are vulnerable to flood risks as a result of rapidly growing urbanization and land consumption, and increasingly variable hydro-meteorological extremes. Urban areas located in floodplains along rivers have a higher risk of exposing assets and properties to river floods (EEA, 2017). In addition, sudden increase in the volume of water caused by heavy precipitation can lead to overflow in the urban drainage system, causing flash floods (Climate Change Post, 2021).

The European Commission has made investments to reduce flood risks in the urban environment through the use of NBS. These investments include enhancements to buildings (for example, green roofs and rainwater harvesting), diverting run-off to bioswales or planter boxes, and increasing the area of permeable surfaces through green parking and permeable pavements (EPA, 2020; Soz, et al., 2016). Some examples of investments are highlighted in *Box 5* below.

Box 5: Investments in urban infrastructure to reduce flood risks

Investments in green infrastructures have made achievements in reducing flood risks in the urban areas and provided inspirations. The investments showcased below include investments in green infrastructure to reduce surface water flooding in Spain and a climate change park in the United Kingdom.

In the municipality of Benicassim in Spain, green infrastructure helped to reduce surface water flooding and yielded a number of co-benefits. Supported by the EU, LIFE CERSUDS (Climate-ADAPT, 2018) is a €1.8 million (€0.99 million EU-funded) project with the goal to promote the use of green infrastructure in urban planning to manage surface water flooding and also improve the resilience of the Spanish city of Benicassim (European Commission, 2021). The project developed a low-carbon Sustainable Urban Drainage System (SuDS), comprising an innovative permeable ceramic tiled pavement surface with a low cost and a small impact on the environment. The surface reduces diffuse pollution by preventing water reaching the sewage system and delays run-off by 45 minutes - reducing peak flow downstream by at least 72 percent. Co-benefits include the reduction of manufacturing/installation emissions through the use of ceramic tiles and improving the quality of the rainwater stored, but further quantified results are not yet available.

Completed in 2012, the Mayes Brook River Restoration project (Restorerivers.eu, 2014) in east London was the first climate change park in the UK that reduces flood risks through the restoration of a 1.6 km river and flood plain storage improvements. The project presents how a public greenspace can help reduce the negative effect of climate change for the local community. Modelling shows that the project reduces flood risks within the park and in the neighbouring residential areas. In addition, the park also generates recreational value and enhances wildlife protection, which increases the project's social and environmental benefits. It was estimated that the project yields a total benefit of £27 million, which produces a BCR of 7 comparing to its total cost of £3.8 million (Burgess-Gamble, et al., 2018).

An example presented by World Bank (Soz, et al., 2016) highlights the experience of Malmö, Sweden, where since 1998 the Augustenborg District underwent an urban renovation program ('Ekostaden', or econeighborhood), which transform it into an ecologically, socially, and economically sustainable city district. While developing new community spaces, green roofs were developed to reduce flood risk. They have been highly effective in capturing runoff, and on average intercept half of the annual total runoff from a 9,000 m2 botanical roof garden in the industrial area. An evaluation (Kibirige & Tan, 2013) concluded that the "open stormwater system in Augustenborg is well suited to handle current climatic conditions and a 10 year extreme event. The 100 year extreme event posed the most risk to the area and flooding was evident" (iv). The project has reduced runoff, created energy savings for residents, improved biodiversity in the region, and led to socioeconomic benefits such as a drop in the unemployment rate.

3.1.4. FLOOD EARLY WARNING SYSTEMS

An EWS is an integrated tool of hazard monitoring, forecasting, and alert that enables individuals, communities, governments, businesses, and others to take timely actions to reduce disaster risks in advance of and during hazardous events. An FEWS requires hydrometeorological observations and forecasts, monitoring of hazard and risk indicators in relation to predefined thresholds, effective channels to disseminate the warning signals, and predesigned response measures by institutions and communities. Accessibility to remote sensing and local meteorological data is key to producing the relevant information, and cooperation among institutions is a critical part of the process.

The engagement of local communities also plays an essential role during the design and operational phases of an EWS. Most EU countries have some form of national EWS linked to disaster management operations. At the level of country or region, there are both dedicated local systems, such as the advanced Flandres waterinfo service (run by VMM Belgium), and cross-national services, such as the EFAS, launched in 2003. EFAS produces alerts bulletin for all member countries, providing complementary pan-European medium-range streamflow forecasts and early flood warning information in direct support to the national forecasting services, with a focus on large transnational river basins.

Assessing EWS costs and benefits in quantitative terms is prone to many uncertainties—the few studies which include a quantitative assessment of EWS benefits necessarily rely on assumptions and generalisations due to scarcity of observations. Further, assessments may take place over different scales—from a single urban area to national scope (for example, (Priest, et al., 2011)). Schroter et al. (2008) estimate the effectiveness of EWS as a function of warning lead time (which however is not the only factor in EWS effectiveness). Pappenberger et al (2015) estimates the potential monetary benefits of early flood warnings based on the continental-scale forecasts produced by EFAS using existing flood damage cost information and calculations of potential avoided flood damages. The evaluation is at the EU scale and it is based on theoretical assumptions and global disaster datasets (EM-DAT). The results suggest that there is likely a substantial monetary benefit in this cross-border continental-scale flood EWS—about €400 for every €1 invested. Another study from the International Commission for the Protection of the Rhine (2002) estimates that flood warnings can help businesses avoid 50–75 percent of flood losses. Damage reduction factors for different response actions were estimated from another study (Parker, et al., 2007; Parker, et al., 2008), ranging from 6 percent by evacuating property content up to 30 percent reduction obtained by operating (flexible) flood defences. At the European level, the factor is estimated around 25 percent, saving an estimated €30 billion over the next 20 years. In comparison, results from local studies such as the case of Grimma in Germany (described later) show much smaller benefits.

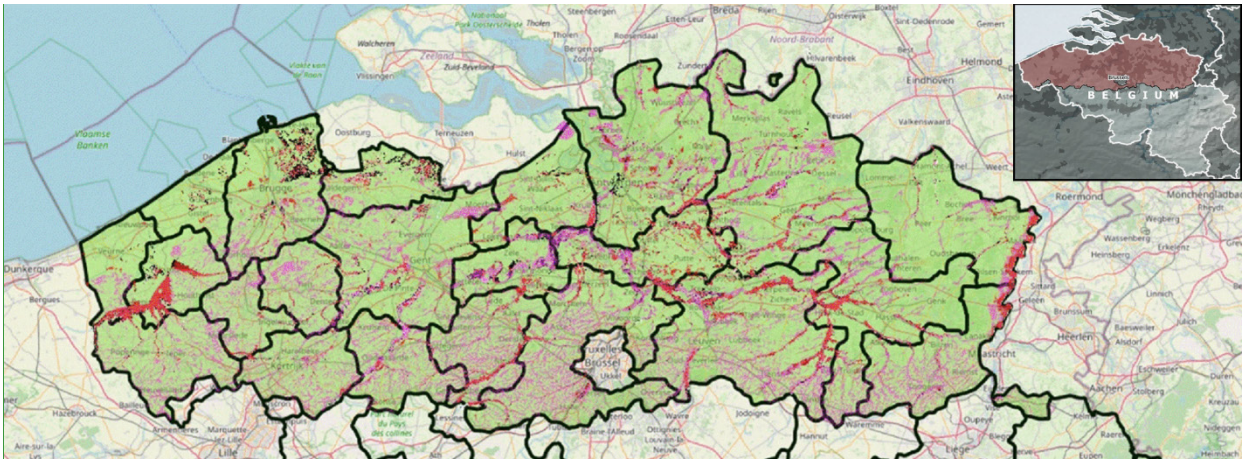
THE FLANDRES FEWS (VMM BELGIUM)

This case study is a new ex-post analysis under this project that involved modelling of hazards.

→ **Description**

The FEWS of Flandres represents the advanced integrated systems running on real-time observations (Perera, et al., 2019). The service produces forecasts every 6 hours for the five provinces of West and East Flandres, Antwerp, Flemish Brabant and Limburg, shown as green-shaded area in *Figure 11* (Brussels is not included). Red and pink areas on the map are susceptible to flooding (more details on flood prone areas also included in *Figure 12*). The EWS forecast can identify extreme river flood events with 32-26 hours lead time, though a warning is only released after two runs of the model confirm that the threshold for issuing a warning will be surpassed (12 h). This means, in practice, that the effective minimum lead time is around 20-14 hours. The EWS warning is issued if the flood intensity is expected to exceed the flood depth of a 1-in-5-year event. Information from the service is published through the website waterinfo.be. The system is not able to forecast pluvial flash floods, which can develop in just 2 hours. The error on water level forecast is 0.3 m on average but can grow to 0.6 m in some locations; an expert validation is always required before releasing the warning.

Figure 11: Areas covered by FEWS in Flanders showing 'flood-prone' areas (red—susceptible to frequent floods) and 'floodable' areas (pink—at risk of less frequent floods)



Source: World Bank analysis; based on flood-prone extents from waterinfo.be

There is no official estimate of economic risk of river flood to Flanders, and no BCA has been produced for the warning system, though insurance statistics suggest €50-€60 million of damage annually due to floods in this region, increasing to €100 million for catastrophic events. For events of higher frequency (return period of 5–10 years), the combination of EWS, public communication, and training, including to conduct maintenance of flood control reservoirs, gates, and other infrastructure ahead of flooding, could reduce risk. For larger events, it is less easy to reduce damage. The cost of deploying the service is about €0.3-€0.5 million per year for each province, but these estimates are a bit outdated (2010). There are many other factors affecting the final price, such as costs IT (website maintenance), therefore it is difficult to give one final measure. As a reference, insurance costs consider each house worth €50 thousand in damage.

→ Methodology

To estimate the effect of the EWS on flood risk we apply the JBA Global Flood Model and residential exposure, per the analysis of structural defences, with the potential damage reduction due to EWS services estimated using assumptions based on the information provided by the service providers (VMM), literature review and empirical information from real cases. The effectiveness of FEWS implementation relies on the combination of hazard forecasting, warning broadcasting, and emergency response, consistently with the approach described by Priest, Parker, and Tapsel (2011). Hazard forecasting capacity includes monitoring of meteorological variables, modelling rainfall runoff, identifying hazard thresholds and evaluation of risk; it can be measured in terms of anticipation and reliability (confidence level approaching the event). Warning broadcasting refers to the communication between institutional actors and dissemination media and is measured in terms of coverage (exposed area or population). Emergency response includes the actions taken by institutions and communities to reduce or avoid the damage in exposed areas, such as setting mobile barriers and relocating properties, and is measured in terms of avoided damage.

Assumptions on FEWS anticipation capacity, warning coverage, and loss reduction are developed on the base of evidence from the location of study. According to the national report on flooding (VMM, 2011) people located within flood-prone areas tend to be more responsive to EWS and to take measures to mitigate the impacts. To reflect this, areas at risk of flooding are classified with different warning uptake/risk reduction classes according to the flood probability. In areas exposed to frequent floods (here termed 'flood-prone'), we assume 90 percent of households act on a warning received. In areas affected less often (here, 'floodable'), we assume a 30 percent of households act. The specific households modelled as acting on the warning (therefore subject to reduced risk) is applied using a stochastic approach, being selected

at random.

Based on these assumptions, the benefits are measured as reduction in direct losses to assets compared to the baseline flood risk, where no EWS is implemented. A damage reduction factor is applied to the loss model for the properties expected to act, by reducing the maximum possible damage sustained. An equal reduction is applied to all properties acting, but due to the uncertainty in levels of damage reduction due to EWS three options are considered, namely 5 percent, 25 percent, and 50 percent for the reduction in maximum damage.

→ **Results of the analysis by Dividends and overall**

The estimate of total loss for the baseline modelled scenario are consistent with the losses recorded after the event of November 2010, before the EWS was set up, which caused a loss of approximately €120 million. Based on the above rates of expected action, it is expected that of 617,314 households (approximately 1.4 million people) in Flanders, 7 percent would act on receiving a warning (*Table 17*). This leads to an expected loss reduction of between €1.5 million (1 percent of the baseline loss) and €15 million (10 percent), depending on the assumption of damage reduction rate (*Table 18*). The avoided damages supply the Dividend 1 estimate; we do not quantify fatalities avoided because the rate of flood fatalities in Belgium is less than 1 per million (EEA, 2020) regardless of EWS. Overall results are presented in *Table 19*.

Table 17: People and households affected by EWS benefits (model estimates)

TOTAL NO. OF HOUSEHOLDS	TOTAL NO. OF PEOPLE	PEOPLE PER HOUSEHOLD ASSUMPTION	NO. OF HOUSEHOLDS BENEFITTING	NO. OF PEOPLE BENEFITTING	PROPORTION BENEFITTING
617,314	1,481,554	2.4	40,592	97,426	7%

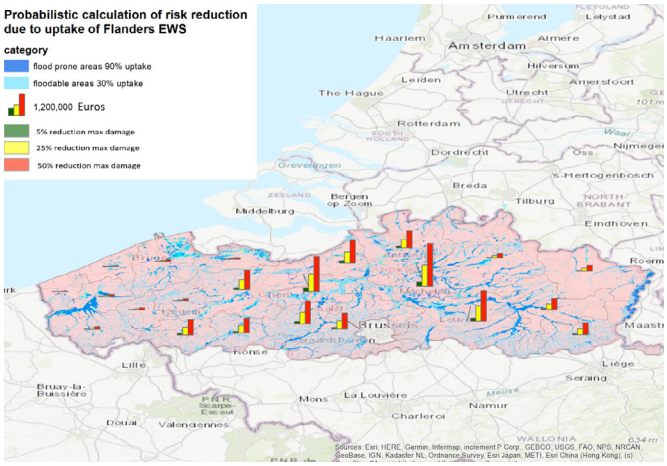
Source: World Bank analysis; based on external data

Table 18: Overall risk reduction (AAL) thanks to EWS for 3 key assumptions (in millions €)

	BASELINE SCENARIO	EWS SCENARIO, 5% LOSS REDUCTION	EWS SCENARIO, 25% LOSS REDUCTION	EWS SCENARIO, 50% LOSS REDUCTION
Total loss, €	161.16	159.6	153.4	145.64
Change, €	—	–1.55	–7.76	–15.51
% change	—	–1	–5	–10

Source: World Bank analysis; based on external data

Figure 12: Map of flood-prone areas in Flanders, Belgium in terms of frequency of occurrence



Source: World Bank analysis; elaboration based on results from the analysis

Dividends 2 and 3 for many soft investments such as EWS are difficult to quantify. While the socioeconomic benefits of reduced damage from using EWS are multi-faceted, such investments are often part of larger DRM projects. Therefore, it becomes difficult to identify specific benefits that can be unambiguously attributed to EWS only. Moreover, as has been discussed by Tanner, et al. (2015) for Bangladesh, variability in direct benefits (that is, dividend 1) from cyclone EWS comes from timing – maximum reduction in damage can be possible if the citizens receive sufficient time to evacuate and relocate themselves and their properties. Especially for floods and storms, indirect benefits of such programs are not well documented, and may not be possible to quantify without investigation involving primary data.

Costs are calculated as annual costs of €0.5 million per province plus an additional €0.5 million estimated for the maintenance of the EWS. In total, the total annual cost of service implementation and operation for the five provinces is estimated at around €3 million. Compared to the cost of implementing the EWS, the benefits are likely much higher (€1.5-€15.5 million).

Table 19: BCR of implementing EWS in Flanders by dividend, over 30 years (Future benefits and costs discounted by 3.5%/year)

	EWS SCENARIO, 5% LOSS REDUCTION	EWS SCENARIO, 25% LOSS REDUCTION	EWS SCENARIO, 50% LOSS REDUCTION
FIRST DIVIDEND			
Fatalities avoided	Negligible	Negligible	Negligible
Annual average property damage avoided (€, millions)	€1.5 million	€7.8 million	€15.5 million
Total first dividend (30 years) (€, millions)	€29.1 million	€151.3 million	€300.6 million
COSTS (€, millions)			
First time capital cost of sensors and monitoring system	€2.5 million	€2.5 million	€2.5 million
Maintenance cost	€0.5 million	€0.5 million	€0.5 million
Total costs (30 years)	€58.2 million	€58.2 million	€58.2 million
BCR	0.5	2.6	5.2
NPV (€, millions)	-€29.1 million	€93.1 million	€42.4 million
IRR/ERR	-100.0	61.54	80.65

Source: World Bank analysis; based on external data and information

→ Challenges faced and lessons learned

Many benefits, especially under dividends 2 and 3, were not quantified due to the unavailability of data. Capturing more details on the proportion of households taking different actions in response to a flood warning and the effect of those actions and households' private adaptation investments requires further research to make a more complete triple dividend analysis. The sensitivity testing undertaken shows that there is likely to be a minimum uptake required for EWS to show a BCR greater than 1, especially in areas of Europe where avoided fatalities are not included due to low rates of flood-related deaths, and where other dividends cannot be quantified.

There are additional benefits from EWS that may belong to dividends 2 and 3. However, calculating those indirect and/or co-benefits to society can be complex and requires sufficient data in a classic DiD framework. For example, there can be social benefits from reductions in emissions. However, there are many confounding factors that contribute towards emissions reduction and separating the contributions of EWS investments may lead to wrong estimates of benefits in the absence of data and information. We therefore have not calculated such benefits for this case study. Moreover, the distributional impacts are unclear and would be interesting to analyse in terms for example of last mile communication to ensure reaching most vulnerable people in remote areas.

There are interesting studies considering additional aspects to improve the analysis of FEWS. These include the implementation and maintenance costs for the investment in FEWS in Grimma, Germany, performance of the forecast system, and uncertainties in damage data for the EFAS. Nevertheless, all analysis show substantial benefits of FEWS under different specifications, with various methodologies and for different types of investments, with considerable benefits found for cross-border floods early warning. Moreover, complementary investments in public awareness or last-mile communication and education are essential to ensure that benefits from EWS can arise and investments in this sense have been undertaken, for example, in Poland or as a collaboration of Greece and Cyprus.

EARLY WARNING SYSTEMS IN THE TOWN OF GRIMMA, SAXONY, GERMANY

This case study is an external ex-ante analysis that involved modelling of hazards.

→ Description of the case study

Grimma is a small town of 28,000 people located on the Mulde river, a tributary of the Elbe. In August 2002 regionally severe flooding occurred on the Elbe and Danube Rivers, estimated to be at least a 1-in-200-year event. Grimma suffered significant damages of €220 million from flooding as deep as 4m as existing dike protection was insufficient for this event. Soon after the experience of 2002, the town council decided to install an autonomous local warning system, in addition to the Saxon regional one, consisting of many components including: a central flood announcement system including sirens, autonomous SMS information network and 24-h flood information to the television media. From 2010, structural protection with a design level of 1-in-100-years were also installed. A study from 2012 compares costs and benefits for both measures, individually and combined (Meyer, et al., 2012). We are in the following analysis focusing on the EWS measure alone.

→ Methodology

The study of EWS in the town of Grimma, Saxony (Priest, et al., 2011; Meyer, et al., 2012) offers an interesting example of BCA with clear implementation and maintenance costs in addition to estimating the benefits of the system. Quantification of EWS costs and benefits is complex, due to the value chain and often-shared costs of establishing or improving an EWS, but in this case the scale of the system has enabled this. The system cost €148,000 (one-off) for setting the EWS and €4,200 (annual) to run the service. Assuming a lifetime of 100 years and using a discount rate of 3 percent, the present value of costs is €291,000. Assuming a lifetime of 100 years and using a discount rate of 3 percent, the present value of costs is €291,000.

The model used to estimate the benefits is a specific one developed for the study and considers eight parallel response actions to characterize the theoretical range of damage-reducing responses to flood warnings. Two of these actions relate to human elements (search and rescue, evacuation of people),

not evaluated in economic terms. The other six are related to reduction in flood economic damages and producing flood warning benefits:

- Flood Defence Operation: integrity of flood defences are monitored and maintained
- Community-based measures: water prevented from reaching buildings where effective
- Contingent resilience measures: water prevented from reaching buildings where effective
- Relocation or evacuation of belongings: property moved away from flood waters
- Watercourse capacity maintenance: freer from debris, less change of flooding
- Business continuity plan: minimises business interruption losses

An estimate of €0.56 million annual average damages has been used as a basis for the application of the model for Grimma, based on a previous meso-scale flood damage estimation when there were no structural defences. This total EAD has been calculated for return periods greater than 1 in 50 years as for events below this level no properties are affected, and damage is assumed to be zero. Following the construction of structural protection infrastructure, the mean EAD for the town are estimated to be reduced by about 69 percent to approximately €0.174 million. On average, 35 percent is suffered by residential properties (€60.9 thousand).

→ Results of the analysis by Dividends and overall

The FEWS is estimated to reduce the total 100-year event damage only between 2.1 percent and 19.5 percent, but its cost efficiency in terms of NPV is most likely positive in the long run. Total annual expected damage saved of €408,585 are estimated, which is 73 percent of the estimated total average annual damage potential (without any flood damage reduction measures). The majority of this (€386,000, 69 percent of total) are generated by the operation of flood defences, and the remaining €22,585 contributed by a combination of business continuity planning, evacuation of house contents, contingent resilience measures, community-based operations, and maintenance of watercourse capacity. These measures however become less effective for more severe floods.

→ Challenges faced and lessons learned

The results of this study are valuable as an example of a well quantified implementation of EWS integrated with structural protection. This is in part made possible by the small scale of the system and target area – which in turn provides a challenge in scaling the findings to larger areas and other locations. Potential distribution effects of this EWS with integrated structural protection include a reduction in damages to homes and settlements near the river, which can include people with lower incomes or who are experiencing homelessness.

EUROPEAN FLOOD AWARENESS SYSTEM

This case study is an external ex-ante analysis that involved modelling of hazards

→ Description of the case study

EFAS was launched in 2003 and produces alerts bulletins for all EU member countries, providing complementary pan-European medium-range forecasts and early flood warning information in direct support to the national forecasting services, with a focus on large transnational river basins. The reported cost to establish four EFAS operational centres was €21.8 million, with additional development costs over 10 years of €20 million (Emerton, et al., 2016).

→ Methodology

Pappenberger, et al. (2015) performed sensitivity assessments of the potential monetary benefits of EFAS early warnings, considering the avoided damage factors, the performance of the forecast system, the discount factors and the uncertainties in the damage data. Avoided damage due to early warning is set at 32.85 percent when flood defence operation, watercourse capacity maintenance and community-based operations are considered together. This increases to a total of 36.68 percent damages avoided when temporary resistance measured are implemented and contents are moved. The study tests

warning system performance improvements of 10 percent, 20 percent, and 30 percent while assuming the forecast model skill remains stationary over the 20-year period. An EU wide discount factor of 5 percent is applied, with some variation for UK (3.5 percent) and France (4 percent). An uplift factor of 2.54 and 1.75 were applied to account for indirect costs, applied as an uplift to EUSF and EM-DAT reported direct costs to estimate event damages.

Benefits of EFAS warnings are estimated by: 1) calculating correctly warned events and missed events against an EU flood damage map, and 2) against EUSF and EM-DAT damage estimates. These benefits were compared against the installation and running costs of the EFAS system. No assessment of a single event is carried out by Pappenberger et al. (2015).

→ Results of the analysis by Dividends and overall

The results show that there is likely a substantial monetary benefit in this cross-border continental-scale flood EWS. The conservative base scenario applied suggests that a BCR of 159 is generated after 20 years of operating EFAS. With improvements in forecast performance this ratio could reach 202, and even up to 400 (400 Euro return for every 1 Euro invested). The analysis suggests that 37 percent of damages could be avoided due to the operation of the EWS, resulting mainly from a 32 percent reduction thanks to avoided damages by warning dependent flood defences, and 5.7 percent reduction thanks to residual damages avoided by moving and evacuating property contents. JRC (Thielen Del Pozo, 2015) averages the damage reduction factor of EFAS at the EU level (around 25 percent) over the next 20 years. Indirect losses avoided, counting towards Dividend 1, and Dividend 2 and 3 benefits were not included in JRC's analysis of EFAS due to difficulties quantifying indirect losses avoided and the potential provision of earlier aid to at risk people.

→ Challenges faced and lessons learned

This example highlights the challenges in estimating the costs and benefits of EWS, which derive from several complex factors - especially in this large-scale case. These include whether a forecasting system already existed and in what form, the scale of forecasting region, temporal lead time required and enabled, in addition to human and resource factors which, in an event, can limit the efficacy of response actions even in cases of effective warnings being issued. The sensitivity study of Pappenberger et al. (2015) shows the significant uncertainty associated with assessing benefits and costs of FEWS – uncertainty in the percentage of damages avoided due to actions following a warning can change the relative monetary benefit of EFAS by over 100 percent, assumptions on forecast performance by up to around 70 percent, and uncertainty in estimated event damage by over 150 percent. Moreover, the distributional impacts are unclear and would be interesting to analyse in terms for example of last mile communication to ensure reaching most vulnerable people in remote areas.

ADDITIONAL EXAMPLES OF EWS BUILDING AND TRAINING FOR IMPROVED FLOOD RESPONSE

A number of additional investments sought to improve awareness and capacity for preparedness that could provide lessons learned and inspirations. In fact, building risk awareness and capacity of governments, emergency services and the public to respond to floods is an important component of increasing resilience and support the operation of effective warning systems. Projects include investments in a cross-border EWS system in Greece-Cyprus with educational tools and a comprehensive mapping system PANDA in Poland. Highlights and main lessons learned of these investments are presented in *Box 6* below.

Box 6: Varied investments in EWS and capacity building for flood response across Europe

A review of investments in EWS and capacity building for flood response across Europe provided a number of lessons learned and inspiring achievements outlined below. A common theme is that individualized early warnings to reach the last mile can be very beneficial for disaster risk prevention and preparedness.

A Greece-Cyprus Interreg-funded project implemented 2017-2020 aimed to bridge the gap between scientific

knowledge and public action (European Commission, 2020; World Bank, 2021). It developed an online Environmental Risk Management Information Service that provides tools and information on flooding to business owners, policy and scientific communities, and the general public. By offering EWS, crowdsource photos, flood-risk maps, entertaining videos and education games for families, the project enables the public to have access to scientific information on natural disasters and thus increase their chances of survival when a disaster strikes.

The Polish Atlas of Rains Intensities (PANDA) is the first online, digital and comprehensive rainfall mapping system in Poland. It is designed to help develop urban stormwater and drainage systems that better protect Polish towns, cities and their residents against the effects of heavy rainfall. Based on three decades of data, the project developed an online rainfall intensity calculator, making it easier to assess potential threats in any area of the country. The data is accessible through a personal PANDA account, which any interested party can open online. The data allows local governments and companies to plan preventive actions and better equip infrastructure works and buildings against heavy rainfall or flooding.

3.1.5. PROPERTY-LEVEL PROTECTION (PLP)

Property-level flood protection is the installation and deployment of flood resistance measures to prevent water from entering individual properties and resilience measures to limit the damage caused once it has entered (White, et al., 2018). Resistance or dry proofing measures include door barriers, nonreturn valves, and airbrick covers, while resilience or wet proofing measures include waterproof plaster. Pumps can also be considered to remove water from properties to reduce the amount of time they are flooded, which in turn reduces the amount of drying time and overall damage. Other retrofit actions include moving ground floors electrical circuits higher to avoid damage at low flood levels, or changing floors and wall coverings to be more resilient when submerged.

There is limited information available on examples of PLP being applied in EU MS. To present the potential costs and benefits of another form of flood risk reduction and compare the BCR, the decision was taken to simulate the hypothetical application of PLP in a prospective analysis. This is applied to a selected flood-prone urban area, which would represent a coordinated effort to mitigate flood risk at the property level over many properties and to represent the potential impact of such a large-scale investment in PLP measures.

PLP measures were implemented from 2008 to 2011 under a government grant scheme in England to evaluate the effectiveness of PLP (Peter, et al., 2014). Total funding of £5.2 million (€6.55 million in 2008 prices) was awarded to 63 individual PLP schemes, offering practical flood protection solutions to 1,100 properties. Based on a sample of 115 properties which had deployed their measures since installation, PLP measures had a positive impact (prevented ingress or allowed only limited ingress of water) at 79 percent properties while 21 percent experienced no positive impact. Potential co-benefits of PLP can include increased property value for those properties with improved defences, the potential to increase energy efficiency, but these are more likely when more substantial PLP or retrofit works are implemented (for example, relocating electrics circuits above the potential flood level, water-resistant plastering, and flooring, or perimeter protection).

THE SIMULATED EFFECT OF PLP IN NORTHERN ITALY

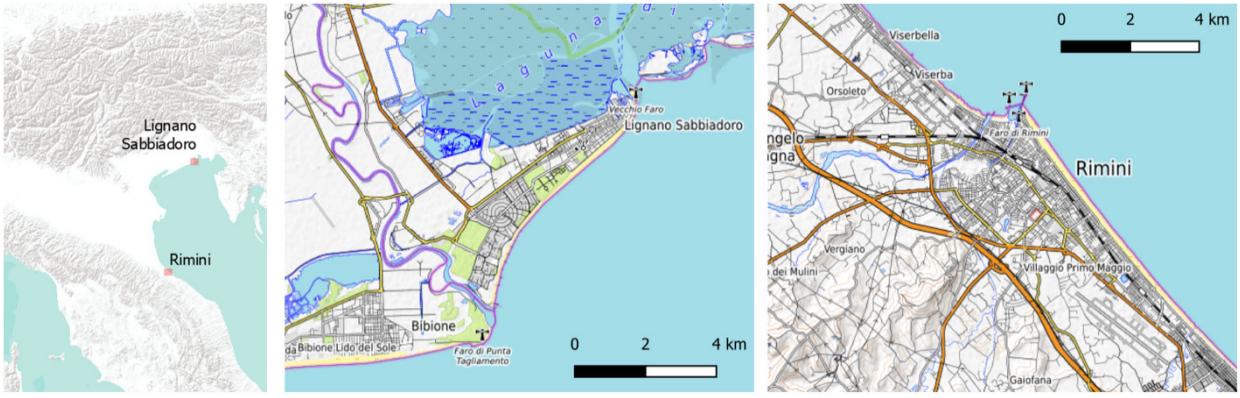
This case study is a new ex-ante / hypothetical analysis under this project that involved modelling of hazards.

→ **Description**

North-Eastern Italy consist of a large floodplain limited by the Adriatic Sea. It is a heavily urbanised area, showing some of the highest rates of soil sealing, and it is often prone to both surface floods and river floods. We chose two locations on the Adriatic coast where recent flash flood events caused severe impacts: Lignano Sabbiadoro and Rimini (two seaside towns with strong touristic vocation). Lignano Sabbiadoro was hit in September 2017 by a severe urban flooding caused by two intense rainstorms that produced a cumulative rainfall depth of 280 mm, estimated to correspond to a return period of 50–100 years. The

rainstorms caused the flooding of large portions of the urbanized area (Samela, et al., 2020). Rimini was hit in June 2013 by intense precipitation (148 mm in 4 hours), generating torrential floods on urban roads which caused 2 deaths and widespread economic damage. Major structural and infrastructural changes would be required to reduce the change of hazard occurring in this context. While there are ongoing efforts in this direction, PLP could be the most easily and quickly implemented risk reduction measure in some locations (see case studies location for modelling PLP measures in *Figure 13*).

Figure 13: Case studies location for modelling of PLP measures: Lignano and Rimini are small towns in Italy located on the North-Adriatic coast



Source: World Bank analysis; based on OpenStreetMaptopographic map

→ Methodology

A study was conducted by ECHO (2014), with support from Politecnico di Milano about the cost-effectiveness of PLP in Italy to prevent pluvial flood damage, accounting for different types of measures (flood proofing of components, flood walls, and relocation) over three classes of buildings. We use the results from this study in a simulation of PLP effectiveness in the context of selected flood locations. The same global flood model as applied for previous flood case study analyses was applied. To represent the impact on AAL and the exceedance probability curve, property vulnerability curves were adjusted to represent the higher level of flood required before inundation would occur.

It is expected that PLP measures are effective at lower flood depths and less effective as flood depth increases. It was assumed that measures where flooding is less than around 1 m would encompass floodproofing components such as raising electrical sockets and installing waterproof doors/barriers and boards to deploy in advance of a flood. It was assumed that measures where flooding is less than around 1 m would encompass floodproofing components such as raising electrical sockets and installing waterproof doors/barriers and boards to deploy in advance of a flood. Above 1.67 m, there is no adjustment to the curve. No adjustment was made to the frequency or severity of flooding for the study area, as no change in large-scale flood protection (for example, flood banks or barriers) was included. We consider a period of 30 years to sum up the total benefits of PLP implementation.

The total cost of PLP measure implementation is calculated based on the unitary prices estimated for Italy by the study mentioned, expressed as euro per m2 per year (see *Table 20*).The annual cost of each measure is obtained by dividing the one-off cost by the expected lifespan of the intervention. The unitary costs are first multiplied by the number of years (30) chosen to compare the benefits. Then they are multiplied by the total exposed area, identified as the sum of buildings' footprint areas. Only residential buildings are accounted. Rimini has about 1 km2 of built-up area located in areas prone to flood depth between 0.5 and 1 m, while Lignano has 0.33 km2 (see *Table 21*).

Table 20: Unitary costs of PLP measures as estimated for the Umbria case study. Adapted from ECHO-SUB-2014-694469

BUILDING CLASS	UNIT COST OF MEASURES (€/M²) OVER 30 YEARS		
	FLOOD PROOFING TO COMPONENTS	FLOOD WALL MEASURE	RELOCATION OF BUILDINGS
Class 'A'	75	112	5,401
Class 'B'	1163	909	47,240
Class 'C'	525	398	17,458

Source: World Bank analysis; Adapted from ECHO 2014

TYPE OF MEASURE (CONDOMINIUM APARTMENT)	COST (30-YEAR LIFE SPAN) (€/M²/YEAR)
Electrical measure	8.57
Interior plaster measure	16.5
Plumbing/sanitary measure	6.5
Floor measure	3.47

Source: ECHO (2014)

→ Results of the analysis, by dividends and overall

Dividend 1 comprised avoided damages, calculated according to the reduction in vulnerability applied across all property types with an assumption of 100 percent uptake of measures at properties affected by flood. Across all Admin 3 sub-district boundaries of Rimini and Lignano, the damage reduction was approximately 7.2 percent. Assuming 50 percent uptake, this might be closer to 3.6 percent risk reduction, though the relationship is not linear given differences in flood depth at individual properties. The lower value is compatible with the percentage reduction estimated in a detailed analysis by property type in the Umbria example Politecnico di Milano study, which estimates an average damage reduction as 1.3–3.4 percent for 'flood proofing to components' and 2.9–4.6 percent where 'flood walls' were included. Fatalities are not quantified due to the low rate of flood fatalities regardless of PLP.

Table 21: Summary of results for PLP scenario simulation compared to baseline. Both locations show a reduction in annual expected losses close to 3.5 percent for PLP measure implementation with percent uptake

LOCATION (MUNICIPALITY)	RIMINI	LIGNANO
Residential buildings footprint area (km²)	1.00	0.33
Baseline damage (€, millions)	10.30	0.62
Damage with PLP if 100% uptake (€, millions)	9.60	0.58
Difference with 100% uptake (€, millions)	0.76	0.035

Source: World Bank analysis; based on external data and information

Dividends 2 and 3 for PLP measures may include the benefit of reduced displacement of residents from affected households (therefore reduced cost of shelter) and reduced business interruption to commercial properties (due to services being able to restart earlier after a flood than would be possible without PLP). There may also be a reduced volume of bulky waste due to reduced damage and replacement of contents and decoration/furnishings (though this is quite a micro impact, likely not quantifiable) and reduced displacement of homeowners (in terms of both number of people and duration of being displaced). Due to lack of available data and information on indirect and/or co-benefits, we were not able to calculate dividends 2 and 3. However, under certain assumptions, we can reflect on the potential sources of those dividends. For example, there can be lower displacement which can be a source of benefits. Appropriate interventions can reduce their stay in temporary shelters and this dividend arises from their shorter stay in shelters (that is, the difference in the durations of shelter stay without and with interventions). While this structure follows the classical DiD framework, its calculation is heavily contingent on the availability of data or appropriate proxies, absence of which restricted our calculation of such benefits. Overall results are presented in *Table 22*.

Table 22: BCR for PLP in NE Italy per dividend (30 years lifespan, benefits discount rate 3.5%)

	RIMINI 100% UPTAKE	LIGNANO 100% UPTAKE
FIRST DIVIDEND		
Fatalities avoided	Negligible	Negligible
Annual average property damage avoided (€, millions)	0.7	0.035
Total first dividend over 30 years (€, millions)	21	1.0
First cost item		
Annual cost of PLP measures (€, millions)	12.9	4.0
Total dividend over 30 years (NPV) (€, millions)	13.4	0.7
Total cost over 30 years (€, millions)	387	120
BCR	0.035	0.006

Source: World Bank analysis, based on external data

→ Challenges faced and lessons learned

The BCR from this case study is smaller than expected and overall discouraging the implementation of PLP for flood loss mitigation in the two case study areas. Interestingly, the BCR for individual PLP measures was estimated as always greater than 1 in the reference study; however, those estimates are produced accounting for river floods and dam failure scenarios that would generate higher hazard intensities and thus larger amounts of losses, compared to pluvial floods. In our assessment, we account for damage triggered by pluvial floods only, because the two locations do not present significant river flood hazard, and only for a specific range of hazard intensities. Moreover, both case study areas have a relatively high density of units in exposed areas, which means the total floodproofing costs are much larger compared to small-density settlements along the river network. These observations highlight the need for caution when transferring the results of BCA from one specific measure and location to different contexts. Investing in PLP for flood loss mitigation is important because it provides a sense of financial security for these densely populated areas in a disaster. Such private initiatives can enhance the property value and reduce the regular maintenance costs of the properties with such protections.

3.1.6. OVERVIEW OF BCA FOR FLOOD RISK REDUCTION

This section has demonstrated the variety of flood protection investments and introduced several examples of BCA. The BCAs have been presented for structural and nature-based risk reduction measures, EWS, and catchment scale to property level.

Quantified benefits of structural schemes focus on avoided property damage (dividend 1), though additional dividend 2 benefits may comprise stimulus of local/regional economy and supply of materials (for example, gravel production in the Odra River example). The examples of NBS demonstrate the broad range of benefits including impact on carbon storage, amenity, and recreation value and therefore health benefits, water quality, and timber production, though conversion of grassland to other habitats can also result in a negative benefit of lost agricultural production. The NBS examples also tend to include assessment of multiple options for the NBS component as well as combination with structural options, resulting in comparison of NPVs for those different options.

Unfortunately, in the examples identified for detailed assessment of avoided damages in this study (Machlandamm, Flandres FEWS, and PLP in NE Italy), there was insufficient information to support quantification of dividends 2 and 3. While the potential dividends are recognised and described in the text, the generalisations and assumptions that would be required in the absence of data resulted in a decision to not quantify those. However, additional examples from the literature where detailed prospective or retrospective economic analyses have been undertaken are used to demonstrate the additional benefits of these dividends in the context of flood risk reduction.

The range of BCRs presented for the included studies strongly demonstrates the range of possible estimates between different types of flood risk reduction and within the same type as well as the strong influence on BCRs of the assumptions and values applied to develop costs and benefit value estimates and the variable inclusion of individual benefits. The structural defence cases here provide a range of BCRs <1–5, though the lower estimates are subject to a lack of dividend 2 and 3 information. The NBS examples, with their quantification of myriad additional ecosystem benefits provide estimates of BCR generally <1–5, but in one case up to 10. The examples of FEWS provide BCR ranging from <1 to 15 depending on the estimated proportion of people acting upon receiving a warning, but due to the large component of human behaviour in reacting to a warning and the various actions people might take, there is significant uncertainty around these estimates.

3.2. Earthquakes

3.2.1. SUMMARY OF FINDINGS FOR EARTHQUAKES

Earthquakes are extremely common across the globe. The National Earthquake Information Centre of the United States Geological Survey (USGS) locates about 20,000 earthquakes each year, which is equivalent to roughly 55 earthquakes recorded per day (USGS, 2021). In many locations, seismic hazards pose serious intermediate-term risks to a society's health, safety, and economic viability. For example, structural damage to buildings, fires, damage to bridges and highways, initiation of slope factors, liquefaction, and tsunami are common impacts caused by an earthquake. In 2011, FEMA initiated a four-phase study (FEMA, 2020), which was aimed at informing community officials and the public about the value of adopting the International Codes (I-Codes) to increase resilience against natural hazard events. To simulate the losses avoided due to prevention of physical damage to buildings and contents, the Building Codes Save Study comprehensively examined records of buildings constructed from 2000 to 2016, including the business parcels, mapped hazard exposure, and building code histories nationwide, notwithstanding data limitations. Results from the study show that total losses avoided amounted to an average of €439 million[7] (US$484 million) for floods, €54.2 million (US$60 million) for earthquakes, and €1 billion (US$1.1 billion) per year for the whole country. Reduction in property losses associated with use of modern building codes for 2000–2040 was estimated to be around €119 billion (US$132 billion).

There are several options for governments to effectively reduce earthquake risk and enhance their earthquake resilience. These include targeted investments into buildings and infrastructure strengthening, development of EEWS, and improvement of emergency response capacity and recovery efforts, among others. The European Commission has made investments that aim at reducing human and economic losses caused by earthquakes. The European Association for Earthquake Engineering (EAEE) was established to promote cooperation between regions in the field of earthquake engineering, which serves a crucial role in mitigating the impacts of earthquakes in Europe (European Union, 2021). Financed by the Horizon 2020 programme of the European Commission, the Real-time earthquake rIsk reduction for a reSilient Europe (RISE) project is a three-year program with the objective to enhance the scientific understanding of earthquakes and Europe's capabilities in future earthquake prevention (RISE, 2021).

Several different economic approaches have been used to quantify the social and economic losses caused by earthquakes and the benefits of earthquake risk reduction investment, yet the infrequent occurrence of earthquakes requires careful interpretation of the results of an earthquake-related BCA. A recent report by NIBS (2019) showcases a comprehensive BCA of natural hazard mitigation in the United States and included BCRs of retrofit measures, which varied widely depending on the measure and hazard level but averaged between 2 and 24. Some studies (Pohoryles, et al., 2020) have shown that combined energy and seismic retrofit investment is economically efficient, as the combined method will

7 Original values were in US dollar.

result in a significant reduction in the payback periods in moderate to high seismicity region compare to separate investments. Investments in Earthquake Early Warning System have also proven to be economically beneficial, yet for systems that depends on eyewitness accounts of earthquake shaking, socioeconomic and literacy factors can have a strong influence on the effectiveness and accuracy of the system (Seismological Society of America, 2021).

In this section, we demonstrate benefit-cost assessments for seismic retrofitting, EEWS, and increased responder capacity. BCRs for the different types of interventions are shown by a combination of detailed case study analysis and review of past BCA, including both prospective and retrospective types of assessments. *Table 23* summarizes main data and information sources.

Table 23: Overview of data and information sources for earthquake analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Seismic strengthening of buildings and infrastructure	Seismic risk prevention in Italy	• Hazard model based on ESHM13 • Exposure and vulnerability models based on GEM Foundation's 2018 Global Risk Model • Information on the intervention type obtained from the report 'The Italian National Seismic Prevention Program' • Data provided by the Civil Protection Department
Seismic strengthening of buildings and infrastructure	Improvement of education facilities in Europe	• Hazard model based on ESHM13 • Aggregated national counts and occupants based on Global Program for Safer Schools (GPSS) GLOSI statistics • Average area and replacement value of buildings obtained from the construction costs from the SERA project • Risk analyses for the baseline and retrofitting case performed with the OpenQuake engine • Primary energy consumption based on the comprehensive study of building energy renovation activities and the uptake prepared for the European Commission • Data for educational facilities obtained from the European Commission -Energy: Long-term renovation strategies • National and European emission factors for consumed electricity and fuels for heating and hot water taken from Covenant of Mayors Technical annex to the Sustainable Energy Action Plan (SEAP) template instructions document • Data from EU buildings database, EU countries' 2013 cost-optimal reports, and EU countries' 2018 cost-optimal reports - Energy, obtained from the European Commission -
EWS	Earthquake early warning in Bucharest	• Total investment information from the 'Danube Cross Border System' project for EEWS cost, half of which is assumed to be applied to Bucharest • Data from the United States (Strauss and Allen methodology) for cost of one train car and cost of maintenance of EEWS, adjusted to Romanian consumer price indexes • Eurostat symmetric input-output tables for construction sector macroeconomic benefits. The EU estimation for construction sector input of every €1 yields €0.47 of value added to other industries. This is an indirect and direct economic value added from the construction or installation of sensors and other infrastructure for EEWS

Responder capacity building	Benefits of knowledge network investments during earthquake (Albania and Croatia)	• Modex and European Union Civil Protection Team (EUCPT) training costs, supplied by DG ECHO and course organisers • Post-disaster needs assessment (PDNA)/rapid disaster needs assessment (RDNA): reports and interviews with PDNA leaders • Further data requested of Albania and Croatia governments but not received. Uncertainty on certain assumptions can be further reduced with this information • Interviews with Croatia civil protection personnel and the Zagreb damage assessment leads • EUCPT final reports for Albania deployments (September and Novovember 2019). Obtainable, as the author of this section was deployed as an EUCPT member on both deployments (Josh Macabuag) • Further references → GRADE reports (Global Rapid post-disaster Damage Estimates, World Bank Group internal documents) for both case study events. → CSES (Centre for Strategy & Evaluation Services), Resilience Advisors Network, Evaluation Study of Definitions, Gaps, and Costs of Response Capacities for the Union Civil Protection Mechanism. → Goretti A., Molina Hutt C., Hedelund L., 2017. "Post-earthquake Safety Evaluation of Buildings in Portoviejo, Manabí Province Following the Mw7.8 Ecuador Earthquake of April 16, 2016." International Journal for Disaster Risk Reduction March 2017. → Woo, G. 2019. "Downward Counterfactual Search for Extreme Events." Frontiers in Earth Science December 2019. → Other references for specific figures assumptions, as provided in the calculation spreadsheet

Source: World Bank analysis; based on external information

Most models can be used to assess infrastructure investments. The common platform that is used to evaluate earthquake hazard and earthquake risk in Europe is OpenQuake—Global Earthquake Model's computational engine. Other analysis frameworks that are used to quantify earthquake consequences to building stock and infrastructure are HAZUS (Kircher, et al., 2006) and FEMA P-58 (Hamburger, et al., 2012). For the Italy and schools across Europe analysis, the OpenQuake platform and ESHM13[8] were used. Moreover, the European Commission has purposed a methodology (European Commission, 2020d) to evaluate the combined approach of both seismic improvement and energy efficiency of a building. The common metrics used for quantification of benefits are the decrease in losses for a particular earthquake scenario and decrease in AALs, that is, reduction in losses from all possible earthquakes that can occur in a given year weighted by their probability of occurrence. While the first approach illustrates benefits for one plausible earthquake scenario without accounting for its probability of occurrence, the second approach considers all possible earthquake but often 'averages out' extreme consequences caused by rare events.

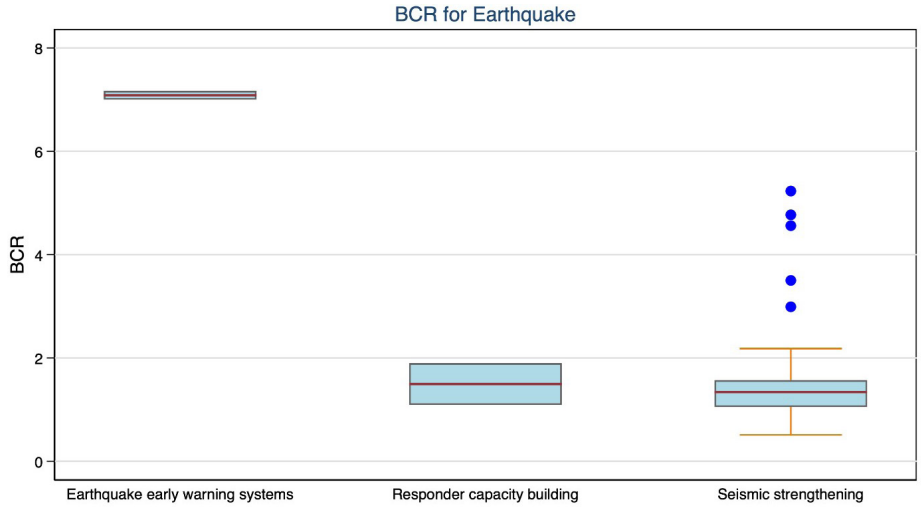
Earthquakes can cause widespread societal and economic losses in a single event, but their infrequent occurrence poses challenges when conducting BCA and interpreting the results. There are several different approaches that have been used to quantify the benefits of earthquake risk reduction investment and care must be taken when selecting and interpreting the results of an earthquake-related BCA. A recent report by the NIBS (2019) showcases a comprehensive BCA of natural hazard mitigation in the United States and included BCRs of retrofit measures, which varied widely depending on the measure and hazard level but averaged between 2 and 24. Some studies have shown that combined energy and seismic retrofit investment is economically efficient, as the combined method will result in a significant reduction in the payback periods in moderate to high seismicity region compare to separate investments.

8 While the ESHM13 model was used for this analysis, it is not consistent with the procedures and the criteria used by the Italian seismic prevention program to identify the areas where the program is applicable, define the initial and the final safety conditions, and so on. The prevention program used the official 2004 seismic hazard model since 2004.

BCA generally yields net benefits, although this varies based on various considerations. In fact, a lack of quantitative data to calculate dividends 2 and 3 as well as lack of prioritized assets to consider may lead to some results where BCRs are smaller than 1. A general message is that detailed risk assessments and consideration of different types of assets are essential to consider in the analysis. More details are included in *Figure 14*, *Figure 15*, and *Figure 16*.

Figure 14 shows the distribution of benefit-cost ratios (BCRs) for earthquake investments, based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). The outliers are shown as dots.

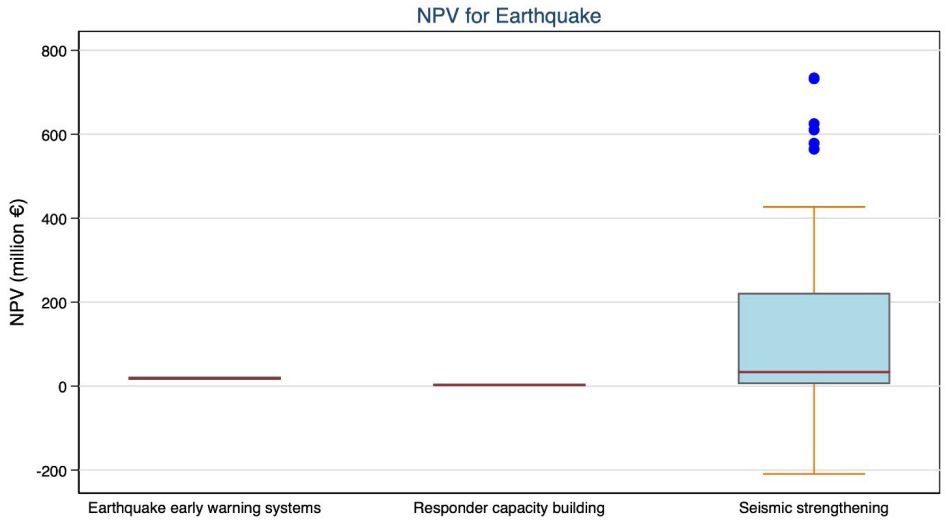
Figure 14: Findings of BCA for earthquakes (BCRs)

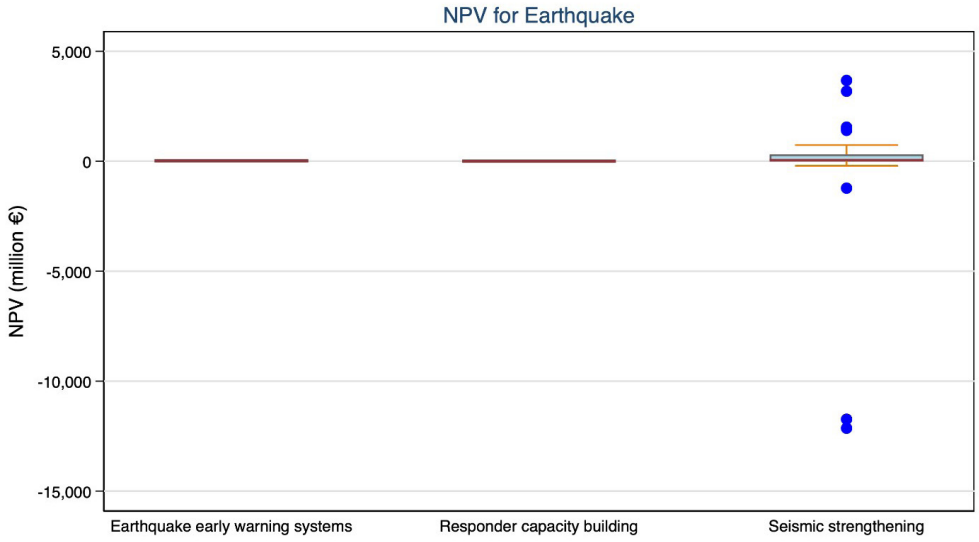


Source: World Bank analysis; based on external data and information; presenting in part results from literature based on external and World Bank reports (2 Seismic strengthening results from World Bank (2018a; 2019c; 2019a; 2019d))

Figure 15 presents boxplots that display the distribution of NPVs (in millions of euros) for different types of investments in earthquake based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). Extreme values are excluded from the top graph and included in the bottom one.

Figure 15: Findings of BCA for earthquakes (NPVs)

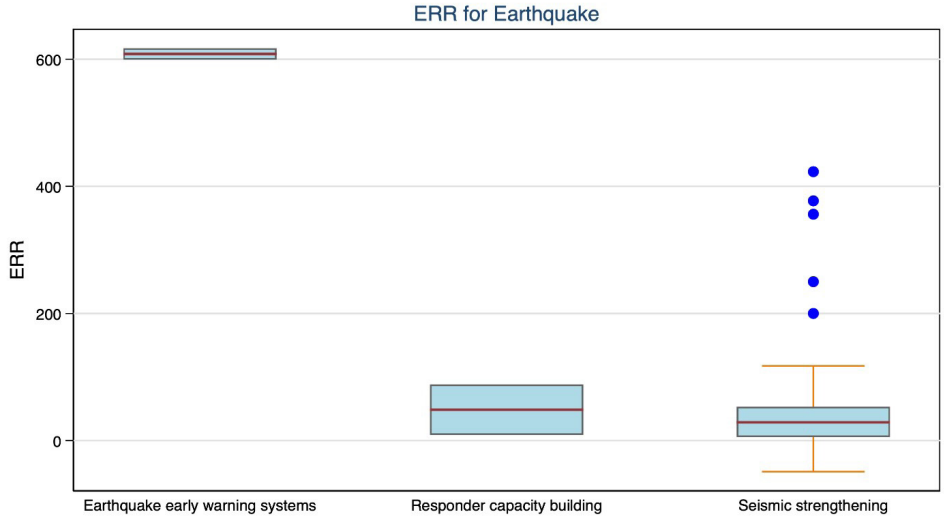




Source: World Bank analysis based; on external data and information; presenting in part results from literature based on external and World Bank reports (2 Seismic strengthening results from World Bank (2018a; 2019c; 2019a; 2019d))

Figure 16 presents boxplots that display the distribution of ERRs for different types of investments in earthquake based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). The outliers are shown as dots.

Figure 16: Findings of BCA for earthquakes (IRRs)



Source: World Bank analysis based on external data and information; presenting in part results from literature based on external and World Bank reports (2 Seismic strengthening results from World Bank (2018a; 2019c; 2019a; 2019d))

Seismic strengthening of buildings and infrastructure is intended to improve the safety of buildings (or infrastructure) and its occupants in an earthquake. Physical earthquake risk reduction can vary in scale and cost, from small works such as securing bookshelves and equipment against improving the structural safety of the entire building by retrofitting structural or non-structural elements. Major retrofits usually require large capital investments and are therefore generally undertaken only when there are legal obligations or allocated funds. This is the case particularly for cultural buildings and governments in certain countries such as Italy that have implemented large programs for retrofitting of infrastructure and safeguarding cultural heritage.

- **Case study 9 (new analysis under this project, ex post (Dolce, 2012; JBA Risk Management, 2021)):** The analysis of the National Plan for Seismic Risk Prevention implemented by the Government of Italy 2010–2016, focusing on investments strengthening private residential and mixed-use buildings and retrofitting of public buildings, zyielded mixed results. The analysis considering AALs found BCR > 1 for local strengthening interventions and BCRs less than 1 for other intervention types, while the probable maximum loss (PML) analysis (475-year return period, rare event) found BCRs higher than 1 for all intervention types for public buildings (BCRs of 1.65, 1.66, and 3.5 for, respectively, seismic upgrading, demolition and reconstruction, and local strengthening; NPVs of €268.6 million, €13 million, and €65 million, respectively; IRR/ERR of 64.68, 65.66, and 250 percent, respectively). Results differed between interventions considered and between public and private buildings. Overall, the analysis shows that (1) policy objective (rare event versus average building lifetime) and related methodology affect possible results, (2) interventions focusing on certain types of buildings and choice of certain interventions (considering broader economic benefits) can yield higher net benefits, and (3) interventions in private buildings were mostly found to be economically viable.

- **Case study 10 (World Bank PAD analysis (World Bank, 2018a; 2019a; 2019c), ex ante):** The analysis of three projects in Romania, financed by the World Bank, focus on the upgrade of critical disaster and emergency response buildings yielded variable net benefits given different interventions and projects and varied among earthquake scenarios (BCRs in the range of 1–2; NPVs from negative to €27 million, IRR/ERR from negative to 73 percent), with a likely underestimation due to the lack of quantitative measurement of second and third dividends (energy audits would be necessary to have quantitative assessments of the latter). These second and third dividends would comprise, for example, wider benefits in terms of economic activity due to adapted investments from the private sector linked to expectations of better emergency response buildings and capacity or energy efficiency and linked climate benefits of improved buildings, among others.

- **Case study 11 (new analysis under this project, ex ante[9]):** The analysis of hypothetical investments into seismic strengthening and energy efficiency in education facilities in European earthquake-prone countries shows mixed results. However, the analysis overall supports the message like on the analysis for Italy that investments become particularly economically viable when considering the potential impact of rare events (that is, PML versus AAL), that investments in school buildings should be prioritized based on spatial vulnerability, and that energy efficiency measures combined with earthquake risk reduction can allow for substantially higher net benefits than when investments are undertaken separately (BCRs range of 0.93–1.46 depending on countries and type of analysis, NPVs of –€63.3 to €422 million, IRR/ERR of –7.19 percent to 46.11 percent). For certain countries such as Greece, Romania, Bulgaria, and Slovenia, the investments would be economically viable based on PML and AAL analyses. Interestingly, interventions are economically beneficial across the board, with only some exceptions, for comprehensive investments in universities. Given the nature of the results from the regional analysis, it is recommended that future BCAs are conducted at an asset level to more precisely identify education facilities that are economically viable to retrofit.

- **Case study 12 (World Bank PAD analysis (World Bank, 2019d), ex ante):** The analysis of the World Bank project in Turkey focusing on the reconstructionand retrofitting of around 350 schools yielded a BCR of 1.53 (NPV €120.4 million). The calculations of energy efficiency benefits could be quite specific given recent benchmark data on characteristics of buildings that the analysis could base itself on.

EEWS consist of physical infrastructure and software that can alert stakeholders about an incoming earthquake seconds to minutes before they experience the resulting strong shaking, which allows for actions (moving to a safer location, shutting off gas pipelines, switching signals to avoid entering a risky area, and so on) to decrease detrimental impacts from shaking. The Euro-Mediterranean area has a strong need for effective EWS: only a few countries have operational systems in place (Romania and Turkey)

9 Data on schools and modelling across Europe, GEM 2021.

and one study found that only 44 percent of examined target sites (Cremen, et al., 2020) benefit from warning times long enough to accommodate effective actions from stakeholders. This is being addressed by projects such as Horizon 2020 TURNkey[10] but country-specific actions would likely have to be highly beneficial to find adapted measures.

- **Case study 13 (new analysis under this project, ex post (European Union, 2020)):** The analysis of the EEWS in Bucharest as part of the DACEA program partially funded by the EU aims at providing warning to authorities to shut down critical infrastructure (nuclear power plants, trains, and so on). Due to the lack of data for critical infrastructure, the analysis for the EEWS investigates incremental and conservative losses avoided. These include the value of one life loss avoided due to appropriate warning and the cost avoided of one train being derailed. In addition, the value of construction to the broader economy is included as an additional benefit. This conservative analysis of the existing EEWS yielded a BCR greater than 1. It has to be noted, however, that few methodologies exist for economic valuation of EEWS and therefore this study should be considered as exploratory research. With the conservative assumptions, the study found a BCR in the range of 3.4–11.1 (NPV of around €19 million linked to BCR of 7, IRR/ERR of 617 percent). Although the benefits are likely to be underestimated given the lack of information/data, the issues of needed complementary investments and therefore potential double counting still remain in general for EWS investments.

Responder capacity building affects the effectiveness of disaster response, as the latter is directly associated with the skills of the responders at a disaster site, as well as their effective coordination with other resources deployed (Sinclair, et al., 2012). It is therefore essential for authorities to establish emergency management training and live exercise programs to build capacity of responders and response coordinators. DG ECHO funds capacity building through the Union Civil Protection Knowledge Network. No methodologies have been developed, so this represents an exploratory systematic attempt at measuring the benefits of these softer investments. Although the case studies had to make a number of assumptions, overall, the intellectual thinking on how to account for the various potential dividends of softer investments is a great contribution to the literature.

- **Case study 14 (new analysis under this project, ex post (Perry, 2004)):** The analysis of investments in training for emergency responders and response coordination through the UCPM Knowledge Network, with focus on two disaster interventions during disaster events (Albania November 2019, Croatia March 2020) showed net benefits of impact realized on the ground and additional softer benefits. The events were different in magnitude, assets, and lives lost, as well as international assistance (in Albania damage assessments were supported and UCPM-trained rescuers helped on the ground whereas in Croatia there were no international rescuers, but local staff had been trained under the UCPM). However, in both cases, the BCRs are greater than 1 (1.9 in Albania, 1.1 in Croatia) as well as NPVs (€5 million and €0.3 million) and ERRs/IRRs (88.33 percent and 8.82 percent). All three dividends have been considered and it has to be noted that in the case of Albania the first dividend was highest given the benefits that could be reaped owing to rapid damage assessments (such as saved costs of temporary shelter/accommodations) and in the case of Croatia where such benefits could not be linked to international assistance, the third dividend was found to be highest (job security and salary increases for qualified staff).

3.2.2. SEISMIC STRENGTHENING OF BUILDINGS AND INFRASTRUCTURE

Seismic strengthening of vulnerable buildings and infrastructure is one of the main ways to reduce existing earthquake risk. Seismic strengthening is intended to improve the safety of buildings (or infrastructure) and its occupants in an earthquake. Physical earthquake risk reduction can vary in scale and cost, from small works such as securing bookshelves and equipment against falling to improving the structural safety of the entire building by retrofitting structural elements (for example, foundation, structural walls, beams, and columns) and non-structural elements (for example, partition walls,

10 TURNkey = Towards more Earthquake-resilient urban Societies through a Multi-sensor-based Information System enabling Earthquake Forecasting, Early Warning and Rapid Response actions.

staircases, facades, and HVAC elements). Seismic strengthening can range from local strengthening of select vulnerable elements to more major retrofits involving the entire structure. In some cases, buildings can be deemed not cost-effective to retrofit where too large of an investment is required and buildings need to be demolished and reconstructed. Given the large capital investments required for seismic strengthening, they are seldom undertaken on a voluntary basis by owners, where strengthening is more commonly carried out when required by the building code or an ordinance, is triggered by a change of use, or is part of a seismic risk reduction investment program.

Seismic strengthening programs at scale require large capital investments, risk assessment, and planning. While large-scale seismic strengthening programs are not widespread in EU MS, there are several examples of successful programs. Seismic strengthening programs are typically designed to prioritize vulnerable buildings and infrastructure that are at high risk, are critical, or are of strategic importance. Therefore, risk assessment and BCA are key tools in helping prioritize and plan for seismic risk reduction investments.

The benefits of seismic strengthening are commonly determined by considering the difference in social and economic losses caused by earthquake damage with and without the intervention (Cardone, et al., 2019; Liel & Deierlein, 2013; Yi, et al., 2020). This is done by conducting risk analysis, simulating damage to buildings and infrastructure, which in turn is used to quantify losses. Seismic retrofit BCAs commonly analyse the effect of several retrofit solutions on a specific type of building (for example, unreinforced masonry, reinforced concrete frames, and soft-story wood structures), where probabilistic earthquake engineering analysis is used to quantify the reduction in post-earthquake repair costs - the main considered benefits. Studies point out that considering reduction in repair cost as the sole benefit does not typically result in a positive return rate of a retrofit investment (Liel & Deierlein, 2013). For this reason, other benefits commonly considered in seismic BCAs are reduction in fatalities (Yi, et al., 2020) and injuries (Cardone, et al., 2019). Similar approaches are used to assess the benefits of investment in infrastructure such as bridges, where a study that used risk-based seismic life-cycle BCA found that depending on the location, type of bridge, and type of retrofit, the BCRs range from less than 1.0 (not cost-effective) to 9.8.

To quantify earthquake consequences with and without strengthening interventions, analysis frameworks such as HAZUS (Kircher, et al., 2006) and FEMA P-58 (Hamburger, et al., 2012) are commonly used. In addition to direct property damage, frameworks like HAZUS provide a methodology for calculating reduction in direct business interruption loss (for example, factory shutdown from direct damage or lifeline interruption), indirect business interruption loss (for example, ordinary economic 'ripple' effects), societal losses (deaths, injuries, and homelessness), emergency response services (for example, ambulance service, fire protection), and other non-market damages (for example, historic sites). A study which evaluated BCRs of the US Federal Emergency Management Agency's mitigation grants used an adaptation of the HAZUS methodology to show that the average BCR of earthquake mitigation grants involving physical strengthening works was 1.4 (Rose, et al., 2007). The study concluded that considering the reduction in property loss reduction alone was not sufficient for the average BCR from mitigation measures to exceed 1.0, and the largest component of benefits (62 percent) came from the reduction of casualties.

A recent report by (NIBS, 2019) showcases a comprehensive BCA of natural hazard mitigation in the United States, considering riverine floods, hurricane surge, wind, earthquake, and WUI fire. The mitigation measures that were evaluated ranged from adaptation and exceedance of up-to-date building codes to retrofit of existing buildings and utility and transportation infrastructure. In terms of seismic strengthening strategies, the study examined BCRs for seven earthquake retrofit measures: strengthening the first story of soft-story dwellings, adding engineered tie-down systems to manufactured homes that are not anchored to the ground, strapping water heaters to the building frame, adding child safety latches to kitchen cabinets, securing tall bookcases to the wall, strapping computer monitors and televisions to desks or shelves, and securing fragile objects to their shelves with museum putty. The BCRs of retrofit measures varied widely depending on the measure and hazard level but averaged between 2 and 24. The two most cost-effective measures across geographies were soft-story retrofit and strapping water heaters to the building frame. However, the building codes have the potential to reduce the most overall damage.

SEISMIC STRENGTHENING IN THE CONTEXT OF TRIPLE DIVIDEND BCA

The following is a brief description of the seismic strengthening benefits considering the triple dividend framework:

- **Dividend 1:** The benefits related to reduced earthquake consequences include, but are not limited to, reduction in losses related to direct and indirect asset damages (caused by secondary hazards), direct and indirect business and service interruption losses, social losses including casualties and psychological trauma, natural capital losses, historical asset damages, and emergency response costs.

- **Dividend 2:** Investment into earthquake risk reduction contributes to economic stability and reduced uncertainty. In terms of benefits, these can translate into improved government/business image and credit rating associated with business continuity (Rose, 2016). Strengthened assets and infrastructure can provide better access to insurance markets and reduced insurance premiums. Investment into seismic strengthening can also support engineering innovation and technology development.

