Economics for Disaster Prevention and Preparedness

Investment in Disaster Risk Management in Europe Makes Economic Sense

SUMMARY REPORT

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STATEMENT FROM EUROPEAN COMMISSION

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European Commission

The COVID-19 crisis has been an unprecedented challenge for Europe and a major stress test for the resilience of our society, infrastructure, and economy. We have adapted to new constraints posed by the pandemic and turned the lessons learned through this crisis into a strengthened Union Civil Protection Mechanism (UCPM). We have upgraded our European emergency management system so that it can be better equipped for responding to future emergencies and offer concrete and timely EU solidarity to the EU's citizens.

At the same time, the COVID-19 crisis has also emphasised the importance of using the scientific and technical resources we have at our disposal to better anticipate, plan, and prepare for the next crisis. Modelling the impact of future risks is an imperative for making sound decisions when developing the next European civil protection capacities. With robust data and technical advice, we can develop more accurate disaster scenarios and review our preparedness accordingly.

Economics for Disaster Prevention and Preparedness is a concrete example of how a partnership between the European Commission and the World Bank can use data to improve our understanding of risks, produce new tools for communicating them, and, ultimately, make our society more resilient and prosperous. A common emergency management system with a joint capacity to model the impact and prepare for increasingly complex risks: this is European solidarity at its best.

In the challenging socio-economic context that the COVID-19 pandemic has put before us, demonstrating the return on investments of prevention and preparedness measures will be critical. The increasing pressure on national budgets make it an imperative to use resources to generate as many benefits as possible. Investing in making Europe more resilient to disasters and crises provides an opportunity to promote green and sustainable development. Reviewing more than 70 Europe-based examples, this study shows that there is a robust economic case for investing in Europe's resilience. Reducing risks with 'smart' investments stimulates economic activity, promotes innovation, and generates multiple social, environmental, and economic benefits that materialise even when a disaster does not occur. The study also modelled the impact of earthquakes and floods on the economies of EU Member States, analysed the financial instruments available to manage these risks, and found that some disaster scenarios may cause potential funding gaps at national and EU level, including for response assistance.

Physical and financial resilience need, therefore, to be tackled jointly. To do so, we need to continue to invest in human capacity for disaster resilience. The UCPM is well placed to provide access to both knowledge and financing. Our recently created "Knowledge Network" is the shared platform for UCPM Member and Participating States that bridges science and decision-making in disaster risk management. In addition, the financing instruments available under the Prevention and Preparedness Programme of the UCPM can be leveraged to develop strategies and the investments needed for resilience.

Understanding the socio-economic impacts of risks and modelling their future trends will allow us to review our response capacity accordingly, so that we do not prepare for the disaster that just happened, but anticipate future crises while contributing to Europe's social, economic, and environmental well-being. This study is a step in the right direction, providing evidence and examples of how we can become more resilient, together.

STATEMENT FROM WORLD BANK

Disasters and hazards, whether natural, technological, or health-related, can have devastating physical, social, and financial effects. In the European Union alone, average economic losses from natural disasters stand at approximately EUR 12 billion per year[1], and are expected to increase further as climate change manifests itself across more and more aspects of our lives. The well-being of society is at stake if appropriate prevention or preparedness measures against disasters are not implemented. For some EU countries that have been affected by natural disasters in recent years, the COVID-19 pandemic has compounded these challenges that have led to a devastating loss of life and extensive economic damage.

To address these challenges, the World Bank is focusing its efforts on supporting a greener, more resilient, and inclusive development.[2] Adopting smart and sustainable approaches is needed considering the investment gap of around EUR 2 trillion per year in order to reach the Sustainable Development Goals by 2030. The collaboration between the World Bank and the European Commission on the economics of disaster prevention and preparedness is offering new evidence for strengthening resilience across the physical, financial, and institutional dimensions. Investments that aim to reduce disaster and climate risks can help contribute to the EU's goal of climate neutrality by 2050 under the European Green Deal.

This summary report shows that enhancing physical resilience is critical and can generate social, economic, and environmental co-benefits even in the absence of disasters. The report shows that holistically-designed investments yield substantially high benefits across a range of developmental goals. Effective design can help reduce impacts of disasters and better protect citizens, particularly when facing risks of cascading or simultaneous disasters that may become more frequent in the future. Similarly, building resilience cannot be achieved without improving the capacity of authorities and stakeholders involved in disaster risk management, including technical knowledge, human capacity, and institutional coordination.

Placing disaster prevention and preparedness within the context of the COVID-19 recovery, and development more broadly, helps save lives and protect livelihoods. It provides a practical way to operationalize the green, resilient, and inclusive agenda. The reports under *Economics of Disaster Prevention and Preparedness* project highlight the importance of enhancing prevention, preparedness, and emergency response, which helps to reduce disaster and climate risks for people, improve sustainability, and enhance the welfare of European countries. It provides recommendations that can help drive Europe's green and resilient recovery through international, Europe-wide, and national programs as well as financing. The report components present a range of good practices that can inspire reforms of financial frameworks, integrated investments, and technical assistance tools on the path to a better and more resilient future.

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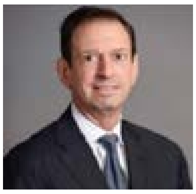

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1 European Environment Agency ,2020. Economic damage caused by weather and climate-related extreme events in Europe (1980-2019). Indicator Assessment. *Link*.
2 World Bank. 2021. *From COVID-19 Crisis Response to Resilient Recovery - Saving Lives and Livelihoods while Supporting Green, Resilient and Inclusive Development (GRID).* Development Committee

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STATEMENT ON COVID-19 PANDEMIC

The COVID-19 pandemic has led to substantial restrictions on travelling, 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.

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GLOSSARY

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.

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 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.

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.

internal rate of return (external rate of return): Metric used in analysis to estimate the benefits of potential investments. The internal rate of return is a discount rate that would make the net present value of all monetary flows equal to zero in a discounted monetary flow analysis. The external rate of return further adjusts for inflation and costs of capital.

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.

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

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.

ABBREVIATIONS

AAL	average annual loss
BCA	benefit-cost analysis
BCR	benefit-cost ratio
DG ECHO	Directorate General for European Civil Protection and Humanitarian Aid Operations
DALY	disability-adjusted life years
DiD	difference-in-difference
DRM	disaster risk management
DRR	disaster risk reduction
ERR	external rate of return
EWS	early warning systems
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
GRP	gross regional product
IRR	internal rate of return
JRC	Joint Research Centre
MS	Member States
NBS	nature-based solutions
NPV	net present value
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PML	probable maximum loss
PS	Participating States
SDGs	Sustainable Development Goals
UCPM	Union Civil Protection Mechanism
UHI	urban heat island
VSL	value of statistical life

Note: Currencies have been converted throughout the report to euro values. Where the original values were in other currencies, this has been indicated in footnotes. The currency exchange rates used in this report come from the Eurostat database (Eurostat Database, 2021). All dollar amounts are US dollars unless otherwise indicated.

ABOUT THIS REPORT

This report 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.

The objective of this report is to provide EU Member States/Participating States (MS/PS) and UCPM members with consolidated analysis and information on the economic value of investing in disaster and climate preparedness and prevention. The analysis can serve as a basis for (i) demonstrating the net benefits of investing in prevention and preparedness for various hazards, (ii) showcasing best practices in investing in prevention for various MS/PS and UCPM members as well as at a regional scale, and (iii) providing guidance on methodological approaches to estimate the net benefits of interventions, including soft investments, with a focus on the application of the Triple Dividend of Resilience framework for economic analysis (Tanner, et al., 2015), though other methodologies are also described in this report. Although the report mainly focuses on Europe, international examples are presented throughout.

Given the variety of disasters and sectors covered and respective methodologies utilized, the report focuses on calculations for specific investments, but does not derive average values of benefits and costs for sectors or hazards. The methods to calculate net benefits include scenario-based analysis or analysis based on average annual losses, as well as hypothetical scenarios or retrospective analysis of real investments. The report also accounts for dividends from the investments in various ways. The results are therefore communicated mostly as case-specific, investment-specific, and location-specific; and wherever possible (based on information availability) they are compared to findings in the literature. Moreover, although the report aims to provide a full assessment of impacts, this has not always been feasible due to data and information limitations and methodological constraints. As the results are based on analysis that is based on inherent uncertainty, results from new analysis under this study are presented as rounded numbers (i.e. to a maximum of two decimal places) and/or as ranges.

This summary report is accompanied by a technical background report that covers (i) methodological approaches for the economic assessment of investments for disaster risk management and climate change, and (ii) summaries of all the case studies featured in this report.

Executive Summary

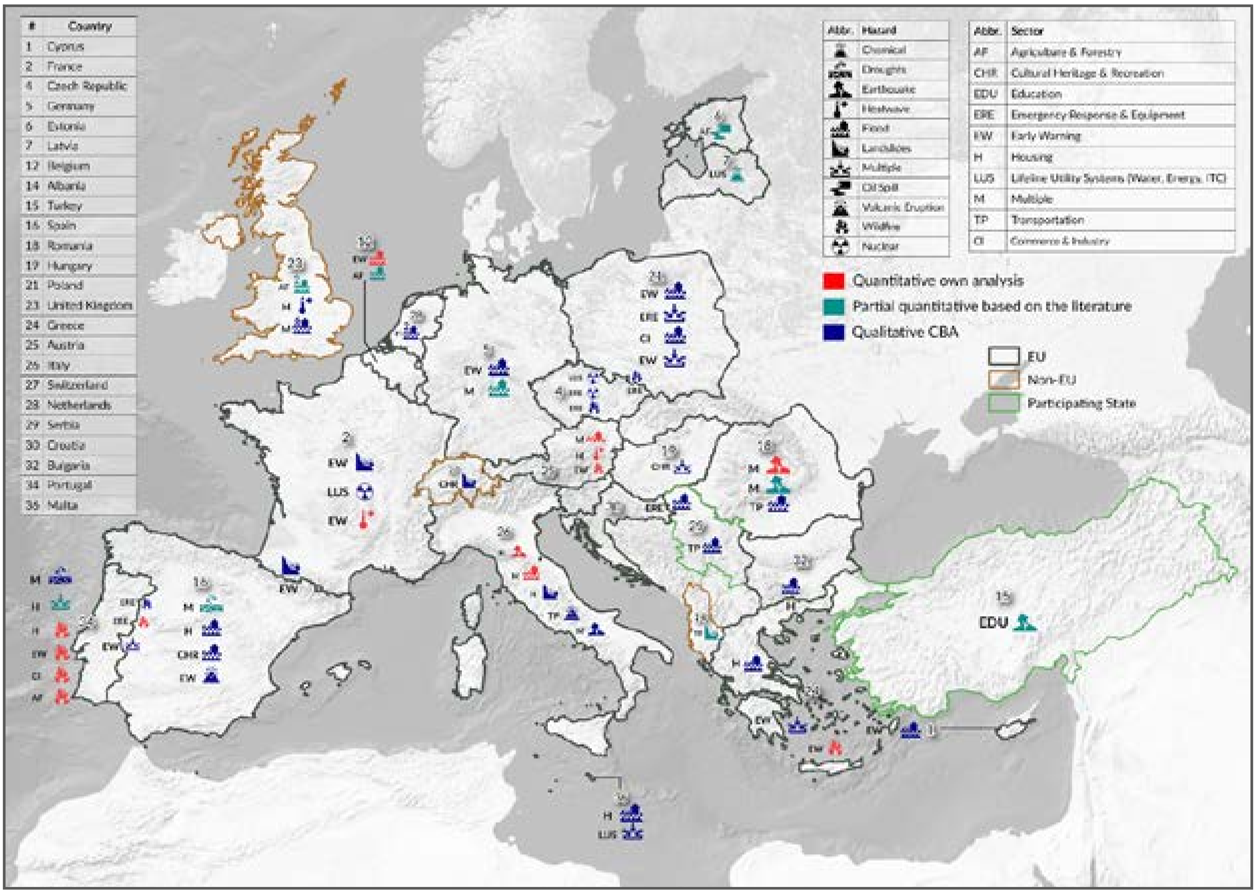
The physical, financial, and social impacts of disasters in Europe are growing and will continue to grow unless urgent actions are taken. In the European Union (EU), during the period from 1980 to 2020, natural disasters affected nearly 50 million people and caused on average an economic loss of roughly €12 billion per year (EEA, 2020). The impacts of flood, wildfire, and extreme heat are increasing rapidly, and climate damages could reach €170 billion per year according to conservative estimates for a 3 scenario unless urgent action is taken now (Szewczyk, et al., 2020). Earthquakes, while rare, have a devastating impact on the ageing buildings and infrastructure of Europe that were constructed prior to modern codes; in Bucharest, for example, nearly 90% of the population lives in multifamily buildings with pre-modern building codes[3] (Simpson & Markhvida, 2020). Within the EU, the top-five countries with the highest annual average loss to earthquake are Cyprus, Greece, Romania, Bulgaria, and Croatia, and for floods the top-five countries are Romania, Slovenia, Latvia, Bulgaria, and Austria.[4] However, disasters do not affect everyone equally: poor, elderly, very young, and marginalized populations are most affected and least able to recover. In Romania, Greece, Croatia, and Bulgaria, for example, the socio-economic resilience of the poor is on average less than 30% of the national average (World Bank, 2020). Moreover, the local and regional administrations in the poorer and more disadvantaged areas have the least capacity to design and implement resilience investments.

The global economic case for investing in prevention and preparedness is unequivocal and wider benefits of resilience measures are likely to be substantially underestimated. The World Bank's *Lifelines* report found that the net benefit of investing in more resilient infrastructure in low- and middle-income countries is €3.75 trillion, with roughly €4 in benefits for every €1 invested (Hallegatte, et al., 2019).[5] Moreover, the benefit-cost ratio[6] (BCR) of investing in more resilient infrastructure was found to be higher than 1 in 96% of scenarios, higher than 2 in 77%, and higher than 6 in 25% (Hallegatte, et al., 2019). When targeted to the most vulnerable areas and infrastructure, overall investment needs were found to be an order of magnitude lower than if no targeting was undertaken. Similarly, a global report on hydro-meteorological early warning systems (EWS) found BCRs ranging from 4 to 35, dependent upon the assumed and quantified co-benefits (Hallegatte, et al., 2012). Finally, review of disaster risk reduction investments in the United States found BCRs of between 2 and 12, with the highest BCRs attributed to ensuring that all buildings met the current building codes (NIBS, 2019).

This study found the economic case for investing in resilience in Europe to be equally robust and clear. This study applied the Triple Dividend of Resilience approach to assessing economic benefits, which considers avoided losses and saved lives, unlocked economic potential as a result of stimulated innovations and bolstered economic activity that arise from the reduction in disaster and climate risks, and social, environmental, and economic co-benefits that accrue even in the absence of a disaster. More than 100 investments focused on prevention and preparedness were reviewed for this report, with quantitative and qualitative analysis conducted for more than 70 investments aimed at reducing the impact of a wide range of natural and technological hazards across Europe (*Figure 1*).

3 For the buildings in this study, pre-modern indicates buildings designed and constructed before the year 2000.
4 Analysis conducted for this report, and the accompanying Report Component 2: Financial Risk and Opportunities to Build Resilience in Europe.
5 Original values in US dollars.
6 The Benefit-Cost Ratio (BCR) is a ratio to summarize results from a Benefit-Cost Analysis (BCA), a process used to identify, measure and analyse the benefits of a project, programme or decision versus the costs associated with it. The ratio summarizes the relationship between benefits and costs and net benefits are positive when the ratio is higher than 1. More details are included in the section Abbreviations or also in the *Annex 1* of this report.

Figure 1. Overview of case studies analysed under this report



Source: World Bank

For the case studies analysed here, **BCRs almost always exceeded 1, which shows that the benefits of investment are higher than the costs. BCRs typically ranged from 2 to 10, with several investments showing BCRs exceeding 20** (*Figure 2*). Considering different hazards and different intervention types, the following results were observed:

1. The median BCR for flood prevention and preparedness was 2.6, with the majority of BCRs found to be greater than 1.5 (with the highest BCR calculated at 14.1). **Flood investments that integrate nature-based solutions and early warning were found to have the greatest benefits, with median BCRs of 4.9 and 2.8, respectively.**

2. For earthquake risk reduction, structural strengthening of existing buildings yielded a BCR of 1.8 for public buildings and 4.8 for private buildings when considering probable maximum losses. The analysis of hypothetical investments in seismic strengthening and energy efficiency in education facilities across Europe yielded BCRs ranging from 0.6 to 2.2. **Earthquake prevention measures that were accompanied by investments in energy efficiency and building modernization provide the greatest BCRs and provide immediate benefits to beneficiaries even if a disaster does not occur.** The application of earthquake EWS to automatically shut off critical systems or provoke rapid action to save lives and assets—by stopping trains, providing energy protection measures, and so forth—was found to have significant benefits, with a BCR of 7.

3. Extreme heat prevention associated with changing the urban landscape through green and white measures[7] ranged from 0.8 to 1.8, **with green measures creating higher BCRs due to the numerous co-benefits generated by urban greening. Heatwave early warnings were found to provide significant benefits, with a mean BCR of 131 (range of 48-246).**

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

4. Wildfire prevention and response was found to be economically very positive, with BCRs ranging from 1.6 to 39. Measures focused on **wildfire prevention, such as managing wildland-urban interfaces, were found to have BCRs of 2.1 to 3.1; addition of fuel breaks in forested areas had a BCR of 12. Decision support tools for climate change adaptation and alerting for wildfire risk reduction yielded BCRs ranging from 5.8 to 39**, while cross-border fire coordination mechanisms had a BCR of 1.6.

5. Case studies on landslides were rare, and the calculated BCRs of 0.1 to 1.1 are considered underestimations. The most disruptive landslides are those that affect key highways and transportation routes; if this full disruption is calculated, and intervention measures are targeted at critical transport sections with limited redundancy, BCRs are expected to be greater than 1.

6. For volcanic eruptions, monitoring and EWS have significant benefits, especially when linked to public awareness and adequate evacuation routes, but economic analysis was not possible due to a paucity of data.

7. In managing pandemics and public health, there is a very clear economic argument for preparedness, as evidenced by the experience of the COVID-19 pandemic. **Even a simple step such as stockpiling equipment and supplies can be seen to provide a definite benefit, considering that the cost of personal protective equipment (PPE) increased between 200% and 1,500% in 2020** (SHOPP, 2020).[8] Moreover, one study of pandemic preparedness determined a BCR of 13.3 for investing in global pandemic preparedness[9] (National Academy of Medicine, 2016).

8. **There is a sound economic argument for investments to address technological hazards and clean-up of environmentally degraded areas, which offer BCRs ranging from 1 to 5.8,** depending on the nature of the technological hazard and the planned investment.

This study also recognizes the numerous impediments which, despite knowledge of the net benefits of investment in DRM and underinvestment, prevent further implementation and enhancing resilience to disaster risks. These range from behavioural biases, information barriers, and distorted incentives to technical and institutional challenges (World Bank, 2013). Moreover, although the societal BCAs may yield net benefits, costs and benefits may be accumulated by different actors so that public investment and support are essential. The report outlines some of these challenges and has shown novel quantitative estimations as well as presented qualitative results showing net benefits of investing in institutional capacity, preparedness of economic actors, and collaborative mechanisms.

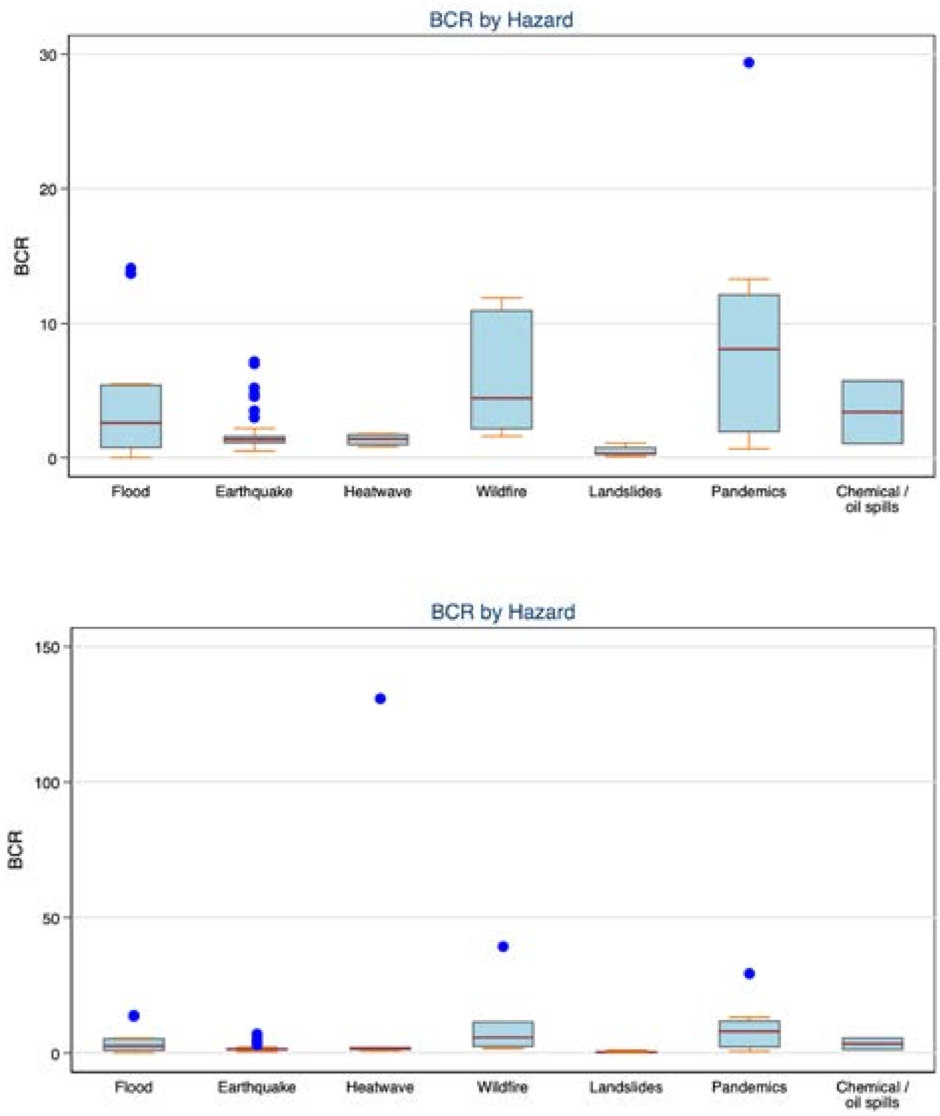
A novel analysis was undertaken in this study **to assess the benefits of investment by the European Commission in emergency responders and response coordinators through the Union Civil Protection Mechanism (UCPM) Knowledge Network.**[10] The analysis focused on two earthquake disaster interventions, in Albania (November 2019) and Croatia (March 2020). A BCR of 1.9 in Albania was driven by the European Union Civil Protection Team (EUCPT) -led damage assessments, which expediated a return to long-term accommodation and work. A BCR of 1.1 in Croatia was driven by international training of Croatian Civil Protection personnel, showing that capacity-building benefits can outweigh costs even where no international personnel are deployed.