- **Dividend 3:** The third dividend relates to co-benefits of DRM investment. Seismic strengthening that involves significant capital works is often accompanied by renovation and functional improvements, which can result in improved working/living conditions, higher asset valuation, and increased revenue in case of commercial real estate.

Co-investment into seismic strengthening and energy efficiency improvements can be a significant co-benefit for EU countries. A large portion of European cities comprise aging building stock, which often present high social, financial, recreational, and cultural values. Currently, 80 percent of the existing EU buildings were built before the 1990s, of which 40 percent were built before the 1960s (European Commission, 2019). These structures tend to be more susceptible to seismically induced damage and are candidates for seismic retrofitting, as many of them need to be maintained as cultural heritages. At the same time, the EU's Energy Efficiency Directive also set a target of reaching 20 percent energy efficiency by 2020 (European Commission, 2021). Retrofitting existing buildings so that they are both seismically resistant and energy efficient usually requires high costs (European Commission, 2019). These conditions lead to a growing need for combined retrofitting and energy efficiency, and this is reflected in the EU's focus on integrating energy efficiency and seismic upgrading into one agency (European Commission, 2020d).

In this context, the European Commission has purposed a methodology (European Commission, 2020d) to evaluate the combined approach of both seismic improvement and energy efficiency of a building. The methodology suggests three important aspects that needed to be considered: (1) reduction of CO2 emissions, (2) energy efficiency of the building, and (3) the building's resilience to natural hazards. However, there are limits and barriers to the combination of seismic safety and energy efficiency retrofits, which include technical difficulties for seismic retrofits, owners' insufficient awareness of the seismic vulnerability and energy performance of their building, and bureaucratic obstacles (Sigmund, 2019). As a result, many of the evaluations of European buildings only consider the reduction of CO2 emissions and energy efficiency as important criteria and hardly address the buildings' vulnerability to natural disasters and hazards (European Commission, 2020d).

Therefore, it is essential to include benefits from co-investments in the integration of energy efficiency and seismic retrofitting of buildings into the BCAs so that such investments can be further promoted. A study has shown that combined energy and seismic retrofit investment is economically efficient, as the combined method will result in a significant reduction in the payback periods in moderate to high seismicity region compared to separate investments. The study also suggests a 3 percent renovation rate for buildings, which will lead to a 30 percent reduction in CO2 emissions across all cities by 2030s. An energy retrofit and seismic upgrading project for a school building in Italy has proved such a benefit. An analysis (Mora, et al., 2018) of the project addresses the efficacy and cost of the project and the results suggest that by

combining energy and seismic retrofit, there is a 53 percent in cost saving and a 96 percent reduction in energy consumption. Therefore, it is concluded that the combined intervention is economically preferable and generates less cost compared to the cost of two different interventions.

BCA MODELLING CHOICES AND IMPLICATIONS ON THE RESULTS

Earthquakes can cause widespread societal and economic losses in a single event, but their infrequent occurrence poses challenges when conducting BCA and interpreting the results. Several different approaches have been used to quantify the benefits of earthquake risk reduction investment and care must be taken when selecting and interpreting the results of an earthquake-related BCA.

Dividend 1 benefits are only realized when an earthquake occurs, whose timing and magnitude are characterized by large uncertainty. The impacts of earthquakes are nonlinear; small and frequent earthquakes may produce little to no damage, where earthquakes with shaking above a certain threshold can cause buildings to suddenly collapse. There are two common approaches to conducting a seismic strengthening BCA: single-scenario assessment and stochastic-event assessment (often referred to as probabilistic seismic risk assessment).

In the first approach, a single earthquake scenario of a specified magnitude is chosen and the consequences with and without strengthening are evaluated. The earthquake scenario is typically chosen based on a significant historic earthquake or a large potential earthquake based on seismologic studies. This approach can be thought of as a 'what if' analysis that does not explicitly consider the likelihood of occurrence of that event. Given that the chosen scenario is typically a large earthquake, the potentially realized benefits from strengthening are often significant and result in relatively large BCRs. They, however, do not reflect the likelihood of this scenarios which may not occur in the investment lifetime. This analysis is often used when the beneficiary is concerned with managing the adverse consequences of rare event and wants results that are easy to communicate. In such cases, there needs to be acknowledgement that the benefits might not realize during the investment time.

The second approach that is commonly adopted in earthquake investment BCAs is based on assessing all possible damaging events considering their probability of occurrence. For example, seismic strengthening can lead to significant benefits in a large earthquake, but the low probability of that will result in a 'lower' weight compared to a more frequent/less damaging event. A common metric that is used in such an analysis is the reduction in AALs, that is, reduction in losses from all damaging earthquakes that can occur in a given year weighted by the probability of earthquakes' occurrence. The BCRs are then calculated by dividing the NPV of the benefits (considering the design life of the asset) by the cost of seismic strengthening. Another metric that is sometimes considered is the payback period of the investment (Cardone, et al., 2019; Yi, et al., 2020), which indicates how many years on average it will take to pay back the investment. The advantage of using this type of analysis is that it considers the likelihood of earthquake events; the downside is that it often results in lower BCRs since extreme consequences are 'averaged out'. Therefore, it might not be a suitable analysis method if the beneficiary is concerned with the consequences of infrequent, large-consequence events which pose a large risk to society. One option to account for infrequent losses is to consider benefits associated with a lower probability of occurrence—another by-product of the probabilistic seismic risk analysis. As an example, benefits associated with a 10 percent probability of exceedance in 50 years can be considered, which is similar to the philosophy of earthquake-resistant design which is based on 'rare' earthquake shaking with 10 percent probability of exceedance in 50 years (or 475-year return period).

EVALUATING THE BENEFITS OF SELECTED INVESTMENTS OF THE 2010-2016 NATIONAL PLAN FOR SEISMIC RISK PREVENTION IN ITALY

This case study is a new ex post analysis under this project that involved modelling of hazards.

→ Description

This case study aims to evaluate the benefits of the investments made by the Government of Italy under the 2010–2016 National Plan for Seismic Risk Prevention (more details on programs for cultural heritage protection are included in *Box 7* below).

Box 7: Cultural heritage protection and seismic strengthening in Italy

Due to Italy's geodynamics, developmental dynamics, and architecture and wealth of cultural heritage, the country is more susceptible to earthquake devastation than other European countries. In 2016, a 6.2 magnitude earthquake (Povoledo, 2016) in Central Italy killed 296 people and severely damaged over 50 historic sites in seismically active areas. Moreover, €541 million out of €23,53 billion in earthquake-induced damages that same year were caused by direct seismic impacts on cultural heritage sites. Despite Italy's progressive approach to improving earthquake resilience, reversible intervention techniques are greatly preferred for cultural sites due to the deeply felt historical connections to assets. As a result, the Italian government has been an involved partner in the ResCult platform ("Increasing Resilience of Cultural Heritage") (ResCult, 2021). Italy has also developed a risk map using comprehensive alphanumeric and cartographic database of cultural assets throughout the country and trained "art squads" to retrieve, categorize, store, and restore cultural assets in case of an emergency.

Moreover, several projects have specifically supported the reconstruction or rebuilding of specific buildings. The Basilica of St. Benedict in Norcia, for example, is an important religious emblem of European monasticism that was heavily destroyed in the earthquake of 30 October 2016. With a €10 million budget, of which half is financed by the EU, the Basilica will be rebuilt using an earthquake-resistant structure, energy-saving air conditioning and lighting, and a continuous data-acquiring remote monitoring system between 2017 and 2023 (European Commission, 2019c). Despite these upgrades, the structure's reconstruction is aimed at ultimately restoring the Basilica's historic, cultural, and social role of fostering social and economic activity for the local community.

Italy is exposed to high seismic hazard, where in the last two decades it saw numerous damaging earthquakes throughout its territory. Following the 2009 Abruzzo (L'Aquila) earthquake, under this program, €963.5 million (Dolce, 2012) was allocated to various activities, which were implemented by the Civil Protection Department over seven years. The program's primary objective was to reduce the human losses during earthquakes and incentivize private owners and administrators to take actions to reduce seismic risk. This includes building an understanding on the vulnerability of buildings, the importance of local amplification, and the use of microzonation[11] studies (Dolce, et al., 2019a; Moscatelli, et al., 2020) to improve urban and emergency planning, as well as ensuring correct implementation of civil protection plans considering the vulnerability of the strategic elements and the interconnection routes. The National Plan for Seismic Risk Prevention allocated financial resources to higher-risk municipalities, whose 475-year return period peak ground acceleration[12] on stiff soil exceeds 0.125 g. The program's activities focused on three main areas (Dolce, et al., 2019):

1. Seismic microzonation studies and analysis of the Limit Condition for Emergency (LCE), to support territorial governance and emergency planning

2. Seismic retrofit and reconstruction of public buildings and infrastructure of strategic interest or infrastructure critical for the consequence of their collapse

3. Seismic upgrading and reconstruction of private buildings.

11 Microzonation studies are aimed at understanding the geological, geotechnical, geophysical, and geometrical characteristics of areas to provide reliable maps of seismic ground shaking parameters and induced hazards, such as liquefaction and landslides.
12 PGA is the largest ground acceleration recorded during an earthquake event.

This case study evaluates the efficiency of selected investments under the National Plan for Seismic Risk Prevention using a Triple Dividend BCA Framework. In particular, it focuses on select assets under the following two investment streams: (a) strengthening of private residential and mixed-use buildings and (b) retrofitting of public buildings. Given the data availability, the BCA focuses on evaluation of dividend 1, or avoided disaster losses, by using probabilistic earthquake risk modelling. It should be noted that only a subset of buildings from the overall investment were considered for the BCA.

Investments and prioritization of public buildings were made based on the potentially devastating consequences in case of collapse and strategic importance of facilities for civil protection purposes. The following categories of buildings were included in the analysed investments as outlined in *Table 24*.

Table 24: Types of buildings included in Italy's seismic retrofitting by sector

SECTOR	TYPES OF BUILDINGS
Public administration buildings	Administrative buildings, city hall, post office, and so on
Civil protection headquarters	Municipal civil protection centres, regional civil protection headquarters, and so on
Health care facilities	Hospitals, health care facilities, nursing homes
Military and firefighting facilities	Carabinieri and public security, firefighters, state forestry corps
Places of social or sporting activity	Gymnasiums, stadiums, paces of social or sporting activity
Education facilities	Schools

Source: Dolce (2012)

Given that the number of private buildings that require seismic strengthening far exceeds the available resources, the investments were prioritized in municipalities with the highest seismic hazard in the region, where the buildings were assigned a score (Dolce, 2012) based on the year of construction and the construction material. For private buildings, government investment was intended to be an incentive rather than a total refund of the expenses, where co-financing by private owners was expected and the government refunded only the costs of the structural intervention up to a certain maximum. Information of private owners' co-financing amounts was not available.

→ Methodology

The benefits derived from the investment were evaluated by modelling the consequences of numerous earthquake scenarios with and without earthquake strengthening interventions. The results of the model quantified the decrease in losses associated with asset damage, fatalities, injuries, and the number of days the building function is interrupted. It should be noted that the estimation on the number of interruption days is a conservative estimate where certain functions can continue through temporary arrangements or in other buildings. The benefits were evaluated based on two analyses: (1) a decrease in AALs (that is , annual loss averaged over a very large number of years) assuming a 50-year building design working life following the investment and (2) a decrease in losses from an infrequent large event corresponding to a 475-year return period, hereinafter referred to as PML analysis. While the 50-year design life period is chosen in line with the Eurocode, in reality many buildings may function beyond that time frame, which would further increase the benefits of the seismic strengthening. The earthquake risk model that was used to evaluate the losses consisted of three major components of earthquake risk analysis: hazard, exposure, and vulnerability.

Hazard model: ESHM13[13], also known as the 'Seismic Hazard Harmonization in Europe' (SHARE) project, was used to conduct the risk analysis (Woessner, et al., 2015). ESHM13 provides a consistent seismic hazard model for all of Europe, whose creation involved several institutions and experts throughout the region, and it was built upon several national and regional seismic hazard models. Within the SHARE project, three alternate seismic source models were developed using historical and instrumental earthquake catalogues, a database of seismic faults, and tectonic regionalization with associated ground motion models. The seismic source models and associated ground motion models were used to perform an event-based risk analysis, which considered all plausible damaging earthquakes and their probability of occurrence. In this process, a stochastic event set is generated, which is indicative of the seismicity of the region over a given period. Each of these rupture events produces a ground-shaking field, which is then used to estimate associated impacts and losses from the modelled exposure.

Exposure and vulnerability models: To estimate the risk, information regarding the exposure (for example, location, building typology, and value) and vulnerability (for example, damageability) is required. The provided exposure data from the 2010–2016 National Plan for Seismic Risk Prevention in Italy denote the location, size, use category, material type, design year for public buildings or construction period for private ones, intervention type, and cost of intervention. The vulnerability models associated with GEM Foundation's 2018 Global Risk Model (as documented in Martins and Silva 2020) have been used as a starting point to relate the ground shaking (for example, peak group acceleration) to a damage level (for example, slight) and loss (for example, repair cost, fatalities, and disruption time). These vulnerability models follow the GEM taxonomy (Brzev, et al., 2013), and therefore a mapping scheme between the provided exposure data and the GEM taxonomy building classes was required. As part of the ongoing European Seismic Risk Model 2020 (ESRM20) study, Crowley et. al. (2020) reviewed the seismic design regulations throughout Europe and proposed a mapping between design year and code quality. These benchmark code years (that is, no code before 1908, low code before 1996, moderate code before 2010, and high code afterwards for the case of Italy) were used to infer a mapping between the design year provided and their associated ductility levels (indicative of seismic vulnerability)[14], which are a fundamental component of the GEM taxonomy. Information regarding the intervention type (for example, local strengthening) was also used to infer a code or ductility level and construction type for both the baseline and retrofitted case, based on background information of the retrofit program provided by Dolce (2012) . For example, any intervention type would lead to an increase in code quality or ductility, but only demolition and reconstruction would ensure high code quality or ductility (whereas the lesser intervention types might lead to only a moderate code quality or ductility). Additionally, buildings that only required local strengthening were assumed to overall be less vulnerable compared with buildings that required seismic upgrading or demolition and reconstruction, as there were specific criteria to ensure that those buildings did not have notable seismic deficiencies, damage, or irregularities.

Benefit estimation: Given the data availability, the BCA explicitly quantified the benefits associated with dividend 1: reduction of losses associated with avoided injuries, avoided fatalities, reduced damage, and reduced disruption associated with building closure. Each of the benefits was quantified as per *Table 25*.

Table 25: Methodologies of benefit estimations

BENEFIT	METHODOLOGY
Avoided injuries	The benefit from the reduction in injuries was evaluated using a method from the US Department of Transportation that estimates the value of preventing injuries as a fraction of VSL. Injuries with and without interventions were estimated using the HAZUS methodology, where Severity 2 and 3 injuries were considered.

13 While ESHM13 was used for this analysis, it is not consistent with the procedures and the criteria used by the Italian seismic prevention program to identify the areas where the program is applicable, define the initial and the final safety conditions, and so on. The prevention program used the official 2004 seismic hazard model since 2004.

14 This is a simplification, where in reality fundamental design standards were issued at different times throughout the territory

Avoided fatalities	The benefit associated with the reduction in fatalities was evaluated based on the VSL.
Decrease in repair cost	The difference between repair cost with and without intervention was evaluated for each of the buildings depending on the level of damage.
Decrease in losses due to interruption of services	First, a decrease in non-functional days was estimated by taking the difference in disruption days without and with the intervention. Then, the benefits associated with decrease in service disruption were calculated using the buildings' area, an assumed employee density, the decrease in disruption days, and the average GDP per employee in a relevant industry. Furthermore, the benefits associated with decrease in disruption of residential buildings were calculated using the number of occupants, the decrease in disruption days, and the average rental price per person. This assumes that the displaced will have to find alternate accommodations while their residences are inaccessible.

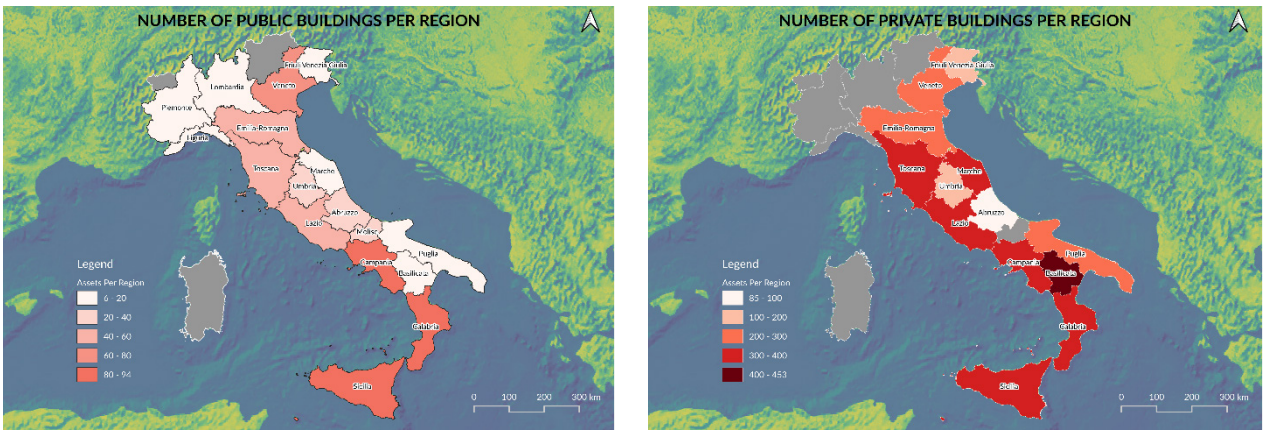
Source: World Bank analysis

The benefits were calculated considering a 50-year investment lifetime (building design working life, as prescribed in Eurocode, Category 4 building structures and other common structures), a discount rate of 3 percent, and a VSL of €6 million.

DATA

The data on select investments of the National Plan for Seismic Risk Prevention were provided by the Civil Protection Department. In total, 3,796 residential and mixed-use private buildings and 694 public buildings were analysed. *Figure 17* shows the distribution of buildings across the 17 regions of Italy, with the color showing the number of assets per region. Various types of building interventions were undertaken as presented in *Table 26*.

Figure 17: Number of buildings per region in Italy (private buildings on left, public buildings on right)



Source: World Bank

'Local strengthening' refers to less involved intervention, where single structural elements or portions of a structure are strengthened without varying the global structural behaviour. In the seismic case, they can be aimed at reducing or eliminating those unfavourable behaviours of single elements or structural parts that, due to inadequate local strength and/or ductility, can produce anticipated brittle failures. Local strengthening is typically done in beam-column joints of reinforced concrete framed structures or in the connections of orthogonal walls and walls with slabs in masonry buildings. The median intervention cost of such an investment among public buildings is approximately 10 percent of the building replacement cost.

'Seismic upgrading' is a more global intervention that alters the overall structural behaviour of the building and therefore requires more investment than local strengthening. Such an intervention is aimed at producing immediate reduction of the seismic risk of vulnerable buildings. The median cost of intervention of 'seismic upgrading' for public buildings is approximately 26 percent of the building replacement cost.

'Demolition and reconstruction' is an intervention type that is undertaken when a building is considered to be too costly to retrofit to acceptable safety standards or is functionally obsolete and requires reconstruction. The required investment for such an intervention strategy is the replacement costs plus the demolition cost.

Table 26: Number of building interventions conducted by sector and type of interventions

TYPE OF INTERVENTION NEEDED	NO. OF PUBLIC BUILDINGS WITH INTERVENTION	NO. OF PRIVATE BUILDINGS WITH INTERVENTION
Local strengthening interventions	70	2,400
Seismic upgrading	606	1,263
Demolition and reconstruction	18	133

Source: World Bank analysis; based on official data from the Italian Civil Protection Department

→ **Results of the analysis**

The following is a summary of results of the BCA for public and private buildings (see *Table 27* and *Table 28*).

Table 27: Investment into public buildings

	PUBLIC BUILDINGS DESIGN LIFE ANALYSIS (50 YEARS)				PML ANALYSIS (475-YEAR RETURN PERIOD)			
	All	By intervention type			All	By intervention type		
		Local strengthening	Seismic upgrading	Demolition and reconstruction		Local strengthening	Seismic upgrading	Demolition and reconstruction
DIVIDEND 1 (€, millions)								
Avoided injuries	26.6	3.4	21.9	1.3	66.1	8.5	54.4	3.1
Avoided fatalities	127.2	14.6	105.8	6.8	298.7	32.3	248.2	18.2
Decrease in repair cost	30.2	3.3	26.0	0.8	123.1	13.9	105.7	3.4
Decrease in losses due to interruption of services	67.7	7.6	58.4	1.7	319.9	36.3	275.6	8.0

Total dividend 1	251.8	29.0	212.2	10.6	807.7	91.0	683.9	32.8
Total benefits	251.8	29.0	212.2	10.6	807.7	91.0	683.9	32.8
Total costs	461.1	26.0	415.3	19.8	461.1	26.0	415.3	19.8
BCR	0.55	1.11	0.51	0.54	1.75	3.5	1.65	1.66
NPV (€, millions)	–209.3	3.0	–203.1	–9.2	–46.63	65.0	268.6	13.0
ERR (%)	–45.39	11.54	–48.90	–46.46	75.17	250.0	64.68	65.66

PUBLIC BUILDINGS DESIGN LIFE ANALYSIS (50 YEARS) BY FACILITY TYPE						
	Civil protection headquarters	Education	Health care	Military and firefighting	Recreation and sporting	Public administration and civic
DIVIDEND 1 (€, millions)						
Avoided injuries	0.8	10.6	2.4	1.5	1.7	9.5
Avoided fatalities	3.4	51.1	14.6	7.0	7.9	43.3
Decrease in repair cost	0.9	6.6	3.9	1.9	0.7	16.3
Decrease in losses due to interruption of services	2.0	11.0	13.2	4.7	2.0	34.9
Total dividend 1	7.0	79.3	34.1	15.0	12.3	104.0
Total benefits	7.0	79.3	34.1	15.0	12.3	104.0
Total costs	10.8	119.0	73.9	22.8	11.3	223.3
BCR	0.65	0.67	0.46	0.66	1.09	0.47
NPV (€, millions)	–3.8	–39.7	–39.8	–7.8	1.0	–119.3
ERR (%)	–35.19	–33.36	–53.86	–34.21	8.85	–53.43

PUBLIC BUILDINGS - PML ANALYSIS (475-YEAR RETURN PERIOD) BY FACILITY TYPE						
	Civil protection headquarters	Education	Health care	Military and firefighting	Recreation and sporting	Public administration and civic
DIVIDEND 1 (€, millions)						
Avoided injuries	2.0	25.9	6.3	3.7	4.3	24.0
Avoided fatalities	8.6	113.1	35.5	17.8	20.6	103.2
Decrease in repair cost	3.7	27.4	14.9	7.5	3.1	66.5
Decrease in losses due to interruption of services	9.2	52.3	60.9	21.0	9.2	167.2

Total dividend 1	23.5	218.7	117.6	49.9	37.2	360.9
Total benefits	23.5	218.7	117.6	49.9	37.2	360.9
Total costs	10.8	119.0	73.9	22.8	11.3	223.3
BCR	2.17	1.84	1.59	2.19	3.29	1.62
NPV (€, millions)	12.7	99.7	43.7	27.1	25.9	137.6
ERR (%)	117.59	83.78	59.13	118.86	229.20	61.62

Source: World Bank analysis; based on external data and information

Note: a. Service interruption in education does not include the social losses and childcare costs due to interruption of education; service interruption in the health care sector does not include casualties associated with loss of hospital functionality but only casualties caused by damage.

Several observations can be made from the public buildings BCR results:

- The BCRs are higher for the PML analysis since it considers the benefits realized in a more damaging event that can cause large losses. The results show that in the case of a large earthquake, the benefits exceed strengthening costs for all types of intervention across all the sectors.
- The design life analysis results show that the projected fatalities decrease by 73 percent, injuries by 80 percent, days of service interruption by 55 percent, and repair costs by 52 percent, as a result of the investment into public buildings.
- The PML analysis results show that the projected fatalities decrease by 84 percent, injuries by 87 percent, days of service interruption by 59 percent, and repair costs by 53 percent, as a result of the investment into public buildings.
- Local strengthening seems to be the most effective investment; however, the benefits from demolition and reconstruction are likely underestimated since the analysis does not account for the benefits associated with functional improvements, including improved use of space and energy efficiency.
- Greatest benefits are derived from decrease in avoided fatalities and service interruption, followed by decrease in avoided repair costs and injuries.

Table 28: Investment into private mixed-use buildings

	PRIVATE BUILDINGS DESIGN LIFE ANALYSIS (50 YEARS)				PML ANALYSIS (475-YEAR RETURN PERIOD)			
	All	By intervention type			All	By intervention type		
		Local strengthening	Seismic upgrading	Demolition and reconstruction		Local strengthening	Seismic upgrading	Demolition and reconstruction
DIVIDEND 1 (€, millions)								
Avoided injuries	18.4	9.9	8.1	0.5	48.3	25.8	21.1	1.3
Avoided fatalities	82.5	44.4	35.9	2.2	212.0	114.9	91.2	5.8

Decrease in repair cost	45.3	25.2	19.0	1.1	210.0	117.1	87.6	5.3
Decrease in losses due to interruption of services	13.9	5.4	8.3	0.2	69.5	26.7	41.7	1.1
Total dividend 1	160.2	84.9	71.2	4.1	539.7	284.6	241.7	13.5
Total benefits	160.2	84.9	71.2	4.1	539.7	284.6	241.7	13.5
Total costs	113.1	62.4	46.2	4.5	113.1	62.4	46.2	4.5
BCR	1.42	1.36	1.54	0.9	4.77	4.56	5.23	2.99
NPV (€, millions)	47.1	22.5	25.0	–0.4	426.6	222.2	195.5	9.0
ERR (%)	41.64	36.06	54.11	–8.89	377.19	356.09	423.16	200.0

Source: World Bank analysis; based on external data and information
Note: The total costs reflect the government investment and do not consider private owners' co-financing.

Several observations can be made from the private buildings BCR results:

- The design life analysis results show that the projected fatalities decrease by 85 percent, injuries by 85 percent, days of service interruption by 58 percent, and repair costs by 53 percent, as a result of the investments in private buildings.
- PML analysis results show that the projected fatalities decrease by 90 percent, injuries by 89 percent, days of service interruption by 62 percent, and repair costs by 55 percent, as a result of the investments in private buildings.
- In majority of the cases, the greatest benefits are derived from avoided fatalities, closely followed by a decrease in repair cost, and then avoided injuries and decrease in service interruption. Since the occupancy per building of private buildings is less than that of public buildings (that is, lower concentration of risk), a larger benefit is derived from reduction of repair costs.

→ Challenges and lessons learned

The earthquake analysis could be completed by inclusion of further aspects as outlined above. Other studies have shown substantial benefits with ex ante analysis for retrofitting of a variety of buildings, for example, in Romania, as well as considerable variability of results depending on types of damages and breadth of benefits considered or VSL assumed.

CO-INVESTMENT INTO SEISMIC STRENGTHENING AND ENERGY EFFICIENCY IMPROVEMENT OF EDUCATION FACILITIES IN EUROPE'S EARTHQUAKE PRONE COUNTRIES

This case study is a new ex ante / hypothetical analysis under this project that involved modelling of hazards.

The objective of this study is to evaluate the benefits and costs of investing in improved education facilities, particularly the returns on capital works intended to make schools and universities safe in earthquakes and improve their energy efficiency. Investment in the safety of education facilities is critical because these facilities house students, provide vital education services to the local community, and can also function as a place for shelter and resources in emergency response. Eight EU MS with moderate to high seismicity were considered: Austria, Bulgaria, Cyprus, Greece, Croatia, Italy, Romania, and Slovenia.

The study considers education facilities in higher hazard areas (475-year peak ground acceleration > 0.2g) and uses a representative school and university building for each of the countries to conduct the analysis (see *Table 29*). A representative building

considers the average number of students per facility and building materials that are commonly used in each of the countries.

Table 29: Number of schools and universities considered in the case study with associated national database websites

COUNTRY	MODELLED COUNTS	
	SCHOOLS	UNIVERSITIES
Austria	275	3
Bulgaria	4,486	21
Croatia	795	70
Cyprus	326	20
Greece	15,083	237
Italy	35,506	266
Romania	7,370	1,076
Slovenia	415	5

Source: World Bank analysis; based on statistics from national databases (Database AT, 2021; Database CY, 2021; Database IT, 2021; Database RO, 2021; Database SK, 2021; Database SL, 2021)

→ Modelling methodology and data inputs

The benefits derived from the investment were evaluated by modelling the consequences of numerous earthquake scenarios with and without interventions and quantifying the decrease in energy consumption from energy efficiency improvements. The quantified benefits include decrease in losses due to asset damage, fatalities, and injuries from earthquakes (dividend 1) and reduction in energy consumption and CO2 emissions due to improved energy efficiency (dividend 3). Dividend 1 benefits were evaluated based on two analyses: (1) a decrease in AALs (that is, annual loss averaged over a very large number of years) assuming a 50-year building design life following the investment period (that is, building design working life according to Eurocode, Category 4 building structures) and (2) a decrease in losses from an infrequent large event corresponding to a 475-year return period, herein referred to as PML analysis. In addition, energy savings and reduction in CO2 emission for a 50-year building design life were considered in both analyses. The following two sections briefly describe the modelling procedures for earthquake consequences and energy efficiency.

EARTHQUAKE CONSEQUENCE MODELLING

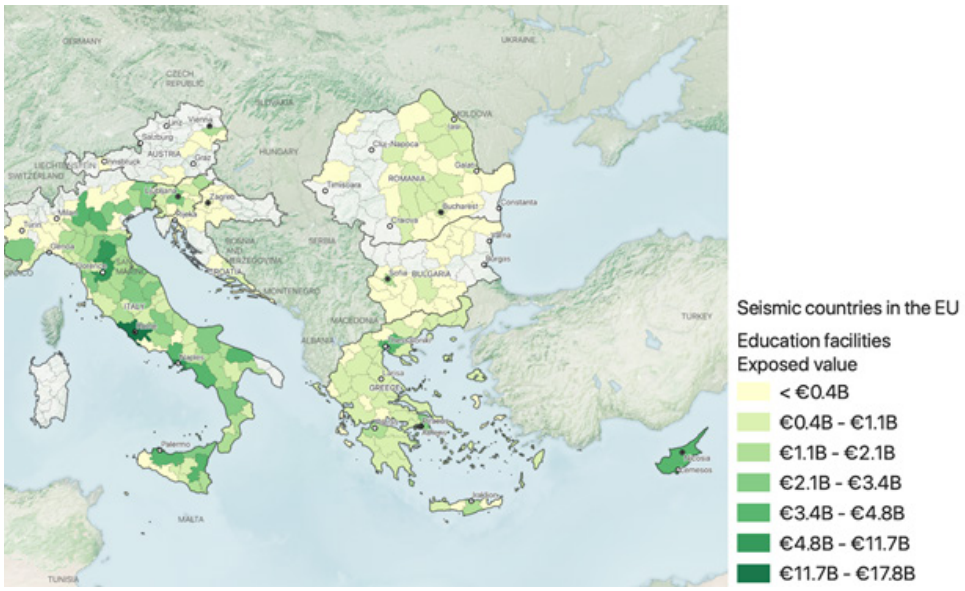
The earthquake consequence model that was used to evaluate the decrease in losses is similar to that in consisting of three major components of earthquake risk analysis: hazard, exposure, and vulnerability.

Hazard model: ESHM13, also known as the SHARE project, was used to conduct the risk analysis (Woessner, et al., 2015). ESHM13 provides a consistent seismic hazard model for all of Europe, whose creation involved several institutions and experts throughout the region, and it was built upon several national and regional seismic hazard models (see map of seismic countries in *Figure 18*, with the colors in map showing the exposed value of education facilities in the countries).

Exposure model and vulnerability model: For the eight countries, an exposure model for school and university buildings was derived. Aggregated national counts and occupants were based on GPSS GLOSI statistics, while the average area and replacement value of buildings came from the construction costs developed in the ongoing SERA project. The spatial distribution of education buildings within each country leveraged national data (where available) and existing OpenStreetMap data, and remaining buildings were distributed to the NUTS 3 areas proportional to the population (as per Eurostat). To identify the proportion of buildings that would be retrofit candidates within this hypothetical retrofit program, the exposure was

reduced further to consider (1) regions of relatively high seismic hazard and (2) building classes with relatively high vulnerability. The seismic hazard threshold was set at a minimum PGA of 0.2 g on soil for the 475-year average return period earthquake - assets in locations that did not meet this threshold were not considered to be candidates for retrofit and therefore removed from the study. Additionally, buildings classes that are known to have better performance (that is, moderate to high ductility levels, reinforced masonry) were not considered as candidates for retrofit and therefore removed from the study.

Figure 18: Map of seismic countries in the EU by the exposed value of education facilities



Source: World Bank analysis; based on external data and information

Construction typologies for the school and university buildings were inferred based on construction data for the residential and commercial buildings from the SERA project. Given the absence of building-specific information regarding construction type, vulnerability models that considered the range of possible construction types were derived. This approach involved the construction of weighted vulnerability curves, where the weight was equal to the proportion of value of each construction type relative to the overall exposed value from the SERA Project (minus the better-performing building classes discussed in the previous paragraph). The better-performing building classes (that is, moderate to high ductility and reinforced masonry classes) were not considered as candidate buildings, as a hypothetical retrofit program is likely to target building classes known to have poor performance (that is, no to low ductility and unreinforced masonry classes).

To inform the BCA, an estimate of the decrease in anticipated losses and the associated retrofitting cost was required (see *Figure 19* for percentage reduction in AAL). The anticipated decrease in seismic losses is due to a decrease in the overall vulnerability of education buildings, which was approximated by considering a step change increase in the level of ductility offered by each building class. For example, if a building was constructed to a 'low' code level for a given country, it was assumed the retrofitted building would now achieve a performance level equivalent to the 'moderate' code level of that country. This improvement would be reflected by an increase in the capacity of that building to resist earthquake shaking but not necessarily ensure that the building would be able to achieve the performance level associated with the latest (or 'high') code level of that country. The retrofit cost was assumed to be 5 percent, 10 percent, and 15 percent of the replacement cost, according to the building's risk level, which captures a range of interventions from local strengthening to more substantial capital works in accordance with the literature review (see *Table 30*).

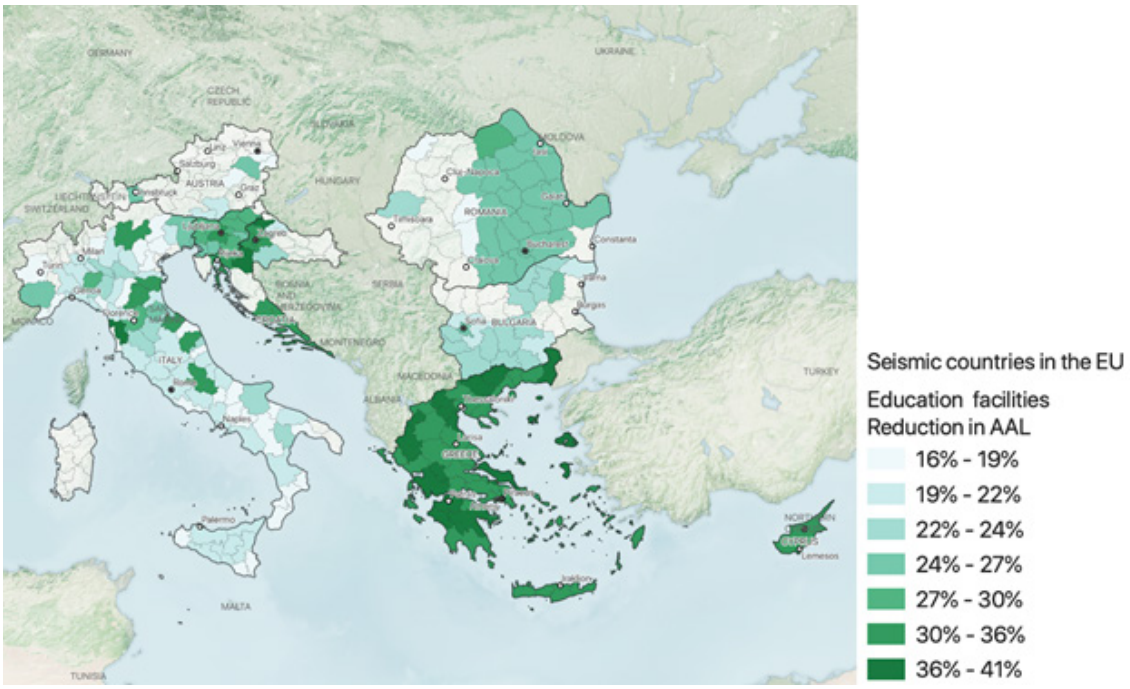
Table 30: Estimated retrofitting cost ratios from multiple sources

SOURCE	DESCRIPTION	RETROFITTING COST RATIO (%)
Italy case study	Seismic upgrading of schools	25
Calvi 2013	Strengthening with jacketing methods (that is, FRP, RC, and steel) applied to 50% of the elements	16
Calvi 2013	Adding new elements (for example, RC walls)	24
Kappos and Dimitrakopoulos 2008	Conventional retrofitting methods	12
Garcia, Hajirasouliha, and Pilakoutas 2010	FRP retrofitting methods in Mediterranean countries (partial - full)	5–15
Liel and Deierlein 2013	FRP retrofitting, RC jacketing, RC walls	10, 40, 30
Smyth et al. 2004	Added shear walls to a multi-story RC frame building retrofitted (partial - full)	32–54

Source: World Bank analysis; based on information and data included in sources reviewed
Note: FRP = Fibre-reinforced polymer; RC = Reinforced concrete.

The risk analyses for the baseline and retrofitting case were performed using the OpenQuake-engine, a free and open-source software that conducts seismic hazard and risk analyses. An event-based (or time-based) analysis was conducted, which allows for a probabilistic risk assessment of spatially distributed assets. The analysis was performed at the NUTS 3 level. Three risk metrics were considered: direct financial loss due to damage, injuries, and fatalities.

Figure 19: Percentage reduction in average annual direct losses due to damage for the retrofitted case



Source: World Bank analysis; based on external data and information

ENERGY EFFICIENCY IMPROVEMENT MODELLING

The objective of this analysis is to provide inputs into BCA for evaluating the costs and benefits of energy efficiency improvement investments in school buildings. The following sections describe the assumptions made, data sources used, and analysis results for energy efficiency improvement benefit estimation. Estimates were first made on per m² annual basis for the reference education buildings in each country, and then multiplied by the total area of the schools in the country.

Key parameters of existing educational buildings.: It should be noted that most of the educational buildings do not correspond to the current energy efficiency requirements for buildings thermal transmittance U-value (lower value means better performance, see *Table 31* for more details). Better energy performance of building elements observed in Austria and Slovenia could be related to the fact that part of the buildings were renovated in those countries including replacement of windows and exterior doors and insulation of whole or part of the building envelope. In other countries, most of the education buildings were still not upgraded.

Table 31: Key parameters of existing educational buildings

COUNTRY	FABRIC OF EXTERNAL WALLS FOR A REPRESENTATIVE EDUCATION BUILDING	AVERAGE U-VALUE OF EXTERNAL WALLS (W/M2K)	AVERAGE U-VALUE OF ROOFS (W/M2K)	AVERAGE U-VALUE OF WINDOWS (W/M2K)
Austria	Reinforced concreate, masonry	0.53	0.49	2.06
Bulgaria	Reinforced concreate, masonry, confined masonry	1.1	0.77	2.64
Croatia	Reinforced concreate, masonry, confined masonry	1.12	0.93	3.58
Cyprus	Reinforced concreate, masonry	1.7	2.1	4.19
Greece	Reinforced concreate, masonry	1.61	1.49	4.18
Italy	Reinforced concreate, masonry	0.6	0.87	4.11
Romania	Confined masonry, masonry	1.34	0.89	2.27
Slovenia	Reinforced concreate, confined masonry, masonry	0.6	0.53	1.71

Sources: European Commission (2020); European Union (2013a; 2013b; 2018)

Energy efficiency measures description. Energy efficiency measures required to improve energy performance of the buildings are presented in *Table 32* and expressed in thermal transmittance U-values. The normative requirements for energy performance of building elements vary among the countries. *Table 31* presents expected parameters of building elements after implementation of energy efficiency measures normalized for all 9 countries. Compared with the U-values of existing buildings in *Table 31*, there is a large gap in terms of achieving energy efficiency levels presented in *Table 32* below.

Table 32: Energy efficiency measures description

WALLS INSULATION	ROOF INSULATION	WINDOWS REPLACEMENT	HEATING, COOLING, VENTILATION	LIGHTING	EXTERNAL SHADING
7–20 cm thermal insulation on exterior walls, beams, and columns (U < 0.35 W/m2K)	20–30 cm insulation (U < 0.2 W/m^{2}K)	Double glass with thermal break (U < 1.5 W/m^{2}K)	Heating/cooling device replacement; installed systems, cleaning optimization	Lamps less than 10 W/ m2 installation	External moving shades installing where relevant

Sources: Thermal transmittance U-values normalized for all countries based on the estimates from European Commission (2020); European Union (2013a; 2013b; 2018)

Primary energy savings: Heat energy savings, expressed in kilowatt hours (kWh) per m2 of building useful area, estimated from 64 to 94 kWh/m2 per year for 'light/medium' renovation with two to three energy efficiency measures from *Table 33* would be implemented. For 'deep' renovation, four to six measures would be implemented, and primary energy savings would reach from 99 to 188 kWh/m2 per year. Electricity savings are estimated based on the electricity share used in each country for heating/ cooling and lighting of educational buildings. More electricity is consumed in southern countries like Greece and Cyprus, which use electricity as the main source for cooling of buildings.

Table 33: Primary energy savings

COUNTRY	NON-RENEWABLE ELECTRICITY SHARE IN SAVED PRIMARY ENERGY (%)	TOTAL PRIMARY ENERGY SAVINGS FROM 'LIGHT/ MEDIUM' RENOVATION (2–3 EE MEASURES IMPLEMENTED) (KWH/ M^2/YEAR)	'LIGHT/MEDIUM' RENOVATION ELECTRICITY SAVINGS (KWH/M2/YEAR)	TOTAL PRIMARY ENERGY SAVINGS 'DEEP' RENOVATION (4 OR MORE EE MEASURES IMPLEMENTED) (KWH/M2/YEAR)	'DEEP' RENOVATION ELECTRICITY SAVINGS (KWH/M2/ YEAR)
Austria	5	88	4	127	6
Bulgaria	15	60	9	116	17
Croatia	25	94	24	169	42
Cyprus	90	64	57	110	99
Greece	90	72	65	113	102
Italy	30	49	15	99	30
Romania	20	94	19	188	38
Slovenia	15	85	13	131	20

Sources: Primary energy consumption were estimated based on the comprehensive study of building energy renovation activities and the uptake prepared for the European Commission (European Commission, 2019b)

Primary consumption for heat and electricity were reviewed and adjusted according to European Commission (2020); European Union (2013a; 2013b; 2018)

Data for educational facilities is from the (European Commission, 2017)
Note: EE = Energy efficiency.

CO2 savings: Primary energy savings from *Table 33* were converted to tonnes of CO2 reduction using CO2 conversion factors for fossil fuels and electricity used in buildings. CO2 reduction estimations were made for 'light/medium' and 'deep' energy efficiency measures packages. For the CO2 monetary benefits, reference values of US$60 per tonne in 2020 and US$117 per tonne in 2050 were used (World Bank, 2017b), which were further extrapolated to the lifetime of the building. CO2-related reduction and CO2 economic price values are presented in *Table 34*.

Table 34: CO2 savings

COUNTRY	CO2 CONVERSION FACTORS FOR FOSSIL FUELS (NATURAL GAS, OIL USED ON-SITE OR DISTRICT HEATING (KG CO2/KWH)	CO2 CONVERSION FACTORS FOR ELECTRICITY (KG CO2/KWH)	CO2 SAVINGS 'LIGHT/ MEDIUM' EE RENOVATION (KG CO2/M²/YEAR)	CO2 'DEEP' RENOVATION (KG CO2/M²/ YEAR)
Austria	0.236	0.276	21	30
Bulgaria	0.29	0.819	22	43
Croatia	0.22	0.236	21	38
Cyprus	0.20	0.874	51	89
Greece	0.24	1.149	76	120
Italy	0.24	0.483	15	31
Romania	0.42	0.701	45	90
Slovenia	0.24	0.557	24	38

Source: World Bank analysis; based on data from Covenant of Mayors (2021)
Note: EE = Energy efficiency.

Energy costs and conversion factors: For the monetary estimation of energy savings of consumed heat and electricity for each country's education buildings, respective energy prices and energy conversion factors were used (see *Table 35*). While CO2 savings assessment uses primary energy savings, the assessment of monetary savings associated with reduction in use of consumer energy used the final energy savings at the building level. Primary energy refers to the energy that is converted directly from natural resources (primary fuels). Primary energy savings are reduced energy from the primary energy supply using less of primary fuels. Final energy consumption covers energy supplied to the final consumer at the building level. Final energy supplied from the distribution network does not include losses of the primary fuel conversion and supply, and thus it is usually lower quantity than primary energy. Final energy savings refer to the saved energy by the final consumer at the building level from the reduced energy consumption or by using energy more efficiently after implementation of energy saving measures.

Table 35: Energy costs and conversion factors

COUNTRY	HEAT ENERGY PRICE (€/KWH)	ELECTRICITY PRICE (€/KWH)	FINAL ENERGY TO PRIMARY ENERGY CONVERSION FACTORS (HEAT)	FINAL ENERGY TO PRIMARY ENERGY CONVERSION FACTORS (ELECTRICITY)
Austria	0.11	0.20	1.17	1.91
Bulgaria	0.06	0.11	1.30	3.00
Croatia	0.05	0.14	1.10	1.61
Cyprus	0.09	0.19	1.10	2.70
Greece	0.07	0.12	1.10	2.20
Italy	0.08	0.23	1.10	2.20
Romania	0.06	0.12	1.10	2.20
Slovenia	0.12	0.18	1.10	2.50

Sources: Conversion factors for heat and electricity were used according to European Commission (2020); European Union (2013a; 2013b; 2018). In case data in cost-optimal reports were not available, 1.1 primary energy conversion factor was used for heat and 2.2 for electricity conversion

Final annual benefit estimation: The investment costs of the 'light/medium' and 'deep' renovation options were determined on the basis of a comprehensive study of building energy renovation activities and the uptake prepared for the European Commission as well as the cost-optimal reports of each analysed country. Results of monetary benefits are presented in *Table 36* and *Table 37*.

Table 36: 'Light/medium' renovation monetary results

COUNTRY	INVESTMENTS (€/M²)	ENERGY EXPENDITURE SAVINGS (€/M²)	CO2 MONETARY BENEFITS MIN VALUE (€/M²)	CO2 MONETARY BENEFITS MEDIUM VALUE (€/M²)	CO2 MONETARY BENEFITS MAX VALUE (€/M²)
Austria	240	8.21	0.70	1.05	1.40
Bulgaria	100	2.50	0.74	1.12	1.49
Croatia	192	5.24	0.71	1.06	1.42
Cyprus	160	4.55	1.73	2.59	3.45
Greece	126	3.93	2.56	3.84	5.12
Italy	151	4.18	0.52	0.77	1.03
Romania	127	5.38	1.50	2.26	3.01
Slovenia	153	8.80	0.82	1.23	1.64

Sources: Costs for energy efficiency measures implementation were estimated based on the comprehensive study of building energy renovation activities and the uptake prepared for European Commission (European Commission, 2019b). Energy efficiency measures costs were reviewed and adjusted according to European Commission (2020); European Union (2013a; 2013b; 2018)

Table 37: 'Deep' renovation monetary results

COUNTRY	INVESTMENTS (€/M²)	ENERGY EXPENDITURE SAVINGS (€/M²)	CO2 MONETARY BENEFITS MINIMUM VALUE (€/M²)	CO2 MONETARY BENEFITS VALUE (€/M²)	CO2 MONETARY BENEFITS MAXIMUM VALUE (€M²)
Austria	294	11.86	1.01	1.52	2.03
Bulgaria	180	4.83	1.44	2.16	2.88
Croatia	288	9.45	1.27	1.91	2.55
Cyprus	227	7.86	2.98	4.47	5.96
Greece	182	6.17	4.02	6.03	8.04
Italy	265	8.48	1.04	1.57	2.09
Romania	246	10.76	3.01	4.51	6.02
Slovenia	225	13.52	1.26	1.89	2.53

Source: World Bank analysis; based on external data

RESULTS

The results of the building design life analysis and PML analysis for schools and universities are presented in the following tables (*Table 38* and *Table 39*).

Schools:

Table 38: BCA for schools

	AUSTRIA		BULGARIA		CROATIA		CYPRUS	
	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)
DIVIDEND 1 (€, millions)								
Avoided injuries	0.5	1.5	19.3	43.2	2.1	5.2	10.7	27.7
Avoided fatalities	5.4	16.7	182.7	486.6	18.6	50.6	87.0	235.0
Decrease in repair cost	2.4	12.3	11.1	27.6	2.2	6.1	52.9	141.6
Total dividend 1	8.2	30.5	213.1	557.5	22.9	62.0	150.6	404.3
DIVIDEND 3 (€, millions)								
Energy savings	227.7	227.7	445.3	445.3	139.9	139.9	464.5	464.5
CO2 savings	49.0	49.0	334.4	334.4	47.6	47.6	444.0	444.0
Total dividend 3	276.7	276.7	779.7	779.7	187.5	187.5	908.6	908.6
Total benefits	285.0	307.2	992.8	1,337.2	210.4	249.5	1,059.2	1,312.9
COSTS (€, millions)								
Seismic retrofit costs	78.0	78.0	270.2	270.2	60.9	60.9	600.9	600.9
Energy efficiency improve-ment costs	219.5	219.5	645.0	645.0	165.8	165.8	521.6	521.6
Total costs	297.5	297.5	915.2	915.2	226.7	226.7	1,122.5	1,122.5
BCR	0.96	1.03	1.08	1.46	0.93	1.10	0.94	1.17
NPV (€, millions)	–12.5	9.7	77.6	422.0	–16.3	22.8	–63.3	190.4
ERR (%)	–4.20	3.26	8.48	46.11	–7.19	10.06	–5.64	16.96

	GREECE		ITALY		ROMANIA		SLOVENIA	
	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)
DIVIDEND 1 (€, millions)								
Avoided injuries	77.8	105.5	139.1	150.2	35.7	35.7	6.0	13.7
Avoided fatalities	859.1	1,247.3	1,366.8	1,781.8	136.8	188.2	55.1	161.7
Decrease in repair cost	403.0	478.1	609.7	590.0	46.8	56.0	25.7	67.0
Total dividend 1	1,339.9	1,830.9	2,115.6	2,522.0	219.3	280.0	86.8	242.4
DIVIDEND 3 (€, millions)								
Energy savings	4,440.3	4,440.3	13,510.6	13,510.6	1,418.1	1,418.1	1,616.8	1,616.8
CO2 savings	7,278.6	7,278.6	4,191.8	4,191.8	998.6	998.6	380.3	380.3
Total dividend 3	11,718.9	11,718.9	17,702.4	17,702.4	2,416.7	2,416.7	1,997.2	1,997.2
Total benefits	13,058.8	13,549.7	19,818.0	20,224.4	2,636.0	2,696.7	2,084.0	2,239.5
COSTS (€, millions)								
Seismic retrofit costs	4,791.2	4,791.2	15,548.2	15,548.2	811.8	811.8	459.8	459.8
Energy efficiency improvement costs	5,087.3	5,087.3	16,410.3	16,410.3	1,259.9	1,259.9	1,045.7	1,045.7
Total costs	9,878.4	9,878.4	31,958.5	31,958.5	2,071.7	2,071.7	1,505.6	1,505.6
BCR	1.32	1.37	0.62	0.63	1.27	1.30	1.38	1.49
NPV (€, millions)	3,180.4	3,671.3	–12,140.5	–11,734.1	564.3	625.0	578.4	733.9
ERR (%)	32.20	37.16	–37.99	–36.72	27.24	30.17	38.42	48.74

Source: World Bank analysis; based on external data

Universities:

Table 39: BCA for universities

	AUSTRIA		BULGARIA		CROATIA		CYPRUS	
	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)
DIVIDEND 1 (€, millions)								
Avoided injuries	0.1	0.4	7.3	20.5	13.5	33.9	2.0	5.3
Avoided fatalities	1.5	5.1	77.5	241.5	129.1	360.6	24.4	69.9
Decrease in repair cost	0.5	2.7	3.8	14.2	13.4	33.1	7.5	20.3
Total dividend 1	2.1	8.2	88.5	276.2	156.0	427.7	33.9	95.6
DIVIDEND 3 (€, millions)								
Energy savings	34.9	34.9	104.8	104.8	431.6	431.6	92.9	92.9
CO2 savings	7.5	7.5	78.7	78.7	146.7	146.7	88.8	88.8
Total dividend 3	42.4	42.4	183.5	183.5	578.4	578.4	181.7	181.7
Total benefits	44.5	50.6	272.1	459.7	734.3	1,006.0	215.6	277.3
COSTS (€, millions)								
Seismic retrofit costs	11.9	11.9	59.5	59.5	183.2	183.2	86.5	86.5
Energy efficiency improvement costs	33.6	33.6	151.8	151.8	511.5	511.5	104.3	104.3
Total costs	45.6	45.6	211.4	211.4	694.7	694.7	190.8	190.8
BCR	0.98	1.11	1.29	2.18	1.06	1.45	1.13	1.45
NPV (€, millions)	–1.1	5.0	60.7	248.3	39.6	311.3	24.8	86.5
ERR (%)	–2.41	10.96	28.71	117.46	5.70	44.81	13.0	45.34

	GREECE		ITALY		ROMANIA		SLOVENIA	
	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)	Building design life analysis	PML analysis (475-year return period)
DIVIDEND 1 (€, millions)								
Avoided injuries	0.018	0.026	0.045	0.066	0.064	0.07	0.0007	0.0003
Avoided fatalities	0.14	0.23	0.27	0.41	0.4	0.53	0.001	0.004
Decrease in repair cost	0.006	0.009	0.21	0.28	0.058	0.068	0.0004	0.0013
Total dividend 1	0.22	0.35	0.52	0.76	0.53	0.67	0.0001	0.005
DIVIDEND 3 (€, millions)								
Energy savings	0.67	0.67	2.25	2.2	1.84	1.84	0.21	0.21
CO2 savings	1.09	1.09	0.7	0.7	1.29	1.29	0.005	0.005
Total dividend 3	1.76	1.76	2.95	2.95	3.13	3.13	0.26	0.26
Total benefits	1.98	2.11	3.47	3.71	3.65	3.8	0.27	0.31
COSTS (€, millions)								
Seismic retrofit costs	0.61	0.61	2.2	2.2	0.62	0.62	0.005	0.005
Energy efficiency improvement costs	0.74	0.74	2.74	2.74	1.63	1.63	0.13	0.13
Total costs	1.37	1.37	4.94	4.94	2.25	2.25	0.18	0.18
BCR	1.44	1.53	0.70	0.75	1.62	1.69	1.49	1.70
NPV (€, millions)	0.61	0.73	–1.47	–1.22	1.4	1.55	0.089	0.13
ERR (%)	44.42	53.29	–29.77	–24.80	62.18	68.68	49.06	70.54

Source: World Bank analysis; based on external data

Several observations can be made from the BCR results:

- Investment into strengthening and energy efficiency improvement of education facilities yields positive returns in the majority of the considered countries, considering both design life and PML benefits.

- Co-investment into energy efficiency yields large benefits and should therefore be considered in tandem with seismic strengthening for higher efficiency of investments and lower disruption to facilities. The use of innovative combined technologies is being widely investigated with a lot of research in this area (for example, a European pilot project on integrated techniques for the seismic strengthening and energy efficiency of existing buildings).

- The relative importance of different benefits differs across countries depending on their seismic risk, climate, and energy profile. In general, dividend 3 benefits tend to be high along with the avoided fatalities from seismic retrofit.

→ Challenges and lessons learned

The earthquake analysis could be completed by inclusion of further aspects as outlined above. Other studies have shown substantial benefits of investing in upgrading of school infrastructure in Turkey or Romania, which also benefitted from previous assessments that calculated benchmark data on characteristics of buildings that allowed for precise calculations of energy efficiency improvement benefits.

BENEFITS OF INVESTING IN RETROFITTING OF BUILDINGS IN ROMANIA

This case study is an external analysis that was undertaken with ex-ante analysis that involved modelling of hazards.

→ Introduction and background

Romania is one of the fastest growing economies in the EU, with growth of 7 percent in 2017 (World Bank, 2018a). Yet, Romania's vulnerability to geophysical and climate-related natural disasters, which will be further exacerbated by climate change, stands in the way of the country's growth trajectory. Romania is one of the most at-risk countries from earthquakes in the EU, with hundreds of lives lost and tens of thousands of buildings damaged in earthquakes in the last 200 years. In addition to seismic risk, the country is also one of the most flood-prone countries in Europe, and it is susceptible to significant damage from hydrometeorological events occurring several times per decade. Lastly, Romania is also experiencing increased frequency and intensity of landslides, wildfires, drought, and extreme heat/cold events. Not only is Bucharest one of the most earthquake-prone capital cities in the EU, but it is also ranked fifth among the fastest-warming cities in the world. With the country's unique natural hazard risks realized, Romania is committed to improving their disaster risk management and making improvements to their country's emergency response system a national priority. And In the last few years, Romania has substantially invested in retrofitting buildings, strengthening the country's preparedness and critical emergency infrastructure, and improving its resilience and emergency response. Below, we will examine these investments using the Triple Dividend BCA.

→ Description

The World Bank is supporting a series of three types of investment programs in Romania since 2018. These investments are all aiming to support the resilience against disaster risks by focusing on the retrofitting and reconstruction of selected public buildings while promoting sustainability aspects such as energy efficiency. In the aftermath of disaster, it is critical that emergency coordination centres and rescue facilities are undamaged and fully operational, with staff uninjured, equipment undamaged, and energy, water, and communication systems functional. It is also critical that expected coverage of emergency operations is not compromised by damage to one or more buildings.

The three investment programs are focusing in a first phase on critical disaster and emergency response buildings:

Strengthening Disaster Risk Management (World Bank, 2018a)[15]

The project that started in 2018 amounting to more than €50.8 million is aiming to enhance the resilience of critical disaster and emergency response infrastructure and to strengthen the Borrower's institutional capacities in disaster risk reduction and climate change adaptation. This is being achieved by enhancing the resilience of critical disaster and emergency response infrastructure and to strengthen the Borrower's institutional capacities in disaster risk reduction and climate change adaptation. The project focuses on around 35 buildings such as emergency coordination centres as well as fire and SMURD (Emergency Rescue Service) ambulance services.

Improving Resilience and Emergency Response (World Bank, 2019a)

The project that started in 2019 and amounting to more than €50.92 million is aiming to enhance the resilience of Romanian Police Facilities that are critical to respond to Emergency Situations and disasters and to strengthen the institutional capacities for emergency preparedness and response. The project focuses on around 37 buildings of the Romanian police.

Strengthening preparedness and critical emergency infrastructure project (World Bank, 2019b)

The project that started in 2019 amounting to more than €41.09 million is aiming to enhance the resilience of Romanian Gendarmerie Facilities that are critical to respond to Emergency Situations and disasters and to strengthen the institutional capacities for emergency preparedness and response. The project focuses on around 27 buildings of the Romanian gendarmerie.

→ Methodology

The BCA for the three investment programs were undertaken in a similar manner using the Triple Dividend framework. Although the components slightly varied between the projects, the BCAs generally included analysis based on two earthquake scenarios. The first, EQ scenario 1, has a higher probability with an AEP of earthquake hazard at 39 percent in 50 years, and a corresponding earthquake with magnitude of approximately 7.5. The second, EQ scenario 2, has an AEP of earthquake hazard at 10 percent in 50 years, and a corresponding earthquake with magnitude of approximately 7.9. The standard discount rate used was 5 percent and the VSL used €559,488 for the first project (and €575,723 for the other two projects).

For the overall BCR, only the results from the first Dividend were considered that were calculated quantitatively and based on modelling scenarios. The other results were presented qualitatively based in parts on partial quantitative analysis to allow an approximation of possible benefits.

For the second Dividend, the Hallegatte framework was used as a benchmark (Hallegatte, 2012). This approach estimates the value of concurrent economic development being equivalent to 8 times the value of avoided asset losses at the lower end of the spectrum, and 15 times at the higher end. Since, emergency response facilities constitute only a small part of an overall earthquake hazard mitigation program; it is assumed that the economic development benefits associated with response building investments would be approximately equal to the value of the avoided assets losses at the lower end, and three times as high at the higher end. This logic allows the use a weighted factor of 2 to multiply the avoided asset losses (and related benefits) and to infer benefits due to triggered economic development.

For the third Dividend, data constraints required an approximate calculation of possible benefits. Factors taken into consideration were the square meters of facilities being rebuild or retrofitted (including the share of types of interventions), energy efficiency standards by shares of buildings (1/3 of buildings 2020 targets, rest with moderate energy efficiency targets), monthly energy costs per square meter of €1.2 and a 20 (or 30 in two last case studies) year planning horizon.

→ Results of the analysis by Dividends and overall

The results of the three projects are summarized in the tables below (*Table 40* , *Table 41* and *Table 42*). Overall, we can see that the BCRs were greater than 1.

15 Original values in US dollars.

Strengthening Disaster Risk Management

Table 40: BCR of strengthening disaster risk management in Romania (in million €)

BCR: 1.73[16]/1.3[17]			
		EQ1	EQ2
	Dividend 1 benefits	€64.5	€48.3
	Dividend 1 costs	€ 37.33	€ 37.33
	Dividend 2		
	Dividend 3		
	Total Benefits	€64.5	€48.3
	Total Costs	€37.33	€37.33
	BCR	1.73	1.30
	NPV	€27.17	€11.02
	IRR	14.6%	9.1%

Source: World Bank analysis; based on data and information from World Bank (2018a)

Improving resilience and emergency response

Table 41: BCR of improving resilience and emergency response in Romania (in million €)

BCR: 1.57[18]/1.05[19]			
		EQ1	EQ2
	Dividend 1 benefits	€64.5	€48.35
	Dividend 1 costs	€44	€44
	Dividend 2		
	Dividend 3		
	Total Benefits	€64.5	€48.35
	Total Costs	€44	€44
	BCR	1.57	1.05
	NPV	€22.26	€2.01
	IRR	10.26%	5.50%

Source: World Bank analysis; based on data and information from World Bank (2019a)

16 Earthquake scenario 1 (EQ1).
17 Earthquake scenario 2 (EQ2).
18 Earthquake scenario 1 (EQ1).
19 Earthquake scenario 2 (EQ2).

Strengthening preparedness and critical emergency infrastructure project

Table 42: BCR of strengthening preparedness and critical emergency infrastructure

BCR: 1.16[20]			
		BENEFITS	COSTS
	Dividend 1	€33.9	€29.1
	Dividend 2		
	Dividend 3		
	NPV	€4.8	
	IRR	6.58	

Source: World Bank analysis; based on data and information from World Bank (2019b)

This *Table 43* compares the cost benefit analysis outputs for all three case studies in Romania considered, giving ranges corresponding to the two earthquake scenarios.

Table 43: Comparison of BCA outputs for case studies in Romania

	STRENGTHENING DRM	IMPROVING RESILIENCE AND EMERGENCY RESPONSE	STRENGTHENING PREPAREDNESS AND CRITICAL EMERGENCY INFRASTRUCTURE PROJECT
FIRST DIVIDEND			
Lives saved	2900 people (1700 building staff and 1200 community member); €671 million	1009-2491 (building staff and community members); €581 million	3636 (building staff and community members); €251 million
Avoided direct stock losses	€25.4 - 54 million (including direct damages to buildings 12.4-23.9, to equipment 2.2-4.1 and fire suppression to surrounding buildings 10.8-26)	€11.3 – 19.3 million (including direct damages to buildings 10.1-17.5 and to equipment 1.2-1.8)	€11.3 (including direct damages to buildings 10.7 and to equipment 0.6)
SECOND DIVIDEND			
Economic development multiplier effects due to avoided asset losses	€44-94 million	€22.6 million	€22.6 million
THIRD DIVIDEND			
Energy efficiency (energy costs savings)	€8 million	€7 million	€8 million

Source: World Bank analysis; based on data and information from World Bank reports cited above

20 Earthquake scenario 1 (EQ1)

→ Challenges faced and lessons learned

It is noteworthy that the project's efficiency parameters in both earthquake scenarios are highly sensitive to the VSL estimate and the number of lives saved, which play a vital role in rendering the project feasible in economic terms. However, when the aspect of lives saved was eliminated from the analysis, the resulting IRR declined to below zero, indicating an infeasible investment prospect. Thus, an important feature of this analysis is that the project will not be able to meet efficiency criteria unless the value of lives saved is explicitly considered. In one of the projects for one of the earthquake scenarios, a negative BCR has been found and this is likely to be due to an underestimation to the lives saved by the personnel of the gendarmerie.

Data constraints on buildings specifically are major, which are preventing more precise calculations on energy efficiency. Ideally energy audits on buildings would be necessary before the project, which would necessitate an advance precise definition of which buildings would be intervened in and this was not the approach taken in these investments projects but may also constrain estimations for other similar large investment programs led by the public sector. The second dividend benefits are an approximation and are constrained by methodological constraints on what can reasonably be accounted for. Additional empirical literature (ideally global comparative estimates) would support future precise calculations for dividend 2.

THE BENEFITS OF INVESTMENT IN SCHOOL INFRASTRUCTURE IN TURKEY (WORLD BANK, 2019D)[21]

→ Introduction and background

Turkey is vulnerable to a wide variety of natural hazards, including earthquakes, landslides, and floods. Among these, earthquakes have caused the greatest amount of human and economic losses, with 90,000 fatalities and direct losses of €22.3 billion spanning 76 earthquakes since 1900. In 2005, the Government of Turkey, with support from the Bank, initiated a comprehensive risk reduction program and launched the Istanbul Seismic Risk Mitigation and Emergency Preparedness (ISMEP) project aimed at improving the resilience of the city's public building stock and its capacity to respond to disasters. Within this ambitious long-term disaster resilience plan, the government is focusing on scaling up risk reduction interventions in the education sector to substantially and systematically reduce the risk that students and teachers face from earthquakes. Improving education infrastructure is an important strategic priority for the Turkish Government, and budget allocations toward such projects have increased in years. The Ministry of National Education (MoNE) is entrusted to oversee the retrofitting and maintenance of public education infrastructure, and between 2003 and 2018, MoNE has invested approximately €14.3 billion in the construction of new schools, reconstruction and retrofitting of existing schools, and the acquisition of sites.

→ Description of the case study

With this €276.6 million investment (US$300 million), 50 schools can be reconstructed and about 300 schools can be retrofitted over a 5-year investment period. As a result, this would correspond to 1,122,500 square meters of floor space, providing protection to approximately 280,000 students at full capacity.

→ Methodology

Using the triple dividend framework as basis, a BCA was performed to inform the Project design. This analysis aims to estimate ERR, NPV and cost-benefit ratios under a set of assumptions. It is conjectured that one or more earthquakes (EQ) are expected to hit the targeted provinces in the order of Mw = 6.5 or higher leading to similar consequences as that of the Marmara EQ, with an expected probability of 5 percent. Human life has been valued as part of the analysis and the concept of VSL was used (VSL of €731,440 or US$820,000).

→ Results of the analysis by Dividends and overall

Assuming that the current asset value is equal to €133.8 million, the market value of the complete buildings that have been reconstructed, retrofitted,

21 Original values in US dollars.

and fully equipped ultimately results in an increment of €160.6 million for the value of the property enhanced and saved as a result of project intervention. Moreover, it expected that the improved buildings will provide a safer school environment for some 280,000 students, 0.6 percent of whom risk losing their lives in the event of an earthquake without this intervention. Consequently, this corresponds to a child mortality estimate of 1680 for daytime and 910 for an average number after adjustments.