It should be noted that the economic co-benefits of resilience measures are regularly and significantly underestimated, and this is also assumed to be the case for the benefits presented in this report. Unfortunately, data on the types of co-benefits available are rarely captured, and it can be difficult to find data on the increase in property prices or reduction in insurance premiums after flood protection, the employment provided during construction and subsequently through operations and maintenance,

8 Results are for calculations in Euro, original values are in US dollars.
9 Results are for calculations in Euro, original values are in US dollars.
10 The UCPM's objective is to strengthen cooperation between the EU Member States and 6 Participating States in the field of civil protection, with a view to improve prevention, preparedness and response to disasters. The UCPM Knowledge Network was created in 2019 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.

biodiversity and amenity improvements, enhanced mental and physical health of beneficiaries, protection of cultural heritage, and so forth. Applied research is critical to develop the data and approaches to monetize these crucial co-benefits for inclusion in future economic analyses.

Figure 2. Findings of benefit-cost analysis by hazard: Benefit-cost ratios, excluding extreme values (above) and including extreme values (below)



Source: World Bank analysis; *based on external data and information; presenting in part results from literature based on World Bank & external reports (4 Flood results from World Bank (2007), Spray (2016), Hölzinger & Haysom (2017), Gauderis, et al. (2005); 2 Earthquake results from World Bank (2018a, 2019c, 2019a, 2019d); 1 Landslide result from Xiong & Alegre (2019); 2 Pandemics/ Epidemics results from Masters, et al. (2017), GHRF Commission (2016); 1 Oil Spill result from European Commission (2020)).*

Note: The figures show the distribution of benefit-cost ratios (BCRs) for disaster risk management investments by hazard type 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 figure and included in the bottom figure. Top graph: The top figure represents the range of values found in 28 out of the 30 case studies based on results from quantitative analysis (17 own analysis, 13 from the literature). Two case studies are not included in the graph because though they are quantitatively analysed in the report, they are not assessed by BCA and thus has no data available for display. The various box-plots show the range of value by hazards found, with the red line representing the median value (i.e. the value at 50% of overall results found). The minimum and maximum values are represented by orange lines. The outlier values are shown as dots (i.e., that are much higher than the maximum values). Overall. we can notice in the graph that the range of BCRs found for floods, wildfires, chemicals / oil spills and pandemics is much larger than for earthquakes, heatwaves and landslides but also have a higher median value. The maximum values of BCRs tend to be higher for wildfires and pandemics. These results have to be interpreted with caution given the lack of comparability and differences in number of results/studies between hazards analysed. Bottom graph: Extreme values are included in this graph.

Investments aimed at achieving and integrating multiple objectives make technical, financial, and social sense. Achieving reductions in greenhouse gas (GHG) emissions through energy efficiency savings in buildings typically does, and rightly should, require a complementary structural strengthening to ensure that buildings constructed prior to modern codes—most of the European built environment—are resilient to snow, wind, and seismic loading and climate change impacts likely to also exacerbate certain disaster risks. Similarly, there is opportunity to ensure simultaneous improvements in fire safety, modernization, and functionality and to ensure access for people with disabilities. Integration of these objectives saves money, reduces disruption, and is more sustainable over the short and long term. This study also highlights the need to accompany early warning systems with public preparedness, readiness for action, and enhanced coordination to achieve the highest return on investment.

Based on this report, a series of forward-looking recommendations is highlighted, noting the ambitious policy agenda in Europe that is aimed at a substantial increase in disaster and climate resilience:

1. **Financing targeted at disaster and climate resilience measures needs to be substantially increased for both public and private financing, with concomitant support for beneficiaries in accessing and using these funds.** It is expected that the financing available for disaster and climate resilience will increase in Europe in coming years through a variety of programs. However, it should be noted that authorities responsible for disaster risk management may need additional support to advocate for increased allocations within national and EU budgets, and that sectoral ministries may not prioritize funding for disaster prevention and preparedness because they lack awareness of the issue which can challenge incentives for public finance. Moreover, support for authorities to learn about, access, and use different funding sources will be critical.

2. **Systems to track, monitor, and evaluate disaster and climate resilience financing are needed.** Right now, it would be difficult for most municipal, national, and European Commission experts to communicate how much funding has been targeted for disaster and climate resilience in the last 5 to 10 years, and for which preparedness and prevention activities. They likely could not say, for example, what the expenditure for modernizing fire coordination and response has been in the last decade, how much is planned in the coming decade, or what the expenditure for public awareness and preparedness campaigns has been. Tracking these funds into the future would be very helpful to identify gaps (e.g., pandemic preparedness) and target awareness, capacity development, and ultimately financing in these areas.

3. **Wide promotion and uptake of integrated and novel approaches is needed to build resilience and maximize co-benefits.** For example, while perhaps more complicated to implement, nature-based solutions provide significantly higher co-benefits than traditional grey flood protection solutions. Similarly, investing in green, white, and/or blue[11] measures in cities is proven to reduce extreme heat but also brings enormous benefits in air quality and increased amenities and liveability for residents. Promoting a single investment with multiple objectives can save time and money and minimize disruption—for example, integrated investments can be carried out to ensure school buildings are modern, safe, resilient, energy efficient, inclusive, and sustainable.

4. **Policy reform is required to address the asymmetry in preparedness and prevention across types of hazards.** There was a clear asymmetry observed in the availability of case studies and investments for different types of hazards, with many more for flood than for wildfire, drought management, extreme heat, and others. In addition to floods being the most common disaster regionally, the EU Floods Directive has been incredibly effective at focusing government attention on the need to understand, quantify, and manage flood risks and the Water Framework Directive has also partly promoted the development of drought risk management plans. Unfortunately, similar directives are lacking for other hazards, and perhaps as a result, awareness of these risks and prevention and

11 Blue measures include bodies of water such as rivers, ponds and wetlands.

preparedness actions in a comprehensive manner are also lacking.

5. **There needs to be a regional transformation in the availability of open data, information, and knowledge on disaster and climate risks.** Compared to other regions of the world, Europe is fortunate to have a wealth of data and information on disaster and climate risks.[12] However, stakeholder consultations highlighted issues associated with accessing a range of data, including open, high-quality, and high-resolution data on historical disaster damages and losses, maps and data on the probability and potential impact of the full range of hazards (and their possible evolution with climate change), data on exposed assets and populations (and their expected change into the future), information on replacement costs, information on typical costs for different prevention and preparedness measures, and data required to assess the range of resilience co-benefits. The costs of investment to ensure that these data are open and available to all users and stakeholders pale in comparison to costs of mis-targeting investments away from the highest-risk areas and assets.

6. **Support to build human capacity to assess, prioritize, design, and implement measures aimed at prevention and preparedness needs to be further scaled up.** Authorities require significant capacity to undertake a wide range of high-quality, timely prevention and preparedness measures: collecting data on assets and infrastructure that may be under risk; developing objective and transparent prioritization that ensures targeting of scarce financing to areas of the greatest vulnerability; undertaking technical, financial, and economic studies; ensuring procurement, permitting, stakeholder consultation, etc. are completed on time; and carrying out management and supervision of works as well as long-term operations and maintenance. Expertise and experience in these areas are often limited within civil protection agencies, line ministries, and especially subnational authorities. This capacity can be built through a combination of trainings, workshops, guides/handbooks, hands-on implementation, and just-in-time support, and the UCPM Knowledge Network is an excellent existing mechanism that can be expanded to provide this support (Parker, et al., 2019).

12 Data and information sources are among others the JRC's Risk Data Hub (*https://drmkc.jrc.ec.europa.eu/risk-data-hub#/*) and Horizon 2020 (*https://ec.europa.eu/research/infocentre/article_en.cfm?&artid=49761&caller=other*).

TRIPLE DIVIDEND OF RESILIENCE

1st DIVIDEND

Avoiding damages and losses by:
- Saving lives & reducing people affected
- Reducing damages to infrastructure
- Reducing losses to economic flows

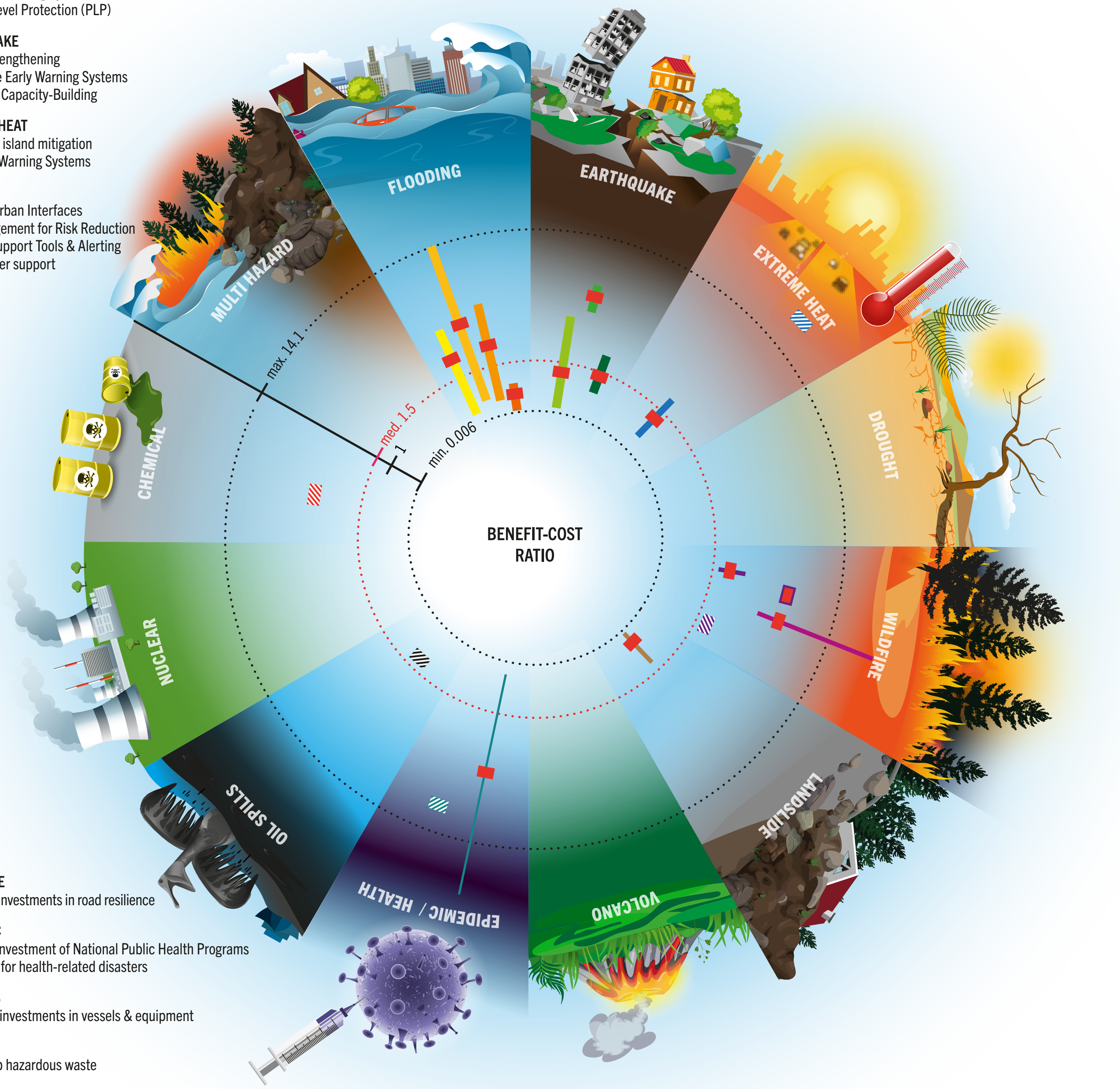
2nd DIVIDEND

Stimulating economy by increasing:
- Business and capital investment
- Household & agricultural productivity
- Fiscal stability & access to credit

3rd DIVIDEND

Co-Benefits such as:
- Eco system services
- Transportation uses
- Productivity gains

BENEFIT-COST RATIO VALUES BY HAZARDS WHERE DATA IS AVAILABLE



FLOODING
- Structural Protection
- Nature-based solutions
- Flood Early Warning System
- Property Level Protection (PLP)

EARTHQUAKE
- Seismic strengthening
- Earthquake Early Warning Systems
- Responder Capacity-Building

EXTREME HEAT
- Urban heat island mitigation
- Heat Early Warning Systems

WILDFIRE
- Wildland-Urban Interfaces
- Fuel Management for Risk Reduction
- Decision Support Tools & Alerting
- Cross-border support

LANDSLIDE
- Preventive investments in road resilience

PANDEMIC
- Return on Investment of National Public Health Programs
- Equipment for health-related disasters

OIL SPILLS
- Preventive investments in vessels & equipment

CHEMICAL
- Cleaning up hazardous waste

MINIMUM, MEDIAN AND MAXIMUM BCR FOR ALL DRM INVESTMENTS REPRESENTED BY THE THREE CIRCLES (extreme values excluded)

median value of BCR by type of hazard
frequency of occurrence (line thickness)

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WORLD BANK GROUP

1. Introduction: Disaster and Climate Risks Are Growing Despite Robust Economic Arguments for Prevention and Preparedness

1.1. Disaster and Climate Change Impacts

Disasters such as earthquakes, droughts, and floods can generate large damages and losses and lead to tremendous social, economic, and environmental disruption. In recent years, the losses caused by disasters and hazards have increased as a result of climate change. From 1980 to 2019, accumulated losses from disasters due to extreme weather and climate change in the EU Member States (EU-27) reached €446 billion, which accounted for 81% of the economic losses caused by natural hazards in the region over that period (EEA, 2020). *Figure 3* presents the economic damage caused by weather- and climate-related extreme events in Europe from 1980 to 2019. However, the impacts of disasters go far beyond the damage to infrastructure, affecting the poorer and more vulnerable members of society the most (*Box 1*). Earthquakes, while rarer in Europe than some other parts of the world, have resulted in significant damage and loss in recent years. Earthquakes highlight the challenges associated with the European building stock and infrastructure, which was mostly constructed prior to modern buildings codes and renders populations particularly vulnerable (*Box 2*). Analysis conducted for this report and the Component 2 report on the financial cost of disasters identifies the EU MS with the most exposure to flood and seismic risk (*Table 1*). Technological and health disasters are also growing threats, with the COVID-19 pandemic a clear manifestation of this risk.

Table 1. Top-10 countries for flood and seismic risk, by average annual loss as a percentage of exposure

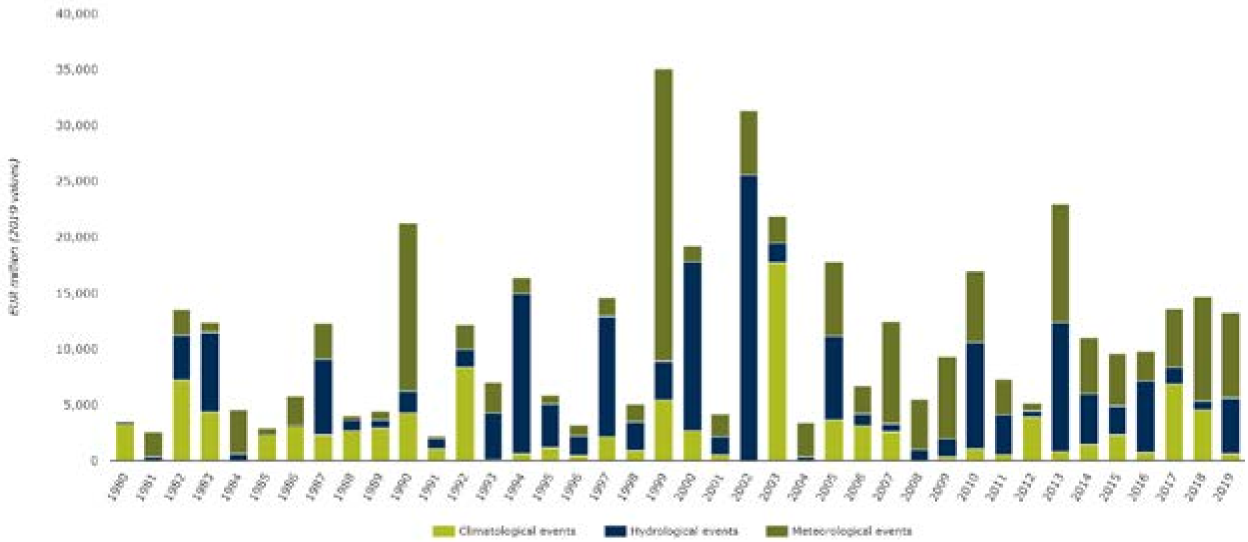
SEISMIC RISK			PLUVIAL AND SURFACE WATER FLOOD RISK		
Rank	Country	AAL ratio	Rank	Country	AAL ratio
1	Cyprus	0.19%	1	Romania	0.15%
2	Greece	0.18%	2	Slovenia	0.13%
3	Romania	0.12%	3	Latvia	0.13%
4	Italy	0.11%	4	Bulgaria	0.13%
5	Bulgaria	0.07%	5	Austria	0.12%
6	Croatia	0.05%	6	Slovakia	0.11%
7	Slovenia	0.04%	7	Germany	0.10%
8	Austria	0.02%	8	Czech Republic	0.10%
9	Portugal	0.02%	9	Hungary	0.10%
10	Slovakia	0.01%	10	Poland	0.10%

Source: World Bank analysis; *based on results from GEM (Global Earthquake Model Foundation). 2020. "Regional Risk Modelling and Scenario Analysis for EU Member States: Seismic Risk Analysis and Exposure Data." Technical report produced for the World Bank. Global Earthquake Model Foundation, Pavia, Italy. JBA Risk Management. 2021. "Flood Risk Analysis for EU Member States: Method Report." Technical report produced for the World Bank. JBA Risk Management, Skipton, UK*
Note: AAL = average annual loss.

When analysing the costs and impacts of climate change, scenarios should also include socio-economic parameters that consider a future potentially different from the present. For example, in some areas, populations and assets continue to grow and concentrate, whereas in other regions the trends are depopulation and abandoned infrastructure.The PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) IV EU project by the Joint Research Centre (JRC) (Feyen, et al., 2020) estimated the economic costs of climate change through climate models and socio-economic scenarios that provide projections for the future. This analysis revealed the severe consequences and losses due to natural hazards associated with climate change if there is no investment in adaptation. For instance, the analysis reveals that by 2100, river flooding will affect about half a million people in the EU and UK and will generate a loss of €50 billion per year. The EU-funded COACCH research project (COACCH, 2019) also presents similar outcomes. Using macroeconomic and climate models, the PESETA IV project examined the negative impacts of climate change and the monetary losses it generates. The study found that under the warming scenarios of 3 °C, 2°C, and 1 °C, the welfare losses for EU households would be €175, €83, and €42 billion per year, respectively (*Figure 4*). Extreme heat, and particularly urban heat island (UHI) effects, are expected to have severe impacts in coming years and decades unless action is taken; the benefits of green, white, and blue adaptation options are well documented (*Box 3*).