As a possible benchmark we have used the Hallegatte framework (Hallegatte, 2012), which deals with hydro-met related hazards, investments and benefits, where the author estimates the value of concurrent economic development being equivalent to 8 times the value of avoided asset losses at the lower end, and 15 times at the higher end. Since safe schools constitute only a small part of an overall earthquake hazard mitigation program, we assume that the economic development benefits associated with safe schools investments would be approximately equal to the value of the avoided assets losses at the lower end, and be perhaps twice as high at the higher end. This logic allows us to use a factor of 2 to multiply the avoided asset losses, yielding some €321 million in benefits due to economic development even when the disaster never strikes (see *Table 44*).

Despite data paucity being a problem in this category of benefits as well, energy efficiency improvements in existing public buildings are in the positive list of co-benefits related to mitigation of climate change and yield savings on lighting, water and heating investments. The recent ISMEP Economic Impact Assessment (World Bank, 2018b) has calculated some benchmark data which have been imported for use. According to ISMEP, the monetary values of saving in lightening, water consumption, and heating per square meter are €0.0021, €0.020, and €2.418, respectively. It is expected that 350 schools with 1.122.500 square meters of surface areas are to be intervened within the Project, which would result in savings of about €2.68 million per annum and €41 million over the planning horizon with or without an earthquake occurring. This analysis is being extended to deal with the question of social value of carbon.

Table 44: BCR of Turkey school infrastructure investment per dividend

BCR: 1.53			
		BENEFITS	COSTS
	Dividend 1	€660 million (gross)	€267.6 million (gross)
	Dividend 2	€160.6 million (gross)	
	Dividend 3		
	Total benefits	€820.6 million (gross)	
	Total costs	€267.6 million (gross)	
	BCR	1.53	
	NPV	€120.4 million	
	ERR		

Source: World Bank analysis; based on data and information from World Bank PADs

→ Challenges faced and lessons learned

In addition to the sensitivity of results to the choice of VSL, it can be said that the economic analysis under this project benefitted from previous assessments that calculated benchmark data on characteristics in buildings (lightning, water consumption, heating per square meter) that allowed for a more precise calculation of energy efficiency improvements benefits.

3.2.3. EARTHQUAKE EARLY WARNING SYSTEMS

An EEWS is an effective measure for reducing risks from European earthquakes, which consists of physical infrastructure and software that can alert stakeholders (for example, the public and civil protection offices) to an incoming earthquake seconds to minutes before they experience the resulting strong shaking. During this time, actions can be taken to significantly decrease detrimental impacts from shaking (Cremen, et al., 2020). These actions include, but are not limited to, performing drop, cover, and hold on (Porter, 2016) to avoid lives lost and injuries; moving to a safer location either within a building or outside to avoid injuries; slowing down high-speed trains (Fabozzi, et al., 2018); shutting off gas pipelines to prevent fires; and switching signals to stop vehicles from entering vulnerable infrastructure components (Le Guenan, et al., 2016).

The Euro-Mediterranean area has a strong need for effective EEWS and measures for mitigating seismic risk (Crowley, et al., 2018). This is due to the estimation of annual European GDP affected by earthquakes which exceeds €17.7 billion (World Bank, 2017a). In addition, the only European countries with current operational EEWS are Romania (Mărmureanu, et al., 2011) and Turkey (Alcik, et al., 2009).

The study by Cremen examines the feasibility of EEWS for Europe. The initial analysis examines the density of station coverage across the continent and finds that over half of the interdistance ranges between 0 km and 20 km are optimal for EEWS performance (Cremen, et al., 2020). This is a preliminary signal that there is significant potential for operational EEWS across the content. The report also finds that 44 percent of the examined target sites benefit from warning times that are long enough to accommodate major risk intervention actions, such as shutting down of industrial equipment or the removal of vehicles from garages. The longest lead times are found in Greece, Turkey, and Iceland, while the shortest lead times are in north-western Georgia and southern Russia. The work provides strong evidence that an operational EEWS could be an effective tool for supporting earthquake-related DRR across a significant portion of Europe. This benefits the new three-year Horizon 2020 European project called TURNkey (European Commission, 2021). The project seeks to develop a holistic earthquake information system that incorporates seismic risk mitigation tools for both operational forecasting and EEWS in real and near-real time, with selected testbeds in Italy and Greece to be the focus of more detailed analysis.

EARTHQUAKE EARLY WARNING IN BUCHAREST

This case study is a new ex-post analysis under this project that involved modelling of hazards.

→ Introduction and background

Currently, the Romanian Seismic Network consists of 73 digital seismic stations that have been installed since 1995 for warning critical facilities. Bucharest is situated 140–170 km from the Vrancea epicentre zone and encountered great damage and casualties from the high energy Vrancea earthquake in 1977 and other events on the same subduction zone. The lead time is predicted to be 25–27 seconds for an EEWS to issue preventive actions at the warned facility. Key facilities that trigger action upon receipt of alerts include the Nuclear Research Institute in Bucharest, the Basarab Bridge, and the Vidaru Dam. The National Institute for Earth Physics (NIEP) that operates the real-time national network is currently testing the communication performance with a restricted group of people with a view to releasing a set of mobile applications that will be freely available for general users (Clinton, 2016).

→ Description

This case study is an appraisal of the EEWS in Bucharest as part of the DACEA program 2007–2013 that was partially funded by the EU (Dimitrova, et al., 2015; European Union, 2021; European Commission, 2015). The DACEA program seeks to prevent natural disasters generated by earthquakes in the cross-border area of Romania and Bulgaria through early warning integrated communication networks. Due to the high seismicity in the cross-border area, the nuclear power plants and chemical plants located along the Danube are particularly vulnerable to earthquakes. The project provides a response system that can alert authorities to help avoid natural disasters caused by earthquakes by promptly shutting down

critical infrastructure like nuclear power plants, elevators, and trains, as well as reducing negative impacts to the environment. The case study undertaken is a hypothetical appraisal of the EEWS operationalized to reduce losses, focusing on the defined investment of the DACEA program for nuclear and infrastructure alerting. The program included the installation of 16 earthquake sensors in the cross border area.[22]

→ Methodology

As few methodologies exist for systematically evaluating the costs and benefits of the EEWS, this study employs a recent methodology by Strauss and Allen (2016) that estimates the costs and benefits of the ShakeAlert system in the Western United States. Quantifying the benefits of the EEWS will include assessing the annual costs of creating and maintaining an EEWS compared to the costs and savings from annual avoided losses. In the methodology applied to Bucharest, benefits are hypothetical and conservative losses avoided are estimated based on infrastructure alerting to the train/transportation sector.

Due to the challenges and variability in predicting the full benefits of earthquake early warnings, the case study intends to compare the expected first-time start-up cost of installation and maintenance to a highly conservative set of benefits. The costs are compared to the avoidance of one fatality avoided and the physical asset loss avoided of one train being derailed. The objective is to compare the incremental losses avoided to the start-up cost and maintenance of the EEWS. Due to a lack of available data, the losses avoided from nuclear and chemical earthquake early warning are not included in the study.

As earthquake early warning has a short lead time (up to 27 seconds in Bucharest) (Neagoe, 2016), its main purpose is to prevent loss of life and injuries. There are also other immediate organizational actions that can be taken (both automatically or procedurally), such as turning off gas pipes to avoid conflagration, or slowing down trains to avoid derailment—and hence lowering the likelihood of causalities and asset loss. Therefore, while other co-benefits may exist, these are largely unexplored in literature and therefore not included in the BCA.

Data used for the case study were as follows:

- Total investment information from the project for EEWS cost, half of which is assumed to be applied to Bucharest (European Union, 2020)
- Data from the United States (Strauss and Allen methodology) for cost of one train car and cost of maintenance of EEWS, adjusted to Romanian consumer price indexes (Strauss & Allen, 2016)
- Eurostat symmetric input-output tables for construction sector macroeconomic benefits. The EU estimation for construction sector input of every €1 yields €0.47 of value added to other industries (European Commission, 2021). This is an indirect and direct economic value added from the construction or installation of sensors and other infrastructure for EEWS.

→ Results of the analysis by Dividends and overall

The overall benefit is greater than 1 compared to the annualized cost including up-front investment for the EEWS in Bucharest (see *Table 45*). The benefits computed are those of direct losses avoided and value added to the greater economy by investment in construction projects. The true BCR is likely much larger but difficult to capture in the life span of use considering the return periods of low-frequency, high-consequence earthquake impacts. However, the inclusion of loss of life avoided when comparing the full costs of implementation will typically yield high BCR values as indicated below. In addition, the losses avoided from environmental pollution due to the reduction and prevention of natural and technical risks will likely increase the BCR. There are also co-benefits such as increased awareness by alerting for EEWS that have positive social consequences but are difficult to capture in a quantitative BCA. High and low values based on upper and lower bound limits of the cost of train derailment (low of €3.2 million per train car and high of €26.8 million) results in a BCR range of 3.4–11.1 (see *Table 46*).

22 The team assumed that half of the sensors were installed in Bucharest.

Table 45: BCR of implementing EEWS in Bucharest, Romania (in million €)

BCR: 7.0		
	BENEFITS (€)	COSTS
Dividend 1	20.64	
Dividend 2	1.34	
Dividend 3	n.a.	
Total benefits	21.98	
Total costs		3.06
BCR	7.17	
NPV	18.92	
ERR (%)	617.33	

Source: World Bank analysis; based on external data and information

Table 46: Detailed breakdown of implementing EEWS in Bucharest, Romania (in million €)

FIRST DIVIDEND (€)	
Life saved	5.91
Train derailment avoided	14.18
Total first dividend	20.09
SECOND DIVIDEND (€)	
Value-added to broader economy from construction of EEWS infrastructure	1.34
Total second dividend	1.34
First cost item	
First time capital cost of sensors and monitoring system	2.85
SECOND COST ITEM (€)	
Maintenance cost	0.21
TOTAL DIVIDEND	21.43
Total cost	3.06
BCR	7.0
NPV (€)	18.36
ERR (%)	599.27

Source: World Bank analysis; based on external data and information
Note: All values are in 2013 euros as this was the end of the programming year for funds.

→ Challenges faced and lessons learned

Very little data exist on the full benefits of an EEWS in Europe, particularly in Bucharest. It is challenging to disaggregate a multi-alert system like the one found in France, and some judgements must be made to estimate a cost per incremental sensor installation and maintenance over time to constitute a meaningful BCA. For future studies with additional data available, the BCA could expand on

- Accurately estimating alerting system as well as monitoring and evaluation costs;
- Determining the efficiency of alerting dissemination of EEWS;
- Providing specific information on costs like nuclear damage, chemical, industrial, and other critical infrastructure damage;
- Including fire following earthquake damage avoided with manual and/or automated gas shut offs;
- Assessing the costs and benefits over a reasonable time horizon, capturing the longevity of such a system as well as longer-return-period earthquakes and their consequences;
- Evaluating the losses avoided of environmental damage from natural and technical disasters in the cross-border area; and
- Quantifying the benefits of increased awareness and use of EEWS by personnel operating critical infrastructure to further reduce losses. This also includes quantifying the level of effective awareness building that should be included as a regular cost to implementing any EEWS (Becker, et al., 2020).

3.2.4. RESPONDER CAPACITY BUILDING

The case studies described in this section are new ex post analyses under this project that involved an innovative quantification of benefits from soft investments.

INTRODUCTION TO THE ASSESSMENT OF ECONOMIC BENEFITS OF CAPACITY BUILDING IN DISASTER RISK PREVENTION

The case studies described in this section are new ex post analyses under this project that involved an innovative quantification of benefits from soft investments.

→ Introduction and background

The effectiveness of disaster response is directly associated with the skills of the responders at a disaster site as well as their effective coordination with other resources deployed (Sinclair 2012). Therefore, it is essential for authorities to establish emergency management training and live exercise programs to build capacity of responders and response coordinators.

DG ECHO funds capacity building of civil protection personnel through what is now called the Union Civil Protection Knowledge Network (capacity-building initiatives are shown in *Figure 20* and see *Annex 4* for further details). Personnel and modules (self-sufficient civil protection capacities capable of overseas deployment) are trained in many aspects of the international response context. Benefits are numerous, ranging from improved coordination between international resources from different countries and the Host Nation to improved effectiveness of on-the-ground personnel in this international response context (Perry, 2004).

→ Description

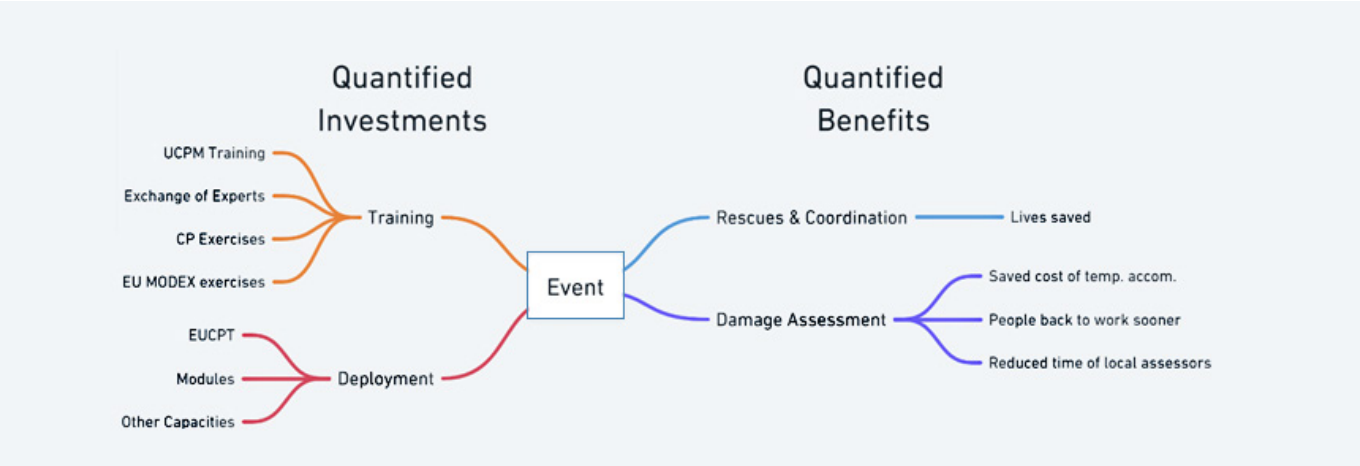
A BCA is conducted of DG ECHO investments in emergency responders and response coordinators through the UCPM/Union Civil Protection Knowledge Network. Two specific events are considered: the November 2019 Albania Earthquake and the March 2020 Croatia Earthquake. The Albania earthquake

was magnitude 6.3; killed 51 people; damaged 39,000 residential buildings; required 17,000 people to be housed in temporary accommodation; and led to a significant international response including personnel on-the-ground, in-kind assistance, and international pledges from multiple donors. The Croatia earthquake was of magnitude 5.5, killed one person, damaged 26,000 buildings, and displaced 30,000, and although there were no EU personnel deployed internationally (due to COVID) many of those responsible for the national coordination of the response had received international training. See *Annex 4* for a more detailed description of the Knowledge Network[23] and the two case study events.

→ Methodology

The costs and benefits assessed *quantitatively* for these events are shown in *Figure 20*. The calculation methodology, the additional costs/benefits assessed *qualitatively*, and key results are described in more detail for each case study in the next sections.

Figure 20: Costs (investments) and benefits considered for quantitative analysis to provide the BCR. Note that additional costs/benefits are analysed both quantitatively and qualitatively and discussed in the text



Source: World Bank analysis
Note: Additional costs/benefits are analysed both quantitatively and qualitatively and discussed in the main report. CP = civil protection; EUCPT = European Union Civil Protection Team; MODEX = module exercises; UCPM = Union Civil Protection Mechanism.

The analysis for both case studies is conducted in four stages:

1. Calculate costs of training and deployment of EUCPT, modules, and other capacities that responded to the case study events, either internationally (Albania earthquake) or nationally (Croatia earthquake).

2. Calculate benefits associated with (a) urban search and rescue (USAR) and (b) post-disaster damage assessment.

3. Outline costs and benefits that have not been included in the BCR calculation above.

4. Evaluate these additional costs/benefits using questionnaires to targeted experts in coordination roles in both case-study events

Costs and benefits are calculated only for the events considered. This means that benefits that may occur for future events are not expressly calculated (for example, trained personnel may deploy to multiple events). that is, calculations are deterministic, based on specific real events, not a probabilistic calculation based on possible future scenarios.

Qualitative analysis of these additional costs and benefits is conducted through questionnaires, which aim to determine whether international training or experience of previous deployments improved response to the case study events. The questionnaire was sent to:

23 Note that the term 'Knowledge Network' is used throughout to refer to the training activities shown in *Figure 20.* This also refers to these activities, even before the term was formalized in 2019.

1. International teams and EUCPT members who deployed to the case study event (Albania) and

2. National civil protection staff who have received international training and were in a coordination role during the case study event (Croatia).

3. Alternative methods considered.

In a theoretical case, we would be able to either directly compare the effectiveness of interventions of international teams in comparable disaster situations before and after a training, and thereby reduced negative impacts or increased benefits, or compare the performance of teams with and without training during the same disaster in geographically separated areas but with similar characteristics. However, as these theoretical scenarios are not available, we instead examine the real emergency responses to the Albania and Croatia earthquakes to create possible counterfactual scenarios ('what-if' analysis) and thereby estimate the possible added value of these teams.

The first approach is to create logical links between coordination mechanisms and training, improved rescue and coordination or provision of damage assessments during a disaster, and lives saved or reduced losses in productivity, for example. As the latter have a monetary value, it is then possible overall to estimate monetary benefits from the original provision of training and coordination mechanisms. However, this is only possible in the case of disasters where these logical links can somehow be created (for example, in the case of the quantitative calculation for Albania outlined below).

Another method often used to estimate more intangible investments such as training or upgrading of natural spaces is to apply a willingness to pay (WTP) method to be able to estimate the perceived benefits of the investment in monetary terms. This method would have the advantage of capturing several benefits of trainings, including (a) better response capacity of teams and individuals during their deployment, (b) improved 'peace of mind' to those displaced by damage assessments providing certainty on damage to their homes and businesses, (c) enhanced potential earnings or career opportunities, (d) enhanced human capital and knowledge that they can transmit to others (positive spillover effects), (e) networking opportunities with peers to create synergies in respective work areas, and (f) intrinsic value of knowledge networks and trainings for people to feel as part of a community of practitioners and contribute to a greater cause. The advantages of WTP to capture some of these more intangible benefits may also be a disadvantage, given that it may be difficult to disentangle the various benefits and therefore to describe what kind of monetary benefits specifically these knowledge networks would have, for example, in terms of actual disaster response. More details on WTP methodologies can be found in Annex 4. Although the team was not using a full WTP methodology, it aimed to create questionnaires and distributed to relevant teams to pilot possible approaches that could approximate WTP methodologies, would collect more qualitative information on benefits of knowledge networks, and would collate subjective estimates from expert practitioners on what they would perceive the share of benefits from knowledge networks and trainings to be in terms of actual disaster response on the ground. More details and results from the pilot surveys can be found below as well as information on the questionnaires sent is provided in *Annex 4*.

→ **Results of the analysis by Dividends and overall**

The analysis finds positive net benefits for capacity-building investments related to disaster risk reduction and response. Overall, for both case studies, the following can be further noticed:

- Effective coordination of USAR and post-disaster damage assessments are significant contributors to lives saved and to saved costs of temporary accommodation and GDP-per-capita loss of displaced people, by facilitating a rapid return to work and to medium-term/permanent accommodation.

- Coordination effectiveness is improved through international training (such as that through the knowledge network).

- A BCR greater than 1 has been found, even where there is no deployment of personnel through the UCPM, in cases where national resources coordinating response have received international training.

- This BCR greater than 1 is found even when making the conservative assumptions to ignore (a) co-benefits (dividend 3) of career benefits for international rescuers, coordinators, and assessors who have received international training/ deployments and (b) economic impacts (dividend 2) of international finance made available due to accurate evidence-based damage assessments.

These results make a quantitative case for DG ECHO's investments in capacity building through the knowledge network, even in cases where the trained personnel are not deployed internationally.

BENEFITS OF KNOWLEDGE NETWORK INVESTMENTS DURING THE ALBANIA EARTHQUAKE

→ Description

During the Albania earthquake in November 2019 in Durres, the EU response to the event included deployment of an EUCPT, and several modules, other capacities, and in-kind assistance were deployed both through UCPM and on a bilateral basis. International assistance facilitated both live rescues and damage assessments. See *Annex 4* for further description of event and international response.

→ Methodology

Costs of deployment are calculated for the EUCPT, modules, and other capacities. Both capacities that are deployed through the mechanism and bilaterally are considered (but only those registered on the VOSOCC[24] or with the Damage Assessment Coordination Centre [DACC]). Costs are separated by those borne by DG ECHO or the sending country. *Figure 21* ranks the various costs and benefits, showing that the cost of training outweighs the costs of deployment, and that modules are a higher cost than the EUCPT. The total of these costs is less than the combined benefits of lives saved and reduced costs of temporary accommodation and production loss for those displaced.

Benefits of damage assessment are calculated based on the time saved due to international assistance/ training. The approach assumes that people are able to return to medium-term/permanent accommodation and work sooner, with faster and more effective damage assessments. This time is then associated with cost savings due to reduced time in temporary accommodation and the associated reduction in GDP per capita. The difference in time with/without international assistance is calculated based on data from the November 2019 earthquake, and observations in the September 2019 Albania Earthquake for which damage assessments were conducted without international assistance. These observations were made directly by the author of this section, who was an EUCPT member in both the September and November 2019 events.

Co-benefits (dividend 3) are calculated as improved job prospects for those who have received international training. This also encompasses capacity-building of local assessors, who received training through knowledge-exchange with international assessors. The benefit is quantified as a small estimated uplift of final salary at retirement, with an assumed linear increase in annual salary from current to final salary.

Benefits of USAR are calculated from the number of lives saved:

1. Direct rescues by internationally trained personnel;

2. Rescues achieved after international coordination established, established through the USAR Coordination Cell (UCC).

Benefits of post-disaster damage assessment are calculated through a counterfactual analysis (Woo G. , 2019) that is, an estimate of the time taken for assessments to be completed with no international assistance/training. The bases for these estimations are described in the case studies below. Benefits considered are shown in *Figure 21* and *Table 47*, and these benefits are achieved through both:

24 VOSOCC = Virtual On-Site Operations and Coordination Centre, part of the Global Disaster Alert and Coordination System (GDACS).

1. Direct assessments by international assessors and

2. Improvements in the overall damage assessment coordination system due to international assistance (Albania earthquake) or national staff with international training/deployments (Croatia earthquake).

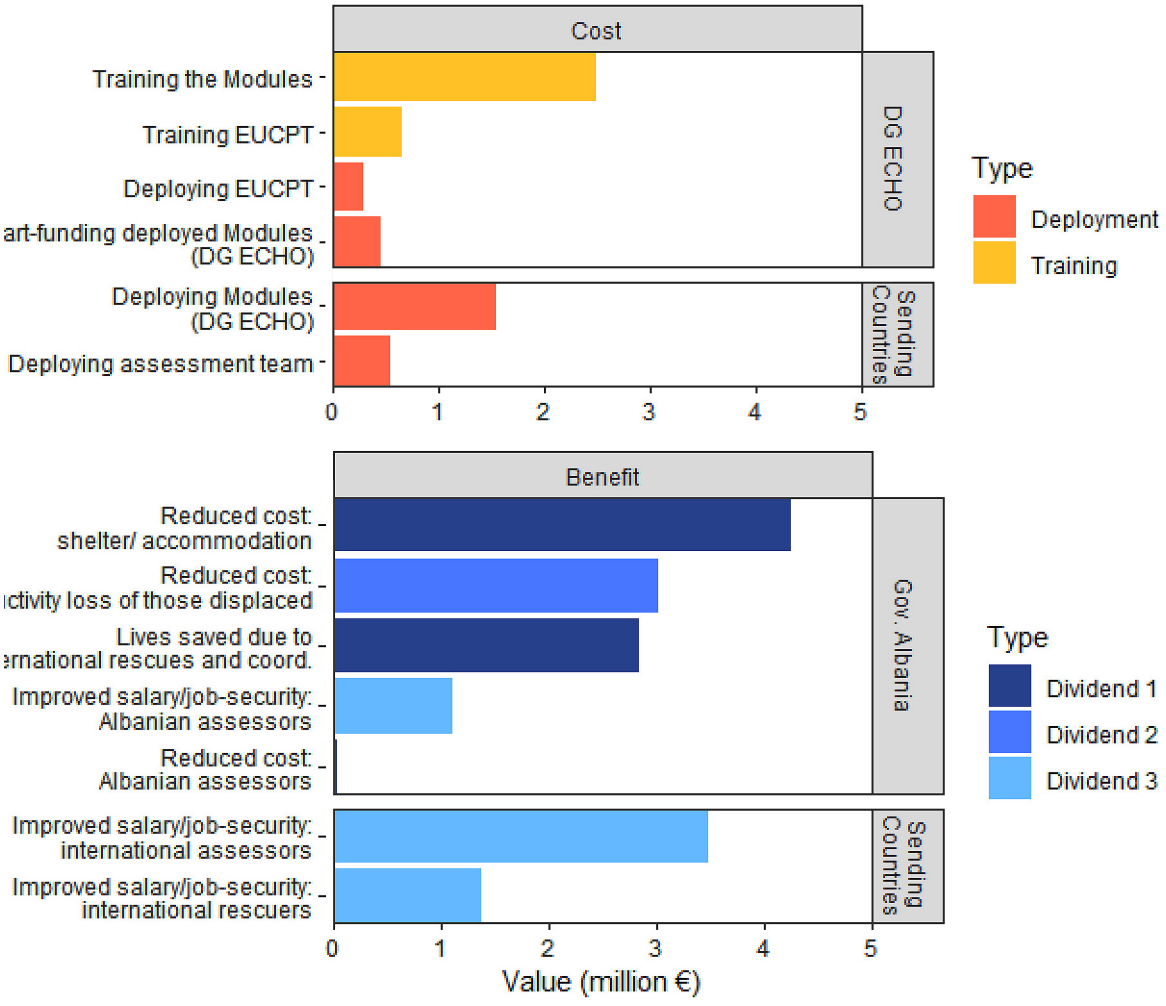
Data are gathered and summarized for other costs and benefits that have not been included in the BCR calculation. These are listed in the text beneath *Table 48*.

→ **Results of the analysis by dividends and overall**

The results of the quantitative analysis (*Table 47*) show that the benefits of saving lives, getting people back to work, and providing certainty on the status of damaged buildings outweigh the costs of training and deploying personnel through the UCPM, even without considering private co-benefits for individuals (Dividend 3). For context, the PDNA-estimated losses (not physical damages) from the event were €141 million (€116 million for housing and productive sectors).

It can be noted that the BCR does not include dividend 3, which includes some private benefits for individuals (see description below). If dividend 3 is included, then the BCR rises to 2.7.

Figure 21: Costs and benefits further broken down and ranked for each actor. Note that costs and benefits are often associated with different actors



Source: World Bank analysis

Note: Costs and benefits are often associated to different actors. DG ECHO = Directorate General for European Civil Protection and Humanitarian Aid Operations; EUCPT = European Union Civil Protection Team.

Table 47: Capacity-building BCA for November 2019 Albania Earthquake

BCR: 1.9		
	BENEFITS	COSTS
Dividend 1 (€, millions)	7.10	
Dividend 2 (€, millions)	3.00	
Dividend 3 (€, millions)	6.00 (1.10 within Albania, 4.90 internationally)	
Total (dividends 1 and 2)	11.30	6.0
Total costs	6.00	
BCR	1.88	
NPV (€, millions)	5.00	
ERR (%)	88.33	

Source: World Bank analysis; based on external data and information

Table 48: Detailed breakdown of BCA items for case study: November 2019 Albania Earthquake

COSTS (€, MILLIONS)	
FIRST COST ITEM (€, millions)	
Deployment of modules and EUCPT personnel	2.8
Second cost item	
Training of modules and EUCPT personnel that deployed to Albania	3.2
DIVIDENDS	
DIVIDEND 1 (€, millions)	
Lives saved due to improved emergency response/coordination	2.80
Saved costs of temporary shelter/accommodations	4.30
Reduced costs of managing national assessors	0.03
Total first dividend	7.10
DIVIDEND 2 (€, millions)	
Reduced loss in productivity or income of those displaced	3.00
Total second dividend	3.00
DIVIDEND 3 (€, millions)	
Improved job security and final salary for deployed Albanian assessors (capacity building of local engineers)	1.10
(not included in BCR) Improved job security and final salary for trained international rescuers	1.40
(not included in BCR) Improved job security and final salary for deployed international assessors	3.50
Total second dividend	3.00
Total cost	6.00

Total benefits (not including dividend 3 benefits to international individuals)	11.30
BCA (not including dividend 3 benefits to international individuals)	1.90
NPV (€, millions)	50.00
ERR (%)	88.33

Source: World Bank analysis; based on external data and information

BENEFITS OF KNOWLEDGE NETWORK INVESTMENTS DURING THE CROATIA EARTHQUAKE

Many of the assumptions and methods used are as per the Albania case study and are therefore not repeated here for brevity. A brief description of the Croatia Earthquake case-study is provided here.

→ Description of the case study

Due to COVID-19 and the smaller size of the Croatia earthquake in March 2020 (no national state of emergency, no USAR undertaken), no EUCPT or modules were deployed to Zagreb. However, in-kind and financial assistance was provided, and many of those responsible for the national coordination of the response had received international training (through the knowledge network or otherwise). International training facilitated a successful damage assessment programme, which in turn facilitated a faster return to work and to medium-term/permanent accommodation for those immediately displaced. See *Annex 4* for further description of the event and international response.

→ Methodology

Costs of training are calculated for Croatia civil protection personnel. Only costs borne by DG ECHO are considered, that is, costs of the activities now part of the knowledge network (*Table 50*).

Benefits of damage assessment are calculated based on the time saved due to international training. See the Albania description above for assumptions/method. The counterfactual assessment is based on the 'what-if scenario' of assessments without the expertise of the Zagreb damage assessment leads. The difference in time with/without international training is estimated based on comparison with other events and responses during interview with the Zagreb damage assessment leads, many of whom had received international training and experience including

- PDNA Training (DPPI SEE, 2020)
- MATILDA Structural Assessment Training,
- Previous deployment to the November 2019 Albania Earthquake for damage assessment, and
- PhD incorporating Damage Assessment in Croatian (ROSE School, University of Pavia).

Co-benefits (dividend 3) are calculated as improved job prospects for those who have received international training/experience. See the Albania description above for the assumptions/method.

Note that the recent earthquake in Croatia is another example where capacity-building benefits accrued and it could potentially be assessed using the same methodology but adapting it to a different scenario in terms of assessors, location, and hazard impact.

Co-benefits (dividend 3) are calculated as improved job-prospects for those that have received international training/experience. See Albania description above for assumptions/method.

Note: The recent earthquake in Croatia is another example where capacity building benefits accrued and it could potentially be assessed using the same methodology, but adapting it to the different scenario in terms of assessors, location and hazard impact.

→ **Results of the analysis by dividends and overall**

The results of the quantitative analysis (*Table 49*) show that the costs of training personnel through the UCPM are outweighed by the benefits of providing certainty on the status of damaged buildings (facilitating getting people back to work and into medium-term/ permanent accommodation), even when trained personnel do not deploy internationally.

Results also show that benefits of capacity building accrue over several events, as those who led the Zagreb damage assessment had received international training and applied that training to both the Albania earthquake and Croatia earthquake. Furthermore, the experience of the recent Albania earthquake aided the rapidity of the response for the damage assessment leads.

Table 49: Capacity-Building BCA for March 2020 Croatia Earthquake.

BCR: 1.1		
	BENEFITS	COSTS
Dividend 1 (€, millions)	0.9	
Dividend 2 (€, millions)	1.3	
Dividend 3 (€, millions)	1.5	
Total benefits (€, millions)	3.7	3.4
Total costs (€, millions)	3.4	
BCR	1.09	
NPV (€, millions)	0.3	
ERR (%)	8.82	

Source: World Bank analysis; based on external data and information;
Note that this is a conservative estimate as costs include all civil protection personnel (who contributed to all aspects of the response), but the benefits are only calculated for the damage assessments.

Table 50: Breakdown of BCA items for the case study: March 2020 Croatia Earthquake

COSTS (€, MILLIONS)	
FIRST COST ITEM (€, millions)	
Training of national civil protection (civil protection staff and modules) through the knowledge network	3.4
BENEFITS (€, millions)	
DIVIDEND 1	
Saved costs of temporary shelter/accommodations (due to more effective damage assessment)	0.8
Total first dividend	0.8
DIVIDEND 2	
Reduced loss in productivity or income of those displaced (due to more effective damage assessment)	1.3
Total second dividend	1.3
DIVIDEND 3	

Improved job security and final salary for deployed Croatian assessors (valuable experience for local engineers)	1.1
Improved job security and final salary for trained CP personnel	0.4
Total third dividend	1.5
Total cost (€, millions)	3.4
Total benefits (€, millions)	3.7
BCA	1.1
NPV (€, millions)	0.3
ERR (%)	8.82

Source: World Bank analysis; based on external data and information

→ **Challenges faced and lessons learned**

Benefits not considered include (not exhaustive) the following:

- **PDNA supported by damage assessment data.** For example, in Albania, the joint EU/World Bank/UN PDNA relied on damage data collected through damage assessment coordinated by the EUCPT and UN Disaster Assessment and Coordination (UNDAC).

- **International finance made available due to accurate evidence-based damage assessments.** For example, in Albania, the PDNA led to a donor conference resulting in €1.15 billion of pledges. In Croatia, the RDNA supported the EU's provision of €683.7 million through the EU Solidarity Fund. These are omitted in the BCR calculation as it is difficult to define which pledges would not have been made without the internationally supported damage assessments.

- **In-kind assistance.** While the monetary value of the donated goods may be estimated, the benefits from their use would require more detailed data and analysis. This could perhaps be addressed in future BCAs, with sufficient data.

- **Benefits accrued over multiple events (national and international).** All costs and benefits are for the specific case study event. Benefits from training being applied to multiple events (past or possible future events) have not been considered. This is to maintain a consistent focus on the known case study events, without including the added uncertainty of probabilistic calculations for possible events.

- **Diplomatic and political benefits.** International responses fall within a range of diplomatic tools used to boost international standing and relations (besides the prime goal of saving lives and livelihoods). The benefits of this would be difficult to quantify and have not been considered.

- **Mental health costs of displacement and 'peace of mind' of international assessments/assistance.** This is evident from experience on the ground but difficult to quantify.

- **Inspection of critical infrastructure (bridges, hospitals, and so on).** The cost-benefit calculations only consider assessment of residential buildings, as it is assumed that critical infrastructure would be prioritized and assessed by local competent engineers regardless of international assistance.

Costs not considered include (not exhaustive) the following:

- **Training personnel who do not deploy internationally.** Not all persons trained through the knowledge network will deploy internationally. The costs of training these additional personnel are not considered, as it is shown in this study through interview and questionnaires that the skills learned are also valuable for national deployments (which trained personnel are assumed to partake in). This is demonstrated clearly with the Croatia case study.

- **Staff and overheads outside of the deployed teams.** For example, the time and overheads for the Emergency Response Coordination Centre (ERCC), EU Delegation, and Copernicus Satellite activation are not considered.

- **Costs of module upkeep/salaries (outside of deployment).** These are not considered, as deployed modules fulfill more 'day-to-day' functions than when they are not deployed. These functions (and costs) occur regardless of international deployment/training.

- **Costs due to non-EU training.** This may include training from the UN, Disaster Preparedness and Prevention Initiative (DPPI), PDNA, International Federation of Red Cross and Red Crescent Societies (IFRC), and so on. This is omitted as the focus of this study is on benefits from DG ECHO investments.

3.3. Extreme Heat

3.3.1. SUMMARY OF FINDINGS FOR EXTREME HEAT

A significant number of studies have been undertaken to analyse heat risk and its social and economic impacts, yet these analyses were usually conducted with the goal of understanding the effects of climate change. As a result, these studies usually exhibit limitations and cannot present the burden of heatwaves entirely (Schmitt, et al., 2016). The Intergovernmental Panel on Climate Change (IPCC) (Murray & Ebi, 2012) also pointed out that many existing studies emphasize the impacts on infrastructures and assets in comparison to those on human health and the ecosystem. Also, there were studies on the costs and benefits of investments in heat risk reduction being conducted across Europe. For instance, an economic assessment has been undertaken to examine the effectiveness of heatwave warning systems (HWWS) in Europe. BCAs were undertaken under several scenarios that represent long-term climate changes and weather variabilities, and the result shows positive outcomes for most of the analyses (Hunt, et al., 2017).

The European Union has supported national and local investments in natural solutions that deal with extreme heat, which reduce the negative impacts of heatwaves on the health of European citizens and have saved thousands of lives during the summertime. With EU funding, the Municipality of Cascais, Portugal was able to transform the Ribeira das Vinhas valley into a natural green wind corridor that provides a cool place for local residents when heatwaves strike. In Bologna, Italy, EU-funded satellite data was used in city-planning, with the goal to install 10 green roofs on public buildings and create more green spaces in the city centre (European Union, 2020). In addition, the European Copernicus Climate Change Service (C3S) (Copernicus, 2021) have provided information about the temperature and climate in European countries as well as useful climate indicator tools that can be accessed by the public, which enhance authorities' preparedness and response to heatwaves.

In this section, we demonstrate benefit-cost assessments for green and white measures[25] to mitigate the UHI effect and heatwave EWS for overall heatwave impacts. BCAs for different types of interventions are undertaken with detailed quantitative analysis including modelling, with both prospective and retrospective assessments, and qualitative reviews of other examples. *Table 51* summarizes main data and information sources.

25 Green measures here refer to green roofs, whereas white measures refer to highly reflective surfaces such as walls, roofs and streets.

Table 51: Overview of data and information sources for extreme heat analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
UHI effects	Green and white solutions to the UHI effect in Vienna	• An estimation of the attributable number of deaths according to the methodology of Gasparrini and Leone, published in *Attributable Risk From Distributed Lag Models* • Urban climate model for Vienna, published in *Modelling Reduction of Urban Heat Load in Vienna by Modifying Surface Properties of Roofs* • Daily climate variables obtained from the Central Institutions of Meteorology and Geodynamics, Vienna Austria • Daily air pollution obtained from the Environment Agency Austria • Daily mortality obtained from Statistik Austria • Reduction in labour productivity estimated with the approach used in *Costs of Climate Change: The Effects of Rising Temperatures on Health and Productivity in Germany* • Heating and cooling savings estimated according to *Green Roof Valuation: a Probabilistic Economic Analysis of Environmental Benefits* • World Bank's *Guidance Note on Shadow Price of Carbon in Economic Analysis*
Heat early warning system(s) (HEWS)	HEWS for reducing health impacts of heat in Paris	• Reduction of heat-related morbidity based on estimations performed by Dé Donato et al. in the article *Changes in the Effect of Heat on Mortality in the Last 20 Years in Nine European Cities: Results from the PHASE Project* • Reduction in heat-attributable deaths based on assumptions from '*Climate and Weather Service Provision: Economic Appraisal of Adaptation to Health Impacts and Valuing Deaths or Years of Life Lost? Economic Benefits of Avoided Mortality from Early Heat Warning Systems'* • Information on cost of HEWS obtained from the National Observatory for the Impacts of Global Warming (*Observatoire National sur les Effets du Réchauffement Climatique,* ONERC) report 'Climate Change: Costs of Impacts and Lines of Adaptation'

Source: World Bank analysis; based on external data and information

Models need to be adapted to the type of investment analysed. To estimate the impacts of extreme heat, epidemiological models are used to determine the temperature-mortality and temperature-morbidity relationships, which indicates the vulnerability of the population. Adequate data on hospital admissions are often not available, and linear approximations are made from the temperature-mortality response. For UHI effects, urban climate modelling is incorporated to estimate reductions in extreme heat (for example, the number of hot days) given a scenario of green or white solutions implementation, which is then combined with spatially explicit population data to estimate the exposure of the population to these extreme temperature reductions. For the HEWS, a comparison of the temperature-mortality relationship before and after the implementation is assessed, and an approximation of the reduction in heat-attributable mortality is made.

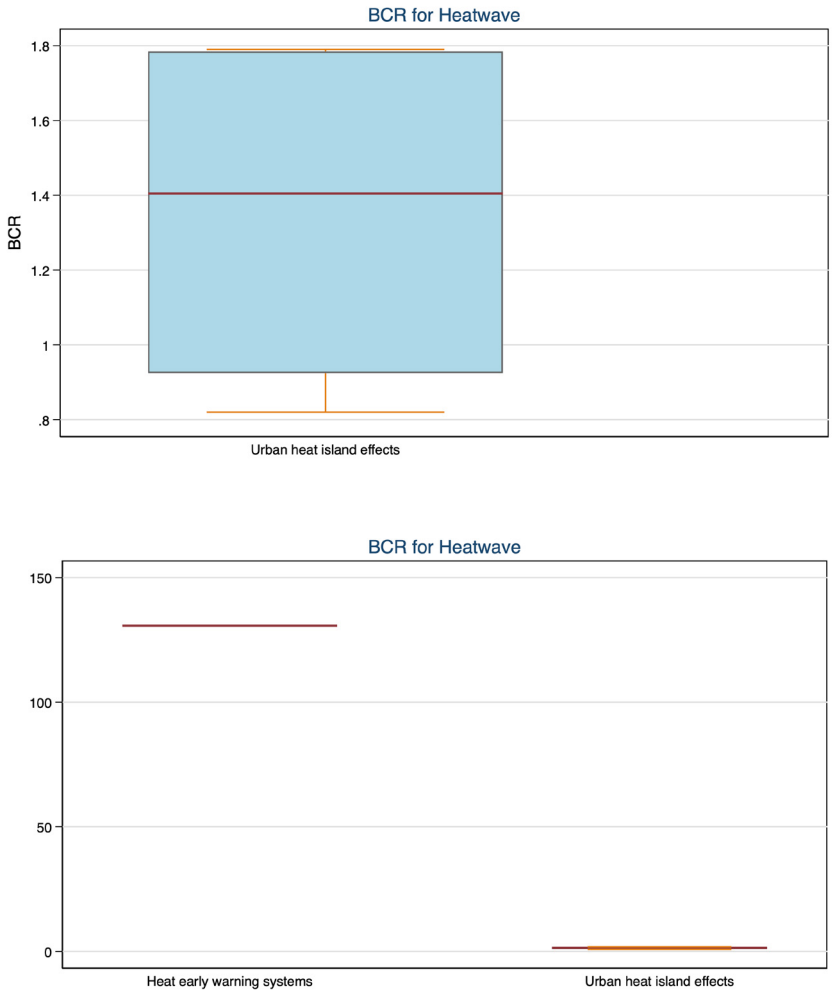
Although significant research has been put into the understanding of the health-related impacts of extreme heat, it is also important to consider costs and benefits, as citywide implementation efforts can incur significant sums. BCRs of HEWS tend to be high even if using a VOLY or a VSL approach. Recent studies from academic literature indicate BCRs to range between 23 (London) to 1,375 (Madrid) (Hunt, et al., 2017) depending on the climate of the city, effects of climate change, socio-demographic change, and how reduced mortality is valued (that is, premature versus displaced deaths) (Chiabai, et al., 2018). For mitigating the UHI effect, complete cost-benefit analyses of citywide application of green and white solutions are still lacking in the literature, with only one study finding BCRs of combined green and white solutions

to range between 1.3 and 2.7 for small and medium-size cities in Austria (Johnson, et al., 2020).

Results of the analysis are generally showcasing net benefits of interventions. This is consistent with findings in the literature for heatwaves prevention, although it has to be noted that the case studies considered are also different in terms of scales of investments. More details are included in *Figure 22*, *Figure 23* and *Figure 24*.

Figure 22 presents boxplots that display the distribution of BCRs for different types of investments in extreme heat based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). The outliers are shown as dots. Extreme values are excluded from the top graph and included in the bottom one.

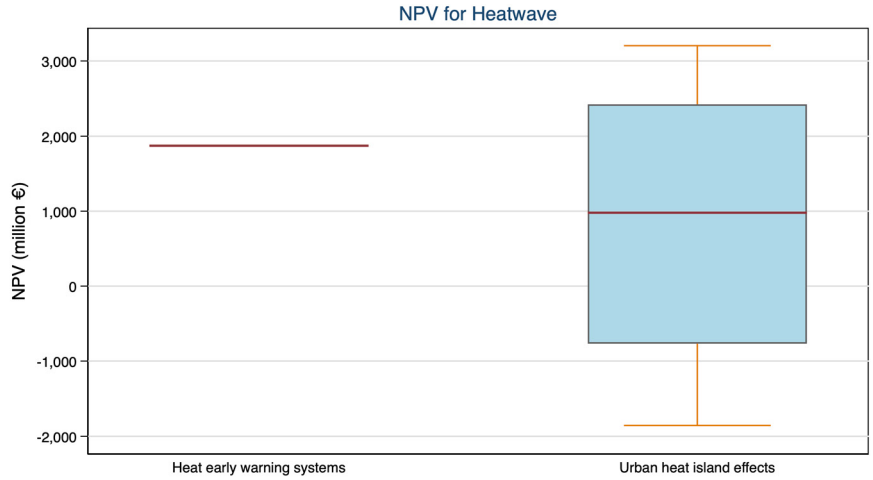
Figure 22: Findings of benefit-cost analysis for extreme heat (B/C ratios)



Source: World Bank analysis; based on external data and information

Figure 23 below presents boxplots that display the distribution of NPVs (in millions of EUR) for different types of investments in extreme heat based on a five number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, maximum (shown in orange).

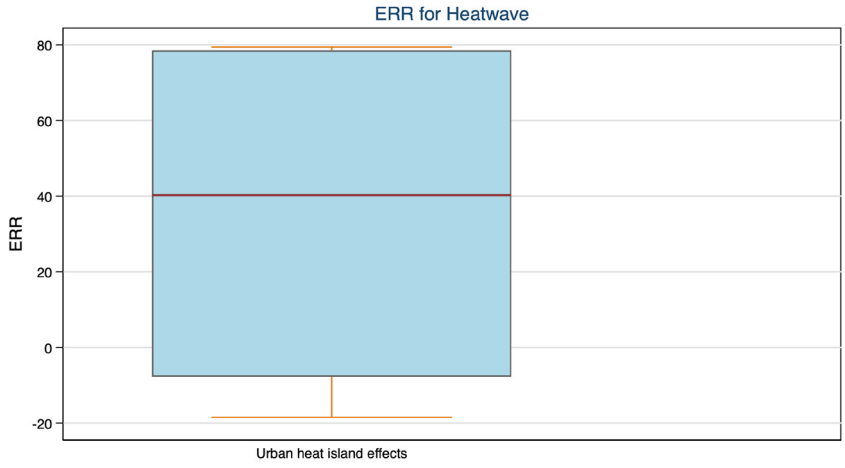
Figure 23: Findings of benefit-cost analysis for extreme heat (NPVs)

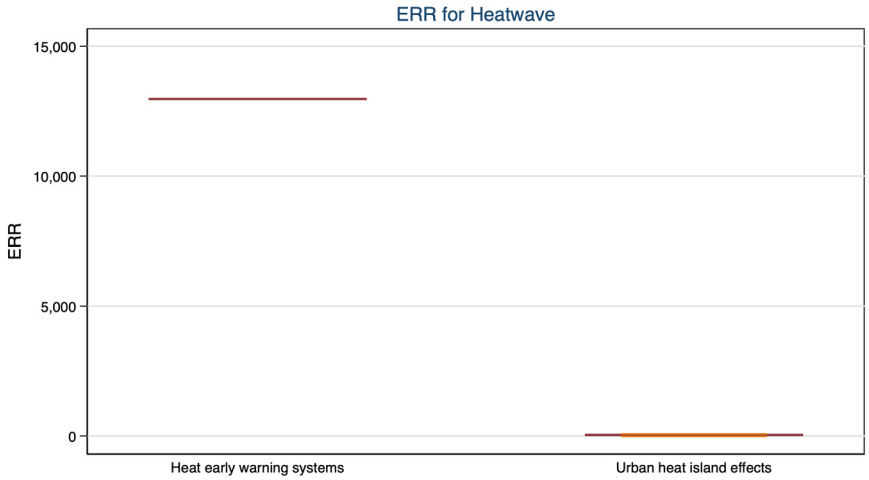


Source: World Bank analysis; based on external data and information

Figure 24 below presents boxplots that display the distribution of ERRs for different types of investments in extreme heat based on a five number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). Extreme values are excluded from the top graph and included in the bottom one.

Figure 24: Findings of BCA for extreme heat (ERRs)





Source: World Bank analysis; based on external data and information

The UHI effect is a result of a high coverage of impermeable surfaces, a lack of vegetation, and dense concentration of structures that absorb and re-emit the sun's heat slower than natural landscapes such as forests (Oke, 1982). The UHI effect can have detrimental consequences for urban populations such as increased heat-related mortality (Dang, et al., 2018) Several EU initiatives such as LifeMedGreenRoof (EU+Life) and the Urban GreenUP Project (Horizon 2020) have promoted the R&D of solutions to the UHI effect. Mitigating the impacts of UHI includes solutions such as the greening of roofs (green solutions), to increase vegetation and modifying buildings to have higher reflectivity of sealed surfaces (white solutions) or enhance the coverage of water for cooling effects (blue solutions). It is important to consider costs and benefits, as citywide implementation efforts can incur significant sums. Other solutions however can be implemented that are more integrated in other interventions and can therefore yield substantial co-benefits, such as the EU co-funded Life+ Programme (LIFE, 2020).

- **Case study 15 (new analysis under this project, ex ante (Schwaiger, et al., 2015)):** The analysis of hypothetical citywide interventions in Vienna to dampen UHI effects such as green roofs and reflective surfaces yielded BCRs higher than 1 for green solutions (depending on intervention choice: BCR 1.78–1.79, NPV €1.6–3.2 billion, and ERR 78–79 percent) but no net benefits for combined green-white interventions with smaller coverage of green roofs (BCR 0.82, NPV –€2 billion, ERR –18.49 percent) or small BCR for green roofs with white solutions (BCR 1.03, NPV €300 million, ERR 2.90 percent). This can be explained by the relatively higher cost of white solution and environmental co-benefits of green solutions, although it has to be considered that this is specific to the case of Vienna (costs may be more affordable in lower-income cities, for example). The analysis could be improved by considering a spatial disaggregation of the age composition and considering targeted placement of measures rather than overall cover, likely to reduce in higher BCRs.

- **Case study 16 (new analysis under this project, ex post (Rey, et al., 2007)):** The analysis of a national program implementing a heatwave EWS (HEWS) in France after 2003 has yielded high net benefits (BCR 130.67, NPV €1.87 billion, and ERR 12,966.7 percent) and a thorough sensitivity analysis has shown that the lowest BCR would be 48, which is consistent with findings in the literature. This is despite the fact that adapted methodologies and conservative assumptions were used to assess this type of disaster (such as using VOLY instead of VSL. This type of research could be improved by having more detailed hospital data to empirically assess the temperature-morbidity relationship and surveys on behavioural changes due to the HEWS to understand third dividend benefits better. As outlined above, a general intellectual discussion of the high BCRs found when assessing EWS could improve the understanding of whether impacts of other complementary investments are captured to ensure how these synergies can be enhanced. Moreover, it has to be noted that the scale of analysis is different from other case studies presented in this report as national-scale programmes.

3.3.2. UHI EFFECTS

GENERAL INTRODUCTION TO MEASURES TO MITIGATE UHI EFFECTS

Cities are increasingly affected by increasing temperatures due to climate change as well as the UHI effect in which urban temperatures are higher than surrounding areas (Oke, 1973). The UHI effect can have detrimental consequences for urban populations such as increased heat-related mortality (Dang, et al., 2018). Two examples of mitigating the impacts of UHI are the greening of roofs (green solutions) to increase vegetation and modifying buildings to have higher reflectivity of sealed surfaces (white solutions) (World Bank, 2020a).

Several EU initiatives have promoted the R&D of solutions to the UHI effect. The EU Life+ funded project LifeMedGreenRoof investigated the properties and feasibility of green roofs for Malta and Italy and supported the development of guidelines for improved uptake of green roofs in reduce energy consumption due to the UHI effect. The URBAN GreenUP project, funded through the EU Horizon 2020 program, is an ongoing project aiming to increase the understanding and awareness of the benefits of NBS for urban areas with a focus on the mitigation of UHI. Moreover, the EEA has highlighted the development of numerous research projects that showcase the UHI mitigating potential of green and white solutions (EEA, 2020b). Numerous initiatives have also supported the climate proofing of social housing such as in the United Kingdom (see *Box 8* below).

Box 8: Climate-proofing social housing

Climate change is expected to cause more extreme weather events across Europe, such as winter flooding and summer heatwaves, and the impacts of these events will be particularly exacerbated in urban areas, as high soil sealings and drainage systems are already at or near capacity. This means that metropolitans are susceptible to increased threat of surface water flooding. Not to mention, the mass of construction material and reduction in vegetated surfaces in urban areas signify a higher risk of overheating in the summertime.

It is important to specifically target climate adaptation interventions towards social housing because these residents are typically more vulnerable to the effects of climate change and are the least likely to afford necessary measures that could help them mitigate this risk. Existing housing structures are not designed to withstand future climate scenarios; therefore, it is important to maximize the limited outdoor space and adopt climate adaptation solutions that minimize the local effects of urban development. Green and white solutions can be low-cost and low-technology solutions that enable cities to achieve their environmental and economic goals.

Between 2013 and 2016, the EU Life+ Programme co-founded the Climate Proofing Social Housing Landscapes project (LIFE, 2020), which had a total budget of €1,615,636, to demonstrate water-sensitive urban design measures and other climate adaptive actions can transform urban housing estates into a vital entity for acclimatizing cities to climate change. This project implemented a package of climate change adaptation measures in three social housing estates in the West London borough of Hammersmith & Fulham. This mix of SuDS, rain gardens, and drought resilient planting and micro green roofs supported by rainwater harvesting tackled the whole housing management cycle while providing effective and affordable low-technology solutions for social housing estates to meet heightened environmental and economic targets. For example, the University of East London monitored the effectiveness of these solutions using technical software and found that green roofs absorbed 89 percent of rainfall and diverted 100 percent of rainfall from storm drain systems. As a result, these climate change adaptation measures implemented during this project demonstrated that these strategies have the ability to reduce water run-off and local flooding, improve water quality, and help mitigate the UHI effect to create wildlife habitats and improve biodiversity, despite limited resources.

Although significant research has been put into the understanding of the UHI mitigating effects of green and white solutions, it is also important to consider costs and benefits, as citywide implementation efforts can incur significant sums. To address these concerns, the EU Horizon 2020-funded Climate Resilient Cities and Infrastructures (RESIN) project created tools to support the development and implementation of various strategies in addressing multiple urban risks. This effort led to the creation of an adaptation option library, which identifies several BCA cases and scientific papers that address heatwaves. The BCRs for green roofs may be as high as 2.4, for example, in Belgium, and just over 3.3 for green facades in Italy (EEA, 2020b) . However, less is known about the costs and benefits of citywide adaption to the UHI effect, with only one study on small and medium-size cities in Austria finding BCRs to range between 1.3 and 2.7 for combined white and green solutions (Johnson et al. 2020). Although some studies estimate the health benefits of UHI mitigation strategies (Chen et al. 2014), and some even quantify the benefits monetarily (Mills & Kalkstein, 2012), complete BCAs of such strategies are lacking. Therefore, the current case study analyses the costs and benefits of green and white solutions to mitigating UHI effects.

GREEN AND WHITE SOLUTIONS TO THE UHI EFFECT– VIENNA, AUSTRIA

This case study is a new ex ante / hypothetical analysis under this project that involved modelling of hazards.

→ Introduction and background

Creating and/or expanding urban green infrastructure (green solutions), such as green roofs, as well as implementing highly reflective surfaces (white solutions) helps decrease the UHI impacts, such as increased mortality, morbidity, and labour productivity loss (EEA, 2020b) . By converting typically dark and heat-absorbing surfaces (that is, roofs, streets, and facades) to highly reflective surfaces, more of the solar radiation is transmitted back into the atmosphere due to higher albedo factors. Implementing green infrastructure in planning against UHIs not only addresses the first dividend but also provides for

numerous other economic and environmental benefits that are addressed through the second and third dividends of the triple dividend of resilience approach.

→ Description

In 2018, the Vienna Environmental Protection Department released the 'Urban Heat Island Strategy - City of Vienna' to implement a strategy for reducing the UHI effect to minimize health and other impacts. Protecting and increasing the implementation of green infrastructure is one of the core aims of the strategy as well as increasing the albedo of surfaces such as roofs, facades, and streets. The framework lays the foundation for consideration of UHI mitigating measures that can be incorporated in the planning of urban areas. Currently, of the total amount of roof space (5,184 ha), Vienna has green roofs on only 2 percent (104 ha), although the potential for implementing green roofs is estimated at 45 percent of the total roof space (Schwaiger, et al., 2015). Moreover, most roofs, streets, and facades do not currently exhibit high solar reflectance. The strategy also maintains the importance of financial incentives to improve the uptake of green roofs. For example, the city of Vienna supports investments in green roofs with €8–25 per m2 of the roof. Given the financial and policy-relevant aspects of the Vienna strategy, we have chosen this as the case study of interest for an appraisal analysis for addressing UHI risks.

→ Methodology and results of the analysis by dividends and overall

Detailed descriptions of the methodology, analysis, and calculations can be found in *Annex 4*.

Dividend 1: Health-related impacts of extreme heat

To understand the effects on the first dividend tier, this case study models the impact of temperature on human mortality. Mortality counts are regressed with daily maximum temperature to understand the relative risk of temperature on mortality and estimate the number of heat-attributable deaths on hot days (days with a maximum temperature greater than 30°C) - the baseline scenario approach for this case study. With this approach, we calculated an annual number of heat attributable deaths above a daily maximum temperature of 30°C to be 106 deaths (ranging 39–165 of 95 percent confidence intervals). The temperature-mortality relationship is then combined with results from an existing urban climate model for the case study site of Vienna, Austria.

The results of the urban climate model indicate the spatially explicit distribution of the current average number of hot days in the city. Furthermore, several scenarios of the implementation of green solutions and white solutions demonstrate the reduction of the number of hot days. Two scenarios indicate the changes in the urban climate for a 50 percent green roof implementation of all technically feasible roofs in Vienna as well as a 100 percent implementation. Two further scenarios include the 50 percent and 100 percent implementation of green roofs while converting the remaining potential roof areas to highly reflective roofing materials and converting potential wall and street space to highly reflective materials. The analysis further incorporates the exposure of the population to the heat hazard with a map of the population distribution across the city and considers the application of these strategies.

To estimate the societal value of reducing mortality risk, we employ the VOLY approach, as extreme heat tends to disproportionately affect older individuals, and valuing complete statistical lives would likely overestimate the economic impact of this hazard (Chiabai, et al., 2018). We estimate the VOLY according to a €7,286,000 value of a statistical life (VSL) for Austria (Viscusi & Masterman, 2017) and an average life expectancy of 80.7 years (Statistik Austria, 2020).

Due to a lack of available hospitalization data at the proper scale, we estimate the heat-attributable morbidity by linear approximating from the number of heat-related mortality counts saved by the implementation scenarios. Donaldson et al. (2001) demonstrated a significant relationship between the number of heat-related deaths and heat-related hospital admissions. In line with Hunt et al. (2017) , we assume 102 patient days avoided per reduced heat-related death. We use the average daily cost of hospital stays (2008–2017) for the city of Vienna to estimate the value of reduced hospital admissions. Furthermore, the avoided time spent in the hospital is also valued by taking the VOLY as an estimate of the quality of a life year and reducing this down to 75 percent (Karlsson & Ziebarth, 2018).

Dividend 2: Property values and building longevity

Green infrastructure, such as green roofs, offers numerous additional benefits besides the reduction of the UHI effect that can be economically valued. The benefits either fall under the second or third dividend. Green roofs have been cited to increase property values in a range of 2–5 percent (Bianchini & Hewage, 2012; Perini & Rosasco, 2016). Assuming a 3 percent increase in the average property values of several sizes in Vienna (PWIB Wohnungs-Infobörse GmbH, 2020), we take a conservative approach in this valuation.

For the second dividend, we also assess the improvement of the building longevity with the installation of green roofs. Green roofs extend the working life of a roof to an average of 50 years (Clark, et al., 2008). Taking the average cost of major repairs and maintenance that would typically accrue in the 25th year of a conventional roof, we value the building longevity improvements of installing green roofs as a saved replacement cost.

Dividend 3: Economic and environmental co-benefits

Several economic and environmental benefits are assessed for green infrastructure under the third dividend. Energy efficiency improvements are valued given the additional insulating layer of green roofs (Berardi, et al., 2014). We compare the differences in the thermal properties of green and conventional roofs according to Clark, et al. (2008) to estimate heating and cooling savings.

Extreme heat can have significant impacts on both indoor and outdoor labour productivity in Europe, leading to large economic losses (Naumann, et al., 2020). Given time and data constraints, we employ the approach of Hübler, et al. (2018) to estimate the reductions in labour productivity loss with scenarios of implementation that would otherwise occur on hot days, assuming an average reduced worker productivity loss of 7 percent (Vöhringer, et al., 2017).

Green infrastructure, such as green roofs, offers numerous environmental benefits alongside the abovementioned economic benefits. Green roofs improve stormwater management in urban areas by reducing the amount of stormwater run-off being conveyed in municipal sewer systems. We assume a 50 percent decrease in the run-off from greened roof surfaces and value this change according to a stormwater charge for sealed surfaces.

Heating savings from the second dividend also incur saved pollution and carbon dioxide as negative externalities that society bears as a third dividend benefit. Therefore, we value the reduction of this externality to society at the EU-wide rate of €12/MWh for reduced heating with combined heat and power with natural gas (Alberici, et al., 2014).

Furthermore, green roofs provide habitats in urban areas for organisms, which was otherwise nonexistent (Currie & Bass, 2010). Since the quality of the green roof is only a fraction of a completely natural space, we value the improvement to urban habitats with 15 percent of the cost (Bianchini & Hewage, 2012) for restoring land (MacMullan, et al., 2009). Lastly, green roofs support urban areas in pollution mitigation and carbon dioxide sequestration. We take removal rates of pollutants, including nitrous oxide, ozone, sulphur dioxide, and particulate matter (Yang, et al., 2008), and carbon sequestration rates of green roofs (Getter, et al., 2009) to estimate the reduction of these negative externalities to society. The valuations incorporate the average of the high and low shadow prices of carbon (World Bank, 2017b), which are increasing into the future, as well as the shadow prices of the air pollutants according to EU-wide damage costs (Holland, et al., 2014).

→ **Costs of green and white solutions**

For the cost estimates of green roof, we used the median estimates of retrofitting roofs from a large sample of actual costs from the literature (Strehl & Offermann, 2017). We also take the estimates of Bretz, et al. (1998) for high albedo measures on roofs, streets, and facades. These are meant to be guiding values of the installation and operation and maintenance costs.

→ **Results of the analysis by Dividends and overall**

Overall, the analysis finds positive net benefits for three types of interventions but not for the intervention with smaller green roof coverage and white solutions (see *Table 52*). This could be explained by the relatively high cost of white solutions and the higher co-benefits of green roofs in terms of environmental benefits, for example.

Table 52: Costs and benefits of green and white solutions to reduce UHI effect (in hundred millions €)

	GREEN ROOFS (50%)	GREEN ROOFS (100%)	GREEN ROOFS (50%) + WHITE SOLUTIONS	GREEN ROOFS (100%) + WHITE SOLUTIONS
FIRST DIVIDEND (€)				
Reduced heat-related mortality	4.25	8.65	39.76	40.84
Reduced heat-related hospitalizations	0.1	0.2	0.91	0.93
Reduced time spent in the hospital	0.04	0.09	0.4	0.41
Total first dividend	4.39	8.93	41.08	42.18
SECOND DIVIDEND				
Increase in property values	16.12	32.25	16.12	32.25
Total second dividend	16.12	32.25	16.12	32.25
THIRD DIVIDEND (€)				
Economic co-benefits				
Improved energy efficiency (savings on heating and cooling)	4.92	9.84	4.92	9.84
Reduced labour productivity loss	2.39	3.88	10.46	10.76
Building longevity increase	4.3	8.59	4.3	8.59
Environmental co-benefits				
Stormwater runoff reduction	2.52	5.04	2.52	5.04
Reduced externalities of energy production	0.51	1.03	0.51	1.03
Habitat creation	1.3	2.6	1.3	2.6
Air quality improvements	0.4	0.79	0.4	0.79
Carbon sequestration	0.18	0.36	0.18	0.36
Total third dividend	16.52	32.15	24.59	39.02
TOTAL DIVIDEND	37.04	73.33	81.79	113.45
Total cost	20.64	41.29	100.34	110.25
BCR	1.79	1.78	0.82	1.03
NPV (€)	16.4	32.04	-18.55	3.19
ERR (%)	79.43	77.61	-18.49	2.90

Source: World Bank analysis; based on external data and information

→ **Challenges faced and lessons learned**

Future studies should disaggregate benefits of reduced productivity loss according to the sector of the economy. A spatially explicit representation of the age composition of the population across cities could further improve the accuracy of the benefit estimations of reduced mortality.

Including white solutions into the scenarios greatly increases the costs and results in lower BCRs than the green solutions on their own. However, it should be maintained that the scenarios assumed complete application of technically feasible areas across the city. However, it may not be necessary to obtain such a level of application across the city, and a strategic placement of measures could improve the balance between the costs and benefits.

3.3.3. HEAT EARLY WARNING SYSTEMS

GENERAL INTRODUCTION TO BENEFITS OF EARLY WARNING FOR HEATWAVES

Extreme heat can have detrimental impacts on human health and well-being. The 2003 heatwave that swept across Europe was estimated to have claimed the lives of around 30,000 people (UNEP, 2004). In just one hospital in Paris, 2,400 additional emergency care visits and 1,900 excess hospital emissions were recorded during the heatwave (Åström, et al., 2013), and the number of excess deaths that occurred due to the 2003 heatwave in France is estimated at 14,800 (Bouchama, 2004). Given that numerous heatwaves in the past have led to considerable excess mortality in France (Rey, et al., 2007), there is significant concern for the human health-related impacts of extreme heat. These concerns are further compounded when considering the future impact of climate change on temperatures and how projections of heat-related mortality show rising rates in many cities across the globe (Gasparrini, et al., 2017).

The PESETA IV project of the JRC of the European Commission alluded to high benefits in terms of reduced mortality, morbidity, and productivity loss if HEWS were implemented for EU regions (Paci, 2014). Furthermore, a study under the EC-funded EUPORIAS project found that improving current warning systems with better forecasts can further improve the heat-related mortality (Lowe, et al., 2016). Current EU-funded work is under way to implement a Europe-wide heat-warning system that addresses workers and productivity loss and is researched under the EU Horizon 2020 HEAT-SHIELD project (Casanueva, et al., 2019). Moreover, these systems can complement other efforts in mainstreaming the use of NBS. For example, to achieve the goals set in France's second national climate adaptation plan and future plans, the €16.6 million Life IP Artisan project (Coreau, 2020) (with an EU contribution of €10 million) attempts to increase the country's resilience to climate change. Its main objective is to generalize the implementation of NBS and good practices to the extent possible by 2030, which creates a good framework for the emergence of local projects that emphasize climate adaptation and the ecosystem.

Several BCAs have demonstrated that the benefits of such systems strongly outweigh the costs. Ebi et al. (2004) estimated net benefits of €417 million (US$468 million) for 1995–1998 for the HEWS in Philadelphia. Hunt et al. (2017) also showed positive results with BCRs of median scenarios of climate change greater than 1 and ranging from 23 for London to 1,375 for Madrid. In a study by Chiabai, Spadaro, and Neumann (2018), BCRs ranged from 42 to 1,350 for the HEWS of Madrid, depending on whether the VSL or VOLY was used and whether displaced versus premature deaths were considered.