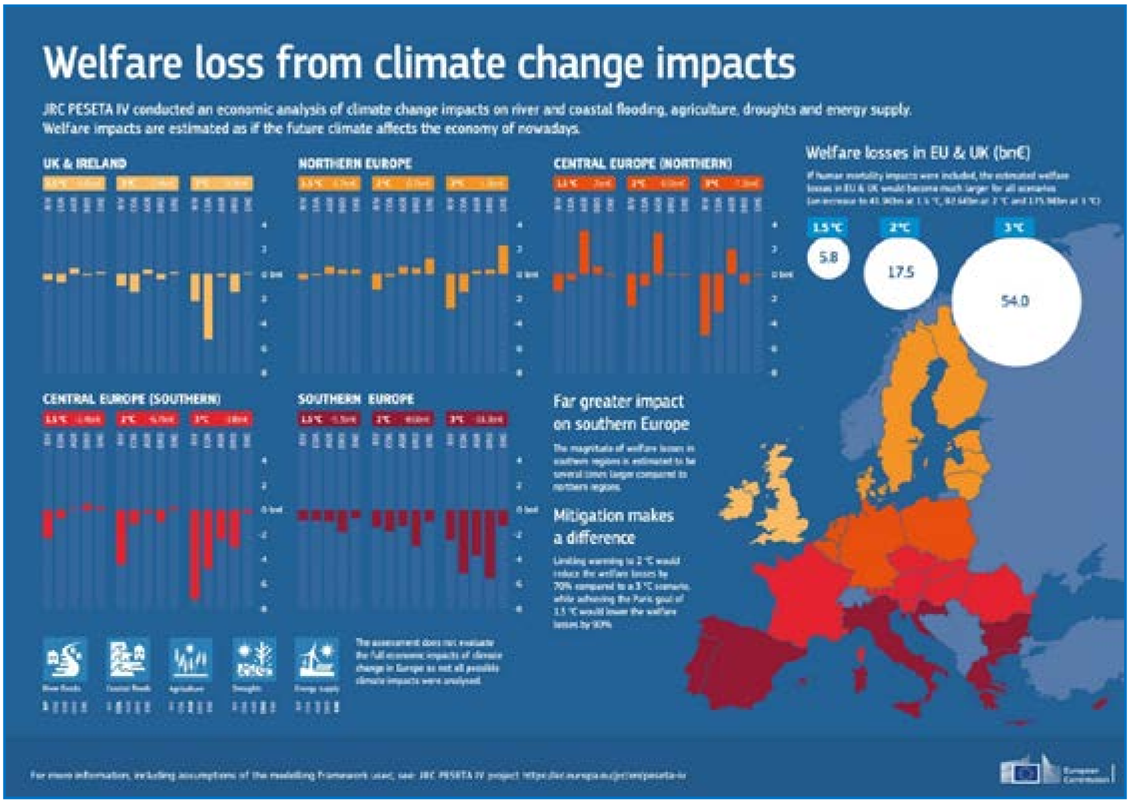
In this context, and in alignment with the Sendai Framework for Disaster Risk Reduction 2015–2030, it is essential for EU countries to rapidly scale up and accelerate investments in disaster risk management (DRM) and climate change adaptation to halt the growth of disasters and ultimately decrease the losses they cause. Such investments include prevention and preparedness measures in areas highly vulnerable to disasters, establishment of early warning systems (EWS), public awareness raising about disasters, etc. Economic analysis shows that these investments are beneficial and economically desirable (Shreve & Kelman, 2014; Mechler, 2016). They can reduce the exposure of assets and populations, make countries' disaster response more efficient and effective, and in turn reduce the economic and social losses of disasters and contribute to the welfare of society. The economic analysis presented here—a compilation of analysis conducted for this study or collected from other expert groups—makes the case for investing in resilience today rather than waiting until tomorrow.

Figure 3. Economic damage caused by weather- and climate-related extreme events in Europe (1980–2019)



Source: EEA (2020)

Figure 4. Economic loss from considered hazards and climate impact at warming levels for the EU and UK (for macro regions; billion €)



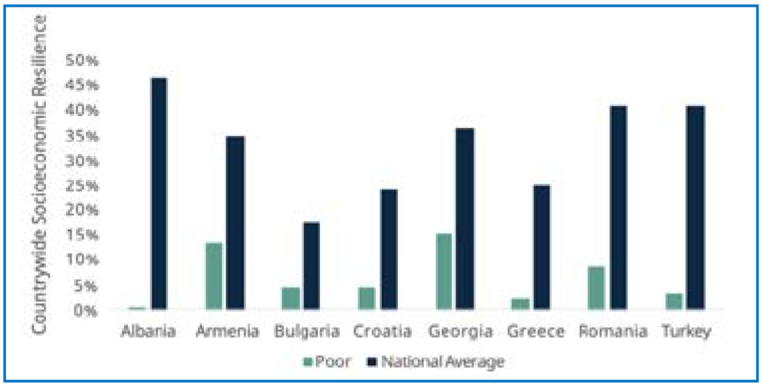
Source: Szewczyk, et al. (2020)

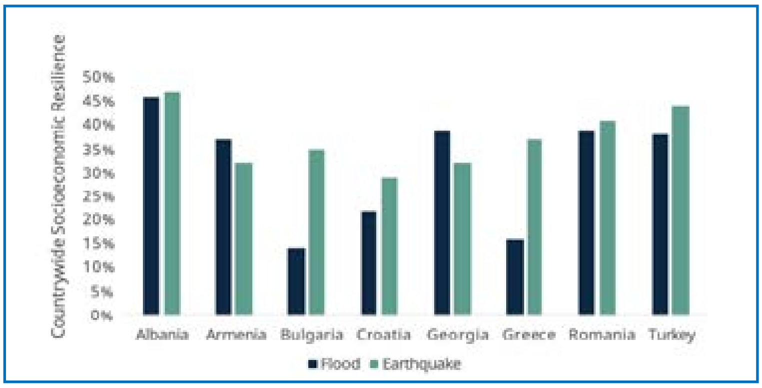
Box 1. Impacts of disasters on poverty and well-being of households in countries from south-eastern Europe

Disasters affect not only households' physical assets, but also their income levels and ability to contribute to the local economy. On a household level, wealthier households may have access to a wide variety of financial and nonfinancial coping mechanisms that can soften the severity of disaster shocks - unlike poorer households. These disparities in socio-economic status end up affecting the duration of subsequent recovery and reconstruction efforts.

Among the cities in the eight countries analysed in the *Overlooked* report (World Bank, 2020b)—Albania, Armenia, Bulgaria, Croatia, Georgia, Greece, Romania, and Turkey—the three cities whose poverty levels would be most affected by earthquakes and floods are Yerevan (Armenia), Tbilisi (Georgia), and Bucharest (Romania). For these two hazards, the socio-economic resilience of the entire population in each of the eight countries is less than 50%.[13] However, this statistic drops to 15% and below once we separate the population in poverty from the national average (see *Figure 5*). The socio-economic resilience gap between the poor and the national average is extremely high in Albania, Romania, and Greece, but relatively lower in Georgia and Armenia. According to the *Overlooked* report, implementing policies that reduce vulnerability, increases incomes, and reduces recovery times would increase countries' socio-economic resilience (see *Figure 6*).

Figure 5. Countrywide socio-economic resilience levels for select south-eastern European countries disaggregated by poverty levels (top) and hazard type (bottom)

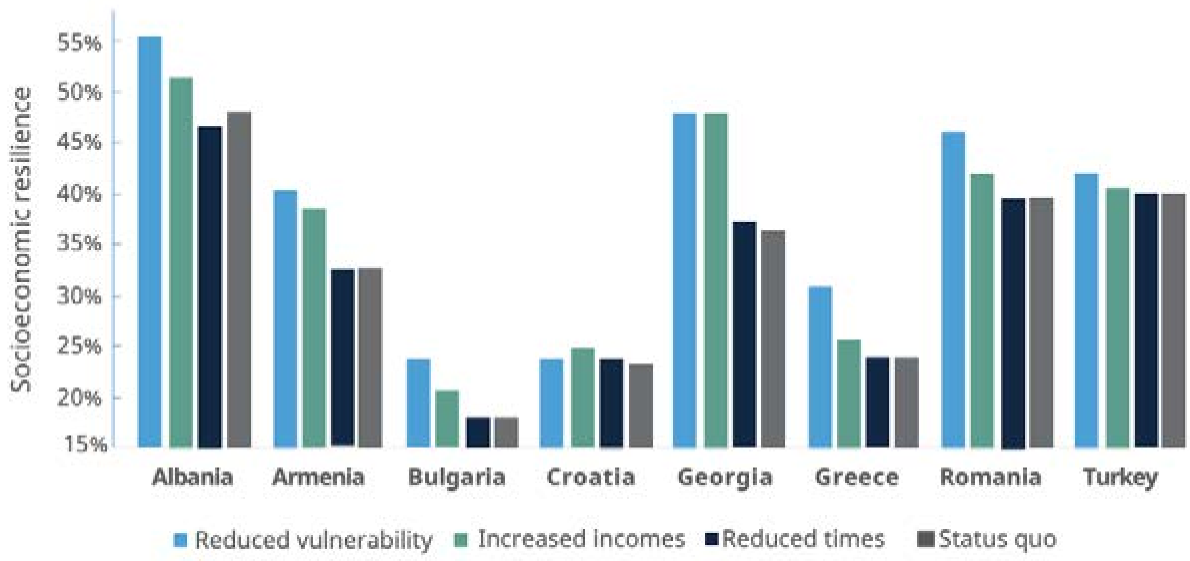




Source: World Bank (2020b)

13 Socioeconomic resilience can be defined as the population's capacity to mitigate the impact of disaster-related asset losses on welfare, and it is derived by dividing asset losses by welfare losses. A socioeconomic resilience below 50% means that, in the case of a disaster, there will be more than double the amount of welfare losses compared to asset losses.

Figure 6. Comparison of socio-economic resilience with different policies for select south-eastern European countries



Source: World Bank (2020b)

In this graph, the socioeconomic resilience of select south-eastern European countries is compared according to different policies implemented. These policies include reducing vulnerability of the poor population by 30% (light blue bar), increasing incomes of the poor population by 30% (sage green bar), and reducing the post disaster response and reconstruction times by 30% (navy blue bar). These were then compared to the status quo (grey line), which depicts a country's socioeconomic resilience without policy intervention. According to the analysis, reducing vulnerability and increasing income has the most positive impacts in a country's development of socioeconomic resilience.

Box 2. Impacts of seismic risks in Europe and Central Asia

The impact of seismic risk in multifamily residential housing is a significant threat in many cities of Europe. Multifamily buildings are commonly found in or near urban areas, and many residents living in these dwellings are vulnerable to two sets of risks: structural deficiencies caused by the buildings' old age increase seismic risk, and the density of urban areas and other factors such as lack of green public spaces increase the risk of extreme heat.

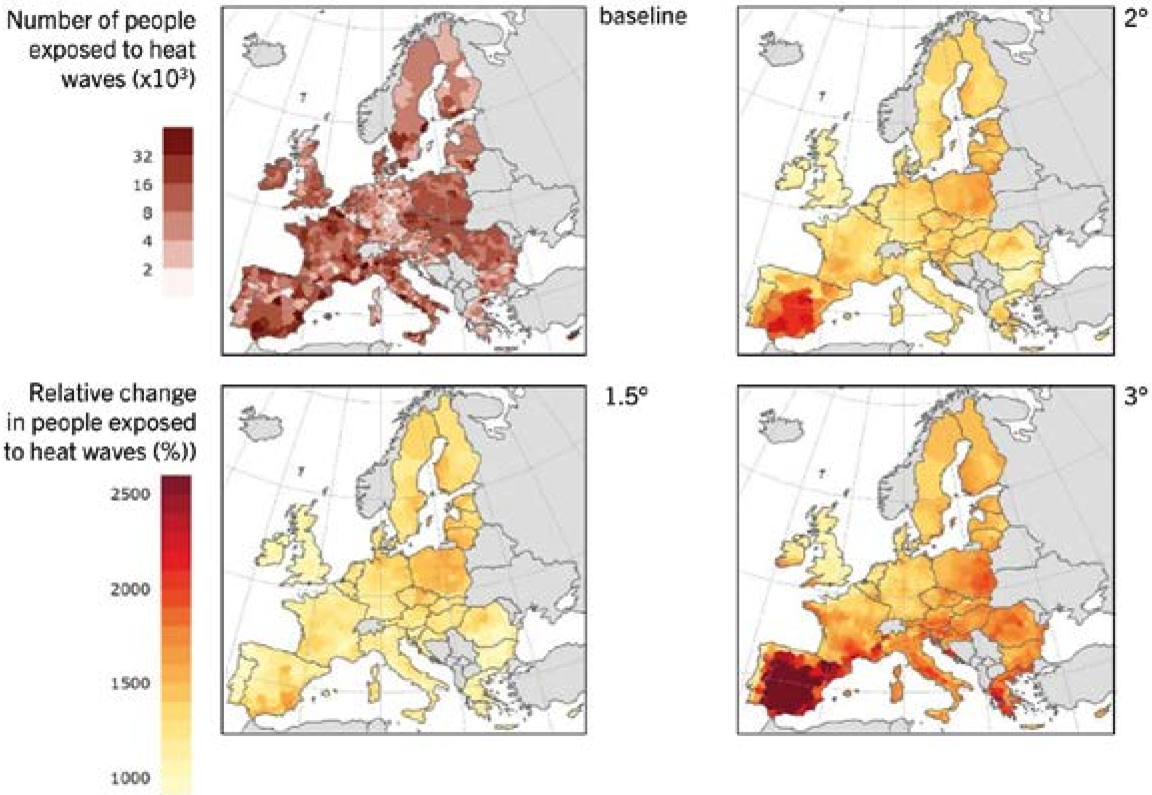
A recent World Bank report (Simpson & Markhvida, 2020) investigated the earthquake risk of multifamily buildings constructed before 2000 across 27 cities in 20 countries within Europe and Central Asia to better understand their behaviour and potential losses when subjected to earthquakes. The report found that on average, approximately half of the population in the cities studied resided in multifamily residential buildings constructed before 2000, and that most of these buildings are classified as either unreinforced masonry or reinforced concrete frame buildings—the two building types most expected to experience damage in an earthquake. Unreinforced masonry buildings are especially susceptible to earthquakes and contribute to a significant portion of the direct financial losses, number of fatalities, and number of people who will be permanently displaced, even in regions with lower seismicity.

Bucharest is an example of a city whose seismic risk is very high: nearly 90% of the total city population lives in pre-2000 multifamily housing; the largest proportion of its population resides in high-risk building types; and the city is expected to experience €200 million in average annual losses from future earthquake events, the highest among all the cities investigated (Simpson & Markhvida, 2020).

Box 3. Impacts of urban heat islands in Europe

Urban heat island effects make urban centres more vulnerable to heatwaves, because cities have reduced air circulation, are often built with materials known to store heat easily, generally lack vegetation, and concentrate heat coming from buildings, factories, and vehicles. These effects are starting to be felt more and more due to climate change, as 27% of cities were about 0.6°C warmer than the global average between 1950 and 2015 (Estrada, et al., 2017). _Figure 7_ presents the number of people annually exposed to a present 50-year heatwave and the projected changes in human exposure to these events under different warming scenarios due to climate change. As shown, these extreme heat risks are expected to be most pronounced in cities in Southern Europe. Heatwaves resulting from extreme heat events can cause harmful effects to human health, ranging from dehydration to strokes and possibly even death. Marginalized communities are at especially high risk from heat. Residents with restricted mobility cannot access parks or other areas with cooler temperatures, and poorer residents are hit hardest, as they often live in low-income neighbourhoods that are densely constructed, with few green spaces or water features to help cool the area. A variety of measures to reduce urban heat, including "green" solutions (i.e., parks), "blue" solutions (i.e., fountains), and "white" solutions (i.e., reflective roofs or roads), are being adopted by many cities in order to promote sustainable urban planning and climate change adaption. More immediately, however, investing in emergency preparedness and public communication of risk is considered critical to protect vulnerable groups from extreme heat.

Figure 7. Number of people annually exposed to a present 50-year heatwave (top left), and projected changes in human exposure to these events for global warming of 1.5°C, 2°C, and 3°C (bottom left, top right, and bottom right, respectively)



Source: Szewczyk, et al. (2020)

1.2. The Global Economic Case for Investment in Resilience

Over the past two decades, natural disasters worldwide have affected over 4 billion people, including more than 1 million people who died as result of disasters, and have caused approximately €2.6 trillion in economic losses (World Bank, 2019).[14] Climate change is expected to considerably increase impacts and damages to critical infrastructure in Europe in the next decades (Forzieri, et al., 2018; Feyen, et al., 2020). The World Bank's *Lifelines* report found that the net benefit of investing in more resilient infrastructure in low- and middle-income countries is €3.75 trillion, with roughly €4 in benefits for every €1 invested (Hallegatte, et al., 2019).[15] Moreover, the benefit-cost ratio (BCR) of investing in more resilient infrastructure is higher than 1 in 96% of scenarios, higher than 2 in 77%, and higher than 6 in 25% (Hallegatte, et al., 2019. Targeting investments in the most vulnerable areas and infrastructure can significantly reduce investment costs (*Box 4*). Similar findings were observed in a recent US-wide assessment of the benefits of investing in DRM (*Box 5*).

It has been stated that "today's decisions will determine tomorrow's risks" (Surminski, 2020). A report from the Global Facility for Disaster Risk Reduction and Recovery (GFDRR) highlights the benefits of using risk assessments to guide decision-makers towards a resilient future, rather than focus on risks at a single point in time. Investing in DRM can encourage forward-looking planning, long-term capital investment, and entrepreneurship, which can generate specific economic, social, and environmental benefits (ODI, 2015).

GREENING INFRASTRUCTURE

The global infrastructure needs for economic growth, jobs, and poverty reduction are extremely high. In developing countries, achieving the infrastructure-related UN Sustainable Development Goals (SDGs) while staying in line with the Paris Agreement would cost between 4.5% and 8% of gross domestic product (GDP), depending on how efficiently it is done (Browder, et al., 2019). Moreover, the European Green Deal and the COVID-19 pandemic also suggest a need for widespread sustainable development (see *Box 6* below). Exclusively focusing on traditional "grey" infrastructure, which employs steel and concrete, would not only make these development costs higher: it would also make the SDGs more challenging to meet. To address this concern, a recent World Bank report explored the possibility of integrating grey and green infrastructure and found that this approach could help fill the need for climate-resilient 21st-century solutions (Browder, et al., 2019). Although this approach is still relatively new, there is mounting evidence that strategically combining natural systems with grey infrastructure can provide lower costs and more resilient services. Implemented properly over time, integrating green and grey solutions to create climate-resilient infrastructure has the ability to tackle the looming financial and environmental crisis facing global infrastructure systems, while also offering the potential to help provide water, food, and energy to growing communities, lift communities out of poverty, and mitigate climate change.

Nature-based solutions (NBS) are gaining momentum internationally as a cost-effective, no-regret, and flexible approach to address water resource management, disaster risk reduction (DRR), and climate change adaptation (EU, 2019). Natural systems can provide protection from natural hazards and maintain a steady supply of water and energy, in addition to offering other co-benefits that help stimulate the surrounding ecosystem and community. An example of NBS is green infrastructure, which is defined as a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (EEA, 2015). Other examples of green infrastructure include green roofs, rain gardens, and bioretention areas.

MOVING BEYOND "HARD" INVESTMENTS

The importance of "softer" investments cannot be overstated. The ongoing COVID-19 pandemic has challenged us to reflect on the systems currently in place and has illuminated the need to focus on investing in ex ante risk reduction and preparedness. Especially in the context of climate change, employing

14 Original values in US dollars.
15 Original values in US dollars.

a holistic strategy that utilizes financial, human, natural, physical, and social capital is the only way to achieve true resilience. Softer investments such as capacity building, coordination mechanisms, or EWS have been proven to yield substantial benefits for relatively low costs, in particular when combined with other complementary infrastructure investments. For example, a World Bank working paper estimates that benefits from upgrading the hydro-meteorological information and early warning capacity in all developing countries to developed country standards would yield benefits of €3.11–28.02 billion per year, with benefit-cost ratios of 4–35, including co-benefits, depending on assumptions and scenarios considered (Hallegatte, 2012).[16] Furthermore, capacity development for DRM has been identified as one of the main methods of substantially reducing disaster losses. Holistically speaking, capacity building should be aimed at institutional and legal framework development, organizational development, and human resource development (Buss, 2010).

THE VALUE OF INTEGRATED INVESTMENTS: ONE INTERVENTION, MANY BENEFITS

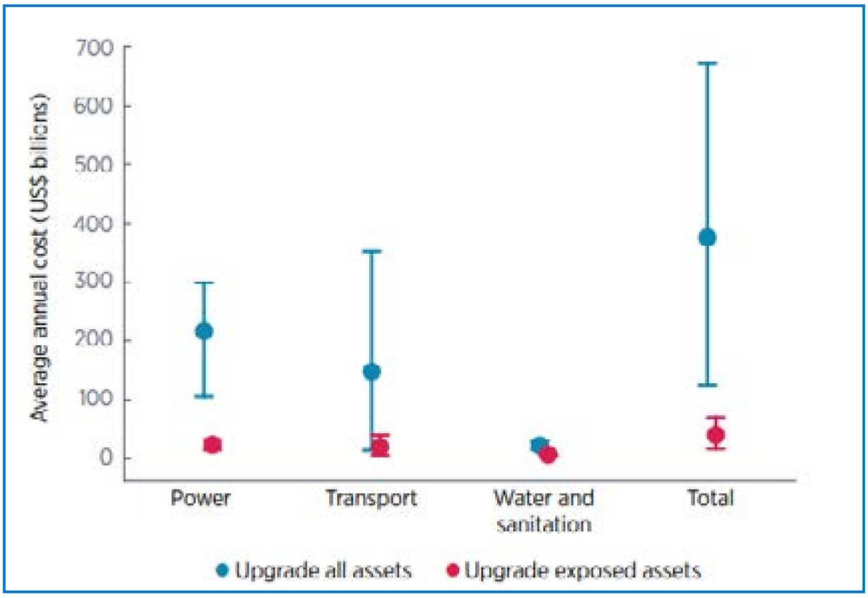
It is rare that a building has only one function. A school building, for example, provides education, may provide hot lunches and services for poorer students, provides a space for community activities and continued learning, and in many countries serves as a polling station and/or a shelter post-disaster. Many schools in Europe were constructed 50 or even 100 years ago, when many of these functions were not considered. The age of these buildings means that they are energy inefficient from a heating/cooling and insulation perspective; that they may not meet building codes for fire, earthquake, wind, and snow; that they lack spaces for food preparation and provision; and that they cannot provide universal access for students, teachers, and community members with disabilities. Too often, capital investments consider only one of these needs at a time and therefore miss opportunities for a holistic investment that upgrades building safety, resilience, climate mitigation and adaptation, sustainability (zero waste, water harvesting and grey water recycling, etc.), and inclusivity. While the example of a school building is given here, the premise applies equally to buildings providing social, health, administrative, and community functions. Beyond limiting the disruption to building occupants by one intervention focused on achieving multiple objectives and benefits, this approach also makes technical and economic sense. Box 7 provides a rationale for the joint implementation of energy efficiency and seismic strengthening objectives.