HEWS FOR REDUCING HEALTH IMPACTS OF HEAT IN PARIS, FRANCE

This case study is a new ex-post analysis under this project that involved modelling of hazards.

→ Introduction and background

HEWS can provide important health benefits in terms of avoided heat-related mortality and morbidity. It supports emergency managers and countries to implement preparedness measures like cooling stations and targeted messaging as well as informing energy providers ahead of time of increased cooling load demand.

→ Description

Due to the high societal losses in the 2003 heatwave, France put forward a plan to help prevent further high excess mortality during heatwaves. The core of the plan was the implementation of HEWS to alert vulnerable groups of the ensuing high temperatures to have better preparedness. Studies have shown positive effects of HEWS in reducing heat-related mortality (Bassil & Cole, 2010). Given indications that the HEWS of France has improved the heat-mortality responses to extreme heat (Fouillet, et al., 2008), this case study analyses the costs and benefits of the system.

The French HEWS was implemented following the disastrous 2003 heatwave that resulted in tens of thousands of deaths. The aim was to provide a system of alerting authorities of ensuing extreme heat events to set up preventive measures that address vulnerable groups. The system is based on threshold temperatures that lead to an excess of mortality when reached and is active between June 1 and August 31. If the three-day averaged minimum and maximum forecasted temperatures are likely to reach predefined thresholds, warnings are issued, and information is disseminated to the media and general population. If high levels of the system are activated, specific advice is provided to vulnerable groups (for example, schools, hospitals, and businesses). Although this HEWS has been studied for its effectiveness, we have chosen this HEWS as the case study because no BCA has been performed for it thus far.

→ Methodology and results of the analysis by dividends and overall

To assess the reduction in heat-related mortality and morbidity through the implementation of the HEWS, we rely on empirical modelling carried out in academic health literature. This method has been proposed due to time and data constraints, especially given the extensive data needs to quantify the heat-related mortality before and after the initiation of the HEWS. We take a city-level approach for calculating the costs and benefits, as the heat-related mortality relationships are usually quantified in such a manner.

The approach of this analysis is to estimate baseline costs and benefits of the HEWS and to perpetuate these into the following 50 years. Climate change and demographic change are not considered in this analysis. However, given the strongly positive results of the analysis, it can be assumed that the BCRs that are greater than 1 will not worsen over time due to these factors. With the progression of climate change on the one hand, the costs of the system will increase since the system is triggered more often (ECONADAPT, 2015). On the other hand, the benefits will also greatly increase as more vulnerable portions of the populations are increasingly addressed to prevent health consequences, which was demonstrated in the analysis by Hunt et al. (2017). Furthermore, given demographic changes trending towards increased portions of the vulnerable population in older age groups, these groups would also be addressed by the HEWS, which would further increase the benefits. Therefore, the changes arising in socio-climatic scenarios can generally be negligible since both the benefits and costs are proportional to the number of extreme heat events (Chiabai, et al., 2018).

Dividend 1: Valuing reduced health-related impacts of extreme heat

Heat-related mortality is modelled by means of a distributed lag nonlinear model that includes the lagged effects of heat on mortality. With this modelling procedure, the main effects of heat on mortality are captured, and the additional effect of a heatwave may only be insignificant (Gasparrini & Armstrong, 2011). Fouillet et al. (2008) already indicated the significant positive effect of the HEWS on the temperature-mortality relationship of France with a modelling procedure using projections of the number of expected deaths that would have occurred in the 2006 heatwave given the number of deaths in the 2003 heatwave. Their analysis predicted a much higher expected number of deaths for the 2006 heatwave than what did occur with a resulting 4,400 deaths saved. However, we rely on the estimations performed by Dé Donato et al. (2015) since their analysis empirically estimates the heat-related mortality for several years before and after the implementation of the HEWS. Dé Donato et al. (2015) regressed daily all-cause mortality with daily mean temperature while controlling for potential confounders, such as air pollution, relative humidity, barometric pressure, and wind speed, to estimate the heat-related risk and attributable deaths. Their analysis concluded a significantly reduced relative risk of extreme heat following the implementation of the HEWS by comparing the relative risks between 1997–2002 and 2004–2009.

The number of heat-attributable deaths was reduced by 787 over the six-year period. For the current analysis, we take this figure and divide by the six years to arrive at an assumed annual reduced heat-related mortality. Given the possibility that many other factors might have reduced the relative risk to heat, we assume an effectiveness of the HEWS of 38 percent considering the assumptions of Hunt et al. (2017). Furthermore, we rely on some assumptions of the analysis by Chiabai, Spadaro, and Neumann (2018) in that a portion of the deaths may have been displaced deaths as opposed to premature deaths. Premature deaths would entail a loss of life at some period in the otherwise healthy individual, whereas a displaced death relies on the harvesting hypothesis that the death occurred for an individual who would have otherwise passed away in a short time afterwards (Hajat, et al., 2005). For the baseline scenario, we assume that 35 percent of the heat-related deaths are displaced deaths, which are valued at 16 days of the VOLY. For the remaining deaths saved, we differentiate between the 0–74 age group and the 75+ years age group, given that 80 percent of the heatwave deaths in the 2003 heatwave occurred in this age group (EEA, 2004). We value the saved years of life in the 75+ age group by subtracting from the life expectancy and multiplying in by the VOLY, whereas the average age is used for the 0–74 age group.

Empirical evidence suggests that the number of hospital admissions rises with extreme heat. Using hospital climate data from 1991 to 1995, Michelozzi et al. (2009) demonstrated that daily hospital admissions rose by 1.3 percent on days with a maximum apparent temperature above 27.8°C. To value the reduced heat-related morbidity, we take a linear approximation of the number of hospitalizations given the number of reduced heat-related deaths. We assume 102 patient days per heat-related death as found by Donaldson et al. (2001) and a central cost value of €750 per patient days in line with the analysis by Hunt et al. (2017). Given that prevented hospitalizations results in less time spent in the hospital, we further adopt the approach in Karlsson and Ziebarth (2018) to value the prevented time spent in the hospital. A 25 percent fraction of the quality of a life year for France (Téhard, et al., 2020) is estimated while scaling down to the number of saved patient days.

The former benefits all address the first dividend of the Triple Dividend Framework of resilience. This analysis demonstrates the significant societal value provided by valuing the impacts of this dividend, although some qualitative impacts in the other dividends are also deemed noteworthy. HEWS are increasingly important to improve the awareness of the population of the health-related impacts of extreme heat, and the implementation of such systems can be of great value to the policy and planning to ensure the safety of workers (Kjellstrom, et al., 2019).

Dividend 3: improved awareness and preparation for the workforce

The effectiveness of the HEWS relies on the behavioural changes adapted by the population. Given the apparent effectiveness of the system in moderating the temperature-mortality relationship at the extreme heat end, it appears that behavioural adaptations are happening at some scale within the population. Moreover, this study has only quantitatively considered impacts to the population in terms of mortality and

morbidity, which excludes the benefits accruing to the population arising from general pressures of extreme temperatures and the decrease of personal comfort. A study in Arizona concerning the awareness and perceived risk of heat given the introduction of HEWS showed that although not all surveyed individuals 65 years and older adjusted their behaviour during alert events, almost 50 percent of all respondents actually altered their behaviour having been aware of the alerts (Kalkstein & Sheridan, 2007). Such behavioural changes as a result of HEWS likely provided some benefits in improved thermal comfort for individuals, and these benefits were not captured quantitively in this analysis. Furthermore, heat-related worker productivity loss is an increasing concern given climate change-related temperature increases. However, the introduction of HEWS sets the stage for future warning systems that also specifically address the health of the workforce, such as the current work in the HEAT-SHIELD project on a European-wide occupational warning system (Morabito, et al., 2019). Given these concerns, it can be assumed that HEWS as in France can help prevent extended health consequences in the workforce by providing timely warnings of extreme heat events. Therefore, we have addressed these under the social co-benefits of the third dividend.

The costs of EWS are generally low compared to other forms of adaptation. The estimated cost of the initial implementation considering preparations was €286,933, and the estimated operational cost from June 1 to the end of August was €454,006 (ONERC, 2009). These costs are similar to the ranges seen for other systems in London, Madrid, and Prague (Hunt, et al., 2017).

→ **Results of the analysis by dividends and overall**

The BCR is high for this type of intervention, which is likely due to the high share of benefits from lives saved, even though this study has used the VOLY approach and assumed 35 percent of the deaths were displaced deaths rather than premature deaths (see *Table 53*).

Table 53: BCR for HEWS by dividends

HEWS	
FIRST DIVIDEND 1 (€)	
Reduced heat-related mortality	€1.8 B
Reduced heat-related hospitalizations	€63.8 M
Reduced time spent in the hospital	€25.7 M
Total first dividend	€1.9 B
THIRD DIVIDEND 3 (€)	
Economic co-benefits	
Improved productivity of outdoor labourers through knowledge of heat-related health effects	(qualitative)
Social co-benefits	
Improved awareness of heat-related health effects and potential for individual adaptation to increase heat stress	(qualitative)
TOTAL DIVIDEND	€1.9 B
Total cost	€14.45 M
BCR	130.67
NPV (€)	€1.9 B
ERR (%)	12,967

Source: World Bank analysis; based on external data and information

To test these results given the assumptions made, we account for the sensitivity of the BCR parameters of the cost-benefit model in a Monte Carlo simulation. The ranges of the parameters are given in *Table 54*, and all parameters follow triangular distributions with the baseline values as the mode and low and high values as the minimum and maximum, respectively. With 10,000 iterations in the Monte Carlo analysis, we arrived at a mean BCR of 131, a median BCR of 119, and BCRs at the 5th and 95th percentiles of 48 and 246, respectively. Furthermore, in all iterations, the BCR remained greater than 1.

Table 54: Ranges of parameters used in Monte Carlo simulation following triangular distributions

	LOW	BASE	HIGH
Installation cost (€)	277,095	346,369	415,642
Operation cost(€)	438,439	548,049	657,659
Discount rate (%)	1.5	3	5
Effectiveness (%)	9	38	68
Deaths in the 75+ age group (%)	60	80	100
Displaced deaths ratio (%)	0	35	75
Attributable deaths (number)	630	787	944

Source: World Bank analysis; based on external data and information

→ Challenges faced and lessons learned

There is generally a lack of publicly available hospital data that could be used to empirically assess the temperature-morbidity relationship. Surveys on the awareness of and behavioural changes due to the HEWS in France could provide insights into the understanding of the third dividend benefits.

BCRs are generally high for HEWS. For these reasons, it is preferred to value reduced mortality according to VOLY, which has been done in this study. Recent studies have found BCRs for Madrid to range from 42 to 1,350 depending on whether the VSL or VOLY is used and whether displaced and premature mortality is valued using VSL or VOLY. In the current case study, we have adopted the VOLY for both premature and displaced mortality (which could provide a conservative estimate) while furthermore assuming that only 38 percent of effectiveness is achieved with the HEWS (that is, only 38 percent of the saved lives could be attributed to the HEWS).

3.4. Droughts

3.4.1. SUMMARY OF FINDINGS FOR DROUGHTS

In terms of DDR investments in droughts, the EU has taken massive strides to transform their approach to water scarcity and drought from being crisis oriented to preventative directed within the last two decades (Stein, et al., 2016). These actions include developing irrigation and water provision systems, EWS, such as the European Drought Observatory (EDO), and multisector partnerships (MSPs) with various stakeholders of a specific region.

In 2000, the Water Framework Directive (WFD) established the EU-wide framework for water management. The occurrence of major drought events between 2000 and 2006, mainly the widespread drought in 2003, catalysed policy conversation on how the Environment Council should address the environmental, social, and economic impacts of water scarcity and drought at a political and a technical level. After several analyses, they found that drought affects all EU countries. Under former European Parliament Environment Commissioner Potočnik, the European Commission's JRC helped establish the EDO as part of ongoing efforts to integrate drought into policy. Since 2011, the EDO has been the leading communicator on drought-relevant information and maps.

Minimum river streamflow is an important indicator when conducting economic analysis and research on droughts because it is a reflection of the spatially integrated shortage in water supply over river basins, which is a great concern to water managers, according to the study conducted by PESETA IV (Cammalleri, et al., 2020). When conducting drought assessments with streamflow simulations, the hydrological and water use model LISFLOOD is used, with high-resolution regional climate projections for RCP4.5 and RCP8.5 being applied. The result of the study shows that in southern Europe, extreme low river flows will become more severe and persistent, especially in the context of global warming. At the same time, most of western Europe will become more vulnerable to frequent and intense droughts (Cammalleri, et al., 2020).

Minimum river streamflow is an important indicator when conducting economic analysis and research on droughts because it is a reflection of the spatially integrated shortage in water supply over river basins, which is a great concern to water managers, according to the study conducted by PESETA IV (Cammalleri, et al., 2020). When conducting drought assessments with streamflow simulations, the hydrological and water use model LISFLOOD is used, with high-resolution regional climate projections for RCP4.5 and RCP8.5 being applied. The result of the study shows that in southern Europe, extreme low river flows will become more severe and persistent, especially in the context of global warming. At the same time, most of western Europe will become more vulnerable to frequent and intense droughts (Cammalleri, et al., 2020).

Though undertaking economic analysis of investments in drought prevention is difficult, some reports have shown the logical links that can support the analysis and research on drought impacts (see *Figure 25* below as well as page 29 of the report from the Global Water Partnership and Central and Eastern Europe (2015)). The literature has mainly focused on estimating the costs of droughts (Pulwarty & Sivakumar, 2014) and the benefits of approaches to drought risk

management. Research on economic impact would benefit from improved drought risk assessments and comparison of scenarios with and without interventions (Pulwarty & Sivakumar, 2014) . The damage caused by droughts in the EU at a 95 percent confidence interval is estimated to be between €7.4 billion and €14.2 billion per year, assuming an annual loss of €9 billion for the baseline conditions (1981–2010) (Cammalleri, et al., 2020). Drought conditions remain unnoticed until water shortages become severe and their adverse impacts on the environment are severe, and therefore their consequences to ecosystems, such as limited public water supplies, agricultural losses, and damage to buildings and infrastructure due to soil subsidence, are not monetized. *Figure 25* demonstrates the framework for assessing the impact of droughts and the approaches and benefits of drought risk management and *Figure 26* shows the share of drought losses by economic sector under the baseline (1981 -2010) and climate projection for 2100.

Figure 25: Conceptual framework of the impacts of drought events and approaches to drought risk prevention

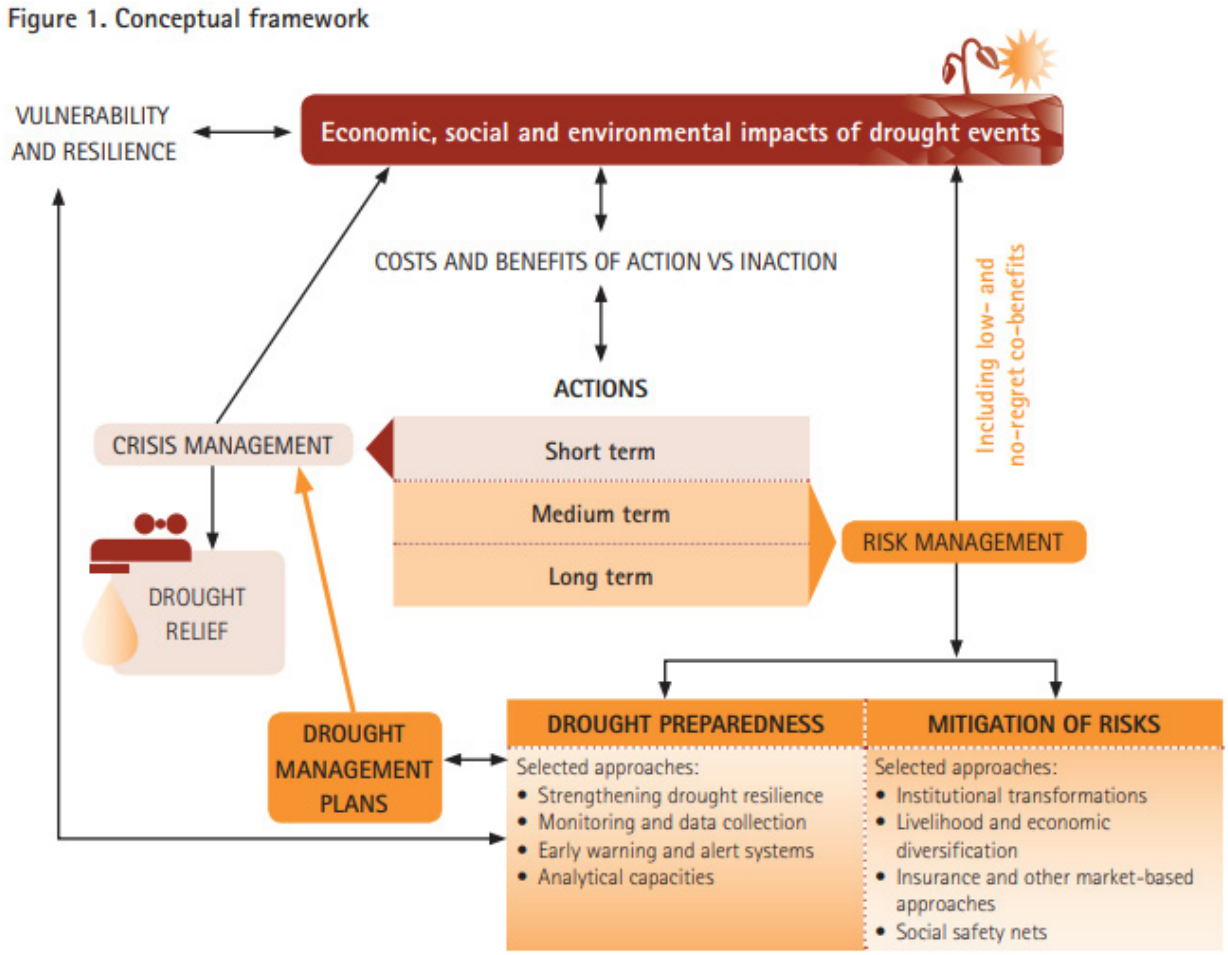
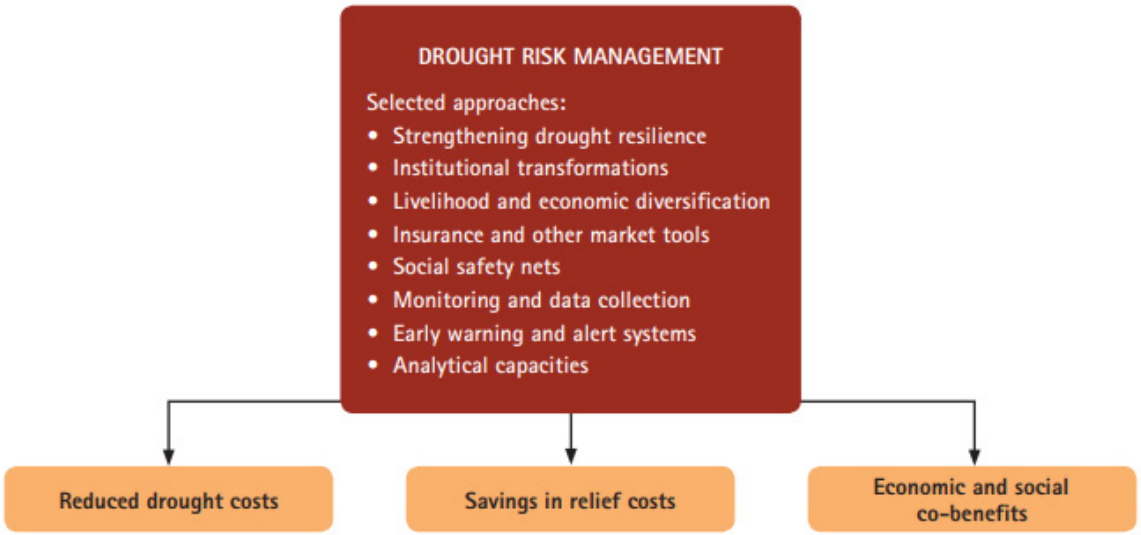
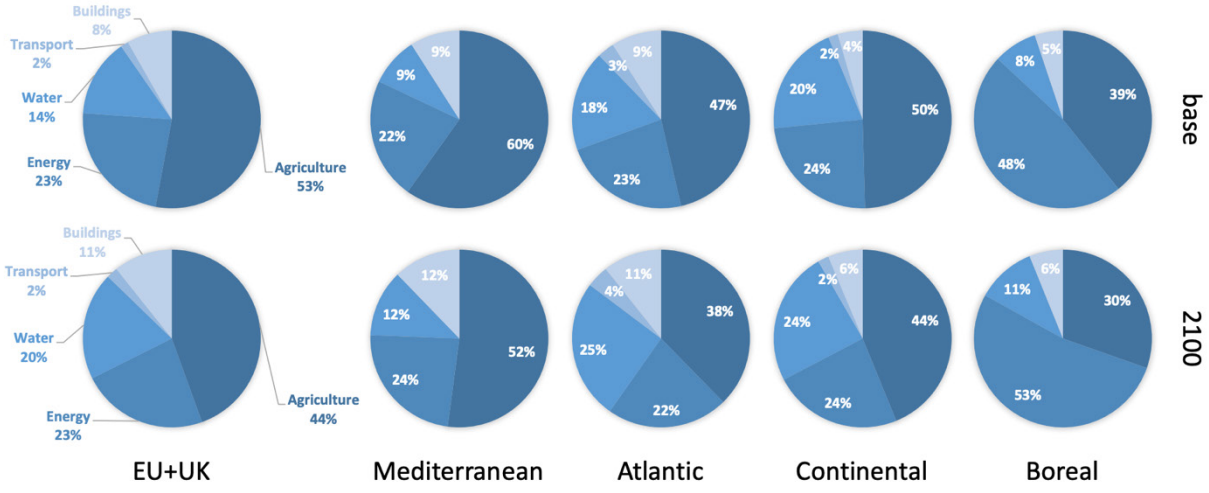


Figure 2. Approaches to drought risk management and benefits



Source: Gerber & Mirzabaev (2017)

Figure 26: Share of drought losses by economic sector (agriculture, energy, water supply, subsidence, and transport) for EU + UK and the four IPCC AR5 European subregions in the baseline (1981–2010) and in 2100



Source: Cammalleri, *et al. (2020)*

In this section, we have presented benefit-cost assessments for irrigation and water provision systems against droughts as well as early warning and capacity building for drought preparedness. Results from one BCA for an investment in drought management are presented for an external analysis that was undertaken with ex-post assessments, while the benefit of other interventions are shown qualitatively. Drought-related risks in most case studies are mitigated through the improvement of water systems. Some examples also show the effectiveness of monitoring and enhancing preparedness and public awareness in terms of drought risk reduction. A table summarizing main data and information sources can be found below (see *Table 55*).

Table 55: Overview of data and information sources for droughts analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Irrigation and water provision systems	Drought planned management in the Jucar River Basin	External econometric assessment from the study *Assessing the Effectiveness of Multi-Sector Partnerships to Manage Droughts: The Case of the Jucar River Basin*

Source: World Bank based on external data and information

BCRs have generally not been calculated for this type of disaster. Droughts are among the most damaging and least understood of all natural hazards and their onset is slow, which makes the economic analysis of preventive investments inherently difficult (Pulwarty & Sivakumar, 2014). Also, models need to be adapted to the type of investment analysed. Generally, estimation of (predicted) 'average' soil moisture is essential to be able to conduct economic analysis and research on droughts.

BCAs generally show net benefits of interventions, although generally in a qualitative manner. Given the lack of understanding of this hazard, there is little comparison possible with the literature, but the case study presented can provide interesting insights into how to consider governance of DRR investments in economic efficiency analysis.

Irrigation and water provision systems constitute preventive investments against droughts. These include investments in structural improvements and interventions of water supplies as well as irrigation systems providing civilians with access to improved water resources and enhanced water and food security. Preventive investments, such as drought wells, dams, and efficient irrigation, have a variety of benefits as they reduce the need for high-cost post-drought rehabilitation and relief efforts, beyond benefits of lives saved, health, and productivity, such as the large-scale water project 'Ligação Pisão-Roxo' (European Commission, 2011) in South Portugal that systematically improved the water supply system or EWS such as the DriDanube project (Interreg Danube, 2020).

- **Case study 17 (external research analysis, ex post** (Carmona, et al., 2017; European Commission, 2011)**):** The analysis of a comprehensive program for drought prevention in the Jucar River Basin in Eastern Spain, including institutional frameworks, environmental protection measures and water saving plans yielded high net benefits. The economic analysis focused on the impact of emergency drought wells, but the study also provides an overview of economic assessments methodologies for droughts, including how to estimate benefits or effectiveness from softer interventions such as governance arrangements (polycentric risk management governance) at least qualitatively.

3.4.2. IRRIGATION AND WATER PROVISION SYSTEMS AGAINST DROUGHTS

→ Introduction and background

Investments in structural improvements and interventions of water supplies as well as irrigation systems provide civilians with access to improved water resources and enhanced water and food security. Preventive investments, such as drought wells, dams, and efficient irrigation have a variety of environmental, economic, and social benefits. Not only are these areas better prepared for drought occurrences, but they are also able to supply residents with water during these times without hesitation or worries of scarcity. This preparedness reduces the need for high-cost post-drought rehabilitation and relief efforts. Moreover, the construction of these structural investments creates jobs for residents, which helps stimulate the economy further. *Box 9* below provides an illustration of the aforementioned benefits obtained from the structural investments.

Box 9: Investing in improving water security infrastructure and supply system

The following example showcases how structural improvements to the water security systems directly benefit civilians and lead to positive economic impacts. In Southern Portugal, a large-scale water project called "Ligação Pisão-Roxo" (European Commission, 2011) was launched with the objective to improve the water supply system of the Guadiana River. As a part of the Alqueva Dam Project, investments were made to build a new dam, which is a part of a larger water network with a canal extension of 23.13 km. The project was implemented with a total cost of €65.2 million, and it is expected to provide greater supplies of water for the region and its residents. An analysis of the benefits and impacts of the project was conducted, which shows that the improved water system benefits an estimation of 44,486 people and also generates economic benefits through the creation of 40 new jobs.

ECONOMIC BENEFITS OF DROUGHT PLANNED MANAGEMENT IN THE JUCAR RIVER BASIN

This case study is an external analysis that was undertaken with ex post assessments.

→ Description

Jucar River Basin, located in Eastern Spain, has suffered many historical droughts with significant socio-economic impacts due to the region's semiarid climate, high water exploitation indexes, and high spatial and temporal variability of precipitation which causes highly seasonal and inter-annual variability in river flows. Future climate change-related impacts can create future hydrological problems, such as increased salinity in coastal aquifers and higher water turbidity, which can have severe social and economic implications. Throughout history, there have been different governance structures established in the Jucar River Basin to tackle the multi-faceted risks associated with droughts and other climate change scenarios. Some of these structures have taken shape as MSPs, and currently, the Jucar River Basin Partnership's Water Council and the Permanent Drought Commission (PDC) are in action to address every officially declared drought. The PDC, which was established in December 2005 after the start of the 2005–2008 Drought Event in the Jucar River Basin, approved measures to address the following goals:

1. Environmental protection ensuring the continuity of streamflow and protecting drought-vulnerable wetlands

2. Management and control of water resources supporting the decision making in the PDC through the use of stochastic forecasting models to estimate future volume stored in reservoirs and use of forecasted scenarios to estimate the evolution of the systems

3. Water saving plans improving the efficiency of water distribution systems and the establishment of irrigation turns adopted by urban and agricultural users

4. Alternative water sources and generation of additional including the use of drought wells, recirculation of irrigation returns back to the head of the system, and reuse of treated wastewater from the urban areas.

The objective of this case study is to demonstrate the positive economic impacts effective water management can have on mitigating droughts and the broader metropolitan communities the basin serves. To do so, we will look at the economic impacts of groundwater pumping from drought wells and how it maintains crop production and production value.

→ Methodology

Two methodologies were used to evaluate how effective the creation and institutionalization of MSPs are in supporting the development of an efficient drought management system. However, for this case study, we will examine the econometric approach in detail to analyse the economic efficiency of emergency drought wells, a key drought mitigation measure suggested and implemented by the PDC.

→ **Results of the analysis by dividends and overall**

Table 56: Fitted impact model to determine economic efficiency of emergency drought wells

Table 2. Fitted Impact Model

	P value	Coefs
W	0.0082	283.84
G	0.0033	1484.98
Ip	0.0421	275,923

Pv=283.84*W+1484.98*G+275,923*Ip

Source: Carmona, *et al. (2017)*

From *Table 56* we see that the dependent variables are statistically significant with a p-value less than 0.05. Therefore, the fitted model is able to simulate the production value, while considering the historic time series of water deliveries (surface and groundwater) [W], index of crop prices [G], and production value of irrigated agriculture [Ip], with a R^2 value of 99 percent. During 2006, 2007, and 2008, the additional groundwater pumping for drought was estimated at 40 mm3, 40 mm3, and 25 mm3, respectively. As a result, according to this model, the additional drought pumping reduced drought losses by €59 million, 59 million, and 37 million during those respective years, compared to a scenario in which this mitigation measure was not implemented. There were no additional costs to the stakeholders for the drought pumping, since the pumping cost was supported by other Jucar River Basin users receiving surface water deliveries, in agreement with the conditions of the Alarcon treatment.

→ **Challenges faced and lessons learned**

The analysis focused on one drought period and a single risk mitigation measure (emergency wells) to analyse the economic benefits of the intervention and comment on the effectiveness of drought/disaster governance measures. The focus of the analysis is on polycentric risk management governance, and methodologies may also be applied to other drought management interventions with sufficient data available.

3.4.3. EARLY WARNING AND CAPACITY BUILDING FOR DROUGHT PREPAREDNESS

Accurate monitoring and effective early warnings are important as they allow people to be better prepared when a disaster strikes. EWS technology is especially important for agriculture and water resource management because it helps decrease risk associated with crop and food loss. According to the Climate Technology Centre and Network (CTCN) (2020), the operational arm of the United Nations Framework Convention on Climate Change (UNFCC) Technology Mechanism, effective drought monitoring warning systems must include appropriate drought indicators, meteorological data and forecasts, a warning signal, public awareness and education, institutional cooperation, and data sharing arrangements. Some environmental and socio-economic benefits of drought monitoring EWS are improved land use practices which decrease soil and land degradation; mitigation of human fatalities caused by health risks, poor water, and food security; a reduction of high costs related to post-drought rehabilitation and relief efforts; and refined network connectivity between and within local communities.

Integrated and comprehensive approaches are essential for effective drought monitoring and early warning given the complexity of the hazard, including the combination of connected local and international capacity and systems (Hayes, et al., 2005; Pulwarty & Sivakumar, 2014). While there have been significant

efforts made to understand the value of early hydro-meteorological warning systems, it remains that the valuations of information may vary by sector since there is no standardized approach. As a result, Liu et al. (2019) narrowed down their literature review to explore four methods and tools used to examine the economic benefits of climatic and meteorological information: direct valuations, indirect valuations, market approaches, and non-market approaches. A project in the Danube regions (see *Box 10*) reveals how an early warning and monitoring system reduces the negative impact of droughts.

Box 10: Investing in Early Warning and preparedness for Droughts

The following example shows the benefit early warning and monitoring systems yield in terms of disaster risk reduction. With the objective of increasing the capacity to manage drought-related risks, the DriDanube project (Interreg Danube, 2020) in the Danube region was launched in 2017. The Danube is a river region that experiences droughts frequently, which leads to water scarcity and negative impacts on the economy and welfare of the people. Therefore, the DriDanube project helps all stakeholders involved in drought management to be better prepared and more efficient when they are responding to drought emergencies. With a cost of €1.97 million, the project accomplished its goal with the output "Drought User Service", which allows efficient and accurate monitoring and early warnings of droughts. This enables better cooperation between agencies and emergency responses to droughts, which decreases the losses in lives and damages when a drought occurs.

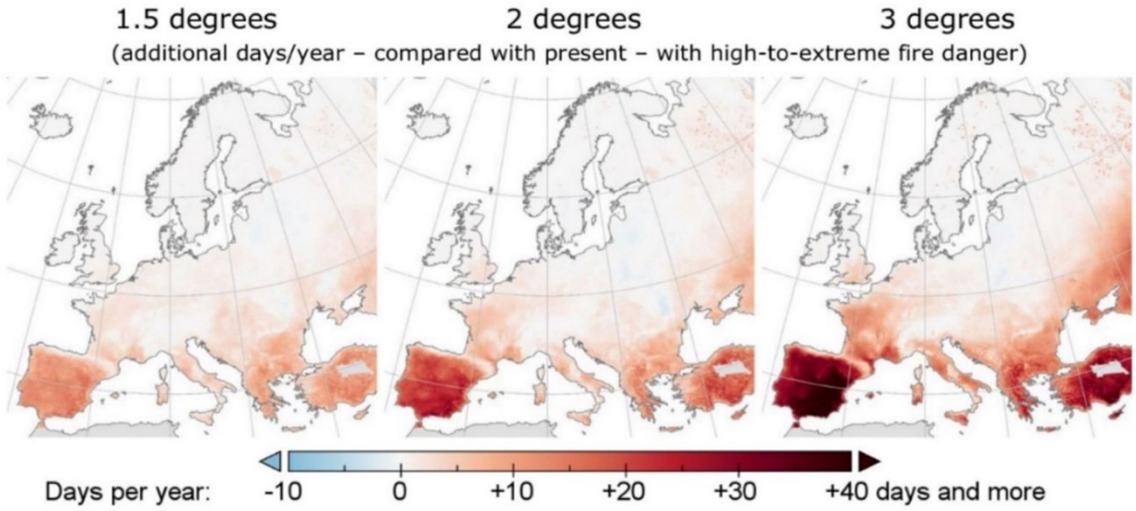
3.5. Wildfires

3.5.1. SUMMARY OF FINDINGS FOR WILDFIRES

Across Europe, forests cover approximately 215 million ha and other wooded lands cover an additional 36 million ha, which amount to over one-third of the continent's total land area (De Rigo, et al., 2017). More European countries suffered from large forest fires in 2018 than ever before, and Sweden experienced the worst fire season in reporting history. The unprecedented forest fires in several European countries in 2017 and 2018 coincided with record droughts and heatwaves in these years (EEA, 2020). In 2010 alone, wildfires were responsible for the damage of 0.5 million ha forests in Europe. Factors that contribute to forest fire occurrence include the moisture content of the forest surface and climate variables, such as wind speed. A wetter surface can decrease potential spreading of a fire and the ease of ignition, while wind speed can affect the rate a fire might spread following ignition. In the southern parts of Europe near the Mediterranean, moisture levels of forests are the lowest. As a result, the countries with the highest danger of wildfires are Spain, Portugal, and Turkey. Greece, parts of central and southern Italy, Mediterranean France, and the coastal region of the Balkans are also susceptible to increased danger.

There are initiatives and studies conducted at the European supranational level to understand the impacts of forest fires. For instance, collaboration between European countries and the European Commission developed the European Fire Database, the largest repository of information on individual fire events and forest fires in Europe. Furthermore, the PESETA IV report analysed how fire danger in most of Europe would increase under different global warming scenarios (1.5°C, 2 °C, and 3°C) and how the severity, frequency, and damage of forest fires throughout Europe will be affected by climate change (see *Figure 27*), (Costa, et al., 2020).

Figure 27: Forest fire danger in the present, and under two climate change scenarios, according to two different climate models (1.5°C, 2 °C, and 3°C)



Source: (Costa, et al., 2020)
Note: The climate models were selected to demonstrate the effects of the different models.

In this section, we have demonstrated benefit-cost assessments for a variety of wildfire prevention investments. These include structural wildfire protection to homes and industries (for example, creation of defensible space, firebreaks, and fuel breaks), decision support tools (for example, cross-border emergent fire information and climate change adaptation information for small forest owners), and wildfire preparedness (for example, EWS, property-level defensible space, and development of evacuation plans). BCRs for the different types of interventions are shown by a combination of detailed case study analyses including both prospective and retrospective types of assessments. The majority of wildfire management case studies considered use structural mitigation at a forest level as well as a property level with creation of fuel and firebreaks as well as clearing for defensible space, respectively. The decision support tools for wildfire risk inform cross-border fire service organizations on coordinated efforts for enhanced fire suppression. Climate change adaptation through improved silviculture as a decision support tool also informs small forest owners how to best manage their own forestlands against future fires. Alerting and preparedness case studies with both government-funded and homeowner-enacted preparedness measures are assessed as priority actions for stakeholders in wildfire-prone areas. *Table 57* summarizes main data and information sources.

Table 57: Overview of data and information sources for wildfires analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
WUIs	Wildland-urban interfaces: Improvements to homes in Portugal	• Housing damage based on data from the Association for the Development of Industrial Aerodynamics (ADAI) at the University of Coimbra in Portugal • Data for housing cost referenced the Portuguese National Institute of Statistics • Loss reduction interpreted from the impacts calculated in the Technical Specifications for the Use and Occupational Charter of Continental Portugal for 2018 (COS2018) • Reduction in death and cost for treatment derived from the October 2017 fires in Portugal in the study Population exposure to particulate-matter and related mortality due to the Portuguese wildfires in October 2017 driven by storm Ophelia as well as consultations with the Regional Tourism Office for the Centre of Portugal • Potential burnt area based on COS2018 data and the emission factors provided in Estimativa de Emissões Atmosféricas Originadas por Fogos Rurais em Portuga • Avoided property value losses estimated from COS2018 data as well as through the database on land value through PORDATA • Avoided lost tourism based on values from the 2017 fires and information provided by the Regional Tourism Office for the Centre of Portugal • Fire suppression costs based on information provided by the Agency for the Integrated Management of Wildfires (AGIF)
WUIs	Wildland-urban interfaces: Improvements to industries in Portugal	• Industry damage calculated as a percent of total destruction using data from ADAI at the University of Coimbra in Coimbra, Portugal • Loss information based on data provided by the Central Regional Coordination and Development Commission (CCDR-C) in Portugal in June 2018 • Average cost of the intervention based on the Manual of Fuel Management for operations with bush cutters • Loss reduction interpreted from the impacts calculated in the Technical Specifications for the Use and Occupational Charter of Continental Portugal for 2018 (COS2018) • Reduction in death and cost for treatment derived from the October 2017 fires in Portugal in the study *Population exposure to particulate-matter and related mortality due to the Portuguese wildfires in October 2017 driven by storm Ophelia* • Potential burnt area based on COS2018 data and the emission factors provided in *Estimativa de Emissões Atmosféricas Originadas por Fogos Rurais em Portuga* • Avoided property value losses estimated from COS2018 data as well as through the database on land value through PORDATA • Fire suppression costs based on information provided by the AGIF • Data on the co-benefit from the sale of biomass obtained through conversations with biomass producers

Fuel Management for Wildfire Risk Reduction in forests	Fuel Management for forests in Poturgal	• Losses estimated by ex post analysis of the 2017 fires in Pedrógão Grande • Reduction of losses to forestry calculated from previous fires in Technical Specifications for the Use and Occupational Charter of Continental Portugal for 2018 (COS2018) • Reduction in death and cost for treatment derived from the October 2017 fires in Portugal in the study *Population exposure to particulate-matter and related mortality due to the Portuguese wildfires in October 2017 driven by storm Ophelia* • Avoided lost tourism based on values from the 2017 fires and information provided by the Regional Tourism Office for the Centre of Portugal • Fire suppression costs based on information provided by the AGIF • The co-benefit from sale of cork trees calculated based on data from the Portuguese Industry of Cork
Decision Support Tools for Climate Change Adaptation and Alerting for Wildfire Risk Reduction	Decision Support Tools for Climate Change Adaptation	• Avoided direct and indirect forest fire costs obtained from the 2020 white paper on Forest Fires in the Alps • The co-benefit from improved silviculture calculation based on information on the economy of Finland • Information on the cost of the tool and the estimated users obtained from consultations and coordination with a senior researcher who developed the decision support tool
Decision Support Tools for Climate Change Adaptation and Alerting for Wildfire Risk Reduction	Alerting and Preparedness for Wildfires in Portugal	• Data on potential injuries and lives lost obtained from assessment of the past fires in Portugal and validated with ex post data on nonexistent DRM measures for extreme hazard events in Pedrógão Grande, Mati, and Rafina cities in Greece • Cost of injuries based on the Portugal Health Regulatory Authority • The cost of alerting obtained by telephone company data interpolated for Pedrógão Grande
Decision Support Tools for Climate Change Adaptation and Alerting for Wildfire Risk Reduction	Alerting and Preparedness in Greece	• Data on potential injuries and lives lost obtained from assessment of the past fires in Portugal and validated with ex post data on nonexistent DRM measures for extreme hazard events in Pedrógão Grande, Mati, and Rafina cities in Greece • Costs of injuries in Mati obtained with data from consultations with Greek fire specialists and on the ground estimations following deployments to Greece
Cross-border support, coordination mechanisms and capacity building for wildfires	Cross-border support and coordination mechanisms for wildfires	• Cost of the tool obtained from the project manager and developer of SPITFIRE[a] • Direct costs obtained from data provided by the Portuguese Institute for Nature and Forest Conservation and by the Polytechnic University of Valencia

Source: World Bank analysis; based on external data and information

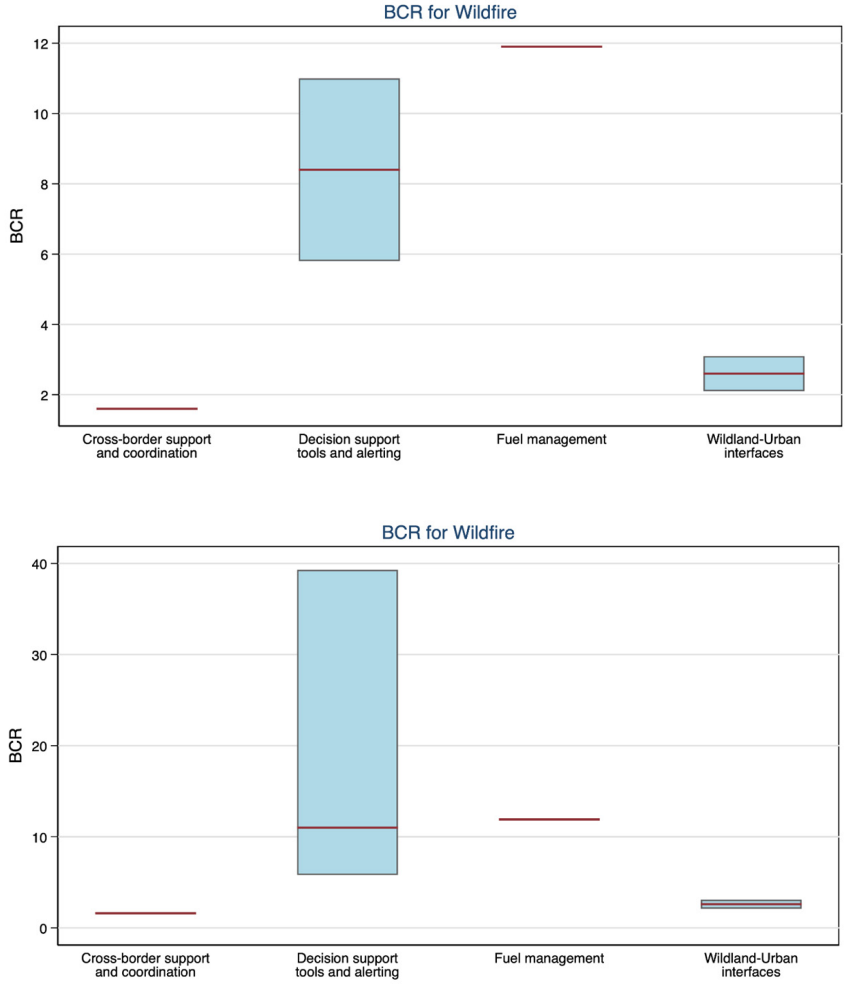
Models need to be adapted to type of investment. When modelling hypothetical prevention investments, such as WUI management and fuel management for wildfire risk reduction, the BCA is assessed over a certain time horizon and includes a sensitivity analysis of low-to-high hazard impacts and discount rates. For the modelling of decision support tools, the start-up and assumed maintenance cost is measured in comparison to forest fire direct and indirect costs avoided in the region as well as improved GDP with efficient silviculture. This model is based on a study from Ireland that was used to estimate the overall GDP improvement as well as studies on Austrian forest management.

Economic analysis and research on wildfires are extremely important because, even with climate change mitigation, the danger of forest fires is imminent unless effective adaptation strategies are adopted. BCRs for investments in wildfire prevention in the context of climate change adaptation reveal how such investments address the detrimental impacts of climate change on forest fires and yield co-benefits in lessening reductions in biomass and biodiversity. The ratios also help decision-makers determine what future climate adaptation strategies should be considered.

Results of wildfire risk reduction investments benefit-cost assessments yield net benefits. However, consistent with research findings, some regional and forest-level infrastructure investments tend to have relatively smaller BCRs. Comprehensive analysis to inform mitigation projects (including considering climate change scenarios) and data on second and third dividend costs avoided could therefore be highly beneficial for investments to maximize benefits temporally and across sustainability goals. More details are included in *Figure 28* below.

Figure 28 presents boxplots that display the distribution BCRs for different types of investments in wildfire based on a five number summary: minimum, first quartile, median (shown in red), third quartile, and maximum. Extreme values are excluded from the top graph and included in the bottom one.

Figure 28: Findings of BCA for wildfires (BCRs)



Source: World Bank analysis; based on external data and information

WUI is a transition zone where wildlands interact with humans and their activities (Stein, et al., 2018), an area where communities and economic activity can therefore particularly be directly affected by wildfires. Studies have shown that there is a lack of standardized building codes and interventions related to development and protection of houses and buildings in WUI areas. These codes and interventions are essential for the reduction of risks and losses to communities. However, the reality is that the development of these standards is complex and implementation non-uniform (Pastor, et al., 2020). Moreover, wildland-industry interfaces are areas of considerable risks as they can lead to large amounts of industrial damages and even follow-up disasters. It is therefore essential for homes and industries in WUI areas to invest in prevention by use of the creation of defensible space. Government-led preparedness and regulations should be undertaken and implemented, such as minimum safety distance or vegetation straps, around homes and industrial facilities. In Europe, research, laws, and monitoring of industrial facilities in or near the forest or wildland perimeters tend to be limited, except fire research projects such as SPREAD (2020).

- **Case study 18 (new analysis under this project, ex ante (Augusto, et al., 2020)):** The analysis of a hypothetical investment of managing WUI in Pedrógão Grande, Portugal, yields positive net benefits (BCR 3.1 greater than 1). This is possibly underestimated given lack of data and information on longer-term impacts such as soil erosion impacts from fires or land and property value increase in areas.

- **Case study 19 (new analysis under this project, ex ante (WUIVIEW, 2019)):** The analysis of a hypothetical investment of managing WUI in Oliveira do Hospital, Portugal, yields positive net benefits (BCR 2.1 greater than 1). Limitations of the research are similar to case study 18.

Fuel management interventions can support wildfire risk reduction. The increase in fire danger is projected to increase in Western-Central Europe, but the absolute fire danger remains highest in Southern Europe. Fuel management interventions such as firebreaks and fuel breaks have been used for fire prevention and fire spread mitigation within forest areas and on their peripheries where buildings and other assets may exist. Firebreaks are strips of bare soil or fire retarding vegetation meant to stop or control fire around buildings, farms, and residential properties as they provide a fixed safety distance that protects the civilians (Natural Resources Conservation Services, 2011; WUIVIEW, 2019). Fuel breaks are strips or blocks of vegetation that have been altered to slow or control a fire and slow the spread of fire because they are managed to provide far less fuels to carry the flames. These adaptation measures are typically implemented by forest managers and have shown to substantially reduce fire risks but are not evenly applied in fire-prone areas.

- **Case study 20 (new analysis under this project, ex post (Bennett, et al., 2010)):** The analysis of an investment in fuel management using fuel breaks in the Central Region of Portugal yields positive net benefits (BCR 11.9 greater than 1). This case study uses a novel methodology to evaluate losses avoided, the additional benefits of implementing fuel breaks as a preventive investment. In addition to limitations of research in terms of data and information like for case studies 18 and 19, general research on effectiveness of fuel breaks would be important as assumptions for this analysis were based on expert judgement. As for other case studies, transferability of this analysis and assumptions is low given that it is a technical management and service-related solution.

Decision support tools can support climate change adaptation and alerting for wildfire risk reduction. Decision support tools are tools based on computers and data that people use during the process of decision-making for various objectives. There has been an increase in the use of decision support tools for climate change planning and adaptation to promote effective investment decisions and sustainable management of areas. These tools have been assessed by EU projects like Impacts and Risks from High-End Scenarios: Strategies for Innovative Solutions (IMPRESSIONS) and it is important that they are tailored to local conditions to produce most efficient outcomes, particularly for decisions on green infrastructure. Early warning and monitoring systems can support preparedness for wildfire risks. An example is the European Forest Fire Information System (EFFIS) developed by JRC that provides warnings and damage assessments (EFFIS, 2021). Alerting for wildfire emergencies can consist of days to minutes of notification to residents in a region or area that has imminent fire danger. Alerting systems are

typically meant to save lives and reduce injuries and are most effective as part of an emergency plan that includes evacuation routes and stationing of victims in safe zones.

- **Case study 21 (new analysis under this project, ex post (Bennett, et al., 2010)):** The analysis of an investment in a Forest DSS (2013) implemented in the forest regions of Carinthia in Austria that was developed for forestry extension services for small-scale private landowners. The intention of the tool is to provide information for owners to improve silviculture in a sustainable manner and simultaneously reduce the chance for forest fires due to climate change. The analysis of the hypothetical future benefits yielded positive net benefits (BCR 5.8, NPV of around €0.99 million). It has to be noted however that this analysis was based on numerous assumptions given lack of data for this project and further research would be needed to understand relationships between improved silviculture and GDP, as this was a main factor assumed that affected the BCR to be higher than 1. Micro- and macro-studies could generally improve the understanding on multiple benefits of improved silviculture in a region, including, for example, socio-psychological factors to private forest owners.

- **Case study 22 (new analysis under this project, ex ante):** The analysis of a hypothetical investment in alerting, evacuation planning, and independent fuel management of homes by homeowners in the Central Region of Portugal is undertaken to assess the benefits of both government-initiated alerting and preparedness as well as citizen-driven fuel management on private homes. This case study yields positive net benefits (BCR 11 greater than 1). Developing incentives for homeowners to manage their fuel loads surrounding personal property requires consistent education and awareness raising as well as developing capacity-building campaigns to encourage informed responses to alerts and executing emergency/evacuation plans. The impact of softer investments such as alerting and community sensibilization to wildfire hazards is understudied in the literature and therefore benefits may not or insufficiently be captured, particularly impacts of behavioural changes.

- **Case study 23 (new analysis under this project, ex ante (BBC, 2018)):** The analysis of a hypothetical investment in alerting, evacuation planning, and independent fuel management of homes by homeowners in the Attica region of Greece yields positive net benefits (BCR 39.3 greater than 1). Developing incentives for homeowners to manage their fuel loads surrounding personal property requires consistent education and awareness raising as well as developing capacity-building campaigns to encourage informed responses to alerts and executing emergency/evacuation plans. The impact of softer investments such as alerting and community sensibilization to wildfire hazards is understudied in the literature and therefore benefits may not or insufficiently be captured, particularly impacts of behavioural changes. The high BCR of this case study can be explained by the scenario on which it is based, namely, the second deadliest fire in the 21st century (Mati fire from 2018). Results of both case studies 22 and 23 would support low-cost investments with potential to save many lives and assets.

Cross-border support, coordination mechanisms, and capacity building can reduce wildfires risks. Disasters and hazards are not bound by the borders of countries and it is essential for European countries to work collaboratively and share their resources and good practices when a disaster strikes, especially in cross-border areas that are vulnerable to disasters such as forest fire and floods. Several EU projects have been launched to enhance cooperation across borders in terms of responses to disasters and emergencies. The project INTER'RED (European Commission, 2020) is an ongoing project that improves rescue services in the cross-border Grande Région, which covers Luxembourg, France, Germany, and Belgium. Capacity-building investments in the Czech Republic, Poland, or Spain have shown qualitatively high impacts and benefits of training for the effectiveness of response.

- **Case study 24 (new analysis under this project, ex ante (FEU Fire Officer Associations, 2020):** The analysis of an investment in creating and deploying the SPITFIRE tool (European Commission, 2017) found net benefits (BCR 1.6). This decision support tool offers high resolution meteorological and forest weather forecasts presented in a GIS environment to allow its joint management with other information needed by end users, such as forest managers and firefighters. This information includes protected spaces, surveillance posts, roads, water points,

distribution of material and human resources, and so on). The results must be considered with caution given lack of research on impacts of this type of investment and lack of data. Future deployments should investigate actual deployments and benefits of information platforms as well as analyse the benefits of tools with a longer lifetime than SPITFIRE.

3.5.2. WILDLAND-URBAN INTERFACES

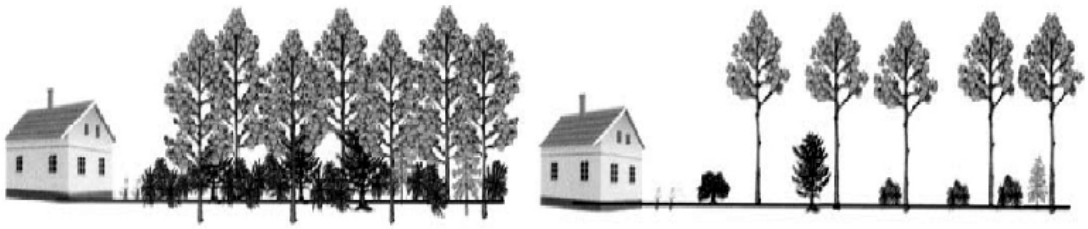
WILDLAND-URBAN INTERFACES: IMPROVEMENTS TO HOMES IN PORTUGAL

This case study is a new ex-ante analysis under this project that involved modelling of hazards.

→ Introduction and background

The WUI is a transition zone where wildlands interact with humans and their activities (Stein, et al., 2018). As a result, forest fires occurring in WUI areas negatively affect urban and rural communities. WUI fires are prevalent in Northern and Southern Europe, which leads to destruction and generates great social and economic losses. The 2017 fire in Portugal resulted in more than 110 deaths and thousands of destroyed buildings, while the two WUI fires in Spain led to the evacuation of more than 2,000 people in the city of Valencia (Pastor, et al., 2020). Moreover, because of climate changes, global warming and the increase in heatwaves have increased the number and duration of forest fires in recent years, which has resulted in an increase of fire risks in European countries (EEA, 2020). In addition, due to housing demands and lack of management, more development is occurring in the WUI without appropriate forest management and those homes and industries near the wildland are increasingly susceptible to fire when interventions to reduce fuel in surrounding areas is not undertaken (see *Figure 29* for an illustration of a fuel break for WUIs).

Figure 29: Image of a fuel break for WUIs



Source: (Portugal Wildfire, 2018)

Studies have shown that there is a lack of standardized building codes and interventions regarding the houses and buildings in WUI areas. An analysis of forest fire prevention and WUI protection systems in Spain suggests that it is essential to establish housing and urban planning standards and regulations in WUI areas. Also, the establishment of such standards requires the coordination of multiple agencies, which includes architects, forest and social scientists, and engineers specializing in landscape, civil, and fire (Pastor, et al., 2020). These regulations are essential for the reduction of risks and losses for the WUI communities. To better understand the factors leading to the vulnerability of people, infrastructure, assets, and the outcomes of loss, it is essential to assess cost benefit analyses since wildfires are ever increasing in the EU region and loss and damage exceed far beyond property and lives.

→ Description

This case study is an appraisal of the hypothetical investment of managing WUI in the municipality of Pedrógão Grande in Portugal to study the fire impacts to homes with and without WUI management. The case study considers the necessary actions taken by regional authorities, whether by incentives, code changes, or direct management, that aid to create defensible spaces surrounding homes to reduce the risk of fire to homes in the WUI. The June 2017 Portugal fires in central Portugal saw the greatest loss of life in Pedrógão Grande, where 66 lives were lost in the area, 254 people faced injuries, and nearly 1,000 homes

were affected by the wildfires. The hypothetical investment is an ex post appraisal of the homes that were burned in 2017 in the municipality of Pedrógão Grande. This study seeks to analyse the advantages of having an acceptable fuel management 10–50 m around dwellings in the area to minimize fire ignition and spread. The approach of this study is to use existing research on losses from fires in Portugal and estimate the triple dividend benefits that could have been realized had there been an investment in the Pedrógão Grande region for WUI management for dwelling fire risk reduction.

→ Methodology

The BCA is over a 30-year time horizon and undertakes a sensitivity analysis of low-to-high hazard impacts and discount rates. A 30-year time horizon was chosen as the Institute for Nature Conservation and Forests in Portugal describes the 2017 fire as the one-in-29-year fire (ICNF, 2020). The discount rates used in the study vary from 3.5 percent to 5 percent based on uncertainty of triple dividend factors calculated during the 30-year period.

→ The methodology is as follows:

- Analysis in the field of 963 houses affected by the fire event with focus on the fuel management distance and its impacts on damage (and damage avoided with intervention). The distances studied are 0–2 m, 2–10 m, 10–50 m, and >50 m.

- Characterization of housing damage from 2017 as a percentage of total destruction using data from ADAI at the University of Coimbra in Portugal. Houses that are totally destroyed are considered 100 percent destruction, severely damaged are those with 75 percent destruction, moderately damaged homes are those with 40 percent destruction, and light damage are those with 20 percent destruction.

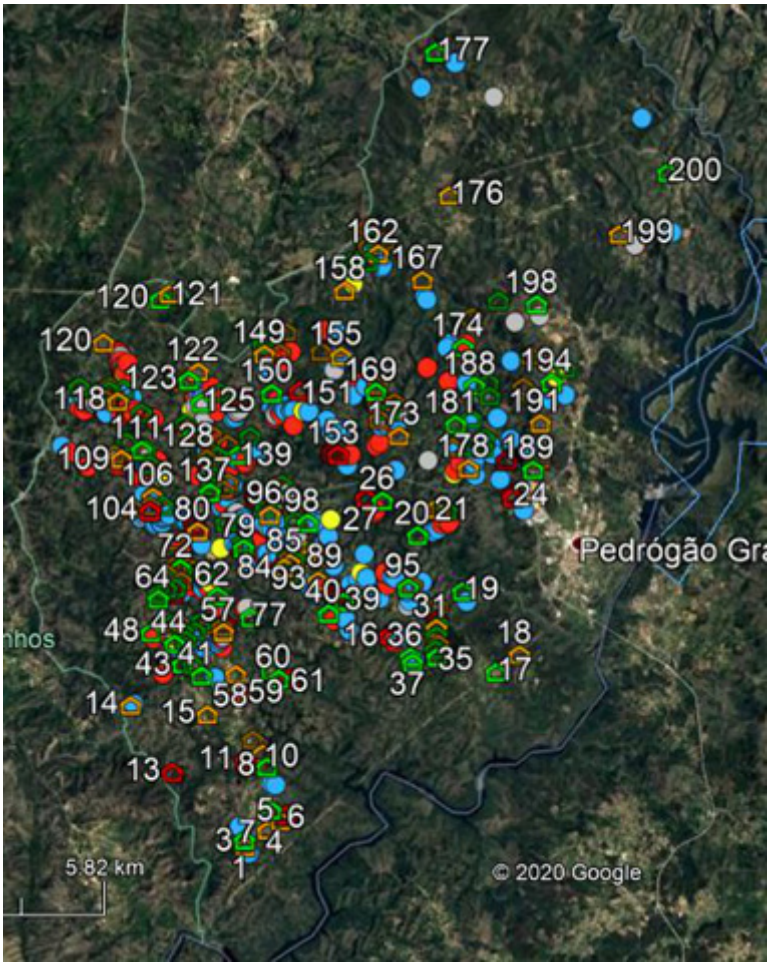
- Analysis through spatial images of houses undamaged in 2017 (0 percent destruction) by the fire event is undertaken to determine fuel management distances (see *Figure 30*). The risk of damage related to the fuel management distance represents the probability of a house being damaged as a function of fuel management distance (University of Coimbra, 2020).

- Determination of the potential damage related to the fuel management distance considering the probability of damage and the potential of destruction (risk of damage and the percentage of loss: 100 percent, 75 percent, 40 percent, 20 percent, 0 percent). See *Figure 31*.

- Next, the cost elements are calculated for economic loss from damage to housing. The estimated area of a typical home in Pedrógão Grande is 10 m × 10 m = 100 m2 and the cost of a house in Pedrógão Grande is €600 per m2. The data used for housing costs referenced the Portuguese National Institute of Statistics (Instituto Nacional De Estatistica, 2020). The average costs of each fuel management strip (0–2 m, 2–10 m, 10–50 m, and >50 m) is estimated to be €1,078 per ha based on the Manual of Fuel Management for operations with bush cutters (Guiomar & Fernandes, 2011). See *Figure 32*.

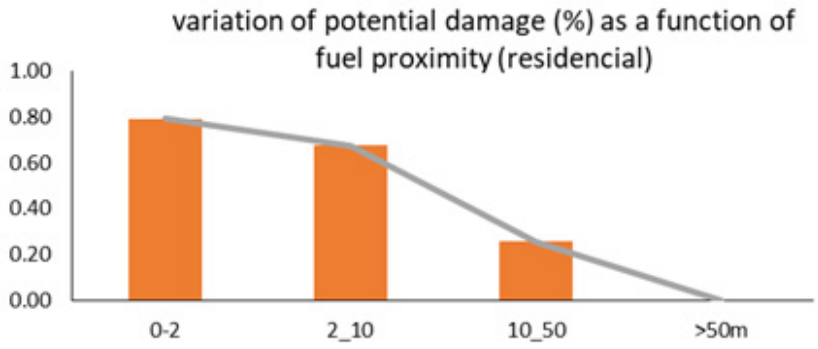
- The cost of fuel management around the typical house in the area as well as the potential damage is determined in euros. The costs include the use of bush cutters, which are normally used in this type of fuel management. Cost figures also include employees, taxes, fuel, equipment, and so on. The discount rate used when evaluating the cost is 3.5 percent over 30 years. The potential damage reduction in euros per home is driven by each fuel management strip option. Therefore, the investment in fuel management in addition to the cost of damage (costs avoided with interventions) is estimated per house per year for each fuel management option. The counterfactual investment compared in the BCA is the difference in losses between a no fuel management case and fuel management of approximately 30 m surrounding the home.

Figure 30: Assessment of housing in Pedrógão Grande for destruction assessment and WUI distances



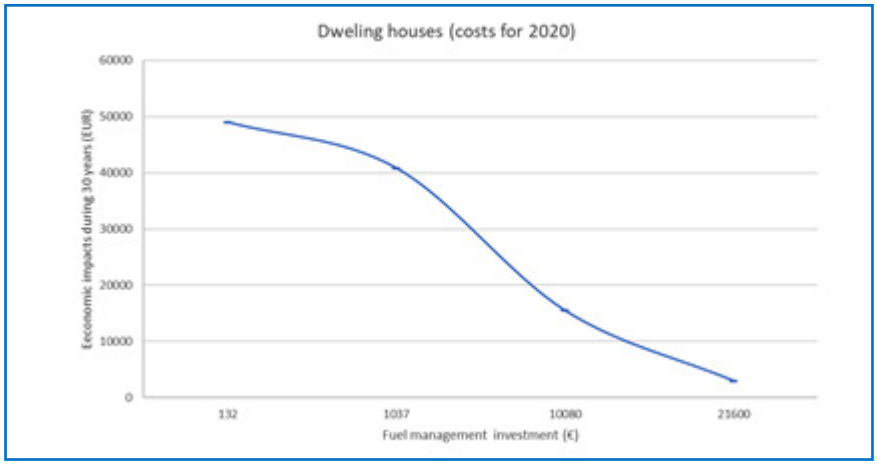
Source: World Bank analysis; based on external data and information

Figure 31: Variation of potential damage (%) as a function of fuel proximity to homes in Pedrógão Grande



Source: World Bank analysis; based on external data and information
Note: the x-axis represents the different types fuel management strip (by length).

Figure 32: Fuel management investments and corresponding economic losses to homes in WUI



Source: World Bank analysis; based on external data and information

The Triple Dividend Framework includes the following benefits described.

Triple dividend 1 (costs avoided):

- Reduction of lives lost was calculated using 2017 fatalities within the municipality of Pedrógão Grande corresponding with fuel management distances.

- Reduction of injuries using 2017 injuries in Pedrógão Grande. The Portugal Health Regulatory Authority (Direção Geral de Saúde) provides the cost per day of injuries based on severity of injury, using which the team estimated that 40 percent of cases were light injuries, 40 percent were medium injuries, and 20 percent were severe injuries (INFARMED, 2020). The total number of injuries is proportional to the deaths during the 2017 event (approximately 4 injuries to 1 life lost) and calculated from the deaths avoided in TD1. The 4:1 injuries-to-fatalities ratio is based on the actual losses and injuries from the Pedrogão Grande fire (June 17, 2017) and the region around Oliveira do Hospital (October 15, 2017) in Portugal as well as in Mati fires in Greece. The discount rate for the cost of treating injuries during the time horizon is 3.5 percent.

- Fire damage prevented to housing is explained above in methodology.

- Reduction of losses to agriculture, forestry, and grazing is considered a direct cost to losses in the region. These values were interpreted from the impacts calculated in the Technical Specifications for the Use and Occupational Charter of Continental Portugal for 2018 (COS2018) (Caetano, et al., 2010).

- The reduction in deaths related to cardiorespiratory problems as well as the costs for treatment are calculated as direct losses avoided, referring to the COS2018 data. The values are derived from the October 2017 fires in Portugal in a paper by Augusto et al. (2020). Based on the actual values of losses of lives and injuries, the ratio of injury to life lost is approximately 4:1. Therefore, the number of injuries is arrived at by the number of deaths multiplied by 4 with the same distribution of injury severity as described above but focused on cardiorespiratory problems.

- The cost of CO2 avoided from the reduction of wildfires is estimated to be €13 per tonne, the area that could be burned based on COS2018 data, and the emission factors provided in Silva et al. (2006).

- Avoided property value losses are estimated using COS2018 data as well as through the database on land value through PORDATA following the 2017 fire land and property value decline (PORDATA, 2020b).

- Avoided lost tourism income is based on actual values from the 2017 fires. Results are based on the information provided by the Regional Tourism Office for the Centre of Portugal (PORDATA, 2020a).

- Cost of sheltering and displacement avoided is estimated by the cost of rental per day per person (approximately €15 per day per person), the number of people requiring shelter (based on damaged housing), and the average time sheltering was needed after the 2017 fires. It is assumed that 50 percent of people stayed with relatives and therefore no additional cost was borne, and the remaining 50 percent stayed in rentals. The average time to recovery is estimated at 6 months. In addition, the loss to productivity by displaced persons is calculated as a GDP per capita reduction per working person per day and assuming that persons staying in rentals/hotels or with family have 50 percent productivity.

- Soil erosion due to the wildfires is estimated based on the cost of soil lost in 2008 at €5.82 per ha (US$7.03 per ha) over 12 years (Pinheiro, 2015). Hectares burned in Pedrógão Grande are quantified in COS2018. A discount rate of 5 percent is used over the period.

- Fire suppression costs avoided are operational costs based on the AGIF that provides national cost values. These costs have been scaled to the Pedrógão Grande region to estimate the reduction in yearly operation costs due to enhanced WUI management (AGIF, 2020). The operational costs are those resulting from service needs during fire suppression, including equipment, hourly payment to firefighters, overtime payment for aerial means, meals in the field of operations, and so on. Over the period of study, a discount rate of 5 percent has been used.

Triple dividend 2 (unlocking economic potential):

- The economic value added to the Portuguese economy from biomass production (TD3) activities is a multiplier of 1.77 based on existing data of biomass production in California (2020) and scaled to Portuguese consumer price indices (University of California, 2020). This multiplier captures the indirect and induced economic contribution from wood biomass production based on the purchasing of materials and services directly within the forestry supply chain (indirect) and the purchasing of goods and services by workers in the industries (induced effects). The economic ripple effects are accounted for in TD2 as they offer additional economic potential regardless of a wildfire occurring.

- Increased security from lessened impacts and less volatility due to wildfire management is assumed to be 1 percent of GDP for the region—this figure was estimated based on the Portuguese economic growth of 1.8 percent forecasted by the Bank of Portugal, which will be lower in inland areas such as Pedrógão Grande. A discount rate of 3.5 percent is used when calculating this dividend over the period.

- Increase in land purchases estimates the value of land that is increased due to a decrease in wildfire risk due to WUI management. A 1 percent increase in land value (approximated as housing value) in fire-prone areas is assumed. Also considered in this conservative estimate is the possibility that people tend not to buy land at typical market value in areas where tragic accidents have occurred, such as lives lost in the 2017 fires, especially in a short time following the event.

Triple dividend 3 (co-benefits)

- Fixed fire suppression costs are those that are related to the existing fire service structure regardless of whether there is a fire or not. It includes fire brigade costs, administration, aerial rentals with basic contracts, and so on. Fire suppression costs are evaluated using data from the AGIF that have been scaled to the Pedrógão Grande region to estimate the reduction in yearly fixed costs due to enhanced WUI management (AGIF, 2020). The justification is that with yearly reductions in fire losses due to improved fuel management, fixed costs could be reduced to a reasonable degree without compromising fire services. A discount rate of 5 percent is used over the period.

- The sale of biomass is considered a co-benefit of WUI fuel management due to increased biomass production from clearing forest fuel. It is estimated as 30EUR/ton plus the cost of operations. The data was obtained through conversations with biomass producers.

→ Results of the analysis by dividends and overall

Overall, the analysis shows a high BCR greater than 1, which indicates a positive economic rationale for undertaking this preventive investment (see *Table 58*). The highest benefits appear to be those from avoided losses, but the second order economic effects

(dividend 2) as well as co-benefits (dividend 3) are likely to be underestimated due to lack of data for protecting over the 30-year time horizon (see *Table 59*).

Table 58: CBR of WUIs in Pedrógão Grande (in million €)

BCR: 3.1		
	BENEFITS (€)	COSTS (€)
Dividend 1	140.68	
Dividend 2	1.45	
Dividend 3	2.17	
Total	144.29	46.75

Source: World Bank analysis based on external data and information

Table 59: Expanded triple dividend BCR calculation of WUIs in Pedrógão Grande (in million €)

WUI MANAGEMENT - HOMES	
FIRST DIVIDEND (€)	
Reduction of lives	107.25
Reduction of injuries	4
Fire Damage prevented (houses)	22.7
Reduction of losses to agriculture	0.84
Reduction of losses to forestry	1.51
Reduction of losses to grazing	0.003
Reduction in deaths related to cardiorespiratory problems	1.14
Reduction in treatment costs related to cardiorespiratory problems	0.01
Cost of CO2 avoided	0.16
Avoided loss of property values	1.03
Avoided loss of tourism income	0.24
Cost of sheltering/displacement avoided - lodging	0.55
Cost of sheltering/displacement avoided - productivity	0.69
Soil erosion costs avoided	0.01
Fire suppression, operational costs, lowered with WUI management	0.54
Total first dividend	140.68
SECOND DIVIDEND (€)	
Longer-term economic add from biomass production (induced/indirect)	0.73
Security/reduced volatility from mitigation/risk perception	0.71
Increase in land purchases	0.005
Total second dividend	1.45
THIRD DIVIDEND (€)	
Economic co-benefits	

Fire suppression, fixed costs, lowered with WUI management	0.02
Sale of biomass for energy production	2.15
Social co-benefits	
Improved awareness of WUI management by homeowners	(qualitative)
Total third dividend	2.17
TOTAL DIVIDEND	144.29
Total cost	46.75
BCR	3.1

Source: World Bank analysis based on external data and information

→ Challenges faced and lessons learned

Data that could not be ascertained from Portuguese sources, including soil erosion from fires, should be investigated for the Portuguese and/or European context since fires are becoming more prevalent and long-term costs are not always evaluated. In addition, accurate estimations of land and property value increase from reduced volatility in the area due to lessened fire starts, direct and indirect fire suppression costs avoided, and other triple dividend 2 and 3 benefits factors could be valuable to an expansion of this study. Distributional impacts of the creation of defensible space for appropriate WUIs are that these zones enable homeowners to avoid property value losses and for tourism in the area to remain uninterrupted in the case of future wildfires. Moreover, the property value of homes and land in the surrounding area is expected to increase with the establishment of appropriate defences in WUI, which benefit home and landowners in the area.

WILDLAND-URBAN INTERFACES: IMPROVEMENTS TO INDUSTRIES IN PORTUGAL

This case study is a new ex-ante analysis under this project that involved modelling of hazards.

→ Introduction and background

While forest fires cause fatalities, injuries, and property losses for residents living in the WUI areas, they also cause industrial damage that can lead to accidents and natural-technological (Natech) emergencies (WUIVIEW, 2019). Wildland-industry interface is a branch of WUI and looks particularly at the impacts of fires on industries and cascading consequences that may arise from fire hazards. Fires near industrial areas can cause accidents where large amounts of toxic or flammable materials are accumulated. Therefore, it is particularly important for industries in WUI areas to be well prepared for the occurrence of forest fires to avoid economic and social losses during fire seasons by the creation of appropriate defensible space surrounding properties. To date, some regulations have been made for WUI improvements to industries. For instance, in Spain, it is required to have a low-density vegetation strap around the industrial infrastructures with a minimum safety distance of 30 m (in Portugal this distance is 50 m for isolated infrastructures and 100 m for industrial parks) (Caballero, et al., 2007).

However, there is still progress that is needed regarding industries in WUI areas. European countries face a lack of standardized laws and monitoring of industrial facilities located in or near the wildlands. Fire and safety measures in Europe are usually categorized based on established activity such as nuclear and chemical, while measures related to WUI scenarios are usually limited to fuel-reduced fringes (WUIVIEW, 2019). Though there are forest fire research projects like SPREAD that produced fire risk maps and analysed fire spread patterns in Europe (CORDIS, 2020), more investments and studies should be undertaken with a focus on WUI improvements to industries to reduce damages and economic losses in the industrial sector. To better understand the factors leading to the vulnerability of people, infrastructure, and assets and the outcomes of loss, it is essential to assess cost benefit analyses since wildfires are ever increasing in the EU region and loss and damage exceed far beyond property and lives.

→ Description

This case study investigates the hypothetical investment of managing WUI in the municipality of Oliveira do Hospital in Portugal to study the impacts to industries with and without WUI management. The case study considers the necessary actions taken by regional authorities, whether by incentives, code changes, or direct management, that aid to create defensible spaces surrounding industries to reduce the risk of fire to industries in the WUI. The October 2017 Portugal fires in Oliveira do Hospital in Portugal's interior led to casualties, losses in industrial facilities, as well as affected other industries in the area. The hypothetical investment studies the industries that were damaged in 2017 and analyses the advantages of having acceptable fuel management around industrial buildings to minimize fire ignition and spread. The approach of this study is to use existing research on losses from fires in Portugal and estimate the triple-dividend benefits that could have been realized had there been an investment in the Oliveira do Hospital region for WUI management of industrial fire risk reduction.

→ Methodology

The BCA is an appraisal of wildland-industry interface over a 40-year time horizon and undertakes a sensitivity analysis of low-to-high hazard impacts and discount rates. A 40-year time horizon was chosen as the Institute for Nature Conservation and Forests in Portugal describes the 2017 fire as the one-in-39-year fire (ICNF, 2020). The discount rates used in the study vary from 3.5 percent to 5 percent based on uncertainty of factors calculated during the 40-year period.

The methodology is as follows:

- Analysis in the field of 65 industrial facilities affected by the fire event with focus on the fuel management distance and its impacts on damages with and without WUI risk reduction interventions. The distances studied are 0–2 m, 2–10 m, 10–50 m, and >50 m. *Table 60* below includes information on the industrial facilities that were totally or partially destroyed by the fire and not the distribution of all 95 industries analysed. Data on the industry types of the 30 facilities that were not affected by the fires were not available. Industries and number of each type are *Table 60*:

Table 60: Industrial facilities affected by industry

CONSTRUCTION AND BUILDING MATERIALS	20
Timber and cork	8
Vehicles, machinery, and equipment	9
Metal products	3
Agriculture, forestry, ranching, and hunting	2
Food and beverage industry	6
Furniture and mattresses	1
Transports	5
Water, gas, and electricity supply	5
Manufacture of textiles	1
Other	5
Total	65

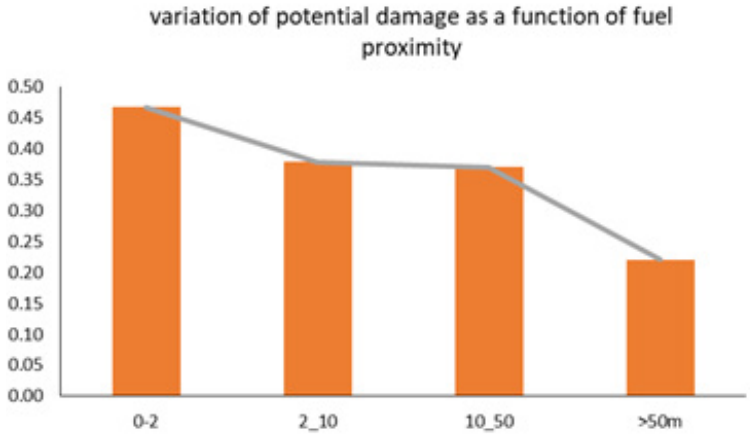
Source: World Bank analysis based on external data and information

- Characterization of industry damage from 2017 is a percentage of total destruction using data from ADAI at the University of Coimbra in Coimbra, Portugal (2020).

- Assessment of fuel management from spatial images[26] of 30 industrial facilities undamaged in 2017 (0 percent destruction) by the fire event to determine fuel management distances. The risk damage related to the fuel management distance represents the probability of an industry being damaged as a function of the fuel management distance.

- Determination of the potential damage related to the fuel management distance which considers the probability of damage and the potential of destruction (risk of damage and the percentage of loss: 100 percent, 75 percent, 40 percent, 20 percent, 0 percent). See *Figure 33*.

Figure 33: Variation of potential damage (%) as a function of fuel proximity to industries in Oliveira do Hospital



Source: World Bank analysis based on external data and information
Note: the x-axis represents the different types fuel management strip (by length).

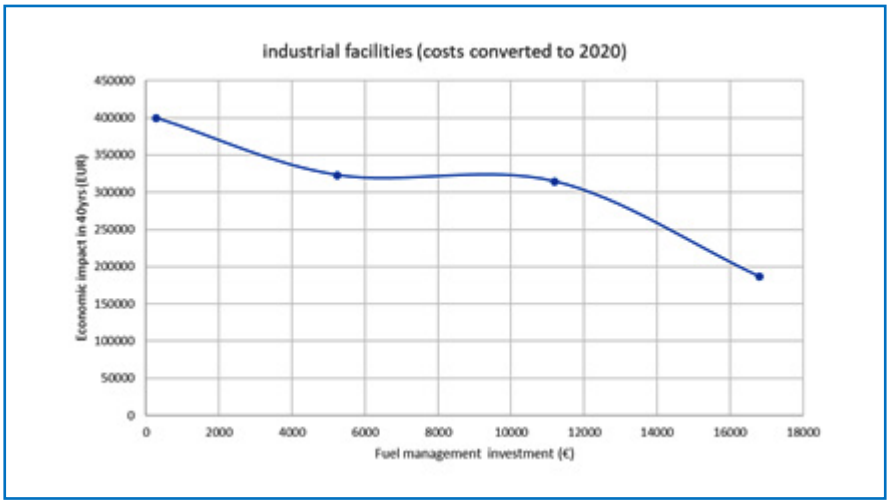
- Next, the cost elements are calculated to determine the economic loss from damage to industrial facilities. The estimated average cost of infrastructure, equipment, and raw materials of an industrial facility in Oliveira do Hospital is around €0.83 million. Data from the CCDRC (CCDRC, 2020) in Portugal provide loss information to industrial facilities from the 2017 October fire from which the number above is derived based on data available for affected facilities that requested support from the government. In addition, based on the image-based analysis, the estimated area of each industrial facility is approximately 50 m × 20 m = 1,000 m2. In addition, based on the image-based analysis, the estimated area of each industrial facility is approximately 50 m × 20 m = 1,000 m2.

- The cost of fuel management around the typical industrial facilities in the area as well as the potential damage was determined in euros. The potential damage reduction in euro per industrial facility is driven by each fuel management strip option (that is, creation of defensible space surrounding the industrial property). Therefore, the investment in fuel management along with the costs of damage (costs avoided with interventions) was estimated per industrial facility per year for each fuel management option. The discount rate used when evaluating the cost is 3.5 percent over 40 years. The potential damage reduction in euro per industry is driven by each fuel management strip option. Therefore, the investment in fuel management along with the costs of damage (costs avoided with interventions) was estimated per industry per year for each fuel management option. The counterfactual investment compared in the BCA is the difference in losses between a no fuel management case and fuel management of approximately 30 m surrounding the industrial facility. The average costs of each fuel management strip (0–2 m, 2–10 m, 10–50 m, and >50 m) around the industrial facilities were estimated to be €1,078 per ha based on the Manual of Fuel Management for operations with bush cutters (Guiomar & Fernandes, 2011). The creation and maintenance of defensible space is considered at

26 These images were taken in August 2017, two months before the fire event.

a frequency of every two years within the time horizon *Figure 34* shows increased fuel management investment costs of industrial facilities as related to a decrease in economic impacts from wildfire losses.

Figure 34: Fuel management investments and corresponding economic losses to industries in Oliveira do Hospital



Source: World Bank analysis based on external data and information

The Triple Dividend Framework includes the following benefits:

Triple dividend 1 (costs avoided):

- Reduction of lives lost was calculated using 2017 fatalities corresponding with fuel management distances.
- Reduction of injuries using 2017 injuries in Oliveira do Hospital. The Portugal Health Regulatory Authority (Direção Geral de Saúde) provides the cost per day of injuries based on severity of injury, using which the team estimated that 40 percent of cases were light injuries, 40 percent were medium injuries, and 20 percent were severe injuries (INFARMED, 2020). The number of injuries is proportional to the deaths during the 2017 event (approximately 4 injuries to 1 life lost) and calculated from the deaths avoided in TD1. The 4:1 injuries to fatalities ratio is based on the actual losses and injuries from the Pedrogão Grande fire (June 17, 2017) and the region around Oliveira do Hospital (October 2017) in Portugal as well as in Mati fires in Greece. The discount rate for cost of treatment of injuries during the time horizon is 3.5 percent.
- Fire damage prevented to industries is explained above in methodology.
- Reduction of losses to agriculture, forestry, and grazing is considered a direct cost to losses in the region. These values were interpreted from the impacts calculated in the Technical Specifications for the Use and Occupational Charter of Continental Portugal for 2018 (COS2018) (Caetano, Igreja, and Marcelino 2010).
- The reduction in deaths related to cardiorespiratory problems and the costs for treatment are calculated as direct losses avoided, referring to the COS2018 data. The values are derived from the October 2017 fires in Portugal (Augusto et al. 2020). Based on the actual values of losses of lives and injuries, the ratio of injury to life lost is approximately 4:1. Therefore, the number of injuries is arrived at by a multiple of four to the number of deaths with the same distribution of injury severity as described above but focused on cardiorespiratory problems.
- The cost of CO2 avoided from the reduction of wildfires is estimated to be €13 per tonne, the area that could be burned based on COS2018 data, and the emission factors provided in Silva et al. (2006).
- Avoided property value losses are estimated using COS2018 data as well as through the database on

land value through PORDATA (2020b) following the 2017 fire land and property value decline.

- Avoided productivity due to lost jobs from damage to industries as the number of labour days reduced (PORDATA, 2020b) is estimated at €104 per labour day per worker.

- Avoided lost tourism income is based on actual values from the 2017 fires based on consultations with the Regional Tourism Office for the Centre of Portugal.

- Soil erosion due to the wildfires is estimated based on the cost of soil lost in 2008 at €5.82 per ha over 12 years (Pinheiro 2015). Hectares burned in Oliveira do Hospital are quantified in COS2018. A discount rate of 5 percent is used over the period.

- Fire suppression costs avoided are operational costs based on the AGIF that provides national cost values. These costs have been scaled to the Oliveira do Hospital region to estimate that reduction in yearly operation costs due to enhanced WUI management (AGIF 2020). The operational costs are those resulting from service needs during fire suppression, including equipment, hourly payment to firefighters, overtime payment for aerial means, meals in the field of operations, and so on. Over the period of study, a discount rate of 5 percent has been used.

Triple dividend 2 (unlocking economic potential):

- The economic value added to Portuguese economy from biomass production (TD3) is a multiplier of 1.77 based on existing data of biomass production in California (2020) and scaled to Portuguese consumer price indices (University of California 2020). This multiplier captures the indirect and induced economic contribution from wood biomass production based on the purchasing of materials and services directly within the forestry supply chain (indirect) and the purchasing of goods and services by workers in the industries (induced effects). The economic ripple effects are accounted for in TD2 as they offer additional economic potential regardless of a wildfire occurring.

- Increased security from lessened impacts and less volatility due to wildfire management is assumed to be 1 percent of GDP for the region - this figure was estimated based on the Portuguese economic growth of 1.8 percent forecasted by the Bank of Portugal, which will be lower in inland areas such as Oliveira do Hospital. A discount rate of 3.5 percent is used when calculating this dividend over the period.

Triple dividend 3 (co-benefits)

- Fixed fire suppression costs are related to the existing fire service structure regardless of whether there is a fire or not. It includes fire brigade costs, administration, aerial rentals with basic contracts, and so on. Fire suppression costs are evaluated using data from the AGIF. These costs have been scaled to the Oliveira do Hospital (AGIF 2020). The justification is that with yearly reduction in fire losses due to improved fuel management, fixed costs could be reduced to a reasonable degree without compromising fire services. A discount rate of 5 percent is used over the period.

- The sale of biomass is considered a co-benefit of WUI fuel management due to increased biomass production from clearing. It is estimated at €30 per tonne plus the cost of operations. The data were obtained through conversations with biomass producers and are referred to 2020.

→ **Results of the analysis by Dividends and overall**

Overall, the analysis shows a high BCR greater than 1, which indicates a positive economic rationale for undertaking this preventive investment (see *Table 61*). The highest benefits appear to be those from avoided losses, but the second order economic effects (dividend 2) and economic co-benefits (dividend 3) are likely to be underestimated due to lack of data (see *Table 62*).

Table 61: BCR of WUI management to industries in Oliveira do Hospital (in million €)

BCR: 2.1		
	BENEFITS (€)	COSTS (€)
Dividend 1	86.44	
Dividend 2	4.49	
Dividend 3	2.1	
Total	93.04	44.48

Source: World Bank analysis; based on external data and information

Table 62: Expanded Triple Dividend Cost Benefit Ratio Calculation of WUI management to industries in Oliveira do Hospital (in million €)

WUI MANAGEMENT - INDUSTRIES	
FIRST DIVIDEND (€)	
Reduction of lives	33.02
Reduction of injuries	0.12
Fire Damage prevented (industries)	7.04
Reduction of losses to agriculture	2.5
Reduction of losses to forestry	1.58
Reduction of losses to grazing	0.01
Reduction in deaths related to cardiorespiratory problems	2.76
Reduction in treatment costs related to cardiorespiratory problems	0.03
Cost of CO2 avoided	0.27
Avoided loss of property values	33.81
Avoided productivity loss	0.35
Avoided loss of tourism income	3.61
Soil erosion costs avoided	0.02
Fire suppression, operational costs, lowered with WUI management	1.32
Total first dividend	85.44
SECOND DIVIDEND (€)	
Longer-term economic add from biomass production (induced/indirect)	0.7
Security/reduced volatility from mitigation/risk perception	3.8
Total second dividend	4.49
THIRD DIVIDEND (€)	
Economic co-benefits	
Fire suppression, fixed costs, lowered with WUI management	2.05
Sale of biomass for energy production	0.06
Social co-benefits	
Improved awareness of WUI management by industry operators	(qualitative)

Total third dividend	2.1
TOTAL DIVIDEND	93.04
Total cost	44.48
BCR	2.1

Source: World Bank analysis; based on external data and information

→ **Challenges faced and lessons learned**

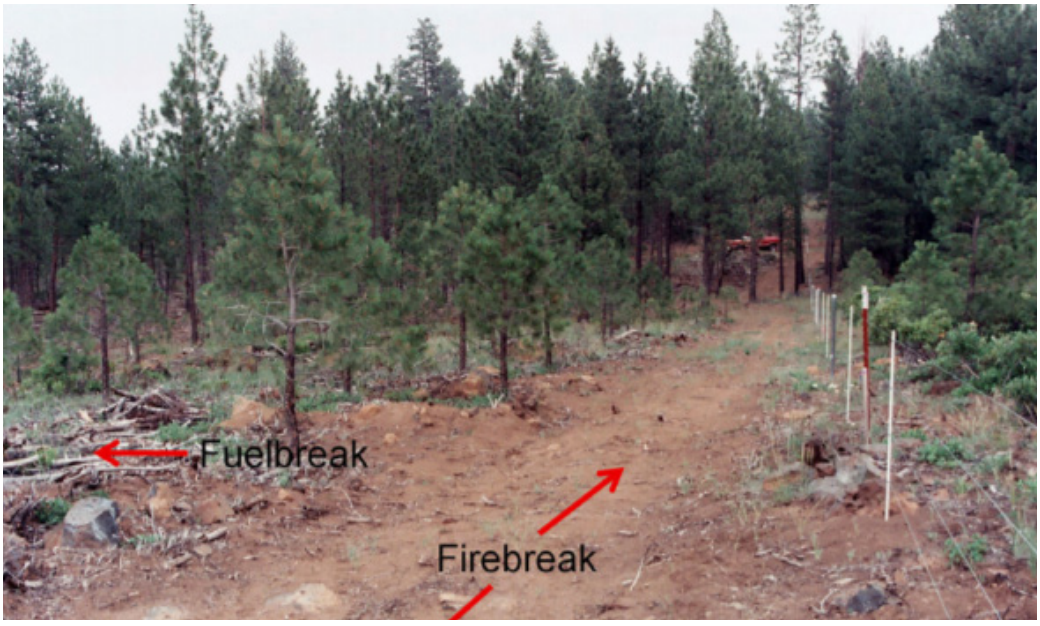
Data that could not be ascertained from Portuguese sources, including soil erosion from fires, should be investigated for the Portuguese and/or European context since fires are becoming more prevalent and the long-term costs are not always evaluated. In addition, accurate estimations of land and property value increase from reduced volatility in the area due to lessened fire starts, direct and indirect fire suppression costs avoided, and other triple dividend 2 and 3 benefits factors could be valuable to an expansion of this study.

3.5.3. FUEL MANAGEMENT FOR WILDFIRE RISK REDUCTION IN FORESTS

→ **Introduction and background**

More severe fire weather in Europe and substantial expansion of the fire-prone area and longer fire seasons are projected in most regions of Europe, particularly for high-emissions scenarios. The increase in fire danger is projected to increase in Western-Central Europe, but the absolute fire danger remains highest in Southern Europe. Fuel management interventions such as firebreaks and fuel breaks (see *Figure 35* and *Figure 36*) have been used for fire prevention and fire spread mitigation within forest areas and on their peripheries where buildings and other assets may exist. Firebreaks are strips of bare soil or fire retarding vegetation meant to stop or control fire around buildings, farms, and residential properties as they provide a fixed safety distance that protects the civilians (Natural Resources Conservation Services, 2011; WUIVIEW, 2019). Fuel breaks are strips or blocks of vegetation that have been altered to slow or control a fire and slow the spread of fire because they are managed to provide far less fuels to carry the flames. These adaptation measures are typically implemented by forest managers and have shown to substantially reduce fire risks but are not evenly applied in fire-prone areas. The countries with the highest absolute danger to wildfire remain Portugal, Spain, and Turkey (De Rigo, et al., 2017).

Figure 35: Fuel-reduced fringes (firebreaks and fuel breaks) provide a fixed safety distance



Source: Bennett, et al. (2010)

Figure 36: View of a fuel break in a pine stand in Central Portugal (photo of ADAI)

Source: ADAI (2020)

Climate change projections suggest substantial warming and increases in the number of heat waves, droughts and dry spells across most of the Mediterranean area and Southern Europe, which would increase the length and severity of the fire season. For these reasons as well as the densification of lived areas near forests, the need to understand the impacts of interventions to reduce and alleviate fire hazards is of paramount importance (EEA, 2020). BCAs such as the one performed for this and other studies attempt to comprehensively quantify the triple dividend benefits that are often not included in wildfire intervention BCAs. More such studies should be undertaken in fire-prone parts of Europe, and this case study can provide a sample methodology on how to capture triple dividend benefits.

→ Description

The case study analyses pine tree forest plots in the Central Region of Portugal to appraise the cost of fuel management using fuel breaks and comparing them to losses avoided, including lives saved, injuries avoided, and losses avoided to homes, forestry, and tourism. Such an intervention would be undertaken by forest managers by direction of the regional government or appropriate ministry. Losses included in this study have been estimated by ex post analysis of the 2017 fires in Pedrógão Grande, as well as other countries that have faced large fires, to develop relationships between fire hectares burned and casualties. Portuguese legislation requires the existence of fuel breaks around a maximum non-urban area of 100 km2. These are called primary fuel breaks as other narrower fuel breaks may exist in the interspatial areas. The primary fuel break can have some vegetation that is less combustible, like cork trees, which are also examined for co-benefits in this study. A novel methodology is employed to evaluate the benefit of fuel breaks as a priority fuel management investment. Based on past fires and literature review of the outcomes, interpolations have been made for the fuel break economic effectiveness for industry, housing, and other asset losses avoided.

→ Methodology

The BCA is over a 30-year time horizon and undertakes a sensitivity analysis of low-to-high hazard impacts and discount rates. A 30-year time horizon was chosen as an analysis carried out using data from the Institute for Nature Conservation and Forests in Portugal shows that this is a median value for the occurrence of very large fires in central Portugal (ICNF, 2020). Lives lost are estimated with an investigation of 22 case studies of large fires with fatalities in different countries that

shows that there is an increase of fatalities with the extension of the fire.[27] Excluding five cases of relatively small fires with many fatalities as outliers, an approximate linear relationship between number of fatalities and burned area in large fires can be found. This amounts to a 0.339 fatalities per 1000 ha burned in very large fires.[28] It should be noted that not all large fires cause causalities, as there are other factors that may cause or avoid casualties. Conversely, we can see that there are fire events that create a large number of victims with relatively small burned areas. From the analysis, it is found that any effort to reduce the area of a large fire will contribute to saving lives at an average rate of 2,950 ha per life.

The cost of fuel management considers an extension of forestland covered by a single species (either Pine or Eucalyptus) in a plot of land 10 × 10 km2 with a fuel break 125 m wide in the case of a very high hazard condition. The fuel break assisted by fire suppression forces will reduce the probability of a fire burning that plot to 70 percent, in comparison to not having a fuel break. The estimated cost of creating a fuel break and converting the species to cork trees is €1 million to protect a plot of 10 kHa. The maintenance of the fuel break using machinery will cost an average of €500 per ha every three years. The total cost of the fuel management intervention in the 250 ha of fuel break is approximately €1.2 million and includes nine fuel management operations over 30 years with a discount rate of 5 percent over that period. The cost also includes the fuel break development costs of €3,000 per ha and plantation of cork at €1,000 per ha.

It is important to note that the effectiveness of a fuel break is not 100 percent as it depends on the hazard conditions and the level of firefighting presence. The percentages in *Table 63* are based on expert assessment of the capacity of a fire crew stopping a fire in a well-managed firebreak (also a designated fuel break) in a 10 × 10 km2 forest plot. In the case of an approaching fire of a very high hazard, it is assumed that in 30 percent of the cases, fire crews will be successful in stopping the fire. The 30 percent also relate to the area of forest that is preserved from fire damage. However, in the case of spot fires or very high winds, the fire suppression efforts by crews might not be as efficacious, and it is assumed that this occurs in 70 percent of cases (70 percent unsuccessful and 30 percent successful fire suppression). The effectiveness of firebreaks is dependent on the fire hazard (extreme to medium in this study), which is a function of weather conditions, fuel loads, topography, and other elements, and its characterization is based on historical data and events in Portugal. The values shown in *Table 63* are used in the study to evaluate the effectiveness of fire break.

Table 63: Estimation of effectiveness of fuel breaks with regard to the hazard level and degree of effective fire suppression

Existence of Fuel Break	Effective or Low Suppression Services	Level ofFire Hazard			
		Extreme	V. High	High	Medium
Yes	Effective fire suppression services	5%	30%	60%	80%
	Low fire suppression services	1%	5%	30%	50%
No	Effective fire suppression services	1%	5%	30%	60%
	Low fire suppression services	0%	1%	5%	30%

Source: World Bank analysis; based on external data and information

27 The countries studied include Portugal, Greece, the United States, France, and Australia.
28 From large fire events in various countries, a linear relationship was made between fatalities per area to determine this value.

The following scenarios on investment in fuel break and fire suppression are considered:

1. No fuel break and effective fire suppression under extreme fire hazard: 1 percent effectiveness

2. No fuel break and effective fire suppression under very high fire hazard: 5 percent effectiveness

3. Fuel break and effective fire suppression under extreme fire hazard: 5 percent effectiveness

4. Fuel break and effective fire suppression under very high fire hazard: 30 percent effectiveness.

The BCA compares the difference in losses avoided between scenarios 2 and 4. The expected burned area in a very high fire hazard within a 30-year time horizon comparing no fuel break and fuel break cases. This results in avoided losses of protected areas of 25 kHa within every 100 kHa of forest managed in the case of an effective fuel break with effective fire suppression. Based on the success rates of fire suppression described previously, on average, 30 percent of the area will be saved from fire burn. On the other hand, if there is no investment in fuel breaks, the probability of protecting the forest from fires will be decreased to 5 percent (considering factors that may contribute to the success of operations, such as the lack of spot fires and crown fires). The difference between the two scenarios (with and without firebreaks but both with effective fire suppression services) amounts to avoided losses of 25 percent (= 30 – 5 percent). As the unit of land used for the calculations is 100,000 ha, the avoided loss is estimated as 25,000 ha of managed forest area.

The Triple Dividend Framework includes the following benefits:

Triple dividend 1 (costs avoided):

- Considering the two cases of with and without fuel break interventions in a plot of 100 kHa the avoided loss of burned area is 25 kHa/100 kHa. According to the present analysis of lives lost explained above, this corresponds to avoided fatalities of about 8.48 lives per 100 kHa of intervention in the case of a major conflagration. A discount rate of 3.5 percent is used for fire damage avoided to housing plots for the time horizon.

- Injuries avoided estimates the number of injured people as four times the number of fatalities based on actual ratios from past fires in Portugal. Therefore, an investment in creating and maintaining a fuel break would avoid about 33.9 injuries per 10 kHa of intervention based on relationships shown in *Table 63* The discount rate of the cost of treatment for injuries over the period analysed is 3.5 percent.

- Fire damage prevented to houses is based on the analysis of 31 cases of fires with an area larger than 10 kHa up to 2 MHa that yielded an average rate of 0.65 houses per kHa. Comparing scenarios 2 and 4 above, the investment in fuel breaks would correspond to an avoided loss of $0.65 \times 3 = 1.95$ houses for each plot of 100 kHa of intervention. The discount rate for fire damage over the time horizon is 3.5 percent. Using data on the average value of houses in central Portugal, provided by the National Institute of Statistics (PORDATA, 2020b), these avoided losses amount to €0.23 million.

- Reduction of losses to forestry considers the impacts calculated from previous fires in Technical Specifications for the Use and Occupational Charter of Continental Portugal for 2018 (COS, 2018; Caetano, et al., 2010).

- The reduction in deaths related to cardiorespiratory problems as well as the costs for treatment are calculated as direct losses avoided, referring to the COS2018 data. The values are derived from the October 2017 fires in Portugal in a paper by Augusto et al. (2020). Based on the actual values of losses of lives and injuries, the ratio of injury to life lost is approximately 4:1. Therefore, the number of injuries is arrived at by a multiple of four to the number of deaths with the same distribution of injury severity as described above but focused on cardiorespiratory problems.

- A stand of pine (Pinus pinaster) emits 26 tonnes of CO2 per each hectare burned (Silva, 2006). The investment in fuel management in creating a fuel breakin plots of 100 kHa would correspond to an avoided loss of 25 kHa after a period of 30 years in an area with a return period of 30 years. This is equivalent to an amount of 650,000 tonnes of CO2 emissions avoided per 100 kHa with intervention.

- Property value decrease assumes a 5 percent decrease avoided with fuel breaks (PORDATA, 2020b).

- Avoided lost tourism income is based on actual values from the 2017 fires. Data were obtained from the Regional Tourism Office for the Centre of Portugal.

- Cost of sheltering and displacement avoided is estimated by the cost of rental per day, the number of people requiring shelter is based on damaged housing at a rate of 0.65 houses per kHa. It is assumed that 50 percent of people stayed with relatives and therefore no additional cost was borne, and the remaining 50 percent stayed in rentals. The average time to recovery is estimated at six months. In addition, the loss to productivity by displaced persons is calculated as a GDP per capita reduction per working person per day and assuming that persons staying in rentals/hotels or with family have 50 percent productivity.

- Soil erosion due to the wildfires is estimated based on the cost of soil lost in 2008 at €5.82 per ha (US$7.03 per ha) over 12 years (Pinheiro, 2015). Hectares burned in Pedrógão Grande are quantified in COS2018. The discount rate of soil erosion losses over the time horizon is 5 percent.

- Fire suppression costs avoided are operational costs based on the AGIF that provides national cost values. These costs have been scaled to the Central Region of Portugal to estimate that reduction in yearly operation costs due to enhanced WUI management (AGIF, 2020). The operational costs are those resulting from service needs during fire suppression, including equipment, hourly payment to firefighters, overtime payment for aerial means, meals in the field of operations, and so on. Over the period of study, a discount rate of 5 percent has been used.

Triple dividend 2 (unlocking economic potential):

- The economic value added to Portuguese economy from the sale of cork from (TD3) the fuel break areas is multiplier of 2.032 based on solid wood product production in California (2020) and scaled to Portuguese consumer price indices (University of California, 2020).

- Increased security from lessened impacts/less volatility due to wildfire management is assumed to be 1 percent of GDP for the region. A discount rate of 5 percent is used over the time horizon for this factor.

- Increase in land purchases estimates the value of the reduction by the increase in land purchases. A 1 percent increase in land value (approximated as housing value) in fire-prone areas is assumed. Also considered in this conservative estimate is the likelihood that people tend not to buy land at typical market value in areas where tragic accidents have occurred, such as lives lost in the 2017 fires, especially in a short time following the event.

Triple dividend 3 (co-benefits):

- Fixed fire suppression costs are those that are related to the existing fire service structure regardless of whether there is a fire or not. It includes fire brigade costs, administration, aerial rentals with basic contracts, and so on. Fire suppression costs are evaluated using data from the AGIF. These costs have been scaled to the Central Region of Portugal to estimate the reduction in yearly fixed costs due to enhanced fuel management (AGIF, 2020). The justification is that with yearly reduction in fire losses due to improved fuel management, fixed costs could be reduced to a reasonable degree without compromising fire services. The implementation of DRM measures will reduce the costs of suppression over time. Initially, it will reduce variable costs such as flight hours, fuel consumed by vehicles, and meals for fire services, and later, it may also reduce the fixed costs (less contracts with aerial means). Over the period of study, a discount rate of 5 percent has been used.

- In the area of the fuel break, the planting of other trees can profit without impairing the risk reduction. For example, olive trees (olive oil), arbutus unedo (alcoholic beverage), oak trees (cork), and paulownia biomass can all be planted in fuel breaks areas. The study considers the use of oak trees in the fuel break. Carbon sequestration is from the plantation of cork trees in the fuel break area that will promote carbon sequestration at a rate of 0.1 kg carbon per ha. This will correspond to 25 kg of carbon sequestration per year.

- Sale of cork trees is calculated with data from the Portuguese Industry of Cork, one hectare of cork plantation can produce a revenue of €388 every nine years, with the required tree separation on a fuel. Given the area of the fuel break of 250 Ha and the period of 30 years, this corresponds to a revenue of €0.291 million. It is considered that the cost of plantation and maintenance of the stand is 40 percent of this value, so the net income would be €0.194 million.

→ **Results of the analysis by Dividends and overall**

Overall, the analysis shows a high BCR greater than 1, which indicates a positive economic rationale for undertaking this preventive investment (see *Table 64*). The highest benefits appear to be those from avoided losses, but the second order economic effects (dividend 2) and economic co-benefits (dividend 3) are likely to be underestimated due to lack of data. Direct losses are likely higher due to the losses avoided to infrastructure (roads, bridges, and so on) for which the study did not have data to capture (see *Table 65*).

Table 64: BCR of fuel management for wildfire risk reduction in the Central Region, Portugal (in million €)

BCR: 12.3		
	BENEFITS (€)	COSTS (€)
Dividend 1	23.32	
Dividend 2	2.63	
Dividend 3	0.35	
Total	26.31	2.21

Source: World Bank analysis based on external data and information

Table 65: Expanded triple dividend BCR calculation of fuel management for wildfire risk reduction in the Central Region, Portugal (in 100000 €)

FUEL MANAGEMENT	
FIRST DIVIDEND (€)	
Reduction of lives	50
Reduction of injuries	5.51
Fire damage prevented (industries)	2.26
Losses of timber production (trees not planted in the fuel break)	-8.75
Reduction of losses to forestry	87.5
Reduction in deaths related to cardiorespiratory problems	25.79
Reduction in treatment costs related to cardiorespiratory problems	0.32
Cost of CO2 avoided	8.68
Avoided loss of property values	6.25
Avoided loss of tourism income	27.88
Cost of sheltering/displacement avoided - lodging	0.03
Cost of sheltering/displacement avoided - productivity	0.04
Soil erosion costs avoided	0.35

Fire suppression, operational costs, lowered with fuel breaks	27.37
Total first dividend	233.23
SECOND DIVIDEND (€)	
Economic value add from sale of cork (indirect/induced)	0.88
Security/reduced volatility from mitigation/risk perception	24.18
Increase in land purchases	1.25
Total second dividend	26.31
THIRD DIVIDEND (€)	
Economic co-benefits	
Fire suppression, fixed costs, lowered with WUI management	0.49
Carbon sequestration	1.08
Sale of cork	1.94
Total third dividend	3.51
TOTAL DIVIDEND	263.06
Total cost	22.12
BCR	11.9

Source: World Bank analysis based on external data and information

→ **Challenges faced and lessons learned**

Data that could not be ascertained from Portuguese sources, including soil erosion from fires, should be investigated for the Portuguese and/or European context since fires are becoming more prevalent and broader understanding of long-term costs are not always evaluated. In addition, accurate estimations of land and property value increase from reduced volatility in the area due to lessened fire starts, direct and indirect fire suppression costs avoided, and other triple dividend 2 and 3 benefits factors could be valuable to an expansion of this study. More research is needed on the effectiveness of fuel breaks in general. While the data used in this case study is based on expert judgement from Portugal fires, it is important to note that this may not be translatable to other countries because it is both a technical management and a service-related (fire crews) solution.

3.5.4. DECISION SUPPORT TOOLS FOR CLIMATE CHANGE ADAPTATION AND ALERTING FOR WILDFIRE RISK REDUCTION

DECISION SUPPORT TOOLS FOR CLIMATE CHANGE ADAPTATION

This case study is a new ex post analysis under this project that involves innovative ways to quantify impacts.

→ **Introduction and background**

- Decision support tools are based on computers and data that are used during the process of decision-making for various objectives. Existing decision support tools usually take the forms of web based, software, or customized for specific regions or countries (Ernst & Blaha, 2015).In recent years, there has been an increase in decision support tools for climate change planning and adaptation, which allows authorities and scientists to make decisions that address both short-term risks and long-term

effects of climate change. These tools promote effective and efficient adaptations and resilience to climate changes, allow better decision-making for risk reduction, and promote sustainable management in areas such as land and forestry.

- In recent years, web-based decision support tools are becoming the most popular and frequently used in the context of climate change adaptation and communication. To examine the efficiency and effectiveness of these tools, EU projects like IMPRESSIONS were launched (European Commission, 2020). These projects enable the decision makers to see to what extent decision support tools help them in modelling and dealing with climate change scenarios and their uncertainties and impacts (Lourenço, et al., 2019).

- When using decision support tools, it is essential to have specific, locally relevant data for the tools to produce the most accurate and efficient outcomes. It is also important to consider and analyse the costs and benefits of such resilience strategies, especially for green infrastructures (Ernst & Blaha, 2015).

→ **Description**

Forest DSS (2013) organizes knowledge about the construction and use of forest DSS for promoting sustainable forest management. The collaborative developed a decision support tool for forestry extension services for small-scale private landowners to improve silviculture in southern forest areas in Austria, not only to reduce the impacts of climate change leading to forest fires in the region but also for efficient and productive ecosystem services from forestry.

The methodology includes the start-up and assumed maintenance cost of the decision-support tool over the horizon of 30 years and compares to forest fire direct and indirect costs to the region as well as improved GDP with efficient silviculture. The methodology references a study from Ireland that was used to estimate the overall GDP improvement (Dhubháin, 2009) as well as studies on Austria forest management that were used to estimate the costs and benefits of the decision support tool (Lexer, et al., 2005). The data gathered for the cost of the tool and the estimated users were provided by a senior researcher who developed the decision support tool.

Major assumptions and factors include the following:

- Value added to broader economy of Austria for forestry from R&D is 10 percent of total forestry output based on initial investment. This is the value of information to the economy, which has been found in a simulation by Khabarov, Moltchanova, and Obersteiner (2008), analysing the benefit of information that resulted in avoided costs from forest burns of up to 21 percent (Khabarov, et al., 2008).

- Maintenance cost of the decision support tool is 5 percent of total cost, annually.

- A 50–90 percent uptake of the tool by private owners is gradually realized in the last 10 years of the 30-year horizon. This is an uptake value considering the time it would take for a forest to grow and the buy-in of the tool users.

- A 1–1.5 percent increase in GDP from forestry in the area is realized within the last 10 years of the 30-year horizon. This is considering the time it would take for efficient and sustainable forestry to grow and for benefits to be realized. This is a conservative estimate.

- Discount rate of 3 percent is used.

→ **Results of the analysis by dividends and overall**

Triple dividend 1 (costs avoided):

- Avoided direct and indirect forest fire costs are obtained from the 2020 white paper on forest fires in the Alps (Mayer, et al., 2020)

Triple dividend 3 (co-benefits):

- The value of improved silviculture that includes an increasing uptake by small forest owners and provides more efficient harvests for forestry over time. This is estimated as a 1.5 percent increase in the last 10 years of the horizon studied (years 20 to 30), after the new growths are ready for harvest.

In the long term, informed decision-making by private forest owners for improved silviculture shows a great benefit compared to the cost of creating the decision

support tool (see *Table 66* and *Table 67*). This implies that with effective information and communication, along with incentives to apply the tool in evaluation of economic output of silviculture, more fire-resilient forests could be created and provide better economic output through forestry.

In performing sensitivity analyses for this study, the lower bound of BCRs are based on higher annual costs over time (10 percent of total cost) with no inclusion of broader economic costs. The higher limit includes greater GDP per year from improved silviculture (up to 3 percent based on information on the economy of Finland showing 3 percent improved harvest per year (Wikipedia, 2020)). The low- and high-range BCR is 3.3 and 10.6, respectively, with a median BCR of 5.8, as detailed below. The NPV for the median case is €994,000, which is positive, indicating that this is a good investment.

Table 66: BCR of climate change adaptation decision support tool in Austria (in 100000 €)

BCR: 5.8		
	BENEFITS (€)	COSTS (€)
Dividend 1	1.85	
Dividend 2		
Dividend 3	9.01	
Total	10.86	1.88

Source: World Bank analysis based on external data and information

Table 67: Expanded triple dividend BCR calculation for the climate change adaptation decision support tool in Austria (in 100000 €)

DECISION-SUPPORT TOOL FOR FORESTRY	
FIRST DIVIDEND (€)	
Direct and indirect cost of fires avoided	1.85
Total first dividend	1.85
THIRD DIVIDEND (€)	
GDP increase due to improved silviculture	9.01
Total third dividend	9.01
TOTAL DIVIDEND	10.86
Total cost	1.88
NPV (30-year time horizon)	9.94
BCR	5.8

Source: World Bank analysis based on external data and information

→ Challenges faced and lessons learned

Many estimations, assumptions, and simplifications were made for this study, largely because of a lack of data for this project. Because the tool was developed in 2005, it would be of value to explore the monitoring and evaluation of the forest owners who employed the tool. The data might be held by the Carinthia government agency that employed the tool.

It is important to note that without the inclusion of GDP benefits as part of this study, the BCR would be less than 1. This means that the assumptions on GDP increase over time due to improved silviculture must be further researched and validated based on existing data of this retrospective project.

The study could also be enhanced by analysing specifically the economic benefit of improved silviculture can have on the economy, both micro- and macro in the Carinthia region of Austria, which can be extended to the whole country. More research on the socio-psychological factors and incentives to private forest owners should be explored to enhance and further specify values for this BCA, which is currently conservative.

ALERTING AND PREPAREDNESS FOR WILDFIRES IN PORTUGAL

This case study is a new ex ante analysis under this project that involves innovative ways to quantify impacts.

→ Introduction and background

As a recurrent hazard in Europe, wildfires cause fatalities, injuries, and displacements of civilians and generate great social and economic losses. Therefore, it is important to provide alerting with emergency planning and increase preparedness before the actual occurrence of a fire to reduce its negative impacts.

Some alerting and monitoring systems have been created in Europe to improve wildfire prevention and risk reduction. The EFFIS[29] developed by JRC is an online geographic system that provides a database of real-time information on fire events in Europe, early warnings, active fire detections, and damage assessments after the occurrence of a fire (EFFIS, 2021). Studies for hydrometeorological alerting systems have averaged BCR between 5:1 and 10:1 but have seen BCRs of up to 2,500:1. Tiesberg and Weiher (2009) find that examples do not suggest that an overall factor indicates that there is a great deal of uncertainty about the true (weighted average) ratio of benefits to costs. Therefore, studies such as the below attempt to enumerate fire alerting benefits which are considered mostly for life safety and injury avoidance, especially in rapidly spreading fires.

→ Description

A hypothetical investment for alerting and preparedness along with local fuel management surrounding homes in the Central Region of Portugal is appraised in this case study. The composite costs of developing an alerting system, undertaking evacuation planning, as well as localized fuel management near homes in the greater region (approximately 50,000 homes) are compared to the benefits of such interventions to the municipality of Pedrógão Grande. This kind of intervention requires first step planning and preparedness by the government through the creation of evacuation plans and alerting systems for the fire-prone region as well as independent fuel management by homeowners as a minimum to creating defensible space. Pedrógão Grande faced immense damage and loss during the 2017 fire season and has therefore been selected for analysis using actual loss values. See Wildland-urban interface: Improvements to homes in Portugal case study for more information.

The alerting and evacuation would require regional government investment, while fuel management could be a combination of private financing and government funding or subsidy. These actions present the minimum that would significantly reduce the loss of life and the chance for injuries and are therefore focused on in this case study.

29 These examples do not suggest that an overall factor of 5:1 or 10:1 is unreasonable, but they do indicate that there is a great deal of uncertainty about the true (weighted average) ratio of benefits to costs. (Tiesberg and Weiher 2009).

→ **Methodology**

Considering the fire risk mitigation activities mainly as contributing to reduce the number of causalities, three scenarios are assessed for fire risk outcomes: extreme, very high, or moderate. Based on existing outcomes from fires in Portugal as well as expert judgement and evaluation, a set of probabilities for casualties are determined given the level of implementation of the following activities:

- Fire danger assessment
- Alerting
- Evacuation or shelter plans
- Fuel management

Table 68 and *Table 69* indicate estimated probabilities of injuries and lives lost as a function of fire hazard and investment in various DRM activities. The tables are developed based on assessment of the past fires in Portugal and validated with ex post data on non-existent DRM measures for extreme hazard events in Pedrógão Grande, Mati, and Rafina cities in Greece (see Alerting and preparedness in Greece). For all risk management and risk reduction activities, it is assumed that if no action is taken by the government and authorities, 20 percent of the people affected will, on average, have the capacity to overcome situations to avoid injuries and mortality. This assessment was evaluated in fire events in which the team observed that the probability of having fatalities or injured persons was lower than the estimated maximum value. This means that more than 20 percent of the persons have the capacity to avoid injuries and mortalities without any DRM activities taking place. However, for reasons of conservativism, a value of 20 percent is maintained for people who could successfully protect themselves even without any DRM measures being implemented.

The probability for each DRM activity described is based on expert judgement of the impact of the activity and the relevance in reducing fatalities or injuries in varying degrees of investment in DRM activities. It is considered that the existence of evacuation and shelter plans, for example, would have a higher effect on reducing deaths rather than injuries. On the other hand, it is assumed that life protection measures could save lives but not so much for the occurrence of injuries. For the high hazard cases, it is assumed that the probabilities are half of extreme hazard. For the moderate hazard cases, it is assumed that the probabilities are one-sixth of the extreme hazard scenario. As mentioned earlier, these values are based on expert judgement and study of consequences of fire hazards in Portugal. The recurrence period for extreme hazard is about 29 years while the return period for very high hazard is about 10 years based on historical events. In practice, the most relevant scenario is that of extreme or very high Hazard, as normally in the average hazard condition fatalities are not expected but injuries may be.

In this retrospective study, the benefits are assumed to accrue over the period of one year and are not discounted, whereas the costs are incurred each year and are therefore discounted.

Expanded DRM activities for wildfire risk reduction are described as follows:[30]

- Community work: Training community members to avoid behaviours that could cause ignition
- Education and sensibilization: Educating community members on fire risk management
- Fire danger assessment: Daily fire risk assessment by authorities
- Alerting: Informing community when fire activity is occurring in the vicinity and actions to take
- Evacuation and/or shelter plans: Advanced planning of evacuation or stay-in-place
- House planning: Land use planning to avoid building homes near WUI
- House construction: Building with non-flammable materials and avoiding weak spots in homes
- Fuel management: Clearing of fuel around homes
- Fire protection: Presence and capacity of firefighter services
- Life protection: Medical protection, ambulances, and medical support.

30 Note that these are comprehensive DRM activities for wildfire risk reduction; only four of these activities have been included and analysed in this case study.

Considering that all mitigation activities are independent of each other, the probability of having an accident given the implementation of the set of activities will be given by the product of the probabilities of each activity.

Table 68: Probabilities of injuries with risk reduction actions taken in moderate to extreme hazard fires

Probability of Injuries based on Fire Hazard Level and Investment Amount in DRM Activities									
DRM Action Undertaken	Extreme Hazard			High Hazard			Moderate Hazard		
	Investment in DRM Activity			Investment in DRM Activity			Investment in DRM Activity		
	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent
Community Work	0.4	0.6	0.8	0.2	0.3	0.4	0.067	0.1	0.133
Education and Sensibilization	0.5	0.6	0.8	0.25	0.3	0.4	0.083	0.1	0.133
Fire Danger Assessment	0.3	0.6	0.8	0.15	0.3	0.4	0.05	0.1	0.133
Alerting	0.3	0.6	0.8	0.15	0.3	0.4	0.05	0.1	0.133
Evacuation and/or Shelter Plans	0.2	0.5	0.8	0.1	0.25	0.4	0.033	0.083	0.133
House Planning	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133
House Construction	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133
Fuel Management	0.2	0.6	0.8	0.1	0.3	0.4	0.033	0.1	0.133
Fire Protection	0.1	0.2	0.8	0.05	0.1	0.4	0.017	0.033	0.133
Life Protection	0.4	0.5	0.8	0.2	0.25	0.4	0.067	0.083	0.133

Source: World Bank analysis based on external data and information

Table 69: Probabilities of fatalities with risk reduction actions taken in moderate to extreme hazard fires

Probability of Fatalities based on Fire Hazard Level and Investment Amount in DRM Activities									
DRM Action Undertaken	Extreme Hazard			High Hazard			Moderate Hazard		
	Investment in DRM Activity			Investment in DRM Activity			Investment in DRM Activity		
	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent
Community Work	0.2	0.5	0.8	0.1	0.25	0.4	0.033	0.083	0.133
Education and Sensibilization	0.4	0.6	0.8	0.2	0.3	0.4	0.067	0.1	0.133
Fire Danger Assessment	0.2	0.5	0.8	0.1	0.25	0.4	0.033	0.083	0.133
Alerting	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133
Evacuation and/or Shelter Plans	0.1	0.4	0.6	0.05	0.2	0.3	0.017	0.067	0.133
House Planning	0.01	0.2	0.8	0.005	0.1	0.4	0.002	0.033	0.133
House Construction	0.01	0.2	0.8	0.005	0.1	0.4	0.002	0.033	0.133
Fuel Management	0.1	0.6	0.8	0.05	0.3	0.4	0.017	0.1	0.133
Fire Protection	0.01	0.2	0.8	0.005	0.1	0.4	0.002	0.033	0.133
Life Protection	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133

Source: World Bank analysis based on external data and information

The study estimates the cost of alerting and evacuation planning in the Central Region of Portugal as well as private home preparedness through creation of defensible space and evaluates the benefits of casualties avoided in the municipality of Pedrógão Grande in the extreme hazard case. Pedrógão Grande is approximately one-fifth of the Central Region by area. Since alerting would not occur at a city level but rather a regional level, the benefits of such a system would be larger than what are stated here. Any municipality within the Central Region with fire risk would be a potential beneficiary from alerting and preparedness. However, since loss estimates are based on Pedrógão Grande from the 2017 fires and for sake of this hypothetical investment to be constrained to real values as much as possible, the analysts have only looked at the triple dividend 1 benefits to Pedrógão Grande.

Costs of injuries to Pedrógão Grande are based on the Portugal Health Regulatory Authority (INFARMED, 2020). The cost of alerting has been obtained by telephone company data interpolated for Pedrógão Grande. The cost of fuel management in the Central Region is an average of €300 per home with 50,000 homes. It is assumed that all homeowners will undertake fuel management in this case study, but the reality is that this will be a slow-onset preparedness measure. This is because the quality and quantity of defensible space created by homeowners surrounding their property is not guaranteed if not mandated and could be non-uniform.

The study looks at a one-year horizon for BCA but computes the five-year costs of communication activities with a 5 percent discount rate.

The Triple Dividend Framework includes the following benefits:

Triple dividend 1 (costs avoided):

As this assessment largely evaluates loss of lives and injuries avoided due to fire danger assessment, alerting, evacuation plans, and fuel management, the benefits are classified as triple dividend 1. The alerting and evacuation planning does not necessarily intend to reduce damage to homes and other assets, as some evacuation plans also encourage sheltering in place if housing is qualified appropriate to do so.

→ **Results of the analysis by dividends and overall**

The benefits are high when comparing the cost of alerting in the Centro Region of Portugal to the losses avoided from casualties in Pedrógão Grande (see *Table 70* and *Table 71*). This can be expected as the costs of alerting are generally much lower than the cost of lives lost or injured. Note also that the benefits are likely underestimated as we are comparing the benefits to the municipality of Pedrógão Grande to the costs of alerting, evacuation, and fuel management of homes to the Central Region of Portugal. There are not enough data to quantify unlocked economic potential or co-benefits in this case study, but they may exist and could be included in future studies. Importantly, the cost of frequent and effective education of alert receivers is not included due to data limitations. This would be an added cost of intervention which would reduce the BCR. Overall, however, the BCR would be greater than 1 which would make this investment a positive ROI.

Table 70: BCR calculation of alerting and preparedness for fires in Portugal (in million €)

BCR: 11		
	BENEFITS (€)	COSTS (€)
Dividend 1	200.29	
Dividend 2		
Dividend 3		
Total	200.29	19

Source: World Bank analysis based on external data and information

Table 71: Expanded triple dividend BCR calculation for alerting and preparedness for fires in Portugal (in million €)

ALERTING AND PREPAREDNESS	
FIRST DIVIDEND (€, million)	
Reduction of lives	198
Reduction of injuries	2.29
Total first dividend	200.29
TOTAL DIVIDEND	200.29
Total cost	19
BCR	11

Source: World Bank analysis based on external data and information

→ Challenges faced and lessons learned

Future studies should further assess the realizable benefits of employing any or all of the DRM activities in other municipalities in the Centro region. Often, 'soft' investments like capacity building and awareness are understudied but a large factor in emergency and recovery contexts and should be included in future BCA analyses. In general, sparse literature exists on the value of awareness for fire and other hazards, and should be evaluated more thoroughly as often they are 'no regret' options in risk communication and risk reduction capacity building. There may be other triple dividend benefits of alerting, like the sense of safety that may unlock additional investment in the area (Dividend 2) or co-benefits like awareness of fire risk and tools available to homeowners and residents to reduce their risk (Dividend 3), which could be qualitatively captured in further studies. In addition, frequent, uniform, and effective communication to the community on understanding alerts and actions to take is essential but was not included in this study due to lack of data. Future studies must consider the element of education and behaviour related to receiving and understanding alerting and fuel management to fully capture the costs of employing this intervention.

ALERTING AND PREPAREDNESS IN GREECE

This case study is a new ex ante analysis under this project that involves innovative ways to quantify impacts.

→ Introduction and background

In 2018, the seaside village of Mati in the Attica region of Greece faced fires that caused tremendous loss to life and property. These fires were considered the second-deadliest event in the 21st century. Over 700 residents were evacuated or rescued. Over 100 people lost their lives and more than 1,000 buildings were damaged or destroyed (BBC, 2018). While multiple factors led to the outcome of this event, this case study aims to enumerate potential benefits from fire alerting, emergency planning, and basic fuel management by homeowners to their properties, which are considered primary mitigation and preparedness measures for life safety and injury avoidance, especially in rapidly spreading fires like in Mati.

→ Description

A hypothetical investment for alerting and preparedness along with fuel management in the Attica region of Greece is appraised in this case study. The composite costs of developing an alerting system, undertaking evacuation planning, as well as localized fuel management near homes in the villages of Mati and Rafina (approximately 20,000 homes) are compared to the benefits of such interventions to the Attica region. This kind of intervention requires first step planning and preparedness by the government through the creation of evacuation plans and alerting systems for the fire-prone region as well as independent fuel management by homeowners as a minimum to creating defensible space. Mati and Rafina faced great damage and loss during the 2018 fires in Attica caused by heatwave and have therefore been selected for analysis using actual loss values.

The alerting and evacuation would require regional government investment, while the fuel management could be a combination of private financing and government funding or subsidy. These actions present the minimum that would significantly reduce the loss of life and the chance for injuries and are therefore focused on in this case study.

→ Methodology

Considering the above fire risk mitigation activities mainly as contributing to reduce the number of causalities, three scenarios are assessed for fire risk outcomes: extreme, very high, or moderate. Based on existing outcomes from fires in Greece as well as expert judgement and evaluation, a set of probabilities for casualties are determined given the level of implementation of the following activities undertaken:

- Fire danger assessment
- Alert
- Evacuation or shelter plans
- Fuel management

Table 72 and *Table 73* include estimated probabilities of injuries and lives lost as a function of fire hazard and investment in various DRM activities. The tables are

developed based on assessment of the past fires in Portugal and validated with ex post data on non-existent DRM measures for extreme hazard events in Pedrógão Grande, Mati, and Rafina. For all risk management and risk reduction activities, it is assumed that if no action is taken by the government and authorities, 20 percent of the people affected will, on average, have the capacity to overcome situations to avoid injuries and mortality. This assessment was evaluated in fire events in which the team observed that the probability of having fatalities or injured persons was lower than the estimated maximum value. This means that more than 20 percent of the persons have the capacity to avoid injuries and mortalities without any DRM activities taking place. However, for reasons of conservativism, a value of 20 percent is maintained for people who could successfully protect themselves even without any DRM measures being implemented.

The probability for each DRM activity described is based on expert judgement of the impact of the activity and the relevance in reducing fatalities or injuries in varying degrees of investment in DRM activities. It is considered that the existence of evacuation and shelter plans, for example, would have a higher effect on reducing deaths rather than injuries. On the other hand, it is assumed that life protection measures could save lives but not so much for the occurrence of injuries. For the high hazard cases, it is assumed that the probabilities are half of extreme hazard. For the moderate hazard cases, it is assumed that the probabilities are one-sixth of the Extreme Hazard scenario. As mentioned earlier, these values are based on expert judgement and study of consequences of fire hazards in Portugal. The recurrence period for Extreme Hazard is about 29 years while the return period for very high hazard is about 10 years based on historical events. In practice, the most relevant scenario is that of extreme or very high hazard, as normally in the average hazard condition fatalities are not expected but injuries may be.

In this retrospective study, the benefits are assumed to accrue over the time period of one year and are not discounted, whereas the costs are incurred each year and are therefore discounted.

Expanded DRM activities for wildfire risk reduction are described as follows:[31]

1. Community work: Training community members to avoid behaviours that could cause ignition
2. Education and sensibilization: Educating community members on fire risk management
3. Fire danger assessment: Daily fire risk assessment by authorities
4. Alerting: Informing community when fire activity is occurring in the vicinity and actions to take
5. Evacuation and/or shelter plans: Advanced planning of evacuation or stay-in-place
6. House planning: Land use planning to avoid building homes near WUI
7. House construction: Building with non-flammable materials and avoiding weak spots in home
8. Fuel management: Clearing of fuel around homes
9. Fire protection: Presence and capacity of firefighter services
10. Life protection: Medical protection, ambulances, and medical support.

Considering that all mitigation activities are independent of each other, the probability of having an accident given the implementation of the set of activities will be given by the product of the probabilities of each activity.

31 Note that these are comprehensive DRM activities for wildfire risk reduction; only four of these activities have been included and analysed in this case study.

Table 72: Probabilities of injuries with risk reduction actions taken in moderate to extreme hazard fires

Probability of Injuries based on Fire Hazard Level and Investment Amount in DRM Activities									
DRM Action Undertaken	Extreme Hazard			High Hazard			Moderate Hazard		
	Investment in DRM Activity			Investment in DRM Activity			Investment in DRM Activity		
	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent
Community Work	0.4	0.6	0.8	0.2	0.3	0.4	0.067	0.1	0.133
Education and Sensibilization	0.5	0.6	0.8	0.25	0.3	0.4	0.083	0.1	0.133
Fire Danger Assessment	0.3	0.6	0.8	0.15	0.3	0.4	0.05	0.1	0.133
Alerting	0.3	0.6	0.8	0.15	0.3	0.4	0.05	0.1	0.133
Evacuation and/or Shelter Plans	0.2	0.5	0.8	0.1	0.25	0.4	0.033	0.083	0.133
House Planning	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133
House Construction	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133
Fuel Management	0.2	0.6	0.8	0.1	0.3	0.4	0.033	0.1	0.133
Fire Protection	0.1	0.2	0.8	0.05	0.1	0.4	0.017	0.033	0.133
Life Protection	0.4	0.5	0.8	0.2	0.25	0.4	0.067	0.083	0.133

Source: World Bank analysis based on external data and information

Table 73: Probabilities of fatalities with risk reduction actions taken in moderate to extreme hazard fires

Probability of Fatalities based on Fire Hazard Level and Investment Amount in DRM Activities									
DRM Action Undertaken	Extreme Hazard			High Hazard			Moderate Hazard		
	Investment in DRM Activity			Investment in DRM Activity			Investment in DRM Activity		
	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent	Very High	Normal	Non-Existent
Community Work	0.2	0.5	0.8	0.1	0.25	0.4	0.033	0.083	0.133
Education and Sensibilization	0.4	0.6	0.8	0.2	0.3	0.4	0.067	0.1	0.133
Fire Danger Assessment	0.2	0.5	0.8	0.1	0.25	0.4	0.033	0.083	0.133
Alerting	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133
Evacuation and/or Shelter Plans	0.1	0.4	0.6	0.05	0.2	0.3	0.017	0.067	0.133
House Planning	0.01	0.2	0.8	0.005	0.1	0.4	0.002	0.033	0.133
House Construction	0.01	0.2	0.8	0.005	0.1	0.4	0.002	0.033	0.133
Fuel Management	0.1	0.6	0.8	0.05	0.3	0.4	0.017	0.1	0.133
Fire Protection	0.01	0.2	0.8	0.005	0.1	0.4	0.002	0.033	0.133
Life Protection	0.1	0.4	0.8	0.05	0.2	0.4	0.017	0.067	0.133

Source: World Bank analysis based on external data and information

The study estimates the cost of alerting in the Attica region of Greece and evaluates the benefits of casualties avoided in villages of Mati and Rafina. These villages are approximately one-third of the Attica region by area. Since alerting would not occur at a city level but rather a regional level, the benefits of such a system would be larger than what are stated here. Any municipality within the Attica region with fire risk would be a potential benefactor from alerting and preparedness. However, since loss estimates are based on the 2018 fires and for sake of this hypothetical investment to be constrained to real values as much as possible, the analysts have only looked at the triple dividend 1 benefits to Mati and Rafina. The cost of alerting and development of evacuation plans in the region of Attica is estimated to be €2 million, including €1 million for maintenance for five years. Information from the Greece Civil Protection Agency has apportioned €5 million for a national-level multi-hazard forest monitoring and EWS (fires, floods, landslides, and so on) with a fire detection and alerting via SMS to surveillance centres and eventually to vulnerable populations. The Attica region is approximately 35 percent of the total population of Greece (2019 Eurostat), and the estimated €2 million for the case study is approximately 40 percent of the budget line item. Therefore, it is reasonable to estimate a cost of €2 million including maintenance costs for alerting and evacuation in the Attica region. Sensitivity analysis of the costs between €1 million and €5 million yields similar BCRs.

Costs of injuries in Mati are obtained with data from consultations with Greek fire specialists and on the ground estimations following deployments to Greece. Costs included are compensation for the deceased and injured, along with emergency health costs.[1] The cost of alerting has been estimated as €250,000 per year based on the calculations made for Portugal, assuming similar costs for the regions affected that have areas of similar size. The cost of fuel management in the Attica region is an average of €300 per home with 20,000 homes. The same cost in relation to that of Portugal was adopted to estimate the cost of fuel management per house in the Attica region. It is assumed that all homeowners will undertake fuel management in this case study, but the reality is that

this will be a slow-onset preparedness measure. This is because the quality and quantity of defensible space created by homeowners surrounding their property is not guaranteed if not mandated and could be non-uniform.

The study looks at a one-year horizon for BCA but computes the five-year costs of communication activities with a 5 percent discount rate.

The Triple Dividend Framework includes the following benefits:

Triple dividend 1 (costs avoided):

- As this assessment largely evaluates loss of lives and costs borne from casualties avoided due to alerting, evacuation plans, and fuel management, the benefits are classified as triple dividend 1. The alerting and evacuation planning does not necessarily intend to reduce damage to homes and other assets, as some evacuation plans also encourage sheltering in place if housing is qualified appropriate to do so.

→ **Results of the analysis by dividends and overall**

The benefits are high when comparing the cost of alerting in the Attica region of Greece to the losses avoided from casualties in Mati and Rafina (see *Table 74* and *Table 75*). This can be expected as the costs of alerting are generally much lower than the cost of lives lost or injured. In this tragic event, many lives were lost than could have been expected given the fire hazard, resulting in a large BCR. Note again that the benefits are likely underestimated as we are comparing the benefits to the villages of Mati and Rafina to the costs of alerting, evacuation, and fuel management of homes to the Attica region of Greece. There are not enough data to quantify unlocked economic potential or co-benefits in this case study. However, they may exist and could be included in future studies. Importantly, the cost of frequent and effective education of alert receivers is not included due to data limitations. This would be an added cost of intervention which would reduce the BCR. Overall, however, the BCR would be greater than 1 which would make this investment a positive ROI.