Box 4. Targeting investment to the most vulnerable infrastructure is critical

According to the World Bank *Lifelines* report (Hallegatte, et al., 2019), disaster shocks are the leading cause of infrastructure damage and disruption in high-income countries, especially where maintenance is neglected. Severe weather events are the most common cause of power outages, and transportation issues arise predominantly due to flooding, cyclones, and earthquakes. When considering new infrastructure, the relatively incremental up-front costs of adding resilience measures are easily offset by lower maintenance and repair costs. For example, use of earthquake-resistant water supply pipes in earthquake-prone areas pays off; in Japan, earthquake-resistant pipes have sustained significant and repeated ground deformation. In New Zealand it is estimated that €3.4 million ($6 million Newzealand dollars) to harden transmission and distribution infrastructure has resulted in a €17-23 million ($30-40 million Newzealand dollars) reduction in direct asset replacement costs (Kestrel Group, 2011). However, unless there is a robust understanding of the potential exposure of infrastructure assets to disaster types, the annual cost of these investments is prohibitive. Figure 8 shows that focusing resilience measures in the areas of highest risk is an order of magnitude less in cost than making improvements in all areas. The development of such risk information is easily covered by the savings generated, and moreover, such data have value and co-benefits far beyond targeting of infrastructure investments.

16 Original values in US dollars.

Figure 8. The incremental cost of increasing resilience of future investments is significantly reduced if asset exposure is determined



Source: Hallegatte, et al. (2019)
Note: "Cost" here is the average annual capital investment cost between 2015 and 2030. The circles represent the median, and the vertical bars represent the full range of possible incremental costs.

Box 5. Economic Analysis in the US

In the US, benefit-cost analysis (BCA) for disaster risk reduction investments was initiated early on and mandated by Congress under the 1936 Flood Control Act. It has been used to evaluate DRR investments since the 1950s, has been standard practice for major organizations such as the Federal Emergency Management Agency (FEMA), and has been a very important criterion for economic efficiency for many decision-makers across the country. Various institutions have funded and published annual reports on the benefits of DRR, as measured by BCA, such as the 2019 National Institute of Building Sciences report *Natural Hazard Mitigation Saves,* which highlights average BCAs for several types of hazards and DRM measures (see Figure 9).

Figure 9. Benefit-cost ratios of disaster risk reduction investments in the US

National Institute of BUILDING SCIENCES

	ADOPT CODE	ABOVE CODE	BUILDING RETROFIT	LIFELINE RETROFIT	FEDERAL GRANTS
Overall Benefit-Cost Ratio	11:1	4:1	4:1	4:1	6:1
Cost ($ billion)	$1/year	$4/year	$520	$0.6	$27
Benefit ($ billion)	$13/year	$16/year	$2200	$2.5	$160
Riverine Flood	6:1	5:1	6:1	8:1	7:1
Hurricane Surge	not applicable	7:1	not applicable	not applicable	not applicable
Wind	10:1	5:1	6:1	7:1	5:1
Earthquake	12:1	4:1	13:1	3:1	3:1
Wildland-Urban Interface Fire	not applicable	4:1	2:1	not applicable	3:1

Source: NIBS (2019), Naumann, et al. (2020), Neagoe (2016)

Box 6. European Green Deal and COVID-19's catalyst for widespread sustainable development

The European Green Deal is an ambitious goal that comprehensively outlines how Europe will become the first climate-neutral continent by 2050. It has eight elements: (1) increasing the EU's Climate ambition for 2030 and 2050, (2) supplying clean, affordable and secure energy, (3) mobilising industry for a clean and circular economy, (4) building and renovating in an energy and resource efficient way, (5) a zero pollution ambition for a toxic-free environment, (6) preserving and restoring ecosystems and biodiversity, (7) from "farm to fork": a fair, healthy and environmentally friendly food system, (8) accelerating the shift to sustainable and smart mobility and three cross-cutting aspects (financing the transition, leave no one behind - Just Transition - as well as mobilizing research and fostering innovation) (European Commission, 2019). To accomplish the EU's increased climate ambitions for its 2030 and 2050 targets, it will need to ensure clean, secure energy, energy-efficient and resource-efficient construction and renovations, and sustainable and smart mobility. This will not be possible without smart, green infrastructure, which has the potential to create jobs while helping to cut continent-wide emissions. The COVID-19 pandemic has demonstrated the need for countries to collaborate—and their ability to do so; and this cooperative spirit can be further amplified to promote green, resilient investments that are also economically sustainable. Unaddressed, global environmental emergencies, such as more intense and frequent natural disasters, can cause social and economic damages far larger than caused by COVID-19.

Box 7. Integrating Energy Efficiency and Structural Strengthening

Long-term sustainable growth requires a reduction in the physical, social, and economic shocks arising from geophysical and climate disasters, with a commensurate reduction in greenhouse gas (GHG) emissions and energy intensity. Buildings with the greatest vulnerability to disasters are typically the most energy inefficient, as these buildings pre-date modern building codes. This is the case for a vast number of public and private sector buildings across Europe. For countries with robust regulatory frameworks related to the structural safety of the existing building stock—Romania and Italy, for example—it is not possible to improve the energy efficiency of a building without assessing and if necessary improving its structural strength. In other words, achieving energy savings and the concomitant reduction in GHG emissions is not possible if these buildings are also not structurally strengthened. Unfortunately, integrated seismic strengthening and energy efficiency interventions have been relatively limited in Europe, especially when the scale of the challenge is considered.

According to the World Bank project "Seismic Resilience and Energy Efficiency in Public Buildings" (World Bank, 2020c), beyond achieving ambitious climate goals, the integration of structural strengthening and energy efficiency brings other benefits, including (i) reduction in total cost through shared labour[a] and complementary concurrent investments; (ii) improved sustainability of energy efficiency improvements through the building lifetime and payback period by ensuring investment in earthquake-resistant buildings;[b] (iii) functional upgrades such as autonomous energy (e.g., solar panels), which are crucial to ensure energy supply and continuity of service in the aftermath of an earthquake, when energy service can be disrupted for days or weeks; (iv) upgrade to roofs associated with energy efficiency, which can increase the performance of buildings during an earthquake (e.g., minimize damage to nonstructural elements) and in storm events; (v) assessment of the full economic case for building improvement versus demolishing and rebuilding; and (vi) minimization of disruption to building occupants and government services.

a. The World Bank analysis "Reducing earthquake risk in large panel multifamily buildings" in Bulgaria (P164887) indicated that over 50% of the cost for the energy efficiency improvements relates to labour. Such a cost can be shared and further optimized if integrated with seismic strengthening.

b. The ongoing Energy Efficiency in Public Buildings (EEPEP) project in Turkey (P162762) will target a minimum energy savings of 20%, with a maximum simple payback period of 12 years. Considering the high frequency of damaging earthquakes in Turkey (one event every 1.5 years on average), seismic events are likely to occur during that period, even more so during the life cycle of the buildings. Therefore, adequate seismic performance of structures is crucial to justify the long-term return on investment for energy efficiency works.

2. Economic Analysis and Triple Dividend of Resilience

2.1. Use of Benefit-Cost Analysis to Assess Investments in DRM

In disaster risk management, most investments would appear to be no-regret investments to save lives and therefore a priority for public investment. In practice, however, preventive investments for reducing disaster risk are limited. Limited investment arises from a confluence of challenges. First, the associated benefits of investment may be uncertain, especially for rare, high-impact events, and especially when compared to the often substantial up-front costs of such investments. In addition, spending public funds on a disaster that may or may not occur can seem a lower priority than meeting the needs that clearly exist now - for example, a municipality might not prioritize the purchase of new fire and rescue equipment over fixing the roads that constituents use daily, and might choose to expand different health and screening services rather than invest in resilient medical buildings. Moreover, DRM investments often need to be made by line ministries that are disconnected from the knowledge of disaster risks and their impacts on infrastructure—knowledge that instead may exist within the national civil protection agencies. Finally, and importantly for this publication, in economic analysis, the neglect of co-benefits or wider impacts of DRR investments has often led to an underestimation of net benefits, which has made investments in prevention and preparedness seem economically infeasible. Recent research and practice have therefore focused on developing methodologies to ensure a more holistic assessment of these investments (Botzen, et al., 2019).

In an ideal situation with perfect information, identifying total benefits from a DRM investment should adopt a difference-in-difference (DiD) framework. Total benefits that can be accrued to the investment can be estimated by comparing gross regional product (GRP) in two different locations (i.e., treatment region, where DRM investments took place, and control region, where no such investments took place) in two different time periods (i.e., pre-treatment and post-treatment periods). GRP necessarily accounts for all the market transactions relating to the production, exchange, and consumption of final goods and services taking place within a region. The regions should ideally be similar before the intervention in terms of GRP and disaster exposure so that they are comparable. In most cases, however, the DiD approach is not feasible. This may be due to lack of baseline data and lack of comparable regions for a counterfactual situation. In that case, the approach is to assume a possible alternative investment, undertake scenario-based analysis, or undertake qualitative analysis to present some of the costs and benefits of the intervention.

Two types of analysis can be undertaken through a benefit-cost analysis (BCA): prospective and retrospective. A prospective analysis aims to analyse the potential benefits of an intervention, either a hypothetical scenario or a real investment planned. This helps determine the added value of the investment compared to alternatives or the status quo and helps identify potential challenges that can be addressed by a modified project or program design. It is therefore a main tool of policy and decision-making that has been used at regional, national and local levels for decision making (see *Box 8*, *Box 9* and *Box 10*). A retrospective analysis generally serves the purpose of impact evaluation to derive lessons learned and to improve the design of potential other interventions, projects, or policy programs in the future, as well as providing evidence of the net benefits of certain types of interventions. For the latter, however, sufficient evidence at scale or across several analyses for similar investments is necessary to ensure that recommendations can be supported with certain confidence levels.

A typical BCA is generally conducted in 10 steps, all of which include various challenges that should be carefully considered *(Figure 10)*; a full practical guide is included in the Background Report (European Commission and World Bank, 2021a). Based on literature reviews and experience developed through this study, a series of practical "do's and don'ts" have been highlighted for undertaking economic analysis (*Figure 11*). For example, it is critical to consider a counterfactual: If no investment is made, are injuries and/or fatalities possible? What could be the cascading effects if a road is blocked or emergency response is hindered due to damage or loss of critical communications or lifelines? What are the additional co-benefits, such as preservation of cultural heritage (tangible and intangible) or ensuring the mental health and safety of a population concerned about the potential or actual impacts of disasters? Are there co-benefits associated with real estate, lower insurance costs, etc.?