Table 74: BCR calculation of alerting and preparedness for fires in Greece (in million €)

BCR: 39.3		
	BENEFITS (€)	COSTS (€)
Dividend 1	314.04	
Dividend 2		
Dividend 3		
Total	314.04	8

Source: World Bank analysis based on external data and information

Table 75: Expanded triple dividend BCR calculation of alerting and preparedness in Greece (in million €)

ALERTING AND PREPAREDNESS	
FIRST DIVIDEND (€)	
Reduction of lives	312
Compensation for the deceased	0.52
Compensation for the injured	0.09
Emergency health costs	1.43
Total first dividend	314.04
TOTAL DIVIDEND	314.04
Total cost	8
BCR	39.3

Source: World Bank analysis based on external data and information

→ **Challenges faced and lessons learned**

The high BCR is mainly due to the tragic events of the 2018 Mati fires, considered the second-deadliest fire in the 21st century and upon which this scenario is based. For a relatively small population affected in Greece, a large number of injuries and high number of fatalities created one of the worst fire disasters in the country that was extremely politicized and sensitive for the Greek population. The BCRs for both Greece and Portugal exemplify the opportunity to save lives with relatively low-cost investments in alerting and evacuation planning.

Future studies should further assess the realizable benefits of employing any or all of the DRM activities in other municipalities in the Attica region. Often, 'soft' investments like capacity building and awareness are understudied but a large factor in emergency and recovery contexts and should be included in future BCAs. In general, sparse literature exists on the value of awareness for fire and other hazards and should be evaluated more thoroughly as often they are 'no-regret' options in risk communication and risk reduction capacity building. There may be other triple dividend benefits of alerting, like the sense of safety that may unlock additional investment in the area (dividend 2) or co-benefits like awareness of fire risk and tools available to homeowners and residents to reduce their risk (dividend 3), which could be qualitatively captured in further studies. In addition, frequent, uniform, and effective communication to the community on understanding alerts and actions to take is essential but was not included in this study due to lack of data. Future studies must consider the element of education and behaviour related to receiving and understanding alerting and fuel management to fully capture the costs of employing this intervention.

3.5.5. CROSS-BORDER SUPPORT, COORDINATION MECHANISMS, AND CAPACITY BUILDING FOR WILDFIRES

The following analysis will focus on a specific investment SPITFIRE in Portugal as a hypothetical investment, but numerous other investments have been undertaken in capacity building for wildfire prevention in countries such as in the Czech Republic, Poland, or Spain.

CROSS-BORDER SUPPORT AND COORDINATION MECHANISMS FOR WILDFIRES

This case study is a new ex ante analysis under this project that involves innovative ways to quantify impacts.

→ **Introduction and background**

Disasters and hazards are not bound by the borders of countries. The impacts of disasters are consistent throughout Europe and generate negative social and economic consequences for all countries affected. In this context, it is essential for European countries to work collaboratively and share their resources and good practices when a disaster strikes, especially in cross-border areas that are vulnerable to disasters such as forest fire and floods.

Several EU projects have been launched to enhance cooperation across borders in terms of responses to disasters and emergencies. INTER'RED is an ongoing project that improves rescue services in the cross-border Grande Région, which covers Luxembourg, France, Germany and Belgium (European Commission, 2020). The project aims at increasing cooperation among nations so that resources such as rescuing equipment and tools can be shared and utilized efficiently if disasters such as a large-scale fire occur. The Federation of European Union Fire Officer Associations also offers a proposal (FEU Fire Officer Associations, 2020) that encourages European countries to increase communications and collaborations, enhance shared legislative frameworks in terms of infrastructure and community safety, and improve rescue equipment as well as the security and safety of firefighters. These efforts ensure the safety of European citizens and reduce damages and economic costs due to the occurrences of fires.

When doing an economic analysis of cross-border services and coordination mechanisms, one must fully address the needs and demands as well as the cost and benefits of such services. This is suggested by a study (Tinholt, et al., 2013) for the European Commission DG Communications Networks, Content, and Technology, which also indicates that

interoperability is an essential factor that needs to be considered.

→ Description

SPITFIRE is a project that was partially co-funded by the European Commission (European Commission, 2017). The main objective of this project was the improvement of information exchange on meteorology and forest fire risk in the border area between Portugal and Spain through the identification, design, and implementation of data interchange protocols and the development of a cross-border service on weather and fire-risk forecast (SPITFIRE platform). The tool offers high-resolution meteorological and forest weather forecasts. The information is presented in a GIS environment, to allow its joint management with other information used daily by users of the service like fire managers and firefighters. Information presented includes protected spaces, surveillance posts, roads, water points, distribution of material and human resources, and so on). The tool is not only applied in cases of urgent response but also in planning and preparation activities. Consequently, not only the firefighters but the entire fire management structure benefit. Besides the immediate positive effects of the tool for Portugal and Spain, this approach can be replicated to other cross-border regions in Europe which are at high risk and suffer greatly from forest fire.

This case study evaluates the cost of developing a cross-border information tool for emergency fire services and firefighters at the Portugal-Spain border and the estimated losses avoided from improved information and coordination of countries and agencies.

→ Methodology

The methodology considers the cost of creating the SPITFIRE tool by the consortium coordinated by ADAI at the University of Coimbra in Portugal[32] and the avoided direct and indirect losses from forest fires. The study is focused on triple dividend 1 losses avoided in the cross-border region of Spain and Portugal. The major assumption in this study is that only 0.5 percent of direct and indirect fire losses would be avoided with enhanced coordination and cooperation facilitated by SPITFIRE. This is from anecdotal evidence by the principal investigator of the project receiving positive responses from emergency services about the utility of the tool. It also provides conservativism as little data exist in terms of cross-border fire consequence reconciliation. Since there was no continued funding in the platform, the life span of the tool was just over a year, so only a one-year estimation of the BCA was undertaken.

Many relevant studies were considered for the evaluation of the BCA. Research shows that sparse literature is available in terms of overall benefits that a decision support or emergency coordination tool can provide during its lifetime of utility.

The cost of the tool was provided by the project manager and developer of SPITFIRE. The losses avoided (direct and indirect forest fire losses) were estimated from an existing report on the 2017 fires (Comissao Tecnica Independente, 2017). Direct costs are losses from burned areas (forests and shrublands). The direct costs were obtained from data provided by the Portuguese Institute for Nature and Forest Conservation and by the Polytechnic University of Valencia (ICNF, 2017; Gomez, 2014). Indirect costs are related to fire prevention, firefighting, recovery, and losses in services and goods due to the fire. Indirect costs were calculated through a ratio between direct and indirect costs based on a report providing historical data on wildfire costs. The direct and indirect costs were scaled to the cross-border area covered by the SPITFIRE project.

Due to the limited data on expanded benefits, this study estimates the costs of forest fire management and suppression in the cross-border regions of Spain and Portugal.

Triple dividend 1 (costs avoided):

Based on actual annual costs to Portugal and Spain, the ratio of cross-border forests to total forests in the respective countries to determine scaled costs of forest fires.

32 Note that four other partner organizations supported development of the tool, with coordination from ADAI. Only the costs from ADAI are considered in this case study.

→ **Results of the analysis by dividends and overall**

The overall BCR is greater than 1 over the period of a year in which this evaluation is considered (see *Table 76* and *Table 77*). The direct and indirect costs of fire damage losses avoided considering a conservative value of penetration and utility of tool still offers a high benefit compared to the cost and maintenance of the tool. While the assessment focused on the first dividend of direct and indirect costs avoided, the full benefits are likely underestimated as dividends 2 and 3 could not be included due to lack of data.

In addition, the costs of the SPITFIRE platform tend to be diluted over time, while the benefits tend to increase. Thus, one would expect that a longer platform lifetime should drive to a much more significant BCR.

Table 76: BCR calculation of the SPITFIRE project (in million €)

BCR: 1.6		
	BENEFITS (€)	COSTS (€)
Dividend 1	1.15	
Dividend 2		
Dividend 3		
Total	1.15	0.7

Source: World Bank analysis based on external data and information

Table 77: Expanded triple dividend BCR calculation for the SPITFIRE project (in million €)

CROSS-BORDER COORDINATION	
FIRST DIVIDEND (€)	
Direct costs of forest fires avoided, Spain	0.06
Indirect costs of forest fires avoided, Spain	0.08
Direct costs of forest fires avoided, Portugal	0.44
Indirect costs of forest fires avoided, Portugal	0.57
Total first dividend	1.15
TOTAL DIVIDEND	1.15
Total cost	0.7
BCR	1.6

Source: World Bank analysis based on external data and information

→ Challenges faced and lessons learned

Lack of data for this particular case and lack of research generally on the topic of cross-border collaboration for fire suppression and emergency services limited the opportunity to expand to a triple dividend analysis. Future studies should investigate the actual deployments, fire response rates, enhanced coordination, and improved containment afforded by the platform. In addition, more research and evaluation on the benefits to the entire fire service structure should be explored. This type of study could greatly inform other such information platforms, especially in cross-border areas where cooperation between fire services is critical. Moreover, the advantage of having decision support tools with a longer lifetime than the SPITFIRE platform is evident in this case study.

CAPACITY BUILDING FOR WILDFIRE PREVENTION

In addition to coordination mechanisms, a number of initiatives have aimed to enhance capacity and provide training for enhanced preparedness of populations and emergency response units across Europe. These initiatives, in combination with EWS, aim to shorten response times and ensure that effective disaster response can be support with human and material resources. A number of initiatives are presented in *Box 11* below.

Box 11: Investments in capacity for enhanced wildfire response across Europe

A review of investments in capacity building for wildfire prevention and response across Europe provided several lessons learned and inspiring achievements outlined below. A common theme is that a combination of equipment, coordinated trainings and peer learning as well as centres to combine human resources to address a number of different disasters, including fires, seem to ensure the greatest benefits in terms of effectiveness of response during disasters.

In the Czech Republic, wildfires caused 155 injuries and 12 fatalities for the past decade (Velinger, 2015) and economic costs could be substantial given that 34 percent of the country is covered by forests (Baranovskiy, 2019). An EU-financed project of €58 million total investment (€50 million financed by the EU) from 2007 to 2013, "Fire and rescue services receive major investments in equipment", aimed at enhancing the capacity of the Fire Services so it can also engage in overlapping activities for flooding situations – intervention management, rescue operations, emergency survival for the population, and salvage operations – identically throughout all of the country's regions.

Moreover, a project Safe Borderlands aimed to strengthen the cooperation between fire and rescue services or other emergency response units (police, medical rescue, public health authorities, and so on) on the shared border of Czech Republic and Poland with more than 7 million inhabitants (European Union, 2020). Firefighters and other emergency response personnel hold organized conferences and trainings, take language-learning courses, purchase special equipment, and exchange data with each other in order to maintain smooth lines of communication between the two countries' emergency response service providers. This helps to ensure that there is cohesion between the different countries during fires, floods, and other disasters, especially given the possibility for these to occur more frequently due to climate change.

The EU supported the establishment of a defence centre against forest fires in Andalusia, Spain (European Commission, 2016b), a region with high fire risk. This centre now covers 11 municipalities and 150,000 residents and has resulted in improved equipment and cooperation in projects that improve forest management, training, and awareness raising. Moreover, the Interreg España-Portugal project (Interreg España-Portugal, 2019) represents collaboration between the cross-border regions of Spain and Portugal, along with over 15 institutions, through exchanges of knowledge and good practices. Both Spain and Portugal are highly vulnerable to wildlife hazards, and there is a long history of institutions fighting forest fires along the cross-border area. Therefore, the implement of the project leads to effective training and execution of infrastructures and technological innovation for the extinction and prevention of forest fires. One result of the project is the establishment of the "Iberian Centre for Research and Fight Against Forest Fires" (CLIFO), which aims to serve as a regional and international benchmark in the fight against forest fires, increase response capacity to forest fires, and reduce the economic cost of fires. While it may be difficult to measure the impacts of this investment using a BCA, it's important to reference qualitatively because this case study exemplifies the impacts of improving capacity.

3.6. Mass movement / landslides

3.6.1. SUMMARY OF FINDINGS FOR MASS MOVEMENT (LANDSLIDES)

Investments in landslide risk reduction can take various forms, such as engineered and natural slope stabilization, control of flooding or run-off that destabilizes slopes, and debris capture or diversion. Engineered retaining structures may include gabion walls, reinforced concrete wall, and retention nets. Modification of slope geometry may be achieved by introducing a stepped-slope embankment. Internal slope reinforcement requires rock bolts, micro piles, soil nailing, and grouting. Drainage can be improved, or slopes can be re-vegetated to provide soil stability.

Investing in landslide prevention is socio-economically beneficial because it is far cheaper to implement proactive remedial investments versus undertaking an array of reactive projects in response to a landslide disaster. For example, after torrential rain provoked a landslide in the northeastern Italian pre-Alps, researchers at the University of Padova conducted a series of quantitative modelling to compare the economic benefits of landslide prevention efforts against the cost of post-event emergency actions. They found that it was more economically convenient to carry out a drainage trench, a form of water removal intervention, to improve slope stability before the landslide event, and if this was done, there would be a savings of 30 percent in relation to the remedial works' total costs (Salbego, et al., 2015a).

In this section, we have presented benefit-cost assessments for interventions for landslide prevention through enhancing the resilience of roads, land use planning investments (for example, drainage trench), and information and cooperation systems (for example, meteorological forecasting system). Benefits for the different types of interventions are presented, including a World Bank ex-ante quantitative analysis, past benefit-cost analysis undertaken in Europe, and qualitative reviews of existing EU projects. The landslide risk in most case studies is earth or debris flow resulting from erosion or heavy rainfalls. The risk of avalanches is also considered in some of the examples. *Table 78* summarizes main data and information sources.

Table 78: Overview of data and information sources for mass movement / landslides analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Preventive investments in the resilience of roads	Resilient road assets in Albania	World Bank ex-ante report *Climate Resilient Road Assets in Albania*

Source: World Bank based on external data and information

Models need to be adapted to type of investment. BCAs are effective when examining traditional landslide management and remediation approaches and can help identify the most cost-effective measure in terms of landslide risk reduction. However, for landslide prevention investments with climate change adaptation, assessment consists of both risk analysis and mitigation measures and BCA is necessary to fully present its benefit in both climate and seismic improvements.

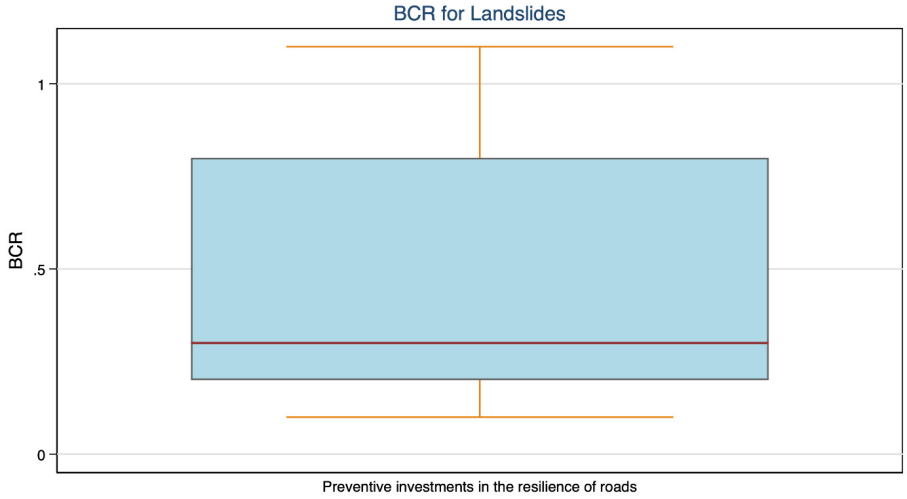
BCRs can be used to reflect the cost-effectiveness of

investments in landslides preventions and prove that these preventive investments with relatively low costs can have considerable net benefits. Therefore, it is considered socio-economically beneficial to invest in landslide prevention as it is far cheaper to implement proactive remedial investments versus undertaking an array of reactive projects in response to a landslide disaster.

Results of the BCA indicate possible benefits from preventive investments. Prioritization of infrastructure such as roads assets seems to be crucial for those to arise, but low-cost land management solutions also seem to be quite effective. Although BCRs found were small or close to 1, societal benefits may have been underestimated, and this could also explain why landslide preventive investments are often undertaken in combination with flood preventive investments to ensure efficiency of interventions. More details are included in *Figure 37*.

Figure 37 presents a boxplot that displays the distribution of BCRs for investments in landslides based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange).

Figure 37: Findings CA for mass movement/landslides (BCRs)



Source: World Bank analysis based on external data and information; presenting results from literature based on external reports (1 preventive investments in the resilience of roads result from (Xiong & Alegre, 2019)

One example of a preventive investment against landslides is upgrading infrastructure to enhance the resilience of roads. Enhancing the resilience of roads is viewed as a crucial way to reduce the impact of landslides on the transportation network, as landslides can cause severe damage to roads and highways that can be either direct (a road or part of a road being destroyed) or indirect (closure or traffic restriction in the affected area) (Bordoni, et al., 2018). Projects have been launched in the EU to enhance resilience of roads against landslides. A World Bank project (World Bank, 2020c) in Serbia has made accomplishment in terms of improving the physical infrastructure and technical expertise on road resilience of the country and promote the resilient transport agenda on a national and global scale.

- **Case study 25 (World Bank analysis** (Xiong & Alegre, 2019), **ex ante):** The analysis of implementing retrofitting landslide risk mitigation measures on the road network in Albania yielded positive net benefits only for one section. It would be important to do the analysis if preventive measures had been implemented, that is, integrated into the design of roads, as this may potentially have yielded higher net benefits for more road sections.

3.6.2. PREVENTIVE INVESTMENTS IN THE RESILIENCE OF ROADS

Landslides cause severe damage to roads and highways, which can be either direct (a road or part of a road being destroyed) or indirect (closure or traffic restriction in the affected area) (Bordoni, et al., 2018). Such damage disturbs the transportation network and negatively affects the safety of vehicles and passengers.

Economic assessments have been undertaken to examine and quantify the socio-economic impact of landslides on the road network. A study (Winter, et al., 2016) conducted in Scotland divides such impacts into three categories: (1) direct economic impacts resulted from clean-up and repairmen costs of the damaged infrastructure, (2) direct consequential economic impacts due to disturbance or decreased efficiency in the transportation network, and (3) indirect consequential economic impacts on the nearby area and its transport-dependent activities. The study examines four Scottish landslide events and presents the huge economic losses associated with these events: the direct repairmen of the infrastructure costs between €295,000 and €1,253,000, while direct consequential costs in the transportation sector range from €133,000 to €1,032,000.

Enhancing the resilience of roads is viewed as a crucial way to reduce the impact of landslides on the transportation network. In Serbia, a World Bank project (World Bank, 2020c) was launched with the goal of increasing resilience against landslides and other climate risks in the country's roads and transportation sector. The project is designed to improve physical infrastructure and technical expertise on road resilience and promote the resilient transport agenda at a national and a global scale.

RESILIENT ROAD ASSETS IN ALBANIA – PROTECTION AGAINST LANDSLIDES

This case study is an external analysis that was undertaken with ex ante quantitative for prioritization of interventions

→ Introduction and background

Albania is the most threatened country in Europe from multiple hazards (Xiong & Alegre, 2019), being prone to a flurry of hydro-meteorological hazards (for example, floods, drought, heavy snowfalls, and extreme temperatures) and geological hazards (that is, earthquakes and landslides). About 88.5 percent of generated GDP, 86.4 percent of the total area, and 88.6 percent of the population are exposed to two or more types of hazards. The results of a major natural hazard can have catastrophic consequences. In December 2017, a major flood event in Albania caused 1,575 people to be evacuated, 3,500 houses to flood, 65 bridges to collapse, 56 public schools to be damaged, and 15,000 ha of land to submerge (Xiong & Alegre, 2019). With the possibility of climate change leading to more intense and more frequent natural hazards in the future, coupled with Albania's risks for river flooding (that is, fluvial flooding), coastal flooding, landslides, and earthquakes already rated high, there has been more attention shifted to investigating the possibilities for DRM in Albania and the broader Western Balkan area.

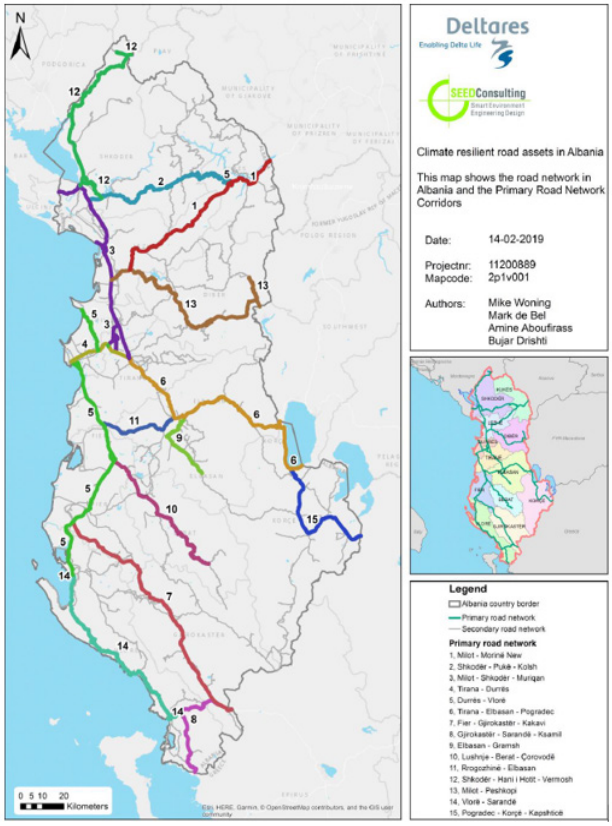
Roads are crucial to the functioning of any society, and transportation plays a vital role in building climate-resilient communities. With roads being unavailable and/or unreliable, Albania will experience significant negative effects to their economic growth. Already, natural hazards pose a great risk to the roads and the roads' users, and therefore it is important to understand how hydro-meteorological and geological hazards affect the national road network of Albania. This will enable the country to build roads that are able to weather the coming effects of climate change, further helping Albania achieve sustainable, economic growth (see also *Figure 50* in *Annex 3*).

→ Description

The main objective of this prospective study is to assist Albanian stakeholders in the prioritization of current and future climate and seismic resilient investments in road assets. The road network under consideration for this study (see Figure 38) encompasses 1,494 km of roads - 1,370 km are primary roads with some extensions to the remaining secondary roads on request of the Albanian Road Authority (ARA). Researchers analysed the value of roads, bridges, culverts, and tunnels. While the potential effects of flooding (both pluvial and coastal) and seismic events were examined, for the scope of this case study, we will primarily focus on how landslides, specifically

precipitation and seismic-induced landslides, affect roads in the primary road network. During this project, a BCA on landslide measures was implemented for five Albanian road corridors: 01 Milot - Morine New; 05 Durres – Vlore; 06 Tirana - Elbasan – Pogradec; 13 Milot - Peshkopi; and 14 Vlore - Sarande.

Figure 38: Map showing the primary network under consideration of this project



Source: Xiong & Alegre, (2019)
Note: The colours indicate the various corridors within the primary road network.

→ Methodology

To achieve the case study's objective, a climate and seismic vulnerability assessment was applied to the Albanian national road network and mitigation measures to improve climate and seismic resilience of national roads were proposed to stakeholders. Thus, the project can be divided into two parts: risk analysis and mitigation measures and BCA. There were 13 actions taken among the two parts that were illustrated in a flowchart (see *Annex 4*).

→ Results of the analysis by Dividends and overall

Retrofitting mitigation measures to protect against landslides come at a relatively high cost compared to their effectiveness levels, but there are economic and social impact reasons as to why these measures are essential (see *Table 79*). In high-volume road sections, such as Corridor 5 Durres to Vlore and Corridor 6 Tirana to Pogradec, these mitigation measures become economically viable. Implementing stabilizing measures in these areas, such as retaining walls, gabions, and soil nailing, would cost €13.8 million. Yet, mitigation measures are still necessary in low-volume road sections because villages may become isolated from the outside world without intervention. The benefits reported would all be considered dividend 1 in the Triple Dividend Framework.

Table 79: BCR for landslide measures implemented by corridor

CORRIDOR	INVESTMENT (€, MILLIONS)	BENEFITS (€, MILLIONS)	BCR
01 Milot - Morine New	15.0	4.2	0.3
05 Durres - Vlore	6.3	6.7	1.1
06 Tirana - Elbasan - Pogradec	7.4	6.0	0.8
13 Milot - Peshkopi	32.1	2.6	0.1
14 Vlore - Sarande	11.0	2.3	0.2

Source: Xiong & Alegre (2019)

The analysis yields a BCR ranging between 0.1 and 1.1. For the road corridor between Durres and Vlore (05), there was evidence that the protective landslide measures were economically beneficial (that is, BCR >1) over a period of 25 years with a net discount rate of 4 percent. Per 10 m of road, it costs €11 thousand for retaining walls, €14 thousand for shotcrete and drainage, €42 thousand for steeped-slope embankment, and €121 thousand for rock anchors and wire mesh. While the BCRs of the other corridors was under 1, protective landslide measures are still socially important because regions of the country can become disconnected and isolated in case of a landslide disaster.

→ **Challenges faced and lessons learned**

The analysis of implementing retrofitting landslide risk mitigation measures on the road network in Albania yielded positive net benefits only for one section. It would be important to do the analysis if preventive measures had been implemented, that is, integrated into the design of roads, as this may potentially have yielded higher net benefits for more road sections. For this study's BCA, a number of measures, including preventative measures, reforestation of slopes, erosion protection, and more, were not taken into account due to a lack of information and/or a lack of the required information to determine the amount of the measure needed. However, these measures should be further investigated, especially when examining the road profiles, geomorphological conditions of the areas adjacent to the road, and specific characteristics of the catchment areas draining to road assets, such as culverts and bridges. Given the connectivity of Albania's road system, applying landslide mitigation measures to even one segment of road would have a distributional effect because it will benefit both the people who live in that community and others outside of that community who use that roadway. Also, it is still important to implement these measures for roads with a lower volume of users, even if it is not as economically beneficial because the demolition of this stretch of roadway could physically and socially disconnect a specific area from the rest of country.

3.6.3. LAND USE PLANNING INVESTMENTS

Implementing prevention and preparedness measures during land use planning is considered as a crucial way to reduce the negative impact of landslides. Many naturally occurred landslides are recurrent and thus can be easily observed or forecasted by experts. Therefore, preventive measures can be implemented in the areas at risk after their geological and land use characteristics as well as the type and location of landslide that may potentially occur have been carefully identified. Such measures can be effective in terms of avoiding human and economic losses. In 2000, the Stoze landslide and the Predelica torrent debris flow of Slovenia caused seven deaths and an economic loss of €36 million. Lessons learned from the event suggest a need for reviewing Slovenia's land use plans and adopting hazard zoning as the best prevention measure for future landslide risk reduction (JRC, 2003).

BCAs have been undertaken to examine the effectiveness of several European investments in landslide prevention and remediation and identify the most cost-effective measure in terms of landslide risk reduction. Outcomes and inspirations from two studies include a BCA of landslide management approaches in Vicenza, Italy and an economic analysis of avalanche risk reduction interventions in Switzerland are showcased in *Box 12* below.

Box 12: Cost-effectiveness of landslide prevention vs. response investments

A number of studies have analysed the cost-effectiveness of landslides prevention investments compared to remediation investments or also other types of investments. These studies show that some low cost interventions can have considerable net benefits and therefore provide arguments for enhanced investments in prevention for these disasters. In the case of the Italy case study, the authors also provide methodologies that can be utilized for local governments to assess the net benefits of preventive vs. remediation investments without having to undertake a full probabilistic/ risk-based assessment.

A study on the cost-benefit of landslide management approaches was conducted at detailed-scale and large-scale for a case of rotational/translational slides and earth flows that occurred in Vicenza, Veneto Region, Italy in 2010 (Salbego, et al., 2015a). A detailed numerical model found that incorporating a drainage trench (aiming to reduce the water table, therefore slope instability) prior to 2010 would have been effective in preventing the landslide. BCA showed that compared to €57 thousand in remediation costs, installing a drainage channel and maintaining it over 20 years would have saved 30 percent of the remediation cost, leading to a benefit of €17 thousand (Salbego, et al., 2015).

As a country in the Alpine region, Switzerland is highly vulnerable to avalanches and landslides due to climate change and other factors, such as geology and rainfall persistence (Climate Change Post, 2020). Since 1936, 24 people on average have died in avalanches annually (WSL Institute for Snow and Avalanche Research SLF, 2020). In this context, Several cost-effectiveness analysis on landslide prevention have been conducted, with the best interventions in terms of net benefits being identified. In Davos, an economic analysis was carried out for different mainstream interventions that attempt to reduce the risk of avalanches in Switzerland, such as technical, organizational, and land use planning measures (Fuchs, et al., 2007). The study shows that the most cost-effective risk reduction measures are interventions with snow fences and land use planning, in terms of direct costs - though for avalanche mitigation the scale of benefit is highly dependent on the amount of snow fences deployed.

3.6.4. INFORMATION AND COOPERATION SYSTEMS FOR LANDSLIDE PREVENTION

Information sharing and cooperation between nations play an essential role in terms of improving the effectiveness and efficiency of landslide prevention. International cooperation enables EU members to share knowledge and expertise on landslide prevention, which allows them to plan, set up, and improve anti-landslide activities within nations and across borders. Some countries have launched landslide prevention projects with guidance and support from international experts and companies specializing in the field, such as the Bulgarian project “riverbanks and seashores protection from water abrasion and erosion and from the landslide processes resulted from them” with the British engineering company “Atkins” as the advisor. Such efforts allow these countries to adopt innovative measures for landslide prevention and mitigation that are both effective and cost-efficient (JRC, 2003). There are several examples of European Commission funding aimed at managing the impacts of slope instability. Although no assessment of benefits could be obtained to compare against project costs, the investments presented in more detail in below can provide interesting insights (see *Box 13* below).

Box 13: Investments in information systems and cooperation mechanisms for landslide prevention

A review of investments in information systems and cooperation mechanisms across Europe provided several lessons learned and inspiring achievements outlined below. A common theme is that alongside information and forecasting systems, all the projects also supported equipment and investments in road conditions to protect assets.

On the French-Spain border, a project co-financed by the EU supported enhanced preparedness. Co-financed by the ERDF, the SECURUS project (Bielsa-aragnouet, 2018) 'Safety from natural risks on the Bielsa-Aragnouet and Espacio Portalet road links' on the France-Spain border (budget €4.22 million) combines investment in information sharing on road conditions and technical support for improved local meteorological forecasting, with implementing measures to protect roads from landslide and erosion risk.

Another project supported mapping and forecasting of landslides in the Pyrenees in France. Also 65 percent co-financed by ERDF, PyrMove (Institut Cartogràfic i Geològic de Catalunya, 2020) focuses on the prevention and management of risks associated with landslides, that cause most damage on roads, dams, towns and activities in the Pyrenees. PyrMove addresses: 1) Large landslides involving complete slopes that can include towns, infrastructures and activities on their surface and that are susceptible to accelerate and end into catastrophic failures; 2) Multiple landslides caused by episodes of intense rainfalls that simultaneously affect large areas of the territory (MORLEs crisis). It seeks to better assess, forecast and manage these risks, presently hindered by a lack of knowledge on the temporal and spatial occurrence and their evolution, and aims to install alerts systems and scenarios simulators for Civil Protection activities.

Co-financed by Interreg, the main objective of the cross-border project safEarth (European Commission, 2019) is to identify areas vulnerable to landslide hazards in parts of Croatia, Bosnia and Herzegovina and Montenegro. The goal is accomplished through the development of by an online landslide susceptibility mapping (LSM) system, which enables the mapping of any potential or ongoing disasters in real time, and development of guidelines for susceptibility mapping. As a part of the project, rehabilitation of infrastructures and equipment in reducing landslide risks have also been undertaken to decrease the negative impact of landslides in the area.

3.7. Volcanic Eruption

3.7.1. SUMMARY OF FINDINGS FOR VOLCANOES

Volcanic eruptions, which occur when magma and other volcanic materials reach the surface of the Earth, are one of the devastating natural disasters that cause losses of life and massive destructions. There are two common types of volcanic eruptions: (1) explosive eruption, which expels fragmented materials (such as volcanic ash, pyroclastic deposits, and assorted gases) into the air; and (2) effusive eruption, which involves the production of flowing lava (Self, 2006).

In this section, we have demonstrated economic assessments of decision-making tools for evacuation during a volcanic eruption (for example, enhancing preparedness through early warning and monitoring systems) and infrastructure for evacuation and response (for example, evacuation and escape routes). Benefits of the investments are presented by a qualitative review of the cost-effectiveness of existing EU projects. In these case studies, volcanic eruptions often pose a risk on urban areas as well as national roads, which thus presents a challenge for large-scale evacuations.

Models need to be adapted to the type of investment. For volcanic activities, BCA has been focusing on the substantial net benefits of investments in volcano monitoring and eruption forecasting and evacuation. When an economic assessment is undertaken, it is necessary to include uncertain factors that depend on the type of eruption and investment, such as time to eruption onset, time required for evacuation, spontaneous evacuation or return, the possible eruption size, and political pressures.

BCRs from economic assessments have been used as a quantitative and auditable method to assist authorities to make key decisions that reduce the risks and impact of volcanic eruptions. BCA serves an important role in decision-making for volcanic crisis management, specifically taking decisions on when to order evacuation of a population or not, given the threat of eruption—balancing the cost of evacuation with the inherently uncertain likelihood of eruption even when there are signs of volcanic unrest. Such assessment can be used to 'segment' populations and assess their BCR of an evacuation, which may vary depending on their circumstances (Woo, 2015).

Benefits of preventive investments can be substantial in terms of decision-making mechanisms for evacuation in the case of eruption. An example is the EWS for volcanic eruptions and earthquakes undertaken in the Canary Islands, Spain (VOLRISKMAC project (European Commission, 2018)). Moreover, infrastructure for evacuation and response can substantially reduce negative impacts from volcanic eruptions. For examples, investments in resilient escape routes that were undertaken in Italy (project financed by the EU 'Redeveloped road to upgrade volcano escape route') achieved benefits in terms of enhanced connectivity and at the same time disaster risk reduction.

3.7.2. DECISION MAKING FOR EVACUATION IN THE CASE OF ERUPTIONS

BCA for volcanic risk is focused on informing volcanic crisis management, specifically taking decisions on when to order evacuation of a population or not, given the threat of eruption—balancing the cost of evacuation with the inherently uncertain likelihood of eruption even when there are signs of volcanic unrest. Several approaches have been proposed for this. Marzocchi & Woo (2007; 2009) and Woo (2008) use static parameters of number of evacuees average socio-economic loss per capita due to the evacuation, and the product of avoided fatalities social WTP to save a human life (Woo, 2015) suggests BCA can be used to 'segment' populations and assess their BCR of an evacuation, which may vary depending on their circumstances. Bebbington & Zitikis (2015) note the need to account for dynamic and uncertain factors in using BCA in, considering volcanic evacuation decisions.

Uncertain factors include time to eruption onset, time required for evacuation, spontaneous evacuation or return, the possible eruption size, and political pressures. In the evacuation context, costs may be the direct costs of evacuation (for example, opening shelters and transport to evacuate people), economic costs of evacuation (due to daily productive activities being disrupted), political cost to decision-makers of evacuation being declared if no eruption occurs, and potential loss of life to people who do not evacuate. Benefits are the avoided loss of life due to successful evacuation. In addition to uncertainty around people's behaviour (decision to evacuate or not and the time taken to evacuate), uncertainty exists in the eventual magnitude of eruption and the area affected by eruptive material (lava, tephra, and so on) - therefore in the definition of area to be evacuated. Bebbington & Zitikis (2015) propose a stochastic approach to account for these factors, whereas previously proposed approaches treated this as a static analysis.

By comparing the incurred costs of eruption with no evacuation, against those incurred when evacuation is declared, decision-makers can be given a probability-of-eruption threshold, above which an evacuation should be declared. Using the static approach, Marzocchi & Wood (2009) determined a probability threshold of 0.01 per month at which point an evacuation should be declared for a defined 1kmx1km area, for Campi Flegrei; Sandri et al. (Sandri, et al., 2012) using the same methods determined the threshold to be 0.014 per month for the Auckland Volcanic Field, New Zealand. The modelled cost of eruption depends on the probability of eruption given the volcanic unrest (higher probability of eruption yields higher expected cost) and is also influenced by the time people would be required to evacuate for (longer period, higher costs), value assigned to a human life, and value of socio-economic activity in the area (for example, GDP per capita). Using dynamic factors, Bebbington & Zitikis (2015) show a probability threshold is much lower for a case of Vesuvius erupting (0.035 for a 30-day evacuation and 0.055 for 90-day evacuation) than using a static model (0.1 for a 90-day evacuation), with absolute costs of evacuation estimated at €8,000 per capita for a 90-day period in their case study. At eruptive probabilities greater than the thresholds, the cost of not declaring evacuation is higher than €8,000 per capita.

In terms of international experience, preventive investments have been proven to yield substantial net benefits. The 2018 lava flow in Puna, Hawaii, that led to the closure of one of the region's major highways and disturbed the local transportation system reveals that there is a need for effective responses and timely sharing of information between authorities, scientists, and community organizations after a volcanic hazard occurs (Kim, et al., 2018). In addition, monitoring, forecasting, and response in advance of the 1991 Pinatubo eruption in the Philippines is said to have saved at least €202 million of damage to property (including substantial amounts of moveable US military equipment) and at least 5,000 lives. The total costs of forecasting and responding in this eruption are estimated at US$45.2 million—a BCR of around 4 (USGS, 2005). There are several examples of European Commission and national funding aimed at enhancing preparedness and response in the case of volcanic eruptions. Some of these investments are presented in more detail in *Box 14* below.

Box 14: Investments in preparedness for volcanic eruptions

A review of investments in early warning or general preparedness for volcanic eruptions in Spain provided several lessons learned and inspiring achievements outlined below. A main lesson is that preventive investments in terms of volcanoes can have a number of co-benefits and therefore be relatively cost-efficient.

An investment was undertaken in Spain that focused on EWS both for volcanic eruptions and earthquakes. Macaronesia, which is comprised of Portugal's Azores and Madeira archipelagos, the Canary Islands in Spain, and the African nation of Cape Verde, is facing increased vulnerability to volcanic eruptions and earthquakes that can be extremely detrimental given its dense population. Therefore, the EU VOLRISKMAC project (European Commission, 2018), implemented from 2017 to 2019, aimed at strengthening research, development, and innovation in the islands to bolster EWS for eruptions and earthquakes and design enhanced crisis management capabilities using simulations and drills that help quantify the susceptibility of areas to direct and secondary environmental consequences. As a result of the project, the monitoring networks for 10 active Macaronesian volcanoes were strengthened, 37 permanent volcano monitoring stations were being set up, and 5 new portable volcano monitoring instruments have been acquired.

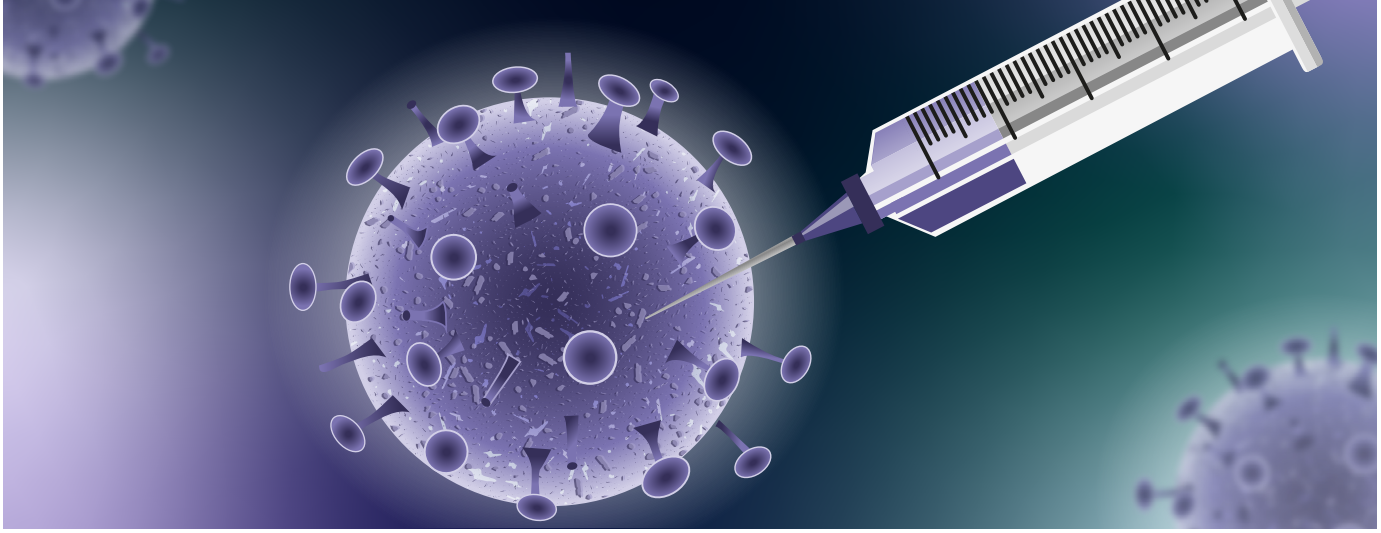
3.7.3. INFRASTRUCTURE FOR EVACUATION AND RESPONSE

During a volcanic eruption, effective roads and transportation network are crucial for rescuing and evacuation. However, transportation networks are vulnerable to volcanic activity, as they can be damaged or blocked during eruptions and disturbed by the impact of volcanic ash, which includes road marking coverage and reduction in visibility and skid resistance (Blake, et al., 2017). Hence, investments in road resilience improvement and escape routes planning in advance can enhance the efficiency of evacuation when an eruption occurs, leading to less fatalities and injuries. In Europe, economic assessments have been undertaken to quantify the impacts and losses due to volcanic eruptions and present the direct and indirect benefits of investing in evacuation and escape routes. An example of such assessments with its inspiring outcome is presented in *Box 15* below:

Box 15: Evacuation routes in volcanic areas

A review of infrastructure investments in evacuation routes in the case of volcanic eruptions in Italy provided interesting messages in terms of potential large co-benefits as outlined below. It also showed that engagement of the population for buy-in of solutions that can provide economic benefits can enhance effectiveness of interventions.

In Italy, investments have been made to establish resilient/escape routes in the case of volcanic eruptions. Though volcanic eruptions rarely occur, some Italian urban areas are highly vulnerable to these destructive natural disasters (European Commission, 2007). In the past few decades, vulnerability of populations has increased because of rising population density in cities and related complex infrastructure. Scientists warn that the impacts of a Vesuvius eruption could be catastrophic given the proximity of Naples, with its population of 3 million people. A 2010 analysis estimated that €55 billion of residential property is exposed to the potential impacts of a Vesuvius eruption (Hofmann, 2010). The highly active and dangerous volcano Campi Flegrei (De Natale, et al., 2017) is also in close proximity with an estimated likelihood of medium-term eruption. Because of the imminent -- and unpredictable -- threat, the Italian government has devised a plan to evacuation a defined 'red zone' 72 hours ahead of an impending eruption and has proposed compensation for people to relocate and creating a national park around the volcano to avoid illegal building (Pasha-Robinson, 2016). However, this has received slow uptake and enthusiasm given that the region is a considerable touristic attraction with related economic opportunities. The project (European Commission, 2007) financed by the EU "Redeveloped road to upgrade volcano escape route" during the programming period 2007-2013 aimed to undergo works on the national road north of Mount Vesuvius to improve regional accessibility and create a better escape route for local people in the event of a big volcanic eruption or earthquake. Total investment was €53.4 million, of which €26.7 million was financed by the EU. This could be seen as a "no regret investment" as it both enhances connectivity and disaster prevention.



3.8. Epidemic and Disaster Health Preparedness

3.8.1. SUMMARY OF FINDINGS FOR EPIDEMIC/PANDEMIC RISKS

The COVID-19 pandemic has shown the consequences of systematically underinvesting in resilience. Climate change, DRR, and pandemic impacts underline the systemic, cascading, and compounding nature of risks and the need to strengthen resilience of societal systems (UNDRR, 2020). To strengthen the preparedness for infectious disease, it is important to learn from the experiences regarding preparedness for natural disasters accumulated over the years (Wilson, et al., 2020).

Epidemic and disaster health should be considered in tandem when developing, updating, strengthening, and funding preparedness planning for the health and well-being of communities. Natural disasters are increasing in their frequency and complexity. Understanding the cascading effects of disasters and how they may lead to infectious disease outbreaks underscores the importance of developing cross-sectoral preparedness strategies. Suk et al. (2020) found that the cascading effect of disasters, such as earthquakes and floods in the EU, has led to the outbreak of infectious disease. The projection that climate change-related extreme weather events will increase in Europe in the coming century highlights the importance of strengthening preparedness planning and measures to mitigate and control outbreaks in post-disaster settings (Suk, et al., 2020).

The COVID-19 public health crisis has highlighted that all countries, including the EU MS, have to increase efforts regarding preparedness and response planning for epidemics and other serious cross-border health threats. The lack of medical countermeasure stockpiles at the EU and MS levels and the vulnerability of EU supply chains for critical medical countermeasures have been one of the main challenges faced during the pandemic (European Commission, 2020c). The EU lacked effective mechanisms and structures to have an overview of demand and supply of critical medical countermeasures to monitor and support MS in addressing shortages.

The Joint Procurement Agreement (JPA) for medical countermeasures was approved by the European Commission, and as of April 2020, it has been signed by 37 countries (European Commission, 2020d). The agreement provides a voluntary mechanism enabling participating EU countries and the EU institutions to jointly purchase medical countermeasures for different categories of cross-border health threats including vaccines, antivirals, and other treatments. It lays down common rules for practical organization and joint procurement procedures. While such agreements during the pandemic can help change the trajectory of supply shortages and unequal distribution of goods, mechanisms could and should be strengthened before the onset of health or other natural hazard crises.

In this section, we have presented benefit-cost assessments for the return on investment of national public health programs and equipment for health-related disasters (for example, PPE). BCRs for the investments are obtained from a review of external BCA undertaken with ex post assessments. Other examples focus on risks from real and hypothetical pandemics as well as the current COVID-19 crisis. *Table 80* summarizes main data and information sources.

Table 80: Overview of data and information sources for epidemics/pandemics analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Return on investment of national public health programs	Return on investment of national public health programs	Ex post assessments based on the external study *Return on Investment of Public Health Interventions: A Systematic Review*
Equipment for health-related disasters	Equipment for health-related disasters	Ex-post assessments based on the US study *The Case for Investing in Pandemic Preparedness*, published in book *The Neglected Dimension of Global Security: A Framework to Counter Infectious Disease Crises*

Source: World Bank based on external data and information

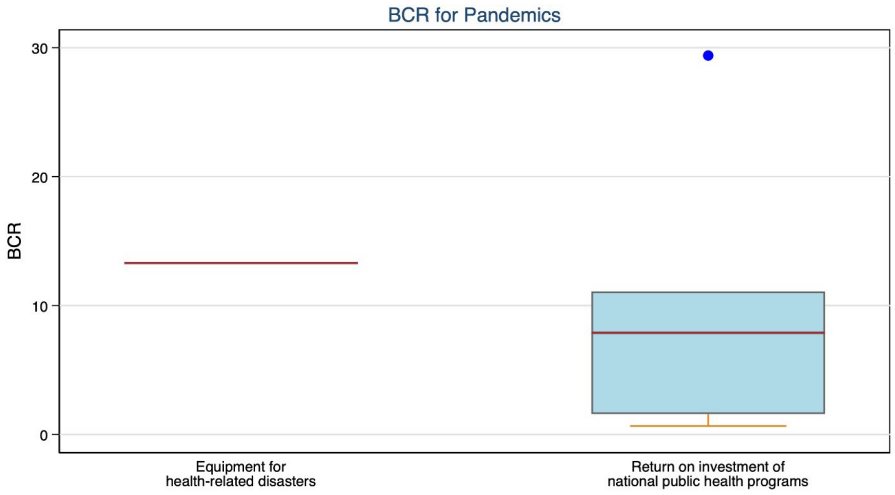
Models need to be adapted to the types of investment. When modelling the impact of epidemic and disasters, it is necessary to include not only the immediate impact on public health and the needs of the health system but also long-term impacts to mental health and well-being. For assessments that examine the effectiveness of governance related to pandemic preparedness, a conservative model is used to estimate the risk of pandemic events, which suggests that the true risk may be underestimated (GHRF Commission 2016).

BCRs for investments in public health system and preparedness planning at local and national levels reveal that such investments are highly cost saving in reducing the negative outcomes of epidemic and natural hazards to health and well-being.

The investments generally yield high positive results. Local and national public health interventions in Europe are highly cost saving, though the specific BCRs vary according to the regions and the types of investments. The BCR for investments for preparedness against pandemics is extremely high, which reveal the benefits of enhancing the world's medical equipment and defense against epidemic risks. More details are included in *Figure 39*.

Figure 39 presents boxplots that display the distribution of BCRs for different types of investments in epidemics/pandemics based on a five-number summary: minimum (shown in orange), first quartile, median (shown in red), third quartile, and maximum (shown in orange). The outliers are shown as dots.

Figure 39: Findings of BCA for epidemics/pandemics (BCRs)



Source: World Bank analysis based on external data and information; presenting results from literature based on external reports (1 Equipment for health-related disaster result from (Masters, et al., 2017), 1 Return on investment of national public health programs result from (GHRF Commission, 2016))

The effectiveness of health prevention activities can be assessed among others by a return on investment of national public health programs. As has been evidenced during the COVID-19 crisis, epidemics and pandemics are inherently related to health and reliant on the robustness of public health systems. The OECD has found that most countries, regions, and cities were not prepared well for this pandemic for several reasons, including lack of crisis management plans for pandemics or lack of basic equipment (OECD, 2020). Moreover, long-term impacts such as on mental health also have to be alleviated with the help from public services.

- **Case study 25 (External analysis** (Masters, et al., 2017), **ex post):** A review of around 3,000 studies (Masters et al. 2017) to determine the return on investment of public health interventions in high-income countries as well as mental health impacts (Tanielian & Jaycox, 2008) yielded interesting insights into the benefits of public health interventions (BCR of 8.3, ROI of 1–14.3) or preventive mental health care. Further research on mental health impacts under a disaster could provide relevant insights for this type of analysis.

Sufficient investment in equipment is essential as part of preventive activities for health-related disasters. Due to the demand surge and global supply-chain disruptions, panic buying has become a headline of the COVID-19 pandemic. Panic buying threatens the health systems' ability to prevent and treat the coronavirus with shortages of hand sanitizers, masks, and pain relievers. Panic buying also depletes medicines for patients with chronic diseases. In addition, to understand the longer-term impacts of preparing or pre-positioning of equipment for pandemics, it is also important to consider the near-term implications of not pre-positioning, as in the case of price surges for health equipment. Better preparedness can result in more streamlined efforts to protect individuals and the EU has started to stockpile medical equipment since March 2020 as part of the rescEU program (European Commission, 2020e), which provides support to member countries as part of the EU Civil Protection Mechanism.

Case study 26 (External analysis (GHRF Commission, 2016), **ex post):** An analysis of preparedness investments compared to the negative consequences of a pandemic would indicate highly positive net benefits. However, more research would have to be undertaken to understand supply-chain mechanisms and constraints of PPE or other equipment for preparedness as well as benefits of pre-positioning equipment.

3.8.2. RETURN ON INVESTMENT OF NATIONAL PUBLIC HEALTH PROGRAMS

This case study is an external analysis that was undertaken with ex-post assessments

→ **Introduction and background**

As has been evidenced during the COVID-19 crisis, epidemics and pandemics are inherently related to health and reliant on the robustness of public health systems. Resilient health systems can meet the surge and demands of patient loads if planned in advance. Additionally, disasters tend to have considerable impacts on health and the resilience of public health systems can be a crucial factor to mitigate the costs and losses in the case of disasters. As described in the introduction, health programs and DRM must be considered together when preparing for resilient societies, as they are highly interdependent.

The OECD (2020) has found that most countries, regions, and cities were not prepared well for this pandemic for several reasons:

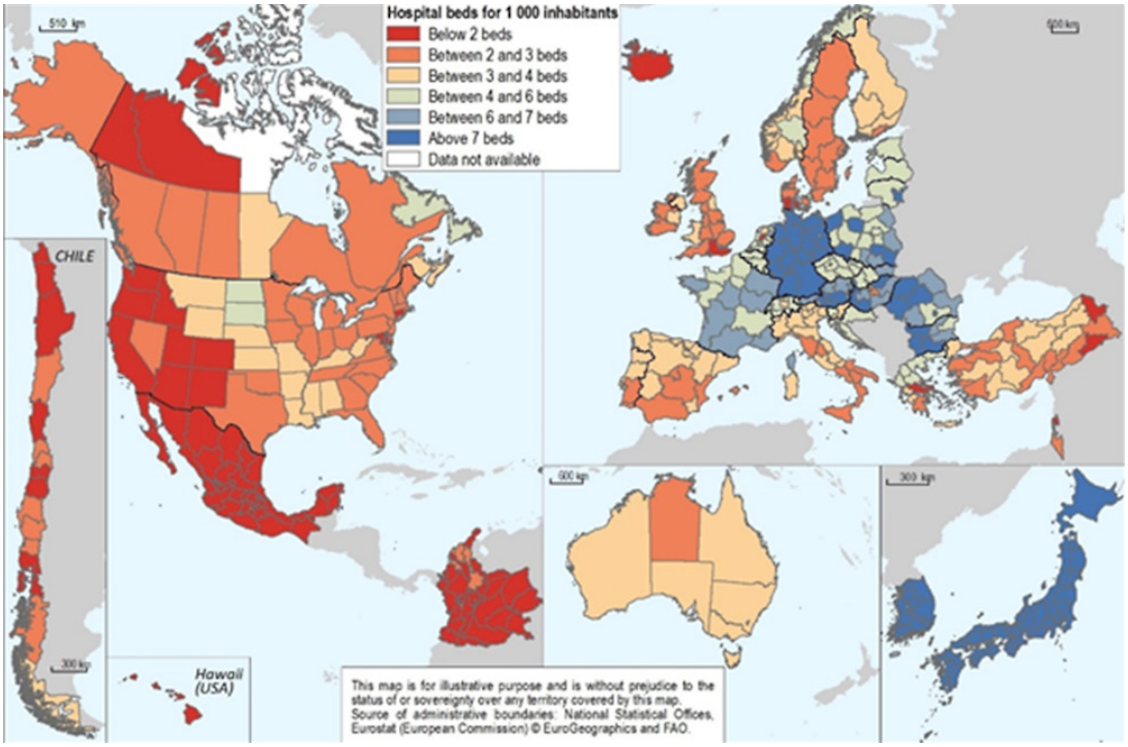
a. They underestimated the risk when the outbreak emerged.

b. Many did not have the crisis management plans for pandemics (with the exception of Asian countries that battled the SARs pandemic and some others, such as the Nordic countries, where crisis management plans are required).

c. They lacked basic, essential equipment, such as masks.

d. They absorbed reduced public expenditure and investment in health care and hospitals. Since the start of the 'Great Recession' launched by the 2008 financial crisis and up until 2018, the number of hospital beds per capita decreased in almost all OECD countries, declining 0.7 percent per year, on average (see *Figure 40*, with the color representing the number of hospital beds per 1,000 inhabitants).

Figure 40: Hospital beds per 1,000 inhabitants by region, 2018

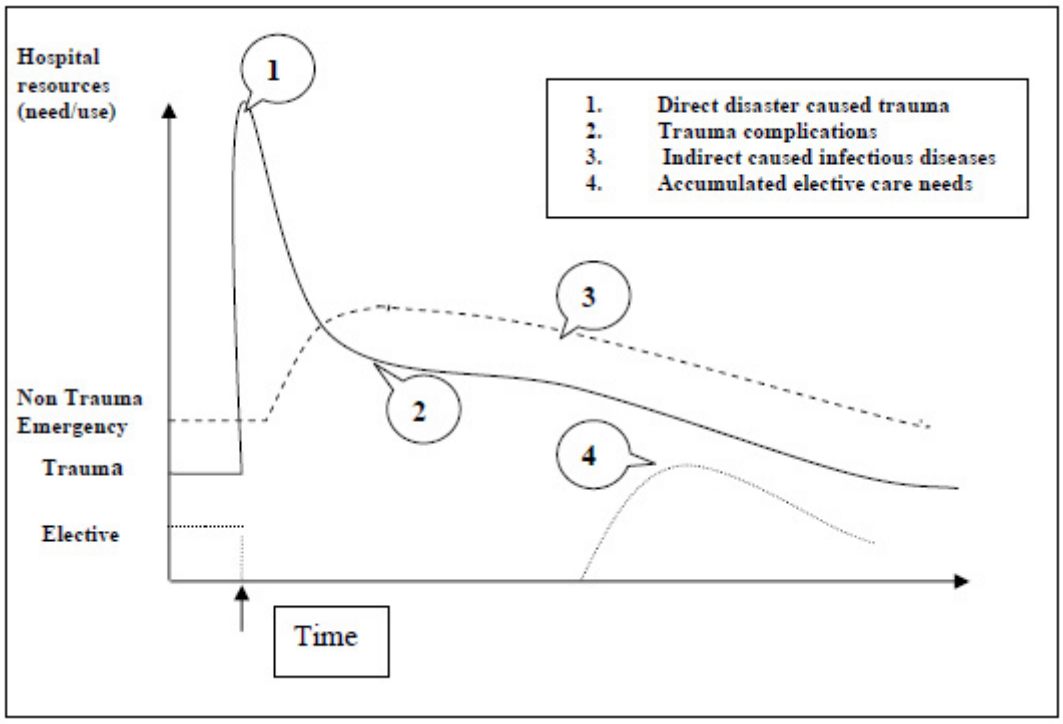


Source: OECD (2021)

The impact of natural hazards on the public's health can be divided into four categories: (a) direct impact on the health of the population; (b) direct impact on the health care system; (c) indirect effects on the populations health; and (d) indirect effects on the health care system (Shoaf & Rotiman, 2000).

Figure 41 provides a schematic of these impacts as well as need and use of hospital resources after a time-point disaster such as an earthquake. Immediately after the event (phase 1), there is immediate and high demand for trauma-related surgery and care above the baseline of medical emergency. After a week or so (phase 2), emergency needs subside but the hospital deals with handling trauma complications. Simultaneously (phase 3) non-trauma emergencies (for example, infectious disease and treatment of chronic diseases) increase; they are related to destruction of infrastructure or disruption of health care system. Finally in phase 4, there is an increase of elective care needs that have been postponed due to the disaster (Louis, et al., 2008).

Figure 41: Schematic phases of natural hazards' effects on public health resources

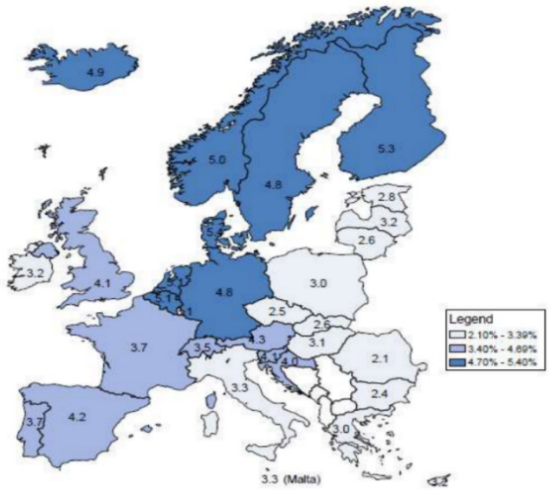


Source: Louis, et al. (2008)

It is necessary to address not only the immediate needs of the health system required for epidemics and disasters but also long-term impacts to mental health and well-being. There is a correlation between the occurrence of a disaster and a decrease in mental health shortly after someone has experienced it (Makwana, 2019). This is because the unpredictable nature of disasters disrupts a victim's fully functioning life, leaving them disoriented from a loss of identity, a daily routine, and a lack of control over their own possessions. Psychological symptoms associated with these feelings include severe and uncontrollable stress, prolonged feelings of grief or sadness, and substance dependency, which can translate into maladaptive physiological reactions. A study of a 2018 Camp Fire in Northern California reveal that many victims to the fire presented symptoms of mental health disorders, especially PTSD and depression (LaFee, 2021). This presents climate change and natural disasters as a chronic mental issue stressor. The most common disaster-induced mental health issues are post-traumatic stress disorder (PTSD), depression, and anxiety (Public Health Emergency, 2020). The total costs of mental health problems are more than 4 percent of the GDP across EU countries, and more than one in six people in EU countries have a mental health problem in any given year (OECD, 2018b). Mental health issues affect the unemployed and elderly disproportionately and have been found to reduce worker productivity by 6 percent, amounting to €600 billion throughout Europe per year (OCED, 2019a) (see also *Figure 42*).[33] The WHO has reported that the COVID-19 pandemic has caused elevated rates of stress or anxiety, and as levels of quarantine are introduced, levels of loneliness, depression, harmful alcohol and drug use, and self-harm or suicidal behaviour are also expected to rise (WHO, 2020).

33 The €600 billion value in the EU or more than 4 percent of the GDP includes direct care cost, social security programs, and indirect public expenses related to unemployment and the reduced productivity of people affected by mental illness.

Figure 42: Estimated direct and indirect costs related to mental health problems across the EU as a % of GDP, 2015



Source: OECD (2018b)

It is imperative for investments in resilient health care systems to be coordinated with DRR efforts. Evaluation of existing health systems in the EU during the short and long term is required as more natural and climate-related disasters disrupt communities, further burdening the health care system. This is made evermore necessary due to the current pandemic. Studies on existing systems can offer insight into systemic gaps of health services and infrastructure with and without disasters influencing needs and demands, better preparing nations for health emergencies and natural disasters.

→ Description

In a study conducted by Masters et al. (2017) , the authors reviewed nearly 3,000 studies to determine the return on investment of public health interventions in high-income countries. The study conducted a literature review and undertook a qualitative assessment on the return of investment in European countries on public health programs.

In another study in 2008, Tanielian & Jaycox (2008) conducted a comprehensive analysis of the post-deployment health-related needs associated with the three conditions among veterans: the health care system in place to meet those needs, gaps in the care system, and the costs associated with these conditions and with providing quality health care to all those in need. The study focuses on PTSD, major depression, and traumatic brain injury, not only because of current high-level policy interest but also because, unlike the physical wounds of war, these conditions are often invisible to the eye, remaining invisible to other servicemembers, family members, and society in general. All three conditions affect mood, thoughts, and behaviour; yet these wounds often go un-recognized and unacknowledged (Tanielian & Jaycox, 2008). The mental health implications of disasters often include war and natural disasters and can cause horror, anger, fear, sleep problems, increased substance abuse, and social isolation along with PTSD (Hamaoka, et al., 2010).

→ Methodology

This is a literature review on existing studies regarding pandemic preparedness and health-related needs following disasters. Masters et al. (2017) undertook systematic searches on all relevant databases (including MEDLINE; EMBASE; CINAHL; AMED; PubMed, Cochrane and Scopus) to identify studies that calculated an ROI or BCR for public health interventions in high-income countries.

Data collection for the study on mental health by RAND began in April 2007 and concluded in January 2008. Specific activities included a critical review of the extant literature on the prevalence of PTSD, major depression, and traumatic brain injury and their short- and long-term consequences; a population-based survey of servicemembers and veterans who served in Afghanistan or Iraq to assess health status and symptoms, as well as utilization of and barriers to care; a review of existing programs to treat servicemembers and veterans with PTSD, major depression, and traumatic brain injury; focus groups with military servicemembers and their spouses; and the development of a microsimulation model to forecast

the economic costs of these conditions over time. Interviews with senior Office of the Secretary of Defence (OSD) and Service (Army, Navy, Air Force, Marine Corps) staff within the Department of Defence and within the Veterans Health Administration informed efforts to document the treatment and support programs available to this population. Note, however, that while the focus on mental health on this particular population is not related to pandemics or epidemics, it does highlight the impacts of prolonged chronic stresses and catalogues experiences through interviews that can be applicable to health emergency and disaster health impacts on populations.

→ **Results of the studies**

Masters et al. (2017) concluded that local and national public health interventions are highly cost-saving, and cuts to public health budgets in high income countries are likely to generate billions of pounds of additional costs to health services and the wider economy. Quantitatively speaking, the research found that the median ROI for public health interventions was 14.3 to 1 and median BCR was 8.3.

For interventions in Europe, the study found the following BCRs:

- Development of 20 mph zones in London, United Kingdom, resulted in a BCR of 0.66–2.19.
- UK parenting programs for the prevention of persistent conduct disorders in the resulted in a 7.89 BCR.
- HIB vaccination program in Sweden resulted in a 1.59 BCR.
- Family planning services in the United Kingdom resulted in a BCR of between 11.09 and 29.39.

There is a clear advantage of having health intervention programs in overall public health, which could serve as a litmus test of robust health systems in a country when faced with epidemics or natural disasters.

According to the study measuring the costs of mental health treatment for military personnel, researchers found that the direct cost of mental health treatment is 10 percent of the overall incidence cost and other costs incurred (for example, lost wages, lost household productivity, and pain and suffering). After a two-year study, RAND found that, in 2008, it cost between €4,450 and €7,837 to treat PTSD in military personnel.[34] However, with co-morbidities like depression, this cost can increase as high as €12,740. The National Hazard Mitigation Saves Report uses the RAND study and estimates €6,789 to indicate direct treatment costs, and because direct treatment costs are only 10 percent of the total cost of mental health treatment, it would take €67,889 of treatment over one's life to avoid a statistical incidence of PTSD (Tanielian & Jaycox, 2008; Multi-Hazard Mitigation Council, 2019).

In populations heavily affected by COVID-19, such as Lombardy in Italy, the issues of service access and continuity for people with developing or existing mental health conditions are also a current major concern, along with the mental health and well-being of frontline workers (WHO, 2020). Often, mental health issues are considered secondary to physiological impacts on humans but can have prolonged or generational impacts. It is pertinent to consider the BCAs of both existing public health interventions and long-duration, mental health illnesses for holistic public health and test the systems that can provide the needed services.

→ **Challenges faced and lessons learned**

Future studies should employ similar studies on the costs of physical health and mental health following small- and large- scale disasters. Mental health following disasters is understudied and underreported but can have lifelong implications. Therefore, the focus on young persons affected by large-scale or frequency disasters should be carefully studied for all-hazards throughout Europe.

In addition, investing in preparedness for detecting and treating cases, reinforcing governance and oversight, building local diagnostic capacity, and strengthening systems for treatment and infection control are needed. Designing public health measures to prevent the spread of disease in the community (quarantining, social distancing, handwashing, limiting travel and trade, and eventually vaccinating) and establishing contingency plans to maintain essential services and supplies are all areas of evaluation for COVID-19 or any future health emergencies (World Bank, 2020b).

34 Original values in US dollars.

3.8.3. EQUIPMENT FOR HEALTH-RELATED DISASTERS

This case study is an external analysis that was undertaken with ex-post analysis.

→ Introduction and background

The global community has greatly underestimated the risks that pandemics present to human life and livelihoods which have affected the policies needed to safeguard lives. At the time of writing, there were more than 59 million confirmed cases in 190 countries and more than 1.4 million deaths (BBC News, The Visual and Data Journalism Team, 2020). To combat the spread of the COVID-19 by vaccinating and assisting those who have been severely stricken with the disease, medical equipment like masks and ventilators is extremely important to have on hand at all times.

Due to the demand surge and global supply-chain disruptions, panic buying has become a headline of the COVID-19 pandemic. Panic buying threatens the health systems' ability to prevent and treat the coronavirus with shortages of hand sanitizers, masks and pain relievers. Panic buying also depletes medicines for patients with chronic diseases. The suppliers' market that has been created has allowed suppliers and distributors to establish new terms and conditions for buyers. The 2014 West Africa Ebola outbreak was exacerbated by the lack of medical supplies and PPE which led to an increased rate of infections and poor control of the epidemic. Panic buying also leads to health scams. For example, in early March, Europol law enforcement confiscated 34,000 counterfeit surgical masks in one coordinated operation.

In addition, to understand the longer-term impacts of preparing or pre-positioning of equipment for pandemics, it is also important to consider the near-term implications of not pre-positioning, as in the case of price surges for health equipment. The information below lists the market prices and markups of essential PPE and equipment following the COVID-19 pandemic. It is found that the cost of PPE supplies increased by over 1,000 percent, according to the Society for Healthcare Organization Procurement Professionals (SHOPP) (2020).[35]

Table 81: Cost of PPE supplies in the United States pre-COVID19 and during COVID-19

ITEM	PRE COVID-19 COST	COST DURING COVID-19	PRICE MARKUP	PERCENTAGE MARKUP
Vinyl exam gloves (€)	€0.02	€0.05	€0.04	300%
Latex gloves (US$)	0.03	0.07	0.05	267%
Nitryl gloves (US$)	0.05	0.09	0.05	200%
3ply masks (US$)	0.05	0.68	0.63	1500%
K95 masks (US$)	Not applicable	3.60	Not applicable	Not applicable
N95 masks (US$)	0.34	5.18	4.83	1513%
3M N95 masks (US$)	0.10	6.08	5.98	6136%
Hand sanitizer (US$)	0.23	0.50	0.27	215%
Isolation gowns (US$)	0.23	4.50	4.28	2000%
Face shields (US$)	0.45	4.05	3.60	900%
Soap (US$)	0.17	0.32	0.14	188%

Source: SHOPP (2020), values as of April 7, 2020. Original values in US dollars

35 Original values in US dollars.

For these reasons and more, the EU has started to stockpile medical equipment since March 2020 as part of the rescEU program (European Commission, 2020e),[36] which provides support to member countries as part of the EU Civil Protection Mechanism. Medical equipment as part of the stockpile will include intensive care medical equipment such as ventilators, PPE such as reusable masks, vaccines and therapeutics, and laboratory supplies. In addition under the JPA, MS are in the process of purchasing PPE, respiratory ventilators, and items necessary for coronavirus testing. This coordinated approach gives MS a strong position when negotiating with the industry on availability and price of medical products.

While efforts are being made to obtain and distribute pandemic equipment to those countries that require it most, it is clear that better preparedness could have resulted in more streamlined efforts to protect individuals from the novel coronavirus through unified mechanisms.

→ Description

This case study is an external analysis that was undertaken with ex-post assessments.

This study on the Case of Pandemic Preparedness (GHRF Commission, 2016) assesses the mechanisms and governance related to pandemic preparedness. It aims to analyse the resources devoted to preventing and responding to threat of pandemics. The study compares various diseases in the world and the national policy, preparedness through pre-positioning, and affording time for procurement that influenced the management of pandemics. Given the large scale of risk for human and economic losses associated with the COVID-19 pandemic, it is easy to demonstrate a compelling case for greater investment. Understanding the importance of supply and distribution of medical equipment and the costs of developing preparedness plans can situate the EU to better prepare for another pandemic or health emergency by promoting greater investment in PPE and other medical necessities, which will in turn prevent potential supply chain interruptions and surge pricing.

→ Methodology

The study by Turabi & Saynisch (2016)simulates the distribution of expected pandemic events per century. The study is referred to in the Case of Pandemic Preparedness and runs 10,000 simulations of random draws from a binomial distribution to simulate the losses that might occur in 10,000 centuries and aggregating the results to show how likely it is that we see different numbers of events per century, on average. The model represents a conservative estimate of the risk of pandemic events, which is to say that the true risk could be higher.

→ Results of the analysis by dividends and overall

The following findings have been noted by the GHRF Commission (2016)[37] in its study of investments for preparedness against the negative consequences of a pandemic:

- The Commission on a Global Health Risk Framework for the Future (GHRF Commission) believes that commitment of an incremental US$4.5 billion (€4.07 billion in 2016) per year would make the world much safer and better prepared for pandemics. €4.07 billion equates to 65 cents per person in the world.[38] This figure includes expenditures for strengthening national public health systems, funding R&D, and financing global coordination and contingency efforts.

- The 1918 influenza killed 50 million people and arguably as high as 100 million in 1918–1920. The consensus among leading epidemiologists and public health experts is that the threat from infection diseases is growing. Emerging infections disease events are increasingly significantly over time, with an ever-increasing global population.

- The World Bank has estimated the economic impact of a severe pandemic (that is, one on the scale of the influenza pandemic of 1918–1919) at nearly 5 percent of global GDP or roughly €2.26 trillion (Jonas, 2014), but according to some recent estimates, the current coronavirus pandemic could mean economic costs in the order of €2.6–4.4 trillion (US$3–5 trillion)[39] in the United States alone (Walmsley, et al., 2020). Some might see this as an

36 Original values in US dollars.
37 Original values in US dollars.
38 Original values in US dollars.
39 Original values in US dollars.

exaggeration, but it could also be an underestimate. Aggregate cumulative GDP losses for Guinea, Liberia, and Sierra Leone in 2014 and 2015 are estimated to amount to more than 10 percent (UNDP, 2015; World Bank, 2014). This huge cost is the result of an epidemic that, for all its horror, infected only about 0.25 percent of the population of Liberia, roughly 0.25 percent of the population of Sierra Leone, and less than 0.05 percent of the population of Guinea (WHO, 2016), with approximately 11,300 total deaths in these countries (CDC, 2016). The Commission's own scenario modelling, based on the World Bank parameters, suggests that during the 21st-century global pandemics could cost in excess of €4.52 trillion, with an expected loss of more than €45.2 billion per year.[40]

- The BCR that can be estimated from the report is €45.2 billion/€3.39 billion = 13.3

Overall, there is a clear case for the benefits of significantly upgrading the world's defences against pandemics. While they may be substantial, they are not out of reach. The flaws in defences costs thousands of lives, and the ultimate cost of a pandemic is always higher than what could be projected. The study finds how relatively little countries are investing to protect the world from the threat of infectious diseases. It is also found that prevention is far more cost-effective than response and that the most effective response is a well-prepared response.

→ **Challenges faced and lessons learned**

In the future, more research relevant to the COVID-19 pandemic must be undertaken to understand the supply-chain mechanisms and constraints of PPE and other COVID-19-related equipment to inform pandemic and health emergency preparedness. In addition, analysing the costs and benefits of pandemic pre-positioning in terms of ready use equipment reserved for crisis situations will be important in future studies. Potential case studies for investigation can include:

- Analysing the impacts to public health when equipment is single sourced versus multi-sourced,
- Evaluating outcomes on export bans for equipment and the impact on health,
- Assessing the outcomes on repurposing facilities for PPE and other equipment development,
- Quantifying the benefit of preidentified health facilities versus no centralized information on hospital/pharmacy/health clinic equipment and capacities, and
- Examining the COVID-19 impacts based on countries that have emergency plans and distribution arrangements versus those that do not.

40 Original values in US dollars.

3.9. Oil spills

3.9.1. SUMMARY OF FINDINGS FOR OIL SPILLS

An oil spill is a technical incident that causes tremendous damages to the environment and the ecosystem, especially in marine and coastal areas as an oil spill often occurs on the sea. Oil spills lead to the immediate consequence of fire hazards and negatively affect wildlife by disturbing the habitats and threating the lives of the species, especially for those living in these ecosystems (Bautista & Rahman, 2016). Clean-ups and assessments after an oil spill are challenging, as it depends on many factors, such as the type of oil spilled and the type of environment and ecosystem involved (Holleman, 2004).

In this section, we have presented a benefit-cost assessment for preventive investments in vessels and equipment in coastal areas. BCR for the case study is shown by a review of external ex ante BCA of the preventive investment. The impacts mostly considered in the case study is the damages from vessel-source oil spills and marine pollution. *Table 82* summarizes main data and information sources.

Table 82: Overview of data and information sources for oil spills analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Preventive investments in vessels and equipment in coastal areas	A multi-functional ship to tackle marine pollution	Ex-ante assessment *Commission Staff Working Document Evaluation: Ex Post Evaluation of Major Projects in Environment Financed by the European Regional Development Fund and the Cohesion Fund between 2000 and 2013*, published by Secretary-General of the European Commission Consultation with the Ministry of the Environment of Estonia (Head of Marine Environment Department), Police and Border Guard Board (Police Captain)

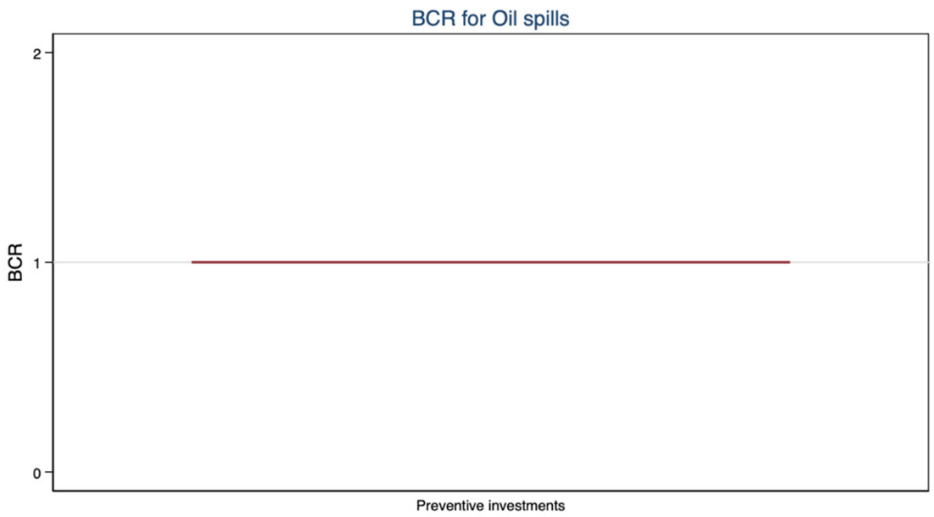
Source: World Bank based on external data and information

Modelling of the effect of a catastrophic oil spill is useful in terms of revealing the benefits of oil spill preventions. In an economic assessment, the frequency and spill size volume of a hypothesized oil spill are viewed as essential factors that can affect the modelling and the result.

When calculating BCRs for investments that prevent or mitigate the impact of oil spills, the quantification of the avoided costs is crucial yet challenging. While it is easy to calculate the response and clean-up costs, the risked social and environmental costs such as the losses in commercial fishing and ecosystem usually do not have common standards and thus difficult to quantify (BOEM, 2016).

The result of the investment shows a small BCR higher than 1 due to a conservative estimation of the net benefits. Nevertheless, preventive investments are still considered as highly beneficial as such investments, among others, require significantly lower implementation costs and thus yield higher net benefits compared to post-disaster remediation. More details are included in *Figure 43*. The figure presents a graph that displays the BCR for investments in oil spills.

Figure 43: Findings of BCA for Oil Spills (BCR)



Source: World Bank analysis based on external data and information; presenting results from literature based on external reports (1 Preventive investment result from (European Commission, 2020a))

Preventive investments against oil spills can constitute, among others, the deployment of vessels and equipment in coastal areas. In recent decades, the EU has become more proactive in preventing vessel-source pollution through the adoption of new, prevention-oriented regulations. The European Commission has provided a range of services and tools to support coastal countries in prevention, such as a toolbox for effectiveness of response (EMSA, 2021b), focusing on equipped oil spill response vessels. Also, the European Maritime Safety Agency (EMSA) was established to provide technical and scientific advice on maritime safety and the prevention of pollution by ship (EMSA, 2021a).

- **Case study 27 (external analysis** (European Commission, 2011b), **ex ante):** An analysis of a preventive investment against oil spills in Estonia, namely, a multi-functional ship to deal with incidents of marine pollution, yielded a BCR of 1, although net benefits were not estimated, particularly the quantification of benefits of potential oil spills being reduced. These benefits could be substantial as oil spills have impacts beyond borders and can cause considerable disruptions to ecosystems.

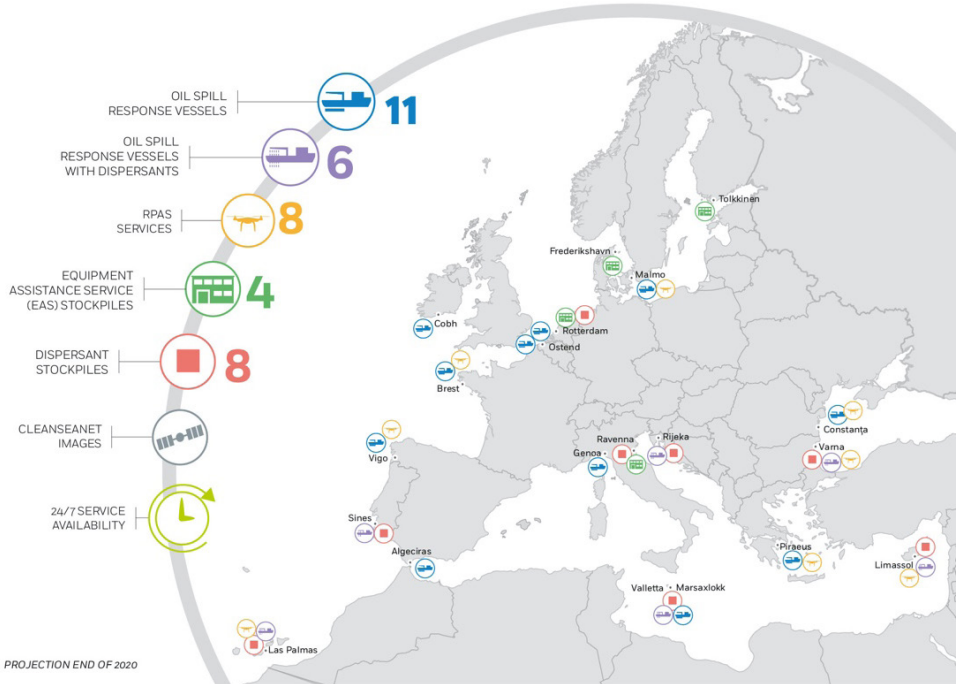
3.9.2. PREVENTIVE INVESTMENTS IN VESSELS AND EQUIPMENT IN COASTAL AREAS

It is far less expensive to prevent an oil spill than to clean one up. That is why preventive investments, such as spill prevention programs and legislation, play an important role in reducing the frequency of major spills. An international example of robust oil spill prevention, preparedness, and response is in Washington, United States. In the wake of the 1988 Washington State 'Netsucca' and 1989 Alaskan 'Exxon Valdez' oil spills, the state of Washington established a comprehensive spill preparedness and response program in July 1990 and a spill prevention program in 1991. Actions for these programs include 24-hour oil and hazardous material spill response capability statewide; oil spill contingency plans drafted for vessels over 300 gross register tonnage (GRT); required tank vessel spill prevention plans, cargo and passenger vessel inspections, and vessel bunkering checklists and inspections that were enforced; and a natural resource damage assessment. These proactive efforts put Washington significantly ahead of the rest of the United States in terms of the reduction of the number of oil spills and rates of oil spills by tonnage transport and transit.

For the EU, the prevention of vessel-source pollution is a cross-sectoral issue that involves the protection of the marine environment and maritime transport. After the 'Erika' oil spill disaster off the coast of France in 1999 and the 'Prestige' oil spill off the coast of Galicia, Spain, in 2002, the EU became more proactive in preventing vessel-source pollution through the adoption of new, prevention-oriented regulations. This is mainly dealt with by the Directorate General of Energy and Transport. Moreover, EMSA was established by Regulation (EC) 1406/2002 as part of the Erika II package (EMSA, 2021a). EMSA provides the European Commission with technical and scientific advice on maritime safety and the prevention of pollution by ships to develop new legislation and evaluate the effectiveness of already-implemented measures. Regulation 724/2004 considerably expanded EMSA's role to include an increased emphasis on maritime security alongside the response to pollution by ships (Liu & Maes, 2010).

The European Commission has provided a range of services and tools to help coastal countries to prevent or reduce oil spills and marine pollution incidents. EMSA offered a 'toolbox' that can respond to oil spill incidents at the request of EU MS quickly and effectively (see *Figure 44* for EMSA's network of Oil Spill Response Vessels) (EMSA, 2021b). The service is accomplished by the operation of fully equipped oil spill response vessels, which has to respond to an incident and set sail within a limitation of 24 hours.

Figure 44: EMSA's Operational Oil Spill Response Services



Source: EMSA (2021b)

PREVENTION OF OIL SPILL IMPACTS IN ESTONIA: A MULTI-FUNCTIONAL SHIP TO TACKLE MARINE POLLUTION

This case study is an external analysis that was undertaken with ex ante assessments that included quantitative estimations of benefits.

→ Introduction and background

The Gulf of Finland and the Baltic Sea are at high risk of marine pollution and oil spills as they are frequently involved in the shipping of oil and oil products. Every year, over 160 million tonnes of chemicals are transported across the Gulf of Finland (European Commission, 2020a). As a result, the Baltic Sea receives 30–60 metric tonnes of oil annually, and it is estimated that 2.87 oil spill accidents take place in the Baltic Sea every year (Elin, et al., 2001).

Estonian authorities have stated that an oil spill can be considered as an environmental emergency that is the most expensive and most probable to happen. A study based on historical spill data found that the average per-unit clean-up cost of marine oil spill in Estonia is €7,616 (US$6,820.62) per tonne (Dagmar, 2001). Also, because fish eggs and larvae are vulnerable to high oil concentration in water, oil spills negatively affect the marine and coastal ecosystem and thus generate economic losses in commercial fishing, tourism, and local recreation (Dagmar, 2004). The per-unit socio-economic and environmental cost of an oil spill is shown in *Table 83* below, according to the EPA Basic Oil Spill Cost Estimation Model.

Table 83: Socioeconomic and Environmental Base Per-Gallon Costs for Oil Spills

Oil Type	Volume (gallons)	Base Cost ($/gallon)	
		Socioeconomic	Environmental
Volatile Distillates[2]	<500	$65	$48
	500 – 1,000	$265	$45
	1,000 – 10,000	$400	$35
	10,000 – 100,000	$180	$30
	100,000 – 1,000,000	$90	$15
	>1,000,000	$70	$10
Light Fuels[3]	<500	$80	$85
	500 – 1,000	$330	$80
	1,000 – 10,000	$500	$70
	10,000 – 100,000	$200	$65
	100,000 – 1,000,000	$100	$30
	>1,000,000	$90	$25
Heavy Oils[4]	<500	$150	$95
	500 – 1,000	$600	$90
	1,000 – 10,000	$900	$85
	10,000 – 100,000	$500	$75
	100,000 – 1,000,000	$200	$40
	>1,000,000	$175	$35
Crudes[5]	<500	$50	$90
	500 – 1,000	$200	$87
	1,000 – 10,000	$300	$80
	10,000 – 100,000	$140	$73
	100,000 – 1,000,000	$70	$35
	>1,000,000	$60	$30

Source: Dagmar (2004)

→ Description

During an EU project (European Commission, 2011b), a multifunctional ship has been procured for Estonia to deal with incidents of marine pollution in Estonian waters and other parts of Baltic Sea. During the programming period from 2007 to 2013, the EU contributed €29.8 million to the total investment of €33.1 million.

Expected results are that in the event of an alert, the ship will be ready to leave from the harbour to the marine pollution area within 2 hours, be at the pollution area within six hours, and start remediation works within 12 hours. This means that under normal conditions the marine pollution should be removed within 48 hours. As the ship is multi-functional, it can also take a 'supervisory' role, carrying out prevention and monitoring duties at sea. The mere sight of this highly visible ship will encourage vessels to adhere to environmental regulations and wilful marine pollution will decrease. The purchase of the ship will see Estonia's capacity to tackle marine pollution rise to 26 percent of HELCOM requirements.

The ship will help also prevent and respond rapidly to pollution incidents to avoid contamination and disturbance of habitats and maintain their favourable status, ensure functioning of critical areas, and reduce risk to human health and life. The project achieved the objectives based on HELCOM recommendations (removing marine pollution within 48 hours). It achieved its main target of improving offshore sea pollution control capacity and reduced the risk of damage from maritime pollution. This is a great improvement as at the time of the project application, the Police and Border Guard Board had only one pollution control ship, which had been donated by Sweden in 2002 and accounted for only 13 percent of the HELCOM recommendation.

→ Methodology

A BCA has been carried out for the project, based on guidance materials developed by the European Commission, such as the 'Guide to Benefit-Cost Analysis Investments Projects' and 'Guidelines for Benefit-Cost Analysis Methodology' (European Commission, 2014; European Commission, 2007). The analysis is based on the cash flow analysis method, while a uniform discount rate of 6 percent (real rate) (Flood, 2014) was used for determining the present value of long-term receivables and liabilities when assessing the financial profitability of the investment.

→ Results of the analysis by Dividends and overall

The result of the analysis (European Commission, 2020a) shows a BCR of 1 for the project, with the low ratio due to a conservative estimation of the net benefits. Because of the unavailability of data, the ship's impact in terms of the number of deliberate oil spills being reduced is not quantified. The analysis shows that the ship achieved its goal of reducing damages from marine pollution and oil spills. The ship supports an effective response to pollution emergencies, which helps reduce the spread of marine contamination and decreases the risk of marine pollution to the environment and human health. Such reduction in oil pollution and marine contamination benefits not only Estonia but also all the countries surrounding the Baltic Sea, including non-EU countries such as Russia.

→ Challenges faced and lessons learned

The project itself is not an ordinary direct investment for profit but a preventive one that helps reduce environmental pollutions. As a result, it does not have a direct investment effect. Therefore, no ex post analysis has been done for the project, and the impact of the ship in terms of the number of oil spills being reduced has not been quantified (European Commission, 2011b; European Commission, 2020a).

3.10. Nuclear

3.10.1. SUMMARY OF FINDINGS FOR NUCLEAR RISKS

In this section, we have presented the benefits of investments in nuclear security and remediation programmes for uranium production. Most investments focus on preventing risks from potential nuclear disasters in the future while enhancing sustainable energy production. One example considers the long-lasting risk from chemical leaching of uranium.

When conducting analysis for nuclear accident prevention, it is essential to carefully quantify the risk of nuclear accidents by addressing the frequency for a nuclear disaster to occur. One of the standard tools to quantify such accidents is the Farmer Curve, which defines the risk of a nuclear power plant as 'probability × consequences' (Wheatley, et al., 2016). A Farmer plot shows the annual frequency of fatalities or damages from a nuclear accident, which can be used in an economic analysis that determines the avoided losses of investments in nuclear risk reduction. Moreover, the decommissioning of chemical leaching of uranium to prevent environmental disasters and health hazards is a complex process that needs to be constantly evaluated and specified to achieve the environmentally and economically most effective measures in a step-by-step process.

BCRs analysis is rare for nuclear investments. While costs on installation, maintenance, and waste management can be quantified for investments in improving the sustainability and safety of nuclear power plants in Europe, no studies could be found undertaking a full BCA for such projects. This is probably because impacts of nuclear can be sustained over millennia, which would indicate precautionary criteria rather than analysis based on mostly economic efficiency criteria.

A number of countries have been investing in the security of their nuclear power plants. Examples are the large-scale long-term investment in France that aimed to enhance the safety and security of plants or the comprehensive research programme centre in the Czech Republic (SUSEN sustainable energy project) (European Commission, 2012; European Commission, 2011) that aims to enhance the sustainability of energy production. Moreover, the Czech Republic, as one of the top uranium-producing countries in the world since the 1960s, has been implementing a large-scale environmental programme for the past 30 years to close the uranium mines and a specific project co-funded by the EU supported the decontamination of sites (European Commission, 2011).

Although no formal BCA was conducted for the investments, qualitative analyses have shown benefits in nuclear risk prevention and remediation of risks related to uranium leakage. Investments in nuclear safety tend to be highly beneficial from a long-term perspective as the potential impacts of unsafe nuclear plants can be major.

3.10.2. SECURITY OF NUCLEAR POWER PLANTS

Because the possibility of a nuclear accident can never be ruled out, there is no room for complacency in the implementation of nuclear safety practices and concepts (Nuclear Energy Agency & Organisation for Economic Co-operation and Development, 2013). The nuclear power plant accident at the Fukushima Daiichi Power Plant, which was catalysed by a 9.0 magnitude earthquake off the coast of Tōhoku, Japan, is considered to be the worst nuclear disaster since Chernobyl in 1986. The Japanese government estimated clean-up costs to be €64.1 billion of the overall Fukushima disaster price tag of €171.5 billion. However, the Japan Centre for Economic Research claims that the clean-up costs can intensify anywhere between €398 billion and €559 billion (Hornyak, 2018). This event demonstrated the need for safety precautions for nuclear power plants in technologically advanced countries, especially in the context of multiple hazards. In September 2011, three months after the accident, the MS of the International Atomic Energy Agency (IAEA) unanimously endorsed the IAEA Action Plan on Nuclear Safety, which intends to foster international collaboration towards strengthening global nuclear safety. Moreover, IAEA MS have also comprehensively analysed its causes and consequences by carrying out 'stress tests' to reassess the design of nuclear power plants against site-specific extreme natural hazards, installing additional backup sources of electrical power and supplies of water, strengthening the protection of plants against extreme external events, and devising changes and reforms of organizational and regulatory systems (Jawerth, 2016).

To improve the safety level of nuclear power plants, the European Commission requires the establishment of general standards of nuclear safety monitoring mechanisms. This allows the public and workers to be protected from radiations from nuclear installations and nuclear accidents. At the same time, the JRC conducted research that ensures safe operations of Western and Russian type nuclear power plants, and it also analyses the effectiveness of existing mitigation mechanisms based on models of hypothetical nuclear accidents (EU Science Hub, 2016). Countries also invest in the safety of their nuclear facilities. For instance, in France, the Nuclear Safety Authority is established to regulate and monitor nuclear safety and protect workers and the public from potential radiation risks.

A number of investments were found that provide insights on how European countries manage nuclear power plants in a safe and sustainable way. The examples include France's investment in nuclear plants security and the Czech Republic's sustainable energy projects. Highlights of the projects are presented in *Box 16* below.

Box 16: Investments in the security of nuclear power plants across Europe

The two cases reveal in practice investments in improving nuclear power plants generate potential co-benefits for the society and sustainability for the future.

A large-scale long-term investment program in France has achieved success in terms of improving safety and extending the lifetime of nuclear power. France (IAEA, 2020; World Nuclear Association, 2021) derives around 75 percent of its electricity from nuclear plants, so it is essential to ensure the safety of the country's nuclear plants. From 2014 and onwards (OCED, 2019a), the EDF (France's state-backed power utility) launched an investment project aimed at improving the safety of the country's nuclear power plants. The overall cost of the project includes maintenance cost of roughly €4.2 billion per year and decommissioning and long-term waste management cost of €75 billion (Tillement, 2018). The project is expected to extend the lifetime of nuclear power reactors to 50-60 years beyond 40 years of operation and improve security of nuclear operations.

As the second phase of the SUSEN sustainable energy project (European Commission, 2012) , Czech Republic has conducted research and analysis on the sustainability of nuclear energy. The project emphasizes on installing technological instruments in a sustainable energy R&D centre, which is used for the study of materials and components used in energy production, construction, and the operation of energy facilities, and research into methods for the safe disposal of nuclear waste. The cost of the project is over €100 million, and the positive impact of the project includes improving sustainability in energy production for the future and enhancing employment as 185 new jobs were created.

3.10.3. CLEANING UP URANIUM

Remediation programmes for uranium production facilities aim to establish long-term, stable conditions that enable the affected areas to return to previously existing environmental conditions or to a land use with long-standing sustainability. These activities encompass the restoration of mines, mills, waste management facilities, tailings containment, and land and water resources (OECD, 2019b). By cleaning up uranium through remediation programmes, there is peace of mind ensuring that both current and future generations will be able to use the site and its surrounding areas safely. Therefore, at all stages of the remediation process, it is crucial to consider the principles of environmental protection, sustainable development, and intergenerational equity.

Decommissioning of the chemical leaching in uranium is a long-lasting and complex process that needs to be constantly evaluated and specified. This overall process is divided into five consecutive stages to accommodate the remediation's long time frame and stringent technical and economic requirements. Therefore, the process of decommissioning may not be standardized for each site. Yet, this stage-by-stage progression allows researchers to verify the steps individually and ensure that the process is achieving the environmentally and economically best solutions possible. Some countries such as the Czech Republic have invested systematically in decommissioning and environmental cleaning.

The Czech Republic has been one of the top uranium producing countries in the world since 1960s, and their extensive production of uranium led to the contamination of groundwaters and widespread environmental impacts. After 1990, a large scale environmental programme was set up to shut down these uranium mines, and the last mine in Europe, located in Rožná, Czech Republic, was closed in 2017. The cost of all remediation activities are expected to be in excess of €25 billion (IAFA, 2005).

During the 2007 to 2013 programming period, the EU invested €20,311,400 into a €23,895,700 project aimed at decontaminating, sanitizing, and re-cultivating the former MAPE Mydlovary uranium processing site (European Commission, 2011). As a result of mining out 24,936 m3 of contaminated material and removing another 24,265 m3 of demolished and decontaminated building structures and technological equipment, the region was able to reduce radiation levels and contamination risks in drinking water and surface water, allow for vegetation to be re-established, and meadows and pastures to exist again. It is important to investigate these types of investment because water contamination and other environmental risks can become cross-border issues if not treated promptly and correctly.

3.11. Chemical

3.11.1. SUMMARY OF FINDINGS FOR CHEMICAL RISKS

Chemical incidents, especially those that are an act of terrorism, can directly cause injury from fire, explosion, or toxicity and indirectly create fear and anxiety in populations. The WHO (2020) states that the adverse health outcomes to toxic chemical exposure may be effects that are local or arise at the site of contact with the chemical (for example, bronchoconstriction from respiratory irritants or irritation of the skin and eyes by gases, liquids, and solids); effects that are systemic or affect organ systems remote from the site of absorption (for example, depression of the central nervous system from inhalation of solvents or necrosis of the liver from the inhalation of carbon tetrachloride); and effects on mental health arising from real or perceived realness, which depends on psychosocial stress associated with an incident. The development of symptoms can vary greatly, ranging from within a day to months or even years.

In October 2020, the European Commission adopted the EU Chemicals Strategy for Sustainability, which is considered to be the first step towards the European Green Deal's ambition for zero pollution and a toxic-free environment (European Commission, 2020f). Flagship actions of this strategy include banning the most harmful chemicals in consumer products, phasing out the use of per- and polyfluoroalkyl substances (PFAS) in the EU unless they are for essential use, boosting the investment and innovation capacity for production and the use of chemicals that are safe and sustainable by design and throughout their life cycle, establishing a simpler 'one substance one assessment' process for the risk and hazard assessment of chemicals, and playing a global climate leader role in championing the continent's high standards and not exporting chemicals banned in the EU. This is in addition to the European Commission's Seveso Directive (European Commission, 2020g) and international cooperation efforts, like the UNECE's Convention on the Transboundary Effects of Industrial Accidents and the OECD's Programme on Chemical Accidents.

In this section, we have demonstrated a benefit-cost assessment for chemical risk prevention and remediation. A BCA for the investment is undertaken with a detailed ex post case study analysis. The chemical risk identified in the case study is the sulphuric acid tar waste and other toxic pollutants from waste dumpsites. *Table 84* summarizes main data and information sources.

Table 84: Overview of data and information sources for chemical analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Cleaning up hazardous waste	Cleaning of hazardous waste in Latvia	Costs of the investment found from the EU programming funds and description Cost of temporary treatment between Phase I and Phase II provided by Latvia's State Environmental Services Assumption for lives saved based on data from a WHO report for the Slovak Republic Health costs avoided based on data from the European Public Health Alliance Cost of sick/affected livestock avoided based on a study for Ethiopia (*Environmental and Health Impacts of Effluents from Textile Industries in Ethiopia: The Case of Gelan and Dukem, Oromia Regional State*) Information on jobs created provided by Latvia's State Environmental Services

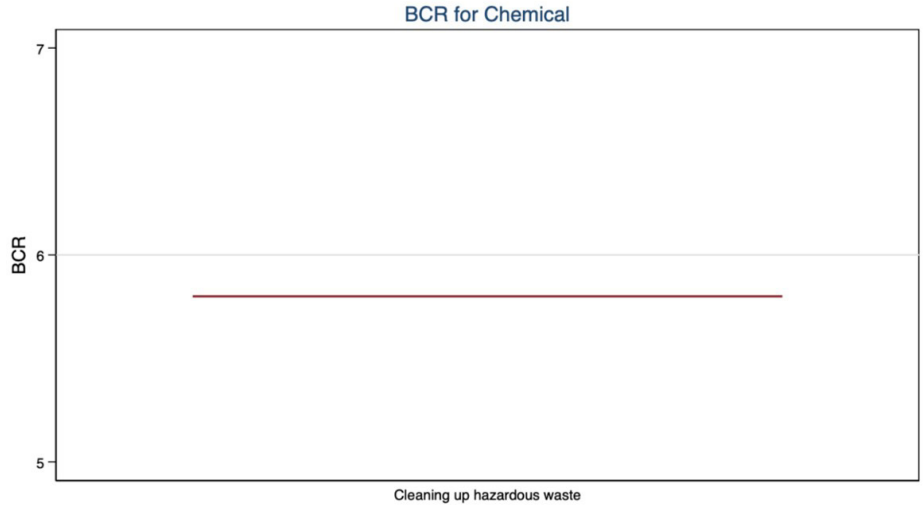
Source: World Bank based on external data and information

Models need to be adapted to type of investment. When modelling the effectiveness of remediation strategies of chemical incidents, it is crucial to consider the direct economic consequences such as property damage as well as costs of mitigating the health risks related to the incident. For some investments, the modelling can be non-time-sensitive and focus on the overall costs and benefits in the lifetime of the capital investment, while future costs or benefits per year are not included.

BCRs are essential for analysing the impact of chemical incidents, as such incidents often lead to a multitude of domino effects and may spawn serious consequences of mass casualties, property losses, and environmental pollution. However, few studies can be found undertaking a BCA that examines the remediation of chemical incidents and the cost-effectiveness of it.

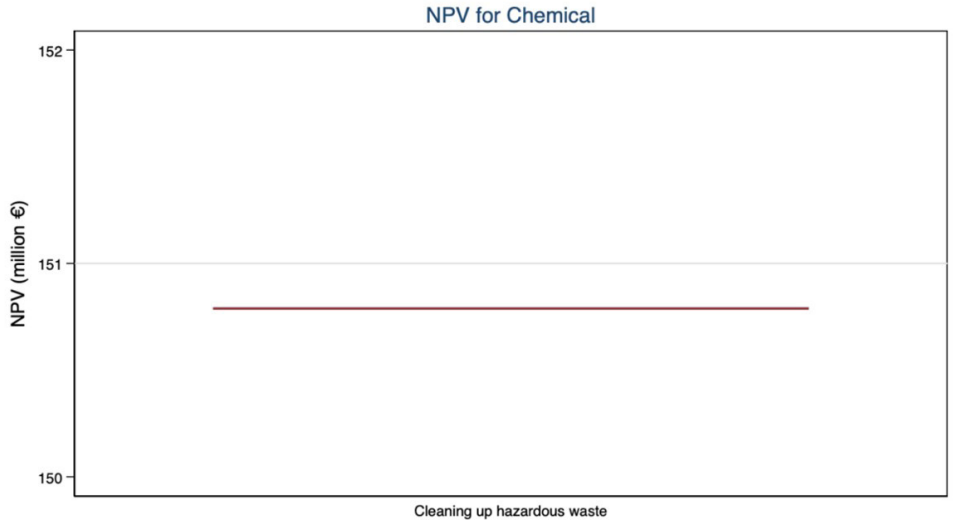
Results from BCA of remediation investments tend to yield net benefits. Complementary investments and comprehensive analysis to better understand historic losses due to chemical spills and other environmental hazards as well as land value appreciation can be highly informative for investments to comprehensively address remediation as well as target socio-economic improvements. More details are included in *Figure 45*, *Figure 46* and *Figure 47*. The figures present graphs that display the BCR, NPV, and ERR for investments in chemical risks (shown in red).

Figure 45: Findings of BCA for chemical risk (BCR)



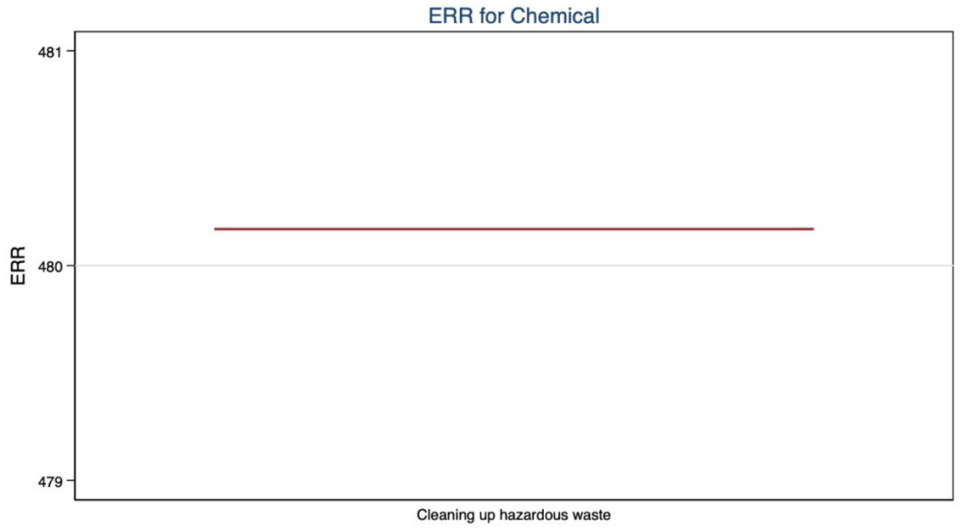
Source: World Bank analysis based on external data and information

Figure 46: Findings of BCA for chemical risk (NPV)



Source: World Bank analysis based on external data and information

Figure 47: Findings of BCA for chemical risk (IRR)



Source: World Bank analysis based on external data and information

Cleaning up hazardous waste is a preventive investment that can prevent chemical risks. Hazardous waste can permeate through and contaminate all types of environmental mediums—atmosphere, groundwater, surface waters, and soil—to cause harmful or even fatal effects on human health. Such health effects includes narcosis, skin irritation, and respiratory diseases, or even chronic health effects, such as leukaemia, liver tumours, lymphomas, and birth defects. Hence, cleaning up hazardous waste is crucial in terms of removing toxins that negatively impacts human health, while it also yields co-benefits in increasing property value of homes near the contaminated commercial site (Gamper-Rabindran & Timmins, 2013; Taylor, 2016).

- **Case study 28 (new analysis under this project, ex post (European Commission, 2020g)):** An analysis of a remediation investment in Latvia to clean up sulphuric acid tar lagoons, once operated as waste dumpsites, yielded positive net benefits (BCR 5.8, NPV €151 million, ERR 480.17 percent). The analysis included direct impacts (particularly on the environment) and economic potential unlocked that can increase land value, construction investments, as well as linked jobs created. Future

case studies could further consider further, among others, the long-term impacts on human health, productivity losses from agriculture avoided, or CO2 emissions avoided.

3.11.2. CLEANING UP HAZARDOUS WASTE

Hazardous waste can permeate through and contaminate all types of environmental mediums—atmosphere, groundwater, surface waters, and soil—to cause harmful or even fatal effects on human health. Prolonged exposure to toxic pollutants can instigate acute health effects, such as narcosis, skin irritation, and respiratory diseases, or even chronic health effects, such as leukaemia, liver tumours, lymphomas, and birth defects.

Cleaning up hazardous waste can have positive environmental, economic, health, and social benefits for the community. Not only do communities benefit from the lack of toxins in the air once 'brownfield' sites are remediated, but studies have shown that the property value of homes near the contaminated commercial site appreciates (Gamper-Rabindran & Timmins, 2013; Taylor, 2016). For instance, using a hedonic method to estimate the residents' WTP to clean up a Superfund site, Kiel and Zabel (Kiel & Zabel, 2012) found that the economic benefits of cleaning up two Superfund sites in Woburn, Massachusetts, range from €55.47 million to €94 million.

REMEDIATION BY CLEANING OF HAZARDOUS WASTE IN LATVIA

This case study is a new ex post analysis under this project that involved innovation of quantitative impacts.

→ Introduction and background

From the 1950s through the 1980s, the Southern and Northern sulphuric acid tar lagoons within the Inčukalns civil parish in Latvia were established and operated as waste dumpsites. Although the landfill was closed in 1986, the pollution already infiltrated into the near-surface groundwater and artesian water up to a depth of 70–90 m. The pollution has migrated northwards towards the River Gauga, and currently, the polluted groundwater extends to 148 ha around the Northern lagoon and 149 ha around the Southern lagoon.

→ Description

The objective of the project, 'Historically contaminated sites 'Incukalns acid tar ponds' remediation works', is to prevent the further discharge and dispersal of sulphuric acid tar waste and other pollutants into groundwater, near-surface ground water, surface water (in ditches), and soil and subsoil that is adjacent to polluted sites. Since this project is being implemented over two EU programming periods (EU Structural Funds programming periods 2007–2013 and 2014–2020), this project is also divided into two phases (that is, Phase I and Phase II). Our approach for this BCA is to compare the cost of the remediation project in each phase of this two-part remediation and foresting investment along with the temporary treatment between Phases I and II. Collectively, this project is the only major environmental project occurring in Latvia and the other Baltic states.

It is important to evaluate the remediating interventions and their holistic benefits to communities near toxic areas. Health issues from such toxic can arise immediately but more often, they are exhibited over time and unfortunately through generations. For this reason, remediation impacts should be forward looking as in the below case study (losses avoided) and consider the morbidity and mortality as comprehensively as possible. These BCAs could also inform health care services that might be needed in the areas with caustic sites such as the acid tar lagoons in Latvia. Cascading impacts to land, assets, livestock, and livelihoods are inevitable from such environmental hazards but often underreported.

The aim of the project is to prevent further discharge of the pollutants, especially the sulphuric acid tar waste, into groundwater, as well as to prevent the further dispersal of the pollutants into near-surface groundwater, surface water (in ditches), and soil and subsoil adjacent to the polluted site. This will happen in two phases. Phase I uses EU Structural Funds for the programming period of 2007–2013 and the Phase II programming period is 2014–2020.

Remediation works started in Phase I included the removal of two deep boreholes that were used for acid tar and a temporary coverage of the pond was also installed before the commencing of Phase II. As Phase II is currently under way and data for the results was not available, this case study focuses on Phase I costs and benefits of the intervention. The approach for this BCA is to compare the cost of the remediation project in Phase along with the temporary treatment between Phase 1 and 2 of this EU-funded (European Commission, 2011b).

→ Methodology

The methodology evaluates the cost of remediation to the tar lagoons in Phase 1 as well as the pre-treatment of contaminated water and deposit or utilization of sludge derived from the treatment between Phase 1 and 2 to the overall estimated benefit of remediation and environmental clean-up. The methodology is not time sensitive and does not include future costs or benefits per year but overall costs and benefits in the lifetime of the capital investment with the data currently available.

The costs of the investment are found from the EU programming funds and description, and the cost of temporary treatment between Phase I and Phase II are provided by Latvia's State Environmental Services. All costs and benefits are in 2013 euros because this was the final year of the programming period.

The Triple Dividend Framework includes the following benefits:

Triple dividend 1 (costs avoided):

- Lives saved from exposure to PM10 and NO2 from landfills and incinerators over individuals' lifetimes. The assumption is that data from the WHO for the Slovak Republic over a 20-year period of exposure to landfills/incinerators could be applied to Latvia as they are similar countries in GDP (Forastiere, et al., 2011).

- Health costs avoided are based on data from the European Public Health Alliance that estimates the cost per capita per country of pollution exposure. For Riga City (capital of Latvia) where the toxic site is near, the approximate cost per person is €1,384 per person (De Bruyn & De Vries, 2020) While this cost is due to transportation-related pollutants, the emission impacts of sulphur also comprise the same harmful chemicals. Therefore, we found it sound to include the value in our analysis. An additional assumption made is that 50 percent of the people in the region of Vidzeme will have health impacts (conservative as there is a lack of data).

- Cost of sick/affected livestock avoided is based on information in Ethiopia on the impacts of effluents to cattle—price adjusted to Latvia (Dadi, et al., 2017). The assumption is that the context in Ethiopia will be applicable to cattle in Latvia. In addition, information on the number of livestock in Latvia is scaled to the regional level to obtain values for this factor (USDA, 2016).

- Environmental costs avoided due to the temporary coverage installed between Phase I and Phase II prevent leachate concentration in the ponds and surrounding areas. The amount of polluted water would increase the amount of contaminated water in the pond and gradually infiltrate through the sides of the pond to increase groundwater pollution if the coverage is not undertaken. The estimated costs of pollution avoided are provided by the State Environmental Agency and amount to approximately €384,000 per year.

Triple dividend 2 (unlocking economic potential):

- Cost of land value reduction avoided is based on existing and estimated housing and value of housing in the Vidzeme region in Latvia with the assumption that 31 percent of the land value of housing will decrease due to proximity to the toxic site. The data are from a study in the United States on Assessing the True Costs of Landfills (Hirshfeld, et al., 1992). The assumption is that the percentage decrease in land value would be constant in the Latvian case. The value used is adjusted for the Latvian consumer price index from the United States.

- Jobs added are considered a benefit to the economy over the project period. The information on the number and types of jobs was provided to the members of the team by Latvia's State Environmental Services. Jobs added included the assumption that there is full employment in the country.

- Value added in construction is the macro-economic benefit of construction works in remediation over Phase 1 of the project. The multiplier for each euro

of input in the investment to the macro-economic output is taken from Eurostat symmetric input-output tables for Latvia. This is the EU-level €0.47 to the broader economy for €1 of investment into the construction sector.

→ **Results of the analysis by dividends and overall**

Environmental clean-up of the acid tar lagoon in Phase 1 of the EU investment to Latvia yields a high BCR when considering the unlocked economic potential as well as direct losses avoided. (see *Table 85* and *Table 86*). While co-benefits likely exist in this case and others of environmental clean-up, data were unavailable to appropriately quantify for this study. Therefore, the true triple dividend is likely underestimated in the per-year context in which the values are assessed and especially in a longer horizon where health costs avoided along with other direct costs would contribute to the triple dividend cumulative value. Sensitivity analyses of low and high values of losses avoided, including rates of health costs, lives lost, affected land value, and cattle/livestock affected, result in a range of BCRs of 2.8–10.5 with the median BCR of 5.8.

Table 85: BCR of cleaning up hazardous waste in Latvia (in million €)

BCR: 5.8		
	BENEFITS	COSTS
Dividend 1 (€)	119.75	
Dividend 2 (€)	62.45	
Dividend 3 (€)		
Total benefits	182.19	
Total costs		31.4
BCR	5.80	
NPV (€)	150.79	
ERR (%)	480.17	

Source: World Bank analysis based on external data and information

Table 86: Expanded triple dividend BCR calculation for cleaning up hazardous waste in Latvia (in million €)

ACID TAR LAGOON CLEAN-UP	
FIRST DIVIDEND (€)	
Lives saved due to remediation of site (long-term estimation)	€114.1 M
Health costs avoided	€5.54 M
Livestock lost avoided	€0.12 M
Total first dividend	€119.75 M
SECOND DIVIDEND (€)	
Land value reduced	€48.43 M
Input-output to economy from construction investment	€12.17 M
Jobs added	€1.46 M
Environmental damage avoided	€0.38 M
Total second dividend	€62.45 M
TOTAL DIVIDEND	€182.2 M
Total cost	€31.4 M
BCR	5.8
NPV	€150.79 M
ERR (%)	480.17%

Source: World Bank analysis based on external data and information

→ Challenges faced and lessons learned

Much data were extrapolated from other countries with research and study on topics of toxic site impacts to the Latvian case. In the future, the study could expand on the following:

- Determining Phase 1 and Phase 2 costs over a time horizon,
- Evaluating actual impacts on health of communities living near tar lagoons for decades,
- Understanding productivity losses from agriculture and other ecosystem services near area,
- Studying and including the actual cost of real estate value losses,
- Including the cost of CO2 or other emissions and costs due to tar lagoons,
- Evaluating current and future benefits of forestry in the area (Phase 2).

3.12. Multi-hazard

3.12.1. SUMMARY OF FINDINGS FOR MULTI-HAZARD RISKS

In terms of multi-hazard risks, a cross-cutting approach encompassing disaster risk reduction and climate change adaptation is vital to ensuring a comprehensive and cohesive effort for early warning, rescue and emergency response, and climate adaptation initiatives. By ensuring that these DRM strategies are capable of performing a wide variety of functions that address a multitude of hazards and are able to be implemented across border territories, researchers and front-line respondents are able to leverage this versatility to their advantage. To bridge the gap between research and practice, a deliverable report for the New Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe (MATRIX) project (Scolobig, et al., 2014) suggests creating forums at the local level to foster discussions with researchers, practitioners, and local advisors.

In this section, we have qualitatively and quantitatively demonstrated the benefits of multi-hazard investments for enhancing rescue and emergency response and community-based mitigation approaches for climate change adaptation. The BCRs for the different types of interventions are shown by a combination of conducting detailed case study analysis and reviewing past BCA, including both prospective and retrospective types of assessments. *Table 87* summarizes main data and information sources.

Table 87: Overview of data and information sources for multi-hazard analysis

INVESTMENT	CASE STUDY	DATA SOURCE NAME AND REFERENCE
Participatory Methodologies for Climate Change Adaptation	Participatory Methodologies for Climate Change Adaptation in Portugal	Ex post, semi-quantitative assessment based on the external study *Benefit-Cost Analysis in Climate Change Adaptation: The Use of Participatory Methodologies*

Source: World Bank based on external data and information

Quantification of the long-term benefits of investments in multi-hazards prevention is essential to fully present the cost-effectiveness of such investments. No formal BCA can be conducted for the EU project 'New vehicles for voluntary fire service units' since available research and data are limited on the true benefits of adding new vehicles. While it improves the demand and provides upgraded equipment in the short term, it is difficult to capture long-term benefits of the investment when undertaking an economic assessment.

Generally, there seems to be some indication of net benefits of multi-hazard investments. However, evidence tends to be scarce and BCA may not be the right tool to assess these types of complex investments. Conducting a comprehensive analysis of the effects of multi-hazard investments to determine how effective these functional investments are for disaster response could help inform policy.

Enhancing rescue and emergency response equipment can support the effectiveness of response. A project in Poland supported the provision of equipment (European Commission, 2020h), and

qualitative insights showed that they enhanced effectiveness of response, although an in-depth quantitative analysis would have to be undertaken. Moreover, digital databases and tools can support early warning and effectiveness of response. A number of investments were undertaken in Poland (European Commission, 2015), Greece (European Commission, 2020i), Malta (European Commission, 2020j), and Spain (European Commission, 2020k) that supported better decision-making, coordination platforms for enhanced response and minimized impacts, and were even qualitatively stated to have wider social and economic impacts by creating jobs or enhancing well-being. Multi-purpose green investments, particularly in urban areas, have been shown to yield positive net benefits including improved resource efficiency, increased aesthetic values, enhanced recreational values improved physical and mental health and job creation, as exemplified in an EU Horizon 2020 research project URBAN GreenUP (UrbanGreenUp, 2020), or the development of the Budapest City Park (Maksimovic, 2017).

In the context of sustainability and climate change adaptation, participatory methodologies and community-based mitigation approaches serve essential roles, as individuals and communities are vulnerable to the effect of climate change. Innovative participatory methods assist communities to understand the causes and impact of climate change, enhance local capacity, and enable the application of adaptation measures at community levels (Reid, et al., 2019). As a part of the EU research project 'Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe' (BASE) (2016), a study was undertaken to examine the effectiveness of participatory methods for 22 European cities, and it concludes that participation can enhance the process of climate adaptation by improving economic efficiency, community unity, and environmental integration and evaluation (Clemmensen, et al., 2015).

- **Case study 29 (external analysis, ex post** (Alves F., 2015)**):** An analysis of an urban-focused climate adaptation program in Cascais, Portugal, showed interesting results from a study using participatory BCA (PBCA) methodologies. The emphasis of the method is more on the process than the results, as it considers as beneficial the fact that populations have been engaged in the analysis. Highest BCRs were found for reforestation (particularly due to long-term benefits), legislation towards bioclimatic construction norms, as well as surveillance systems (BCRs 4.755, 4.74, 4.34, respectively). This could serve as a model for other cases analysing investments yielding mostly intangible benefits and to differentiate while combining short- and long-term benefits.

3.12.2. RESCUE AND EMERGENCY RESPONSE EQUIPMENT

Purchasing advanced equipment and technology for rescue and emergency response allows emergency respondents to be adequately prepared to protect human lives, property, and the environment. Investing in multi-purpose equipment that can be used when responding to a multitude of hazards is not only cost-effective but also convenient for municipalities because the versatility of its utility can be easily maximized by emergency authorities and responders. Several countries have invested in equipment for improved preparedness and response, such as in Poland.

Between 2016 and 2018, a project called "New Vehicles for voluntary fire service units" was launched in Poland's Lubelskie region (European Commission, 2020h). The EU supported the purchase of 43 firefighting and rescue vehicles for voluntary fire services and other equipment necessary for emergency rescue and post-disaster clean-up operations in Poland. These vehicles provide a high level of technical support for 1,753 voluntary fire services spanning 60,000 firefighters, which consequently improves the speed and efficiency of local rescue and firefighting operations in municipalities throughout Lubelskie. As a result, it is possible to significantly mitigate many adverse effects related to fires, forest fires, floods, serious industrial accidents, and other incidents that threaten life and health. Such efforts bolster protection of human life and property while enhancing safety and preventing the degradation of the natural environment, thus benefitting all 2.14 million inhabitants in the region. The total investment of the project is €7.51 million, and €4.28 million was funded by EU. As a result of this investment, a population of 36,750 people are benefitting from increased forest fire protection measures and 289,818 people are benefitting from other disaster recovery methods besides fire and flooding.

Since there is limited qualitative information provided by department contacts regarding the improvement of

services due to the addition of the new vehicles, no formal BCA has been conducted for the project. In general, research is limited on the true benefits of adding new vehicles; while it improves the demand and provides upgraded equipment in the short-term, it is difficult to capture long-term benefits using the triple-dividend methodology. To expand on this study in the future, the following should be considered:

- Assess the improved response time due to new fire vehicles,
- Assess the number of fire starts reduced, or fire damage reduced along with casualties reduced since the new vehicles were introduced in 2017,
- A more comprehensive solution would be to develop a radial plan based on the spatial fabric of the region. This includes identifying s emergency routes, critical facilities, dense and vulnerable buildings, as well as critical infrastructure. There is no indication on how the 43 trucks were distributed to the various stations, which is an important aspect of the efficiency in reducing losses based on the vulnerability to fires in areas in Lubelskie region.

3.12.3. MULTI-HAZARD EARLY WARNING SYSTEMS

In the digital era, EWS often incorporate online databases and digital tools that record available rescuing resources and provide real-time information on disasters. The use of digital tools increases the efficiency and effectiveness of the authority's response to disasters and public awareness. Some examples include the IT system for hazard protection in Poland, the Aegis Intelligent System that improves Greece's responses to disasters, Malta's high-tech mapping equipment for disaster, and the cross-border early warning networks across Spain and Portugal. More information on the use of digital tools for multi-hazard EWS is included in *Box 17* below.

Box 17: The use of digital tools in the early warning of disasters

The following examples showcase how the mplementation of digital tools supports the effectiveness of EWS and generates additional benefits to the society.

Established in Poland, the project "IT system for protection against extraordinary hazards (ISOK)" (European Commission, 2015) is an innovative system that decreases losses from floods, improves land development, and increases the public's sense of security and the efficiency of crisis management responses. The system was built at a cost of €75.54 million, and it allows Poland to meet the EU'S requirements on flood prevention. It provides valuable and useful IT and communication resources for decision-making when disasters and hazards occurs and also 40 new and permanent jobs.

The Aegis Intelligent System (European Commission, 2020i) is an innovative tool that enables Greece's North Aegean Region and Cyprus to have more efficient and effective responses when a natural disaster strikes. The system was built with a total investment of €0.92 million It provides a database that records available resources and equipment such as disaster vehicles and medicine and first aid supplies so that they can be mobilized immediately in a disaster. At the same time, it also provides a platform that allows authorities, first responders, and the public to visualize the location and impacts of the disaster.

As a part of the country's national digital strategy, an EU project (European Commission, 2020j) was implemented in Malta with an emphasis on data management and the use of hi-tech mapping equipment. The project creates 3D maps of the nation's geography and infrastructure, which provide not only valuable information on town planning to non-governmental, external users, but also important data for effective responses during a disaster, such as the strike of an earthquake or tsunami. The project generates positive social and economic impacts by boosting Malta's economic growth, creating new, specialized careers in the government based on spatial qualifications, increasing sustainability, and improving the wellbeing of the citizens.

With the objective to manage and use resources efficiently during the occurrence of natural disasters such as forest fires, floods and erosion, the EU project ARIEM+ (European Commission, 2020k) was launched under the collaboration between the Spanish regions of Galicia and Castile and Leon and those in northern Portugal. The project developed early warning networks as part of its environmental monitoring systems that highlights risks in the region, which improves response coordination between nations and maintains efficient communications in response to disasters. By doing so, they hope to shorten response times on both sides of the Portugal/Spain border to prevent forest fire or flood disasters and minimize their impact on human lives, property, and the environment.

3.12.4. PARTICIPATORY METHODOLOGIES FOR CLIMATE CHANGE ADAPTATION

Individuals and communities are vulnerable to the effect of climate change. As a result, it is crucial to integrate participatory tools and community-based mitigation approaches into DRR in the context of sustainability and climate change adaptation (Laukkonen, et al., 2009). Innovative participatory methods assist communities to understand the causes and impact of climate change, enhance local capacity, and enable the application of adaptation measures at community levels (Reid, et al., 2019). In addition, a study from Australia has also shown that participatory methods are effective and beneficial in terms of creating shared knowledge and empathy in the community, which helps policy making and actions in future climate adaptation (Ross, et al., 2015).

As a part of the EU research project BASE (2016), a study was undertaken to examine the participatory and methods and process for 22 European BASE case studies. The main goal of the study is to explore the significance and effectiveness of participation methods in the context of climate change adaptation. The study concludes that participation can enhance the process of climate adaptation by improving economic efficiency, community unity, and environmental integration and evaluation (Clemmensen, et al., 2015).

PARTICIPATORY METHODOLOGIES FOR CLIMATE CHANGE ADAPTATION

This case study is an external analysis that was undertaken with ex-post assessments and semi-quantitative methods to estimate benefits from interventions.

→ Introduction and background

The municipality of Cascais in Portugal is highly dependent on climatic conditions for its economic activities (particularly tourism) yet highly vulnerable to climate change impacts and disasters such as floods, wildfires, droughts, and heatwaves (BASE, 2014). The municipality became one of the first ones in the country in 2010 to develop a local Strategic Plan for Climate Change in consultation with experts that ranked adaptation measures according to vulnerability, risk assessments, and potential benefits.

→ Description

The BASE (2016) project from 2012 to 2016 focused on the development of 'Green Corridors' in the municipality through the rehabilitation of the existing riparian galleries and the unification of the parks, gardens, and florists, a connected and integrated green infrastructure. This was supposed to reduce the city vulnerability to floods as well as heatwaves while at the same time contributing to a greater quality of living and increased sustainability of the municipality. Moreover, the city wanted to enhance water savings in distribution (water waste from 17 percent to 6 percent) and training and awareness campaigns would support the resilience of municipal staff and civil society.

→ Methodology

This is a literature review of an existing research looking at the inclusion of participatory processes in conducting BCA for appraising projects as an alternative or supplement to traditional BCAs. It uses the PBCA to evaluate the benefits of climate change activities in Cascais, Portugal. This case reviews the following study on the BCA in climate change adaptation with the use of participatory methodologies (Alves, 2015).

→ Results of the analysis by dividends and overall

The study finds that climate change adaptation planning and intervention requires a holistic review of the complex interdependencies in time and space. A PBCA is an economic appraisal tool which has been developed and tested by the centre for climate impact, modelling and adaptation (CCIAM) from the university of Lisbon, under FP7 Project BASE. PBCA aims to combine the advantages and strengths of MCA with the rationality of BCA. The PBCA as applied to investment measures in Cascais, Portugal, being explored for climate change adaptation is listed in *Table 88*.

Table 88: Value of various participatory climate adaption measures

Adaptation measure	CB Short term	CB Long term	Discount rate	Final present value (original, 2013-2020)	Final present value (original 2013-2050)	Final present value (3,5% 2020)	Final present value (3,5% 2050)
Green corridors	0.5	2.25	-1%	1.445	1.8653875	1.13425	0.575125
Reforestation of the Sintra-Cascais Park	0.8	6.5	-5%	4.755	20.998175	2.9545	1.33925
Action plan to manage invasive species	0.79	3	-5%	2.404	9.90185	1.574	0.8285
Eliminate water pollution points	2	2.42	1%	2.14	1.84579	1.95106	1.34969
Raising awareness in households regarding good sanitation practices	2.25	3.5	1%	2.7	2.34825	2.5005	1.63075
Legislation towards bioclimatic construction norms	5.25	4.5	1%	4.74	4.19775	4.3935	3.27525
Vector surveillance system in the municipality	3.5	5.5	1%	4.34	3.67225	3.9115	2.54475
Awareness raising campaigns for heat waves and heat stress	1.25	2.2	1%	1.68	1.3939	1.4896	0.9429

Source: Alves, *et al. (2015)*

After running the PBCA tool in three separate workshops with more than 40 participants, the key findings regarding the methodology were as follows:

- The emphasis of this method is more about the process than the result itself as people engaged seriously in technical and also ethical/moral debates with great sharing but then disregard the final present value.
- It can lead to counter-literature, but intuitive, results, such as the selection of negative discount rates for some particular adaptation measures in some groups.
- Simple to use and understand, mainly if there is good facilitation/focalization of the debate.
- The introduction of the time factor and the inherent use of a discount rate enriches the debate and contributes significantly to the usefulness and maturation of the tool.
- The impact measurement scale (1 to 5) was considered too short to clearly distinguish between adaptation measures and a (1 to 10) scale has been proposed for future workshops.
- Inexpensive to use and implement as it can be applied in the context of an existing workshop and represent a one-hour add-on to the program with minimum marginal costs.
- It allows stakeholders to point in the right direction regarding the most important effects of an action if deeper BCA is needed for quantitative valuation.

→ **Challenges faced and lessons learned**

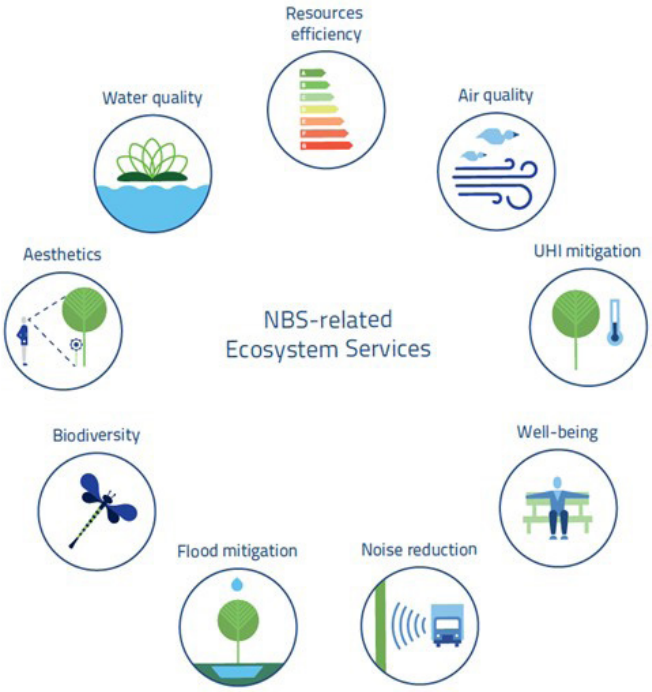
This unique methodology could be employed in other case studies where a WTP approach is assessed for long-term investments for mitigating the negative consequences of climate change. The PBCA tool could be applied before a full data-based BCA to potentially rule out investments that participants (stakeholders) may evaluate as non-starters. More research should be conducted on the validity and usefulness of this approach, evaluating the possible beneficial outcomes to such a study in lieu of or as a supplement to a traditional BCA.

3.12.5. LOCAL MULTI-PURPOSE GREEN INVESTMENTS

In the past few decades, urbanization has taken place in Europe rapidly, causing environmental problems including air and water pollutions and the loss of biodiversity. At the same time, cities are negatively affected by the effect of climate change, which increases the severity and frequency of natural

hazards such as droughts, floods, and extreme heat. In this context, implementing nature-based, blue green solutions in cities is viewed as an effective and promising approach to offset the negative impacts of urbanization and enhance sustainability as well as urban resilience to climate change. Other benefits of such investments include improving resource efficiency, increasing aesthetic value for properties, creating areas for recreational purposes, and creating jobs (Maksimovic, 2017) (see *Figure 48* below).

Figure 48: Benefits of NBS in urban environments



Source: Maksimovic (2017)

In Europe, investments in blue green measures have yielded promising results and inspirations. Some examples of such investments are showcased in more detail in *Box 18* below.

Box 18: Examples of investments in urban blue green infrastructure

A review of investments in blue green infrastructure in cities across Europe provided several lessons learned and inspiring achievements outlined below. A common theme is that the two investments improve the cities' adaptation to climate change while enhance their sustainability.

Funded under the EU's Horizon 2020 research and innovation programme, URBAN GreenUP (2020) is a project that promotes the use of NBS in urban areas to reduce the negative impact of climate change and improve air and water quality. It provides digital tools to assist policymakers and city planners to choose the most effective NBS based on a city's capacity and the expected outcomes. The project is currently on-going in three European cities (Valladolid of Spain, Liverpool of the UK, and Izmir of Turkey) and will take place across Europe, Latin America, and Asia in the future.

Covering about 100 hectares, the Budapest City Park of Hungary is a multi-functional area redeveloped with the goal to create a sustainable urban metabolism system (Maksimovic, 2017). To achieve the goal, a systematic analysis of the water, energy and waste flow was conducted for the park by the design team of the project. The park is expected to mitigate the effect of urban heat and heavy participation and is estimated to yield a 35 percent saving in energy and 95 percent saving in water and reduce waste by 65 percent. The overall payback time of the project is less than 6 years comparing to the cost of the infrastructure.

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5. Annexes

5.1. Annex 1: Key terms and definitions related to methodologies to the estimation of costs and benefits of DRM investments

Benefit-cost analysis: Process used to identify, measure, and analyse the benefits of a project, program, or decision versus the costs associated with it.

Benefit-cost ratio: Ratio used in BCA to summarize the relationship between overall relative benefits and costs of a project. A BCR lower than 1 means that the project net benefits could be negative—that is, benefits are lower than costs.

Direct and indirect benefits/costs: Benefits/costs can directly be associated with the impact of the project/program/decision, for example, asset losses prevented or environmental value enhanced due to a flood prevention measure preventing a substantial impact on the asset as well as direct costs of the flood prevention measure. They can also be indirectly associated with the impact, for example, productivity losses prevented given the measure as well as increases of prices in the area leading to displacement and loss of welfare/well-being of certain populations.

Discount rate: Rate of return used to discount future cash flows back to their present value. Financial discount rates are the interest rates used to calculate the present value of future cash flows from a project or investment. Social discount rates indicate a society's average valuation of future versus present impacts of interventions (benefits and costs). A high discount rate indicates a lower valuation of the future and a preference for the present, which particularly in the context of climate change also concerns intergenerational equity aspects.

Internal rate of return (external rate of return): Metric used in analysis to estimate the benefits of potential investments. The IRR is a discount rate that would make the NPV of all monetary flows equal to zero in a discounted monetary flow analysis. The external rate of return also considers inflation and costs of capital.

Net present value: Difference between the present value of monetary inflows and the present value of cash outflows over a period. The idea behind the NPV is to project all future monetary inflows and outflows associated with a project/program/decision, discount all these flows to the present day, and add them together. A positive NPV means that, after accounting for the time value of monetary flows, the project/program/decision could yield net benefits.

Sensitivity analysis: Determines and showcases how results change when assumptions, particular parameters, or variables of an analysis are changed.

Value of statistical life and value of a life year: The value of statistical life (VSL) is the marginal rate of substitution between income (wealth) and mortality risk, that is, how much individuals are willing to pay on average to reduce the risk of death. It does not therefore indicate the value of an actual live but the value of marginal changes in the likelihood of death. The value of a life year (VOLY) is derived from the willingness to pay (WTP) for increasing life expectancy by one additional year, which is considered more appropriate for disasters that are mostly displacing mortality (that is, affecting certain age groups) rather than causing mostly premature deaths. Theoretically, measurements of actual changes in life expectancy would be the exact measure to consider.

5.2. Annex 2: A step-by-step practitioner report on applying the Triple Dividend BCA

This part includes a detailed description of methods and approaches used at each step of the Triple Dividend BCA as well as lessons learned. It can be used as a guide as it outlines many of the practical difficulties that may be faced when undertaking Triple Dividend BCA with limited resources (time, budgets, data) and with the objective of covering a large number of investments to review.

1. DEFINING THE GOALS AND OBJECTIVES OF THE PROJECT

For this particular analysis, the goals and objectives described for each investment were the ones described in project documentation for EU and World Bank projects. The case studies that were mostly considered for more in-depth analysis were those that had goals and objectives closely related to DRR investments. Otherwise, additional objectives of the investments were outlined qualitatively and were considered as much as possible in the analysis as co-benefits to ensure that costs considered would be in line with the scope of benefits.

The overarching goal of each of the projects evaluated using the triple dividend BCA is disaster risk reduction and ultimately building resilience. This can occur either directly (for example, building dams and EWS) or indirectly (for example, school retrofit program). Examples of disasters include floods, earthquakes, heatwaves, wildfires, and storms. Investment in each of these projects is pre-defined, and the consequent objectives and benefits are well perceived. However, most of the benefits are often qualitative, and often range between direct financial and indirect societal benefits. Under the triple dividend approach, we capture and quantify as many of these benefits as possible using a combination of robust methodologies.

We identified DiDs as being theoretically the best methodology to calculate the benefits of DRM/DRR investments. However, identifying a suitable counterfactual in addition to the limitation of panel data were challenges that limited our analysis to more fact-finding than sophisticated econometric or statistical estimation. Second and third dividends are often overlapping, and the possibility of confounding effects of other unrelated interventions made the assessment particularly difficult.

Existing data and literature allowed us to directly identify the first dividend (that is, lives saved) of a project in most cases, but only in some cases or partly the second and third dividends. Although the third dividend of investments can be multi-faceted, we were able to quantify only a handful of those benefits. Therefore, our calculation of BCRs is necessarily a lower bound estimate rather than overestimation. Despite the limitations, we were able to identify benefits beyond the first dividend often using the best available yet coarse data.

2. LIST ALTERNATIVE PROJECTS

Due to the unavailability of data, we mainly focused on a retroactive analysis of investments without using a DiD approach. A theoretical best practice approach with a perfect counterfactual was mostly not possible in this analysis. However, some analysis was undertaken with theoretical investments so that the counterfactual could reasonably be assumed, which also served as theoretical synthetic controls.

Unlike the private sector investment projects, DRM/DRR projects generally are managed and funded by the public sector and therefore seldom have alternatives. Aimed at maximizing societal benefits, such investment projects often do not have alternatives, meaning that we have to resort to BCA of a given project instead of additionally identifying the cost-effectiveness of alternative projects with same goals and objectives (that is, with similar benefits) but with different benefits. Under this simplified scenario, we only considered specific projects undertaken for disaster risk reduction in the EU and neighbouring countries.

3. LIST STAKEHOLDERS (THAT IS, BENEFICIARIES)

Difficulties were faced in defining the beneficiaries that could be reasonably assumed for certain types of investments with broader potential reach or high

positive spillover effects. While all the economic subsectors are interconnected, separating out the impacts of an investment on all economic subsectors across different regions requires detailed input-output data. In the absence of such an ideal set of data and information, we rather took a conservative approach and assumed beneficiaries would be those outlined as direct beneficiaries of intervention. However, some notable exceptions were made, for instance for EWS.

4. SELECT AND MEASURE ALL COST AND BENEFIT ELEMENTS

Overall, we only included what could be a certain benefit and with sufficient evidence available in order to avoid overestimation. The selection of possible costs and benefits was based on a review of literature, discussion with senior experts, consultations and brainstorming within the team. The major component of cost comes directly from project documents where direct investments are listed. In addition, we also identified other operational costs associated with the implementation of the said project. Wherever possible, we matched costs with each dividend. However, some costs such as direct investments are overlapping across dividends and we do not categorize them by dividends.

In particular, first and third dividends are reasonably outlined and quantified. For the first dividend, economic benefits stem from quantifying the value of lives saved due to interventions. On the other hand, the third dividend, whenever identified, comes from quantifying the co-benefits of such interventions.

However, the literature around the broader economic benefits of DRR investments (second dividend) is less established. In addition to the common challenges of attribution and data for management, there were also difficulties in determining the benefits that could be reasonably considered for disaster risk investments under the second dividend.

The basis for the prediction of benefits and costs in DRR investments (specifically Dividend 1) is based on risk assessments. There are alternative approaches to calculating the direct benefits of DRM when disasters strike outlined below. The report has aimed to model future risk as much as possible as the other options were not considered given lack of data, information and scope of the study.

- *Modelling future risks.* This is the *direct approach* – projecting the future risks will allow us to identify how much damages and losses would have been avoided from DRM investments.

- *Existing case studies. Indirect approach.* Especially case studies conducted by the WB can be useful in this regard. Assuming all necessary data and information are available, we can then extract them to calculate TD and conduct the BCA. Selection of case studies will be a tricky matter – we need a comparable DRM project for this purpose.

- *Past disasters and DRM investments.* This is another indirect approach to calculate the first dividend. If we have data on past investments, and also have a DiD set up (that is,, pre- and post-DRM data from treatment and control regions), then we can calculate the first dividend using DiD econometric method.

Risk analytics supported the estimation of avoided losses and lives saved through comparing impacts with and without interventions. The principle was to assess the lives lost and losses incurred in a case study location, with and without the intervention being studied, using a combination of recorded impacts and simulated impacts. For instance, in areas where an engineered structure is expected to have an impact on replicable physical processes (for example, flood protection impact on flood extent), we would propose to model the effect of that protection adjusting the frequency of flooding using a suitable model (for example, a disaster risk model). In the case of non-engineered interventions, other exposures or impact analysis on a scenario basis were considered, with attention to how multiple factors might affect the impact beyond the limits of the intervention itself.

5. PREDICT OUTCOME OF COSTS AND BENEFITS OVER THE RELEVANT TIME PERIOD

For the prediction of costs and benefits over a relevant time period, two parameters are particularly important to consider including i) lifespan of infrastructure/ measure considered and ii) valuation of lives saved.

In this report, the selection of lifespan varied for various types of investments given different lifetimes of infrastructure, also dependent on the type of

intervention (retrofitting, building, and so on). The time period used in the economic analysis of projects should reflect reasonable estimates of the full duration of costs and benefits associated with the project, rather than be capped at 20 years or some arbitrary cut-off date.

World Bank's investments in DRM consider that prevention saves lives, so that BCAs associate some numerical estimate to the value of life, the so-called VSL. The literature (Braathen, et al., 2009; David, 2000) outlines problems with using VSL for valuation of lives saved. In fact, high VSLs tend to bias impacts and risks upwards, leading to leading to overestimation of benefits relative to costs. Moreover, country VSLs are relative to GDP, so that any analyses focusing at different than country levels would need to consider how to resolve this/what value to apply (such as average/median EU GDP and so on).

After multiple considerations, this report has undertaken a consistent approach to the calculation of the VSL. The choice of valuation of lives saved to estimate the first dividend required an in-depth review of the literature and approaches of different institutions (for example, EC, OECD, and the World Bank) as well as discussions with the client and advisors to ensure an approach that would apply methodological best practices, ensure the relevance of estimations to the EU context and ensure least possible controversy over estimated values.

This report has used country-specific BCAs based on an average value for upper income countries (considered suitable for EU countries). For non-EU countries under consideration, we have adjusted the VSL for relative income (that is, the ratio of per capita GDP of the country of interest to the average per capita GDP in the EU) and income elasticity of VSL (set at 1 which is consistent with the suggestion that the income elasticity of VSL is slightly above 1 for non-US countries). These values are all based on research by Viscusi and Masterman (2017) for VSL or Chiabai, Spadaro, and Neumann (2018) for VOLY (Value Of Life Years) approach would be used wherever applicable and possible with data available for assessing certain investments such as heatwaves. We will also be using QALYs, which is more common and used in BCAs as a proxy for time spent in hospitals due to heat.

Alternative approaches or values considered for estimating the value of lives saved were as follows:

- PESETA III report value with a VSL of €1.3 million per person
- OECD VSL US$1.8–5.4 million (median of US$3.6 million)
- VSL of €400,000 per fatality and €65,000 per injury as per 2014 European Commission BCA guidelines
- Adjusting the US VSL US$9.7 million with income elasticities (Viscusi and Masterson (2017) values)
- DALYs that can be used for health impact assessments globally but are generally not used as an economic measure.

6. CONVERT ALL COSTS AND BENEFITS INTO A COMMON CURRENCY

For comparison purposes, it is important to convert all costs and benefits into a common currency. Given the regional focus of this analysis, we express all monetary values in the Euro currency. For this purpose, we use the official annual average exchange rates as reported in the World Bank's World Development Indicators.

Since the BCR is unitless but sensitive to currency year, we made sure to express both the costs and benefits in the same fiscal year. When necessary, we use consumer price index (2010 base year, that is, 2010 = 100) for converting monetary values from one year to another. We employ the same strategy for all historical monetary data.

7. APPLY THE DISCOUNT RATE

Standard economic analysis links social discount rates to the long-term growth prospects of the country where the project takes place. Higher (lower) growth prospects would normally imply a higher (lower) discount rate for a particular country. Given reasonable parameters for the other variables in the standard Ramsey formula linking discount rates to growth rates, a 3 percent per capita growth rate translates into a 6 percent discount rate, and per capita growth rates of 1–5 percent yield discount rates of 2–10 percent (World Bank, 2016).

The literature (Gollier, et al., 2014) outlines challenges associated with the choice of discount rates. This applies particularly for investments that are mainly addressing future challenges with high uncertainty but

substantial negative impacts (Weitzman, 2011). It was even argued by some to apply a very low discount rate, or close to zero. Considering the debate whether the discount rate should be zero for environmental investments, we resort a low value of social discount rate.

World Bank financed projects consider that economic analysis should link social discount rates to long-term growth prospects of the country where the project takes place. Given reasonable parameters for the other variables, the standard Ramsey discount rate formula is generally used. The discount rate is relative to GDP, so that any analyses focusing at different than country levels would need to consider what value to apply (such as average/median EU GDP and so on). It is noted that the JRC also applies specific discount rates, and it is important to understand differences between sectors as DRM investments are cross-sectoral.

This report applies varied discount rates aligned with appropriate values for social DRR investments but also market values. Given the controversy over discount rates but also the tendency for economists to apply discount rates aligned with market values, the report includes country-specific discount rates ranging from 1.5 percent (which is suggested by the UK treasury for health-related assessments) to 5 percent (which is consistent with the Imperial College's suggested 4 percent discount rate). Specialized discount rates are used for example for environmental investments.

8. CALCULATE THE NPV OF THE PROJECT UNDER CONSIDERATION

All the projects under consideration have streams of future benefits. These needs, for the sake of comparison, to be valued at current prices. That is, we converted all future monetary values to present monetary value using the appropriate discount rate. For this purpose, we use the standard formula:

$$P_t = \frac{F_{t+\tau}}{(1+r)^{\tau}}$$

where P and F denote present and future values, t denotes time and τ denotes time difference between present and future. Finally, r denotes the discount rate.

In addition, we calculate the net present benefits (NPV) of an investment according to

$$NPV = \sum \frac{B_t}{(1+r)^{\tau}} - \sum \frac{C_t}{(1+r)^{\tau}}$$

NPV is the difference between the present values of benefits $(\mathrm{B\_t})$ and costs $(\mathrm{C\_t})$ from all the future years. When all the economic benefits are accounted for, a project is economically/socially beneficial if $\mathrm{NPV}>0$.

Finally, we calculate the ERR which provides the estimated rate of return equating the present values of benefits and costs. That is, the rate of return at which the DRM project will be equally beneficial to a market-based investment project. This is calculated as

$$ERR = 100 \times \frac{NPV}{\sum \frac{C_t}{(1+r)^{\tau}}}$$

9. PERFORM SENSITIVITY ANALYSIS

Regardless of the choice of different parameters, it is good practice to provide a sensitivity analysis. This analysis is undertaken with respect to model parameters that are based on judgement and expert opinions instead of established practices. In this analysis, since the choice of discount rate is somewhat arbitrary, it is important to investigate how sensitive the results of this analysis are to different discount rates. In particular, we perform sensitivity analysis for the range of discount rates from 1.5 percent to 5 percent.

Generally, net benefits calculated tend to be quite sensitive to the choice of valuation of lives in particular and lifespan (as related to different disaster scenarios). This is also linked to the choice of disaster risk scenarios and therefore these parameters should generally always be included in a sensitivity analysis.

10. OUTLINE POTENTIAL EQUITY ISSUES

It is widely recognized that most DRM projects have positive net benefits, but the concrete distributional effects of such projects are mostly unknown. A known fact is that the impacts of disasters disproportionately affect poorer households (World Bank 2020a) and it would therefore be of crucial importance to assess the differential impacts of DRR investments as the value of

avoided losses in terms of developmental impacts and reduced recovery times may differ depending on the characteristics of individuals or households benefitting from it. However, an investigation into the distributional effects of DRM investments will require quantile regression analysis based on detailed household level survey data, which is not available for our analysis.

Equitable distribution of benefits intrinsically depends on the capacity of local communities to capitalize on the employment opportunities created in the process of project implementation. For example, construction of large DRM infrastructures requires labour, who can be locally recruited. One potential way of ensuring this could be to include local communities in the implementation of the project, either through allocating property rights or through legally binding contracts with local authorities. However, such policies might have their own costs and benefits, and require more focused analysis.

Moreover, employment opportunities furthered by large DRR investments may not be permanent. Local workers with the experience of working in those projects will have to seek future employment elsewhere instead of locally. It is possible that experienced workers may not be available locally, which will complicate the project appraisal even further.

Environmental factors should be covered by Triple Dividend 3 considerations. However, those have not been estimated it is worth at least qualitatively describing the potential impacts the investment could have, positive and negative, in terms of environmental externalities or climate change. Whenever data is missing, these equity, environmental and intergenerational factors could be considered and addressed through scoring/rating based on qualitative analysis.

11. SUMMARY AND RECOMMENDATIONS

The triple dividend approach to identifying additional societal benefits is becoming increasingly popular, especially for environmental project appraisals in recent years. While the multi-faceted benefits were qualitatively justified, this analysis quantifies as many of them as possible using the best possible approach. In addition to the educational value of this analysis, we also identified important caveats in conducting a full-scale triple dividend BCA for DRM projects.

Available information enabled us to identify the first dividend in all the cases, and the third dividend in most of the cases. However, the complicacy remains around identifying and quantifying the second dividend. Most of the benefit items under the second dividend may arise from alternative sources, implying that a dedicated investigation with the scope of primary survey is necessary for identifying those benefits, which is beyond the scope of this analysis.

While the report has aimed to further as much as possible comprehensive analysis, many caveats still remain. In addition to difficulties of estimating more intangible benefits included in the third dividend such as environmental benefits or externalities, distributional impacts in terms of poverty and employment growth could also not be estimated. This will remain as a limitation, and a potential future scope of investigation.

5.3. Annex 3: Additional Information on the Methodological Approach

ALTERNATIVES TO TYPICAL BCA PROCEDURES

Several studies have identified the limitations and criticized the use of BCA to evaluate DRM investments. These studies (Mechler, 2016; Kull, et al., 2013; Shreve & Kelman, 2014) have argued for a shift in the emphasis on BCAs and proposed alternative economic analysis tools. They have mainly criticized the lack of (a) risk-based analysis and sensitivity analysis undertaken as part of BCAs (due also to lack of historical data for probabilistic estimations of losses), (b) consideration of potential impacts of climatic changes and high uncertainty or irreversibility, (c) evaluation of reasonable durations of benefits, and (d) broader considerations of processes of vulnerability and technical limitations for the estimation of non-market goods. The studies have also highlighted potential negative externalities from DRR measures such as environmental or health impacts and distributional considerations (given the emphasis on

maximizing social welfare instead of optimizing the distribution). Discretionary discounting and ethical concerns over associating a monetary value to life have been mentioned as additional challenges to use BCA. They also propose to shift from purely infrastructure-based/'hard' solutions to more systemic interventions emphasizing preparedness/'soft' solutions.

There are several alternatives to BCA proposed in literature. These approaches can be valuable to determine under which conditions a particular investment might be considered economically viable and to collect useful information (expert and stakeholder judgment) on the possible consequences of a project and opinions about parameters (river flows or bridge span for floods for example). The approaches are particularly critical for consideration when investing in infrastructure that has a long life span.

- Cost-effectiveness analysis (CEA) is used to identify least-cost options to meet a specific, predefined target or policy objective. Because project costs are the variable of consideration, CEA does not require the quantification of benefits and can therefore also be applied with intangible or more qualitative benefits.

- The MCA methodology emphasizes low cost and is organized around objectives, criteria, and indicators that can be compared to the performance of different (policy) options over time in achieving one's stated objectives (economic, social, environmental, and fiscal criteria). A form of MCA is multi-criteria evaluation (MCE), also called criticality analysis.

Criticality analysis (Rozenberg, et al., 2019) has been used in several contexts for the prioritization of infrastructure projects and maintenance and to combine social and economic assessments of critical interventions.

- Differentmethodologies have been proposed for decision-making under deep uncertainty (Marchau, 2019). These are BCA under uncertainty, BCA with a real options approach, robust decision-making, and climate-informed decision analysis and all have different strengths for different applications. One of the most significant challenges when incorporating climate change in BCA is the calculation of total benefits when longer time horizons are considered and where there may be considerable uncertainty. In particular, broad-scale climate changes represented in coarse-resolution regional climate models cannot be used with confidence to determine local trends in precipitation at the scale of a single case study without significant uncertainty, added to which is the likely contribution of other environmental and socio-economic factors (for example, catchment management and development of floodplains) affecting changes in flood hazard in the same time frame. This will imply that instead of taking an optimal decision, implying reliable descriptions of the future, we may engage in a process of robust decision-making that would enable the best outcomes under a range of futures and worldviews. Like the criticality model, this approach enables us to look beyond the infrastructure and consider the broader user and welfare perspective to investments with potential large impacts. Hallegatte et al. (2012) even conclude that there should always be a discussion of a menu of possible investments in various contexts and a variety of methodologies applied.

Robust decision-making approaches involve a process of dialogue given acceptance of uncertainty and are by nature iterative and adaptive. However, different approaches can be used, including 'no-regret' strategies (for example, controlling leakages in water pipes) or minimizing regrets (building larger reservoirs when applicable), reversible and flexible strategies (adjustable insurance and EWS), safety margin strategies (calibrating drainage infrastructure with higher runoff figures), and strategies that reduce decision-making time horizons (stepwise investments in infrastructure starting with lower cost options).

POTENTIAL ECONOMIC BENEFITS OF ECOSYSTEM SERVICES

Ecosystem services should be valued in a similar manner to any other economic asset: their social value (that is, aggregate WTP) must equal the discounted NPV of these flows. However, the values attributed to these services can only be measured indirectly, since they are derived from supporting and protecting

activities (that is, strategically implemented DRM projects) that have directly measurable values.[41] Following Barbier (2007), a production function approach[42] can be used, which requires the information on the change in an ecosystem – in terms of service that people care about – to place a value on those services.[43] This is particularly relevant for regulatory and habitat functions that support or protect economic activities. If the benefits of these services enhance the productivity of economic activities, or protect them from possible damages, the aggregate WTP for such services can be estimated as if they were a factor input in these productive activities.

The production function approach involves a two-step procedure. The procedure includes assessing (i) the physical effects of changes in a biological resource or ecological service on an economic activity are determined; (ii) the impact of these environmental changes is valued in terms of the corresponding change in the marketed output of the relevant activity. Key features of this production function approach include: (i) an ecological function is effectively a direct input into production, and the value marginal product of changes in this function can be derived to determine its value; (ii) adopts either profit-maximizing or social welfare maximizing framework; (iii) can be applied in a static or a dynamic framework.

ECOSYSTEM FUNCTIONS	ECOSYSTEM PROCESSES AND COMPONENTS	ECONOMIC SERVICES (BENEFITS)
Regulatory Functions Gas regulation Climate regulation Disturbance prevention Water regulation Soil retention Soil formation Nutrient regulation Waste treatment	Role of ecosystems in biogeochemical processes Influence of land cover and biologically mediated processes Influence of system structure on dampening environmental disturbance Role of land cover in regulating run-off and river discharge Role of vegetation root matrix and soil biota in soil structure Weathering of rock, organic matter accumulation Role of biota in storage and recycling of nutrients Removal or breakdown of nutrients and compounds	Ultraviolet-B protection Maintenance of air quality Influence of climate Maintenance of temperature, precipitation Storm protection Flood risk reduction Drainage and natural irrigation Maintenance of arable land Prevention of damage from erosion and siltation Maintenance of productivity on arable land Maintenance of productive ecosystems Pollution control and detoxification
Habitat Functions Niche and refuge Nursery and breeding	Suitable living space for wild plants and animals Suitable reproductive habitat and nursery grounds	Maintenance of biodiversity Maintenance of beneficial species Maintenance of biodiversity Maintenance of beneficial species

Source: Barbier (2007, 2009)

41 For example, coastal and estuarine wetlands, such as tropical mangroves and temperate marshlands, act as "natural barriers" by preventing disturbance of storm events, thus providing valuable storm prevention and flood mitigation services.
42 Such PF approaches are being increasingly employed for a diverse range of environmental quality impacts and ecosystem services, including the effects of flood control, habitat-fishery linkages, storm protection functions, pollution mitigation and water purification.
43 On the other hand, stated preference studies (contingent valuation, conjoint analysis and choice experiments) additionally require that the change in the ecosystem must be explained in the survey instrument in a manner that people will understand and not reject the valuation scenario.

5.4. Annex 4: Background Information on case studies

EARTHQUAKE

Summary of WTP methodologies

A contingent valuation is a method of estimating the value that a person associates with a good or service. This can be measured in two ways: WTP and willingness to accept (WTA). The first one seeks to comprehend an individual's willingness to obtain a good/service, while the latter focuses more on how much it would take for someone to give up a good/service. WTP and WTA are most commonly used to place value on commodities that are not exchanged in a hypothetical marketplace. As a result, this methodology is most commonly applied to public goods and private non-market goods, and in the context of the environment, this pertains to issues including, but not limited to, improvements to water or air quality, national parks, and reducing the risk of death.

Researchers measure a person's environmental WTP or WTA by conducting environmental valuation surveys that measure both their stated preferences as well as their revealed preferences. In "Aesthetic Value of Lakes and Rivers" by Corrigan, Egan, and Downing (2009), the co-authors found that people would be willing to visit Clear Lake (Iowa, USA) more often if the lake's water quality was improved.

There is some concern about how accurately hypothetical WTP overestimates a person's real WTP. To understand this, Blumenschein et al. (2008) compared two methods of removing hypothetical bias: cheap talk approach and certainty approach. A cheap talk approach takes a survey respondent's answer as is, meanwhile the certainty approach further asks participants how confident they are in their answer. They found that unprocessed contingent valuations have a hypothetical bias, and that this could be easily removed by implementing a follow-up question about the certainty of their responses.

Another factor that impacts someone's WTP is the framing of a hypothetical situation during a contingent evaluation exercise. In order to limit the projected increase in natural disaster risks caused by climate change, adaptation measures are recommended to partially or fully eliminate this risk. Literature in behavioural economics found that individuals rarely undertake measures that reduce risk partially, but they are willing to considerably invest in adaptation measures that reduce risk to zero. This was shown for example in a study by Botzen, Aerts, and van den Bergh (Botzen, et al., 2009) to determine households' willingness to invest in flood insurance versus elevating newly built structures in order to adapt to the flood risk that climate change imposes on the Netherlands. The results indicated that 52 percent of homeowners are willing to make a substantial investment of €10,000 to elevate a new house to a level that is safe from flooding. A household's decision to invest in an elevated home strongly stems from their expectations on the negative effects of climate change, perceptions of flood risks, individual risk attitudes, and how close they live to a main river.

As noted from the thought process Dutch citizens go through when deciding to invest in elevating their house to avoid flood risk, expectations and perceptions are critical to determining an individual's WTP or WTA. In fact, for people in developing countries, the WTP for an environmental protection premium is determined by a combination of beliefs and perceptions about one's own knowledge rather than facts about climate change. This supports insights from other research that it is generally more effective to appeal to people's existing values and beliefs in order to communicate the importance of investing in climate change or taking actions to mitigate the effects of climate change.

In Song, Wang, and Li (2016) paper, "Residents' attitudes and WTP for solid waste management in Macau," researchers structured their survey in four parts: (1) general questions regarding the basic environmental issues, (2) questions measuring respondents' knowledge and attitudes on solid waste recycling, (3) a description of the WTP, and (4) questions collecting socio-economic data on the respondents. By measuring residents' insight on the environment, the type of adaptation measure in question, and their demographics, Song and his co-authors are able to paint a better picture of the types of people in the neighbourhood who more willing or less willing to pay for solid waste management. They are also able to test if there is a correlation between an individual's views and demographic factors or the

degree to which they understand waste management and/or broader environmental issues.

Civil Protection Capacity Building

The following descriptions of the UCPM Knowledge Network and the Albania Earthquake are useful as background information for the work showcased in section 3.2.4.

1. UCPM and Knowledge Network

UPCM/Union Civil Protection Knowledge Network - The 2019 revision to the UCPM created a Union Civil Protection Knowledge Network to bring together a number of existing civil protection and disaster management programs under one umbrella to support experts, practitioners, policy-makers, researchers, trainers and volunteers to increase DRM knowledge and its dissemination within the UCPM.

The various programs under the Knowledge Network include:

UCPM Training - Offering both DRM coordination and technical experts training from a programme of 11 courses. These range from basic training to high-level sessions for future mission leaders, including specialised courses such as security training and assessments.

Exchange of Experts in Civil Protection – Allows for secondment of civil protection experts between UCPM MS, PS and eligible third countries. Through exchanges on topics like firefighting, communication, search and rescue, or new and emerging threats, participants gain practical experiences and knowledge of the different approaches of national systems.

Civil Protection Exercises - Alongside full-scale exercises, which are organised by civil protection authorities of countries and co-financed by the EU, modules field and table-top exercises (EU MODEX) are organised under the supervision of the UCPM.

EU MODEX exercises - test the self-sufficiency, interoperability, coordination and procedures of participating experts, 'modules' and other Response Capacities. A 'module' is defined under Decision No 1313/2013/EU as a self-sufficient and autonomous predefined capability or a mobile operational team (both the human and material resources needed). Example modules defined under the 2014 or 2018 Implementing Decisions include, for example, Advanced Medical Posts, BCRN capabilities, Emergency Medical Teams, Emergency Temporary Camp, Flood Containment, Forest Firefighting, Field Hospital, Flood Rescue, High Capacity Pumping, Urban Search & Rescue, Medical Evacuation, Technical Assistance and Support, Water Purification (most with several sub-categories within these classes). In 2019, civil protection experts took part in nearly 50 UCPM training courses. 14 MODEX exercises and 2 full-scale exercises took place, and plug-in and host nation support exercises were introduced. 48 countries in and around Europe participate in the exchange of experts programme, with experts being hosted by 36 countries.

2. Albania UCPM and EU/World Bank/UN response to major 2019 earthquakes

In 2019, Albania was struck by two major earthquakes: a magnitude 5.6 struck on 21st September, and a magnitude 6.4 on 26th November. The 21st September mainshock had an epicentre 5km Northwest of Durres (35km West of capital, Tirana) and, according to the assessment of Albania's General Directorate for Civil Emergencies (GDCE), 3329 residential buildings were damaged. The 26th November mainshock was 22 km Northeast of Durres (30km from Tirana) and, according to the joint EU-World Bank-UN PDNA, damaged 11,490 housing units, injured more than 913 people, caused €843m in direct damages and tragically caused 51 fatalities. 48 people were rescued from collapsed buildings by first responders.

The UCPM was activated for both events, and a joint EU-WorldBank-UN PDNA was conducted after the November event.

The September activation saw DG ECHO's ERCC deploy an EUCPT of experts from 6 EU MS (NL, IT, UK, FI, DE, EL) and Norway, an EU liaison officer, and a regional information officer of DG ECHO. The EUCPT facilitated the coordination of incoming in-kind assistance from 13 countries, including 11 EU MS (HU, HR, AT, EL, FI, SL, SK, IT, FR, BU, LV) and Montenegro and Norway. The EUCPT included a Structural Engineer who, in close exchanges with national and local authorities and engineers, identified areas for improvement in the damage assessment

process and methodology. Working with the relevant authorities and institutions, a unified damage assessment method was proposed based on best Albanian practices supplemented by international standards.

In response to the 26th November activation, ERCC deployed 2 EUCPTs (alpha and bravo), with Alpha deploying on 27th November, and handing over to team Bravo on 4th December. A two-person UNDAC team was also embedded into the EU-led team. The teams facilitated the coordination of in-coming modules and in-kind assistance. USAR coordination was led by the Italian team, and other USAR teams included those from Greece, Romania, France, Israel, Turkey and others. Given the relatively small number of active rescue sites, much of the USAR capacity was not being engaged fully, and so EUCPT-alpha used the available USAR engineers to assist the Albanian authorities with damage assessment.

EUCPT-alpha established the DACC to assist the Albanian authorities with damage assessment, utilizing the available USAR Engineering capacity and building on the recommendations of the September UCPM activation. The DACC was operated jointly by EUCPT, UNDAC and USAID, and as the DACC proved effective, the Albanian government made further request for international engineers, both bilaterally and through the UCPM, culminating in 185 international engineers from 18 countries registering with the DACC and coordinated by them to assist ongoing damage assessment.

The PDNA occurred during 18th December – 24th January, encompassing partners from the EU, World Bank and UN who provided financial and Technical support to conduct the assessment in addition to the resources the government made available. The PDNA presents quantitative findings and recommendations on the education, health, housing, infrastructure, productive and DRR sectors, as well as findings on social protection.

EXTREME HEAT

Detailed methodology for UHI analysis

Methodological aspects of the triple dividend approach for green and white solutions in UHI mitigation.

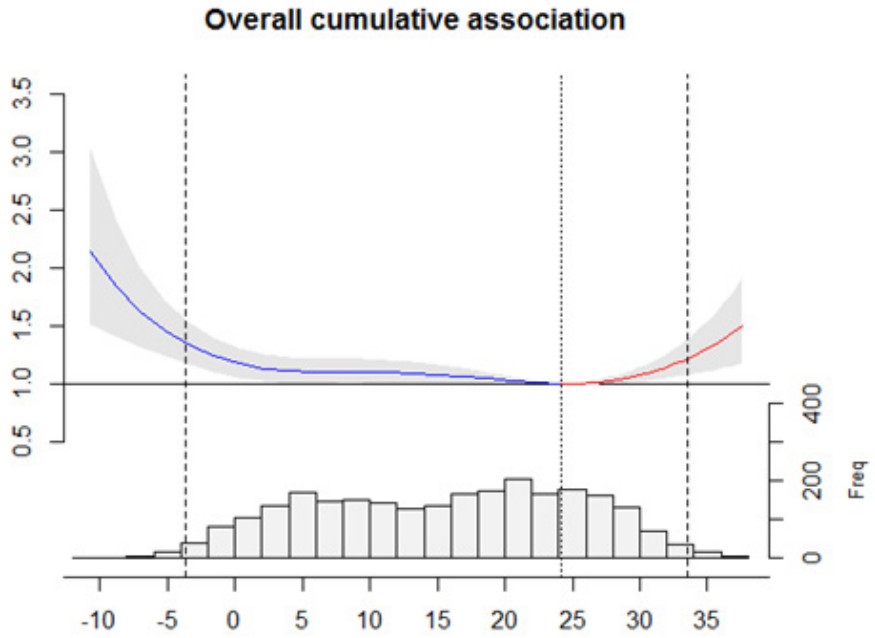
Epidemiological models provide for the estimation of the level of risk associated with extreme temperatures. These models are distributed lag nonlinear models which allows for the estimation of the relative risk of extreme temperatures by accounting for lagged effects on mortality and the nonlinear nature (Gasparrini, et al., 2010). To estimate the heat-related excess mortality in Vienna, Austria, this modelling procedure was carried out along with an estimation of the attributable number of deaths according to the methodology of Gasparrini and Leone (2014). By pursuing such an approach, we also capture the main effects of heatwaves (Gasparrini & Armstrong, 2011).

Daily all-cause death counts for Vienna and daily maximum temperature for 2003-2009 were used for modelling the temperature-mortality relationship while controlling for the effects of daily air pollution levels (O3, NO2, PM10). To capture the exposure-response and lag-response relationships, a cross-basis function [CB(Tempt)] is defined with a quadratic B-spline (two internal knots of temperature with 4 degrees of freedom) for the exposure-response function and a natural cubic B-spline (three equally-spaced knots on the log scale) for the lag-response for use in the quasi-Poisson regression model:

$$Y_t \sim Poisson(\mu_t)$$
$$\mu_t = \alpha + CB(Temp_t) + NS(Time_t,\ 8\ df/year) + DOW_t + O3_t + NO2_t + PM10_t$$

where we controlled for seasonality and long-term trends with a natural spline of time [NS(Timet, 8 df/year)], days of the week [DOWt], and air pollution [O3t, NO2t, PM10t]. The association between temperature and mortality and the empirical estimates of the confidence intervals obtained through Monte Carlo simulations can be seen below (see *Figure 49*).

Figure 49: Overall cumulative association between temperature and mortality



Source: Gasparrini and Leone (2014)

Note: the graph represents the association between mortality (in the scale of relative risk) and temperature distribution. The association is represented in the scale of relative risks. The dotted and dashed vertical lines represent the centre point and values for defining extreme heat and cold, respectively.

With this approach, we calculated an annual number of heat attributable deaths above a daily maximum temperature of 30ºC to be 106 deaths (ranging 39-165 of 95 percent confidence intervals). Given the spatial dimension of UHI effects, we include address exposure the heat hazard by employing the urban climate models already produced for Vienna (Žuvela-Aloise, et al., 2018), population distribution on a raster of Vienna and the results of the temperature-mortality regression. The results of the urban climate model show the current annual average number of hot days in a year for each cell in the raster and the average reduced number of hot days given the set of green measures or a combination of green and white measures. Given the attributable fraction of deaths due to heat (AF), the total deaths (TD) and years (Y) over the time period, and the total population (Poptot), we estimate the reduced heat-related mortality counts (Dred,c) in Vienna for a scenario of measures:

$$\sum_{c=1}^{n} D_{red,c} = \frac{AF \times TD}{Y \times Pop_{tot}} \times \frac{HD_{red,c} \times Pop_c}{HD_{avg,c}}$$

where HDavg,c is the current average annual number of hot days in a cell (c), HDred,c is the reduced average annual number of hot days given the scenario and Popc is the population in the cell. In this spatially explicit approach, we sum over the cells to estimate the total reduced heat-related mortality counts given the scenario of measures and propagate this amount for the following 50 years.

Extreme heat can have significant impacts on both indoor and outdoor labour productivity in Europe, leading to large losses economic losses (Gosling, Zaherpour, and Ibarreta 2018). Given time and data constraints, we employ the approach of Hübler, Klepper, and Peterson (Hübler, et al., 2018) to estimate the reductions in labour productivity loss with the scenarios of implementation that would otherwise occur on hot days. Bux (2006) found that productivity losses can range between 3-12 percent for temperatures of 26-36ºC. For hot days, we assumed an averaged reduced worker productivity loss of 7 percent (Vöhringer, et al., 2017). To estimate the reduced loss in productivity for the city of Vienna, we scale down to the city according to the population (Pop).

$$GRP_{loss} = HD \times \frac{GRP + \left(\frac{p}{1-p} \times GRP\right)}{365} \times w \times p \times Pop$$

We calculate the loss in GRP according to the average number of reduced hot days per year (HD), the current GRP per capita, the average productivity loss on a hot day (p; 7 percent) and the wage share (w; 69 percent).

Several economic and environmental benefits are assessed for green infrastructure under the third dividend. Energy efficiency improvements are valued given the additional insulating layer of green roofs (Berardi, GhaffarianHoseini, and GhaffarianHoseini 2014). We compare the differences in the thermal properties of green and conventional roofs according to Clark, Adriaens, and Talbot (2008) to estimate heating and cooling savings as in the following.

$$H_{sav} = \left(\frac{1}{R_{conv}} - \frac{1}{R_{GR}}\right) \times HDD_{15°C} \times 24\ hrs \cdot days^{-1}$$

$$C_{sav} = \left(\frac{1}{R_{conv}} - \frac{1}{R_{GR}}\right) \times CDD_{18°C} \times 24\ hrs \cdot days^{-1}$$

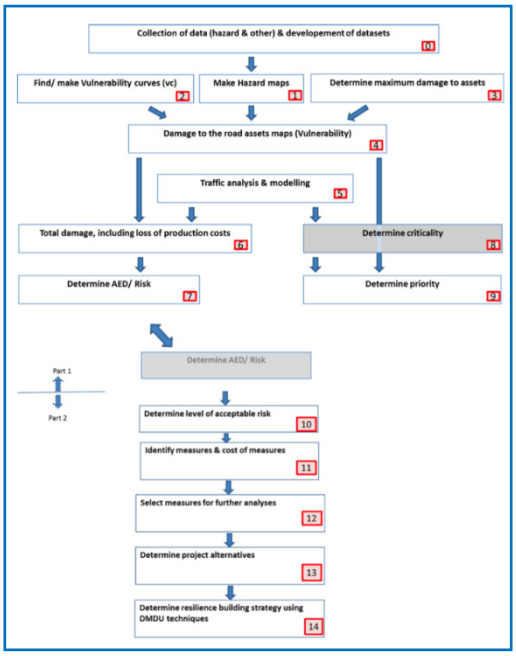
The heating (Hsav) and cooling (Csav) savings are calculated given the thermal conductivities of conventional (Rconv) and green roofs (RGR) and the average heating (HDD15°C) and cooling (CDD18°C) degree days for the past five years of Vienna (BIZEE, 2020). To estimate the monetary amounts of savings, we use the average price of electricity of 0.196 €/kWh and the average price of natural gas heating at 0.068 €/kWh (Bundesministerium für Nachhaltigkeit und Tourismus, 2018). Since Vienna does not currently have a high uptake of air conditioning, we assume the cooling savings are an estimate the value of lower indoor temperatures to society.

Green roofs also improve stormwater management in urban areas by reducing the amount of stormwater run-off being conveyed in municipal sewer systems. We assume a 50 percent decrease in the run-off from greened roof surfaces. Although Vienna does not have a specific stormwater charge per area of sealed surfaces, many Austrian cities, such as Klagenfurt and Salzburg, charge annual rates of 2.2 €/m2 for sealed area. We estimate these benefits by multiplying the total greened area with a 50 percent reduction of the charge. Furthermore, green roofs provide habitats in urban areas for organisms, which was otherwise non-existent (Currie & Bass, 2010). Since the quality of the green roof is only a fraction of a completely natural space, we value the improvement to urban habitats with 15 percent of the cost (Bianchini & Hewage, 2012) for restoring land (MacMullan, et al., 2009). Lastly, green roofs support urban areas in pollution mitigation and carbon dioxide sequestration. We take removal rates of pollutants, including nitrous oxide, ozone, sulphur dioxide and particulate matter (Yang, et al., 2008) and carbon sequestration rates of green roofs (Getter, et al., 2009) to estimate the reduction these negative externalities to society. The valuations incorporate the average of the high and low shadow prices of carbon (World Bank, 2017b), which are increasing into the future, as well as the shadow prices of the air pollutants according to EU-wide damage costs (World Bank, 2017b).

MASS MOVEMENT / LANDSLIDE

Flow chart for criticality analysis process of roads in Albania

Figure 50: Flow chart showing Albania's climate-resilient roads' project approach for parts 1 and 2



Source: Xiong & Alegre, 2019

5.5. Annex 5: Netherlands results from national assessments and BCAs over a century

Table 89: Highlights of one century of BCAs for Dutch flood risk management: conclusions and applications

Year	Topic of CBA	Size of investment mln euro	% GDP	Conclusion or application
1901	Enclosure of the Zuiderzee and land reclamation	43	6.3	Enclosure of the Zuiderzee and land reclamation is a good investment for Dutch society and should include compensation for fishermen.
1954	Delta Works for flood risk protection of the south-western part of the Netherlands (Tinbergen)	890	7.4	The Delta Works are cheaper and safer than raising dikes. The price (net costs) of 0.5 bln euro for the Delta Works for increasing safety does not seem too high and is equal to the material damage during the 1953 floods.
1956	Optimal strength of dikes formula (Van Dantzig)			Water safety is for the first time formulated mathematically as an economic optimization problem. Dikes should be raised until the benefits of the flood risk reduction in terms of less material damage and loss of life and other *imponderabilia* is equal to the additional costs of raising dikes.
1960	Optimal strength of dikes formula applied (Van Dantzig and Kriens)	68	0.4	Formula Van Dantzig applied to dike ring Central Holland and further analysis of the Delta Works. This study played a major role in setting the new safety standards for dike rings.
2000	Room for water (Stolwijk and Verrips)	235	0.1	More water safety not only by technical solutions like dikes, sluices and storm surge barriers, but also spatial solutions, like temporary water basins and making the rivers less straight.
2005	More room for rivers: Optimal strength of dikes (Eijgenraam)	2,215	0.5	Formula Van Dantzig improved by making it more dynamic, i.e. take account of economic growth. This approach was applied to all dikes in the Dutch river regions.
2011	Delta Program for next century: Optimal safety norms for Dutch dikes	10,438	1.8	Improved formula of Van Dantzig applied to all major dike rings in the Netherlands. Extensive set of new estimates of failure rates, economic damage and costs of heightening dikes rings. Detailed modelling of dike rings into parts. Conclusion: in the most urbanized areas it is efficient to raise safety standards before 2050. However, the recommendation by the second Delta commission to raise all current safety standards by a factor 10 is not efficient.
2011	Delta Program for next century: Renovating the Zuiderzee enclosure dam	1,390	0.2	Installing major pumps at the Zuiderzee enclosure dam may result in major safety benefits. The safety of the Zuiderzee enclosure dam has a major impact on the safety of dikes around the former Zuiderzee. This interaction was overlooked in previous analyses on the safety of Dutch dike rings.
2012	Delta Program for next century: Safety and fresh water in the Zuiderzee-region	1,098	0.2	In order to meet rising sea water levels, installing major pumps at the Zuiderzee enclosure dam will save billions of euro's as dikes around the former Zuiderzee need not to be raised substantially any more. Limited investments suffice to triple the fresh water stock in the former Zuiderzee-region in about a decade.
2014	Delta Program for next century: Optimal safety norms for dikes in the Zuiderzee-region			Installing major pumps at the Zuiderzee enclosure dam will indeed result in major safety benefits. In order to take account of the interaction between safety of the Zuiderzee enclosure dam and dikes surrounding the former Zuiderzee, six new types of failure are defined. The study results in new economically optimal safety norms for two barrier dams ('Afsluitdijk' and 'Houtribdijk') and all dikes around the former Zuiderzee.

Source: Bos and Zwaneveld 2017

Table 90: Highlights of one century of BCA's for Dutch flood risk management: benefits and uncertainty estimations

uncertainty estimations

Year	Topic of CBA	Benefits Safety	Biodiversity	Other benefits	Uncertainty estimations
1901	Enclosure of the Zuiderzee and land reclamation	Monetary benefits and costs	No	Value of land reclamation, saving in costs for drainage	No
1954	Delta Works (Tinbergen)	Monetary benefits and costs	No	Value of land reclamation, benefits for agriculture due to less salination and dehydration, time saved in transport, new opportunities for leisure activities	No
1956	Optimal strength of dikes (Van Dantzig)	Expected savings of the value of material damage and loss of lives (static method)	No	No	No
2000	Room for water, 6 projects	Reduction of high water level in m^2	Yes, extra landscape with high quality of biodiversity in hectares	Extra landscape with spatial beauty per kilometer along the river, extra landscape attractive for leisure activities per kilometer along the river	No
2005	More room for rivers: Optimal strength of dikes (Eijgenraam)	Expected saving in the value of material damage and loss of lives, damage increases due to economic growth	No	No	No
2011	Delta Program for next century: Optimal safety norms for Dutch dikes	Expected saving in the value of material damage and loss of lives (extension of Eijgenraam method)	Compensating costs	No	Yes, extended Monte-Carlo analysis showing the sensitivity of the results for different assumptions and scenarios
2011	Delta Program for next century: Renovating the Zuiderzee enclosure dam	All alternatives should meet the same safety standards. Only additional safety benefits are expressed in monetary terms	Yes, different measures including compensating costs, legal standards and biodiversity points	Qualitative discussion of impact on fresh water supply, monuments, mobility, recreation and quality of landscape	Yes, sensitivity analysis showing the extra costs in case of a much faster rise in the sea level
2012	Delta Program for next century: Safety and fresh water in the Zuiderzee-region	Expected saving in the value of material damage and loss of lives minus any extra costs to avoid damage due to raising the water level in the Zuiderzee	Yes, different measures: legal standards, biodiversity points, costs of avoiding or compensating environmental deterioration	Extra fresh water in euro/m^3	Yes, sensitivity analysis with different scenarios for economic, demographic and climatic change
2014	Delta Program for next century: Optimal safety norms for dikes in the Zuiderzee-region	Expected saving in the value of material damage and loss of lives (dependencies between dikes are taken into account)	No	No	Yes, sensitivity analysis with different scenarios for economic, demographic and climatic change

Source: Bos and Zwaneveld 2017

Table 91: The history of Dutch BCA

1901	CBA enclosure of the Zuiderzee and land reclamation
1954	CBA Delta Works by Tinbergen
1956	Economic analysis of optimal strength of dikes by van Dantzig
1959	CBA of two tunnel highway under a channel and river near Amsterdam
1965	CBA land reclamation of the Waddenzee
1969	CBA Schiphollijn, a railway track from Amsterdam to The Hague
1971	Official report by the government recommending cost-benefit analysis:
1975	CBA second national airport in the Netherlands
1976	CBA extending the harbour of IJmuiden/Amsterdam
1985	European act on reporting environmental effects of public and private investments: start of environmental effect reporting in the Netherlands
1993-1995	Reports by CPB on freight railway track Betuwelijn from Rotterdam harbour to Germany
2000	National guidelines on cost-benefit analysis for infrastructure projects
2013	National guidelines on cost-benefit analysis in general
2016-2017	Guidelines on CBA for specific policy themes

Source: Bos and Zwaneveld 2017

5.6. Annex 6: Consultations table for case studies

NUMBER	NAME OF CASE STUDY	INSTITUTIONS CONTACTED (WITH TITLE OF THE CONTACT PERSON, IF AVAILABLE)	NUMBER OF PEOPLE CONTACTED	EMAIL WITH QUESTIONNAIRE	FOLLOW-UP EMAIL EXCHANGE	TELEPHONE CONVERSATION & DISCUSSION
1	Strengthening of residential buildings in Italy	Department of Civil Protection, Ministry	2	Yes	Yes	Yes
2	Building safer schools	World Bank	3	Yes	Yes	Yes
3	Resilient transport modelling	World Bank	1	Yes	Yes	No
4	Resilient roads and escape routes	POR FESR Campania	2	Yes	No	No
5	Climate resilient rail transport	World Bank	2	Yes	Yes	Yes
6	Rate of Return on Health Investments	National Institute for Health Research	3	Yes	Yes	No
7	Response capacity of fire and rescue services	Mol-DG Fire Rescue Service of the Czech Republic	2	Yes	Yes	Yes
8	New vehicles for voluntary fire service units	Marshall Office of Lublin, Voivodeship executive board	1	Yes	No	No
9	Strengthen firefighters to improve preparedness	Joint Secretariat Czech Republic - Republic of Poland	1	Yes	No	No
10	Civil protection and emergency response around the border	Interreg V-A - Spain-Portugal European Commission Programme (Manager)	1	Yes	Yes	Yes
11	Preparedness for heatwaves France	Hydromet agency in France (Météo France)	1	Yes	Yes	Yes
12	Flood protection and liveability	World Bank	1	Yes	Yes	Yes

13	Flood defence infrastructure Austria (Machland dam)	RIOCOM	4	Yes	Yes	Yes
14	Flood risk management on the Sava river	International Sava River Basin Commission, Interreg Europe	6	Yes	Yes	No
15	Flood protection and job creation	Deputy Minister of Development and Investment	2	Yes	Yes	No
16	Flash floods resilience	European Commission (Director General)	1	Yes	No	No
17	Flood protection in cross-border areas	Department of European Union Projects, Regional Development Fund of Central Macedonia (MSc Civil Engineer)	1	Yes	Yes	No
18	Green infrastructure to reduce surface water flooding	European Commission	1	Yes	Yes	Yes
19	Storm surge barriers	RWS (Economist)	1	Yes	Yes	Yes
20	Irrigation and resilience to droughts	Spain Ministry of Environment and Agriculture	1	Yes	No	No
21	Water security	APA - Agência Portuguesa do Ambiente	1	Yes	Yes	No
22	Green roofs in Vienna	FFG/BMVIT, City of Vienna Austria	1	Yes	Yes	Yes
23	Retrofitting buildings for safety	World Bank	3	Yes	Yes	Yes
24	Earthquake early warning in Bucharest	World Bank	3	Yes	Yes	Yes
25	Portugal managing wildlife-urban interface: Industries	University of Coimbra in Coimbra, Portugal; Agency for the Integrated Management of Wildfires	3	Yes	Yes	Yes
26	Portugal managing wildlife-urban interface: Homes	University of Coimbra in Coimbra, Portugal; Agency for the Integrated Management of Wildfires	3	Yes	Yes	Yes

27	Multifunctional ship to tackle marine pollution	Ministry of the Environment of Estonia (Head of Marine Environment Department), Police and Border Guard Board (Police Captain)	3	Yes	Yes	No
28	Dealing safely with hazardous waste	European Commission	2	Yes	Yes	Yes
29	Cleaning up uranium site	Ministry of Environment of Czech Republic, State Environmental Fund	2	Yes	Yes	No
30	Security of nuclear plants	ISRN, Institut de Radioprotection et de Surete Nucleaire	2	Yes	No	No
31	Flood early warning system Flanders	Belgium Environmental Agency	1	Yes	Yes	Yes
32	INTERREG project Eddleston Water	Tweed forum	1	Yes	Yes	Yes
33	Sigma plan – coastal protection of the Scheldt Estuary	vlaamsewaterweg	1	Yes	Yes	Yes
34	Union Civil Protection Knowledge Network in Albania Earthquake	Disaster Preparedness and Prevention Initiative for South-EasternEurope (Head of the Secretariat); Knowledge Network	3	Yes	Yes	Yes
35	Union Civil Protection Knowledge Network in Croatia Earthquake	Disaster Preparedness and Prevention Initiative for South-EasternEurope (Head of the Secretariat); Knowledge Network	3	Yes	Yes	Yes
36	Fuel management in Europe	University of Coimbra, Portugal, Department of Mechanical Engineering; EFI group	2	Yes	Yes	Yes
37	Alerting and Preparedness in Portugal	Portugal Health Regulatory Authority	1	Yes	Yes	Yes
38	Alerting and Preparedness in Greece	Wildfire Management Consulting & Training (Founder)	1	Yes	Yes	Yes

39	Forest management for wildfire prevention	Austria Federal Ministry for Sustainability and Tourism	1	Yes	Yes	Yes
40	River Climate Park for flood protection	Rivierklimaatpark project Team	1	Yes	Yes	No
41	Value of meteorological services Finland	World Meteorological Organization	1	Yes	Yes	Yes
42	Value of the Meteorological services for the transport sector	Wea. Climate Soc (Economist)	1	Yes	Yes	Yes
43	Wetlands restoration	Danish implementing agency,	1	Yes	Yes	Yes
44	Protection against erosion and coastal flooding	Consultancy for Environmental Economics (CEEP) & Policy	1	Yes	Yes	No
45	Restoration of coastal habitats	LIFE/EU	1	Yes	Yes	No
46	Earthquake proof hospital	Assessorato Regionale della Salute	1	Yes	Yes	No
47	Value of the Meteorological services	London Economics	1	Yes	Yes	Yes
48	Network of cities for climate change adaptation	LIFE Veneto ADAPT	1	Yes	Yes	No
49	Multiple resilience measures and economic opportunities	European Commission	1	Yes	No	No
50	Ecological water security	La Région Provence Alpes Côte d'Azur	1	Yes	Yes	No
51	Flood Resilience	World Bank	3	Yes	Yes	Yes
52	Mutual assistance and managing cross-border risks	Interreg V-A - Spain-Portugal European Commission Programme (Manager)	1	Yes	No	No
53	Drought planning in water resource systems	Spanish National Research Council	1	Yes	No	No

54	Protection of sea from wastewater contamination	Parliamentary Secretary for EU Funds - Planning and Priorities Coordination Division	1	Yes	No	No
55	Flood protection and agriculture	Hungary Ministry for Innovation and Technology	1	Yes	Yes	No
56	Blue-green infrastructure for flood protection	City of Dordrecht	2	Yes	Yes	Yes
57	Investments in National Meteorological and Hydrological Services	World Bank	2	Yes	Yes	No
58	COVID19 Lessons Learned	World Bank (Former STC)	1	Yes	Yes	Yes
59	Drina Flood Protection	DPPI SEE Secretariat	1	Yes	Yes	Yes
60	Resilient rebuilding of cultural buildings following an earthquake	Regione Umbria- Servizio Programmazione Comunitaria	3	Yes	No	No
61	Effective monitoring and early warning investments of earthquake and nuclear risks	University College London, Earthquake Engineering	1	Yes	Yes	No
62	Investments in National Meteorological and Hydrological Services	World Bank	2	Yes	No	No
63	Nature-based Solution Investments in Flood Risk Reduction	European Commission: DG ECHO	1	Yes	Yes	Yes
64	Overall Report	European Commission: DG ECHO, DG ECFIN, DG CLIMA, DG ENV, DG REGIO; JRC	8	Yes	Yes	Yes

5.7. Annex 7:
Full overview of final case studies by hazards, sectors, countries and funding

Note: This list is not including all case studies that were considered for this report, which were more than 100 (as included in the inception report), although it has to be considered that some case studies were dropped, and others added since the inception report delivered in June 2020.

NBR	NAME OF CASE STUDY	COUNTRIES	TYPE OF INVESTMENT	SECTOR	HAZARD	TYPE OF ANALYSIS	FUNDING INSTITUTIONS	TOTAL FUNDING (EURO)	CLOSING DATE
1	Strengthening of residential buildings in Italy	Italy	Seismic Strenghtening	Housing and public buildings	Earthquake	Quantitative, Own Analysis	National	1,000,000,000	On-going
2	Cultural heritage protection	Italy	Seismic Strenghtening	Housing and public buildings; cultural heritage	Earthquake	Qualitative	EU	10,000,000	On-going
3	Climate-proofing social housing	United Kingdom	Urban Heat Island Effects	Housing and public buildings	Heatwaves	Qualitative	EU and national	1,615,636	2016
4	Building safer schools	Turkey	Seismic Strenghtening	Education	Earthquake	(Partial) Quantitative, based on the literature	World Bank	270,000,000	2024
5	Schools in seismic countries across Europe	Across Europe	Seismic Strenghtening	Education	Earthquake	Quantitative, Own Analysis	National	57,866,800,000	hypothetical scenario
6	Resilient transport modelling	Serbia	Structural protection	Transport	Flood	Qualitative	World Bank	830,000	2018
7	Resilient roads and escape routes	Italy	Preventive Investment	Transport	Volcano	Qualitative	EU and national	53,415,000	2013
8	Climate resilient rail transport	Romania	Structural protection	Transport	Flood	Qualitative	EU	2,000,000,000	2020

NBR	NAME OF CASE STUDY	COUNTRIES	TYPE OF INVESTMENT	SECTOR	HAZARD	TYPE OF ANALYSIS	FUNDING INSTITUTIONS	TOTAL FUNDING (EURO)	CLOSING DATE
9	The Case of Pandemic Preparedness	EU	Equipment for health-related disasters	Health	Epidemic	(Partial) Quantitative, based on the literature	EU	4,500,000,000	2021 (tbc)
10	Rate of Return on Health Investments	EU (Italy, UK, Sweden, Netherlands)	Return on Investment of National Public Health Program	Health	Epidemic	(Partial) Quantitative, based on the literature	National	varies	2020
11	Response capacity of fire and rescue services	Czech Republic	Cross-border support, coordination mechanisms and capacity building	Emergency response	Wildfires	Qualitative	EU and national	58,377,714	2013
12	New vehicles for voluntary fire service units	Poland	Rescue and emergency response equipment	Emergency response	All hazards	Qualitative	EU and national	7,510,000	2018
13	Strengthen firefighters to improve preparedness	Czech Republic/ Poland	Cross-border support, coordination mechanisms and capacity building	Emergency response	Wildfires	Qualitative	EU and national	7,936,284	2019
14	Civil protection and emergency response around the border	Portugal/ Spain	Cross-border support, coordination mechanisms and capacity building	Emergency response	Wildfires	Quantitative, Own Analysis	EU and national	3,856,250	2020
15	Early Warning and preparedness for Droughts	Danube region	early warning and capacity building for droughts preparedness	Early warning	Droughts	Qualitative	national	1,974,750	2019

NBR	NAME OF CASE STUDY	COUNTRIES	TYPE OF INVESTMENT	SECTOR	HAZARD	TYPE OF ANALYSIS	FUNDING INSTITUTIONS	TOTAL FUNDING (EURO)	CLOSING DATE
16	Preparedness for heatwaves France	France	Early warning	Early warning	Heatwaves	Quantitative, Own Analysis	National	286,933	2020
17	IT and communication for early warning	Poland	Early warning	Early warning	All hazards	Qualitative	EU and national	75,538,065	2013
18	Integrated flood services and climate change awareness	Greece/ Cyprus	Early warning	Early warning	Flood	Qualitative	EU and national	1,159,248	2020
19	Intelligent system for better disaster response	Greece	Early warning	Early warning	All hazards	Qualitative	EU and national	922,631	2020
20	Early warning for volcanic activity	Spain	Decision making for evacuation	Early warning	Volcano	Qualitative	EU and national	1,590,032	2019
21	Information and early warning for preparedness	Malta	Early Warning	Communication/ ICT	All hazards	Qualitative	EU and national	7,000,000	2019
22	Flood protection and livability	Poland	Structural protection	Industry	Flood	(Partial) Quantitative, based on the literature	World Bank and national	505,000,000	2020; 2023
23	Delta Works	Netherlands	Structural protection	Housing and Public Buildings	Flood	Qualitative	national	5,000,000,000	1997
24	Flood defense infrastructure Austria (Machland damm)	Austria	Structural protection	Water; Housing and Public Buildings	Flood	Quantitative, Own Analysis	National	182,600,000	2020 (tbc)
25	Flood risk management on the Sava river	Croatia/ Serbia	Nature-based Solutions	Response & Equipment	Flood	Qualitative	EU and national	1,626,842	2020
26	Flood protection and job creation	Greece	Structural protection	Housing and Public Buildings	Flood	Qualitative	EU and national	84,000,000	2013

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27	Flash Flood resilience	Malta	Structural protection	Housing and Public Buildings	Flood	Qualitative	EU and national	62,505,662	2013
28	Flood protection in cross-border areas	Bulgaria/ Greece	Structural protection	Housing and Public Buildings	Flood	Qualitative	EU and national	9,902,960	2020
29	Floodplain Restoration	United Kingdom	Nature-based Solutions	Agriculture	Flood	(Partial) Quantitative, based on the literature	National	3,079,000	2017
30	Green infrastructure to reduce surface water Flood	Spain	Nature-based Solutions	Housing and Public Buildings	Flood	Qualitative	EU and national	1,817,972	2019
31	Storm surge barriers	Netherlands	Nature-based Solutions	Housing and Public Buildings	Flood	Qualitative	National	450,000,000	2007
32	Irrigation and resilience to droughts	Spain	Irrigation and water provision system	Agriculture; water	Droughts	(Partial) Quantitative, based on the literature	EU and national	31,300,000	2013
33	Water security	Portugal	Irrigation and water provision system	Agriculture; water	Droughts	Qualitative	EU and national	65,000,000	2013
34	Green roofs in Vienna	Austria	Urban Heat Island Effects	Buildings	Heatwaves	Quantitative, Own Analysis	National	varies	On-going
35	Retrofitting buildings for safety	Romania	Seismic Strenghtening	Emergency response; Public buildings	Earthquake	(Partial) Quantitative, based on the literature	World Bank	54,432,000	2024
36	Earthquake early warning in Bucharest	Romania	Early Warning	Emergency response; Public buildings; Early Warning	Earthquake	Quantitative, Own Analysis	EU and national	3,064,328	2013

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37	Portugal managing wildlife-urban interface: Industries	Portugal	Wildland-urban interfaces	Industries	Wildfires	Quantitative, Own Analysis	EU and national	44,482,550	hypothetical scenario (40-year time horizon)
38	Portugal managing wildlife-urban interface: Homes	Portugal	Wildland-urban interfaces	Housing and Public buildings	Wildfires	Quantitative, Own Analysis	EU	2,000,000	hypothetical scenario (30-year time horizon)
39	Avalanche mitigation strategies	Switzerland	Landslide prevention and response investments	Recreation	Landslides/ avalanches	Qualitative	National	varies	2007
40	Mapping landslide hazards	Croatia/ Bosnia and Herzegovina/ Montenegro	Information System and cooperation mechanism	Response & Equipment	Landslides	Qualitative	EU	974,695	2019
41	Multifunctional ship to tackle marine pollution	Estonia	Preventive investments in vessels and equipment in coastal areas	Fishing	Oil spills	(Partial) Quantitative, based on the literature	EU and national	33,100,000	2013
42	Dealing safely with hazardous waste	Latvia	Cleaning up hazardous waste	Water	Chemical	Quantitative, Own Analysis	EU and national	29,000,000	2013
43	Cleaning up uranium site	Czech Republic	Cleaning up Uranium	Water	Radiological	Qualitative	EU	23,895,700	2013
44	Security of nuclear plants	France	Security of nuclear power plant	Energy	Nuclear	Qualitative	National	24,000,000,000	On-going
45	Flood early warning system Flanders	Belgium	Early Warning	Early Warning	Flood	Quantitative, Own Analysis	National	22,763,074	On-going

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46	INTERREG project Eddleston Water	Scotland	Nature-based Solutions	Agriculture & forestry	Flood	(Partial) Quantitative, based on the literature	EU and National	2,387,000	2020
47	Early Warning System in Grimma	Germany	Early Warning	Early Warning	Flood	Qualitative	National	148,000	2010
48	Sigma plan – coastal protection of the Scheldt Estuary	Belgium	Nature-based Solutions	Agriculture & forestry	Flood	(Partial) Quantitative, based on the literature	National	397,000,000	On-going
49	European Flood Awareness System	Across Europe	Early Warning	Early Warning	Flood	Qualitative	EU	21,800,000	2003
50	Property Level Protection	Italy	Property Level Protection	Housing and Public Buildings	Flood	Quantitative, Own Analysis	National	22,763,074	2016
51	Union Civil Protection Knowledge Network in Earthquake	Albania & Croatia	Responder Capacity – Building	Emergency response & equipment	Earthquake	Quantitative, Own Analysis	EU	6,000,000 & 3,700,000	2019 & 2020
52	Safety from natural risks on the Bielsa-Aragnouet and Espacio Portalet road links	France/Spain	Information System and cooperation mechanism	Early Warning	Landslides	Qualitative	EU	4,220,000	2020
53	PyrMove Landslide Prevention	France	Information System and cooperation mechanism	Early Warning	Landslides	Qualitative	EU	**1,042,144.82**	On-going
54	Climate Resilient Road Assets	Albania	Preventive investments in the resilience of roads	Transportation	Landslides	(Partial) Quantitative, based on the literature	World Bank	13,800,000	2019

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55	SUSEN sustainable energy project	Czech Republic	Security of nuclear power plant	Emergency response & equipment	Nuclear	Qualitative	National	100,219,918	On-going
56	Atlas of Rains Intensities (PANDA)	Poland	Early Warning	Early Warning	Flood	Qualitative	National	1,154,517	2020
57	fuel management in Europe	Portugal	Fuel Management for Wildfire Risk Reduction in forests	Forestry	Wildfire	Quantitative, Own Analysis	EU	2,212,203	On-going
58	Alerting and Preparedness in Portugal	Portugal	Decision Support Tools for Climate Change Adaptation and Alerting	Early Warning	Wildfire	Quantitative, Own Analysis	National	19,264,600	On-going
59	Alerting and Preparedness in Greece	Greece	Decision Support Tools for Climate Change Adaptation and Alerting	Early Warning	Wildfire	Quantitative, Own Analysis	National	8,000,000	On-going
60	Interreg España-Portugal	Spain/ Portugal	Cross-border support, coordination mechanisms and capacity building	Emergency response & equipment	Wildfire	Qualitative	EU and National	704,138	2014
61	Landslide management	Italy	Land use planning investments	Housing and Public Buildings	Landslide	Qualitative	National	57,000	2010
62	ARIEM+	Spain/ Portugal	Early Warning	Early Warning	All hazards	Qualitative	EU	4,193,521	2020
63	BASE Project for Climate Change Adaptation	Portugal	Participatory Methodologies for Climate Change Adaptation	Housing and Public Buildings	All hazards	(Partial) Quantitative, based on the literature	National	7,555,674.25	2016

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64	Forest management for wildfire prevention	Austria	Early Warning	Early Warning	Wildfire	Quantitative, Own Analysis	Regional	188,168	hypothetical scenario (30-year time horizon)
65	Mill Brook Scheme	United Kingdom	Nature-based Solutions	Recreational; water	Flood	Qualitative	National	15,181	2016
66	Padgate River Restoration	United Kingdom	Nature-based Solutions	Recreational; water; Agriculture & forestry	Flood	Qualitative	National	281,125	2015
67	Mayes Brook River Restoration Project	United Kingdom	Nature-based Solutions	Recreational; Agriculture & forestry	Flood	Qualitative	National	4,273,100	2012
68	Slowing the Flow at Pickering	United Kingdom	Structural Protection	Agriculture & forestry; water	Flood	Qualitative	National	4,500 ,000	2015
69	Green and Grey solution in Elbe River flood protection	Germany	Nature-based Solutions	Agriculture & forestry; water	Flood	(Partial) Quantitative, based on the literature	National	10,250 (per ha)	2012
70	Sandwich Tidal Defence Scheme	United Kingdom	Nature-based Solutions	Agriculture & forestry; water	Flood	Qualitative	National	24,400,000	2015
71	Alkborough Flats Managed Realignment	United Kingdom	Nature-based Solutions	Agriculture & forestry; water	Flood	Qualitative	National	12,480,000	2015
72	FP7 OPERAs in Barcelona	Spain	Nature-based Solutions	Recreation	Flood	Qualitative	EU and local	11,459,749	2017
73	URBAN GreenUP	Across Europe	Local multi-purpose green investments	Housing and Public Buildings; recreation	All Hazards	Qualitative	EU	15,000,000	On-going
74	Budapest City Park	Hungary	Local multi-purpose green investments	Recreation	All Hazards	Qualitative	national	617,100,00	2017

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