A summary of the main methodologies used for the economic analysis of DRM investments is highlighted in *Table 2*. In addition, the Background Report provides more information on approaches to economic analysis, covering cost-effectiveness analysis, multi-criteria analysis, robust decision-making under uncertainty, and others (European Commission and World Bank, 2021a). Further discussion on economic analysis and the methodology applied in this report focuses on the Triple Dividend of Resilience.

The World Bank and Overseas Development Institute (ODI) Triple Dividend of Resilience framework identifies and quantifies three types of benefits (dividends) in any DRM investment. These are avoiding losses and saving lives during a disaster (dividend 1), unlocking economic potential as a result of stimulated innovations and bolstered economic activities that arise from the reduction in background risks related to disasters (dividend 2), and generating social, environmental, and economic co-benefits of DRM investments even in the absence of a disaster (dividend 3); see *Figure 12*. A main advantage of the Triple Dividend framework is that it presents a broad business case for reducing and managing disaster and climate change risks. It also promotes cross-sectoral, cross-disciplinary, and multi-hazard reflections that are more likely to promote the integrated investments essential for achieving the SDGs. The Triple Dividend approach is innovative, and where enough data are available it enables the full benefit of ex ante investment in prevention and preparedness to be calculated. It was applied throughout this report in line with the development of this thematic field. A summary of main lessons learned from the analysis can be found below in *Figure 19* (section 4.1.). More details on the specific calculations and challenges faced to estimate various dividends can be found by investments and hazards in the Background Report (European Commission and World Bank, 2021a).

2.2. Application of the Triple Dividend of Resilience Framework

The Triple Dividend of Resilience framework involves a risk-based assessment to calculate dividend 1, which is important for a thorough economic analysis, as outlined in papers critically reviewing the use of BCA (Mechler, 2016). However, it also considers other types of benefits typically neglected in the economic assessments of DRM investments. The consideration of other benefits beyond avoided losses makes it possible to enhance linkages to other disciplines (economics, environmental science, etc.) and furthers the intellectual exercise of thinking about design options to maximize co-benefits. Concrete indicators for the three dividends are included in *Table 3*.

DIVIDEND 1: SAVING LIVES AND REDUCING LOSSES

This dividend 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, as well as the reduction in those impacts due to a set of resilience measures being implemented (Ghesquiere, et al., 2006). 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 (GFDRR, 2014). For example, these modelling approaches 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 average annual loss (AAL) or a loss at a particular return period. When a scenario is used to evaluate avoided losses, typically a higher-impact and lower-frequency event is chosen to illustrate the scale of damages that can occur. However, to understand the range of impacts that disasters can cause, it is important to also consider high-frequency and lower-impact events. This can be done by considering a loss corresponding to a lower return period or an average loss over a given time period, both of which can be obtained from probabilistic analysis (i.e., an analysis that considers the likelihood of events).

DIVIDEND 2: UNLOCKING ECONOMIC POTENTIAL

Several research projects have attempted to estimate in practice the wider economic benefits from DRM investments that arise ex-ante because of changed expectations of risk from economic actors. One study highlighted in Hallegatte et al. (2020) shows the wider economic impacts of investments or policies in DRM. Madajewicz, Tsegay, and Norton (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 (also an important reserve in case of floods or droughts) and their investments in productive assets. Such type of analysis shows 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 a 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.

DIVIDEND 3: GENERATING SOCIAL, ENVIRONMENTAL, AND ECONOMIC CO-BENEFITS

A few studies have attempted to quantify some environmental or ecosystem co-benefits of DRM investments. An 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" (products obtained from ecosystems, such as resource harvests, water, and genetic material), "services" (recreational and tourism benefits or certain ecological regulatory functions, such as water purification, climate regulation, erosion control, etc.), and cultural benefits (spiritual and religious, heritage, etc.). A table in the Background Report lists potential economic benefits of ecosystem services (European Commission and World Bank, 2021a).

Table 3 provides a framework for presenting Triple Dividend results that is used in this study, and Table 4 highlights some of the key data sets and considerations for each dividend during preparation of the economic analysis. The following are some of the challenges encountered during application of the Triple Dividend framework.

1. **Data requirements are a significant constraint for in-depth analysis,** so it is advisable to undertake baseline data collection (ex ante analysis) and consultations with stakeholders (ex post analysis), as well as to leave sufficient time to undertake the analysis during preparation/evaluation (three to six months).

2. **A collaborative and consultative exercise should be undertaken to think through the potential impacts** (positive and negative) of each investment, since investments can differ quite substantially across regions and hazards.

3. **The choice of certain parameters or hazard scenarios can significantly impact the results,** so sensitivity analysis and presentation of a range of results is always advisable.

4. **It is rare to find literature on, and practical analysis of, wider economic impacts** (second dividend) or distributional impacts of disaster risk management investments, particularly those that are case- or hazard-specific. For this reason, the analysis of those impacts may be underestimated quantitatively, but they should still be qualitatively addressed and documented.

Box 8. Typical approaches to economic analysis in Europe (2014–2020)

BCA is defined in the EU cohesion policy guidelines as "an analytical tool to be used to appraise an investment decision in order to assess the welfare change attributable to it and, in so doing, the contribution to EU cohesion policy objectives" (EC, 2014). In this framework and according to legal guidelines, BCA was explicitly required as a basis for decision-making on the co-financing of major projects included in the operational programmes of the European Regional Development Fund (ERDF) and the Cohesion Fund.[a] The ex-ante assessment of a project's economic value followed a clear procedure with several criteria.

Major projects were found to be eligible for EU funding if (i) they needed co-financing, as indicated by a negative financial net present value and a financial rate of return lower than the discount rate used for the analysis (which would indicate that involvement from the private sector was unlikely); and (ii) they were desirable from a socio-economic perspective, as demonstrated by a positive economic net present value. Moreover, they needed to demonstrate methodological soundness. A risk assessment (sensitivity analysis and qualitative or probabilistic risk analysis) was to be included if a positive economic net present value was found. Moreover, the report was to be (i) self-contained (include results of previous studies), (ii) transparent (with complete sets of data and sources of evidence), (iii) verifiable (assumptions and methods made available for replicability), and (iv) credible (based on well-documented and internationally accepted theoretical approaches and practices).

In terms of climate change, all major projects had to undertake an ex ante vulnerability and risk assessment in order to consider climate change aspects (EC, 2014), as outlined in the relevant regulation.[b] They also needed to undertake a quantification of greenhouse gas emissions that could be integrated into the BCA. For major projects, there were three climate change requirements: (i) projects should be integral to mainstreaming climate action into EU policies and funds; (ii) they should be adaptable and applicable to a wide range of infrastructure projects; and (iii) they should be designed to be updated and further developed based on evolving experience and emerging best practices.

a. Major projects were defined as those where eligible costs exceeded €50 million, or €75 million where the project contributed to thematic objective 52 under Article 9(7), promoting sustainable transport and removing bottlenecks in key network infrastructure.

b. Commission Implementing Regulation (EU) 2015/207, Article 2 and Annex II.

Box 9. Economic analysis in Austria

In Austria, legislation requires project implementors to undertake a detailed economic analysis for certain disaster prevention investments (BMLFUW, 2009). Protective measures against avalanches, mudflows, and floods must be evaluated with a BCA for an investment valued at €110,000 or more. Although the application of BCAs in Austria is theory-based, the approach has some distinct features from a societal perspective. These mainly concern the categories of damage under consideration. Damage to assets assigned a non-use value (such as cultural assets) is generally not analysed quantitatively but is discussed partly qualitatively. The main impacts analysed are on buildings, infrastructure, and agriculture and forestry areas, as well as revenue losses in tourism. Indirect economic losses are described in terms of the number of companies and their employees.

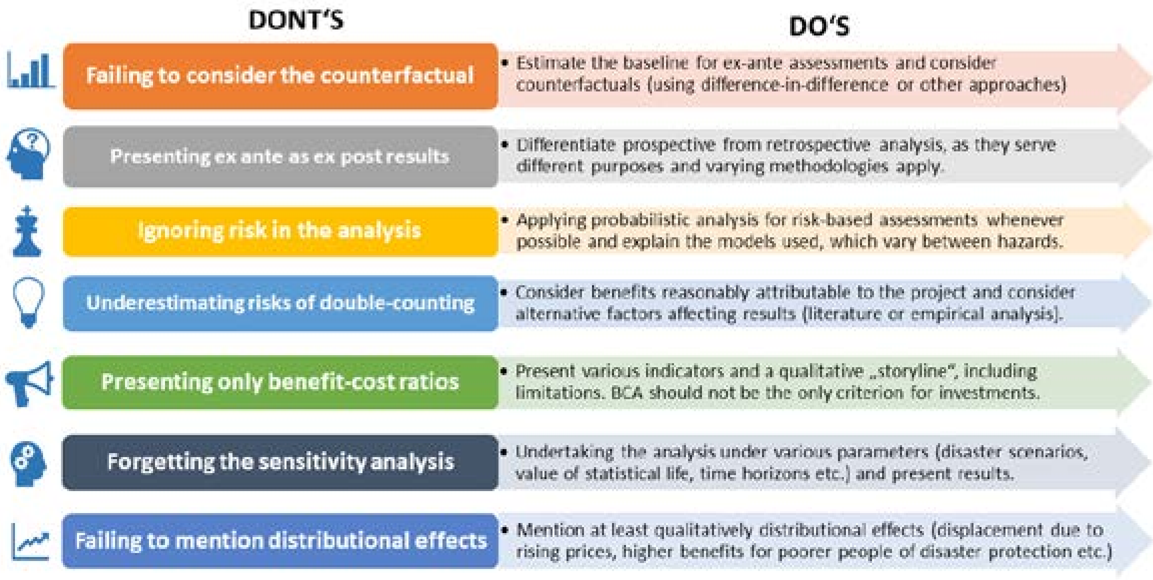
Box 10. Economic analysis in the Netherlands

In the Netherlands, although not legally required, economic analysis has facilitated and improved public decision-making on flood protection and water governance for more than a century. A study by Bos and Zwaneveld (2017) provides an overview of the evolution of this practice. At the end of the 19th century, BCA was used for the first time in Dutch flood risk management and water governance. A lobby group of citizens and local government wanted to engage the central government in organizing and financing enclosure of the Zuiderzee and reclamation of major pieces of land. After the enormous technical challenges of this project had been tackled, public debate about the economic and budgetary consequences began. These concerns were addressed by drawing up an overview of costs and benefits of the project and by providing additional economic analyses. In the end, this lobby was successful: the Dutch Parliament agreed on the construction of the Zuiderzee Works in 1918, and construction started in 1927. The role of the BCA was acknowledged by a cost-benefit table in the draft Act on the Zuiderzee Works of 1901. Results from national assessments over the course of a century are summarized in Bos and Zwaneveld (2017); of note is the finding that the 1954 investment in the Delta Works (€0.5 billion) was equal to the direct damage in the 1953 floods and has more than paid for itself in reduced damage and loss.

Figure 10. The 10 steps of a BCA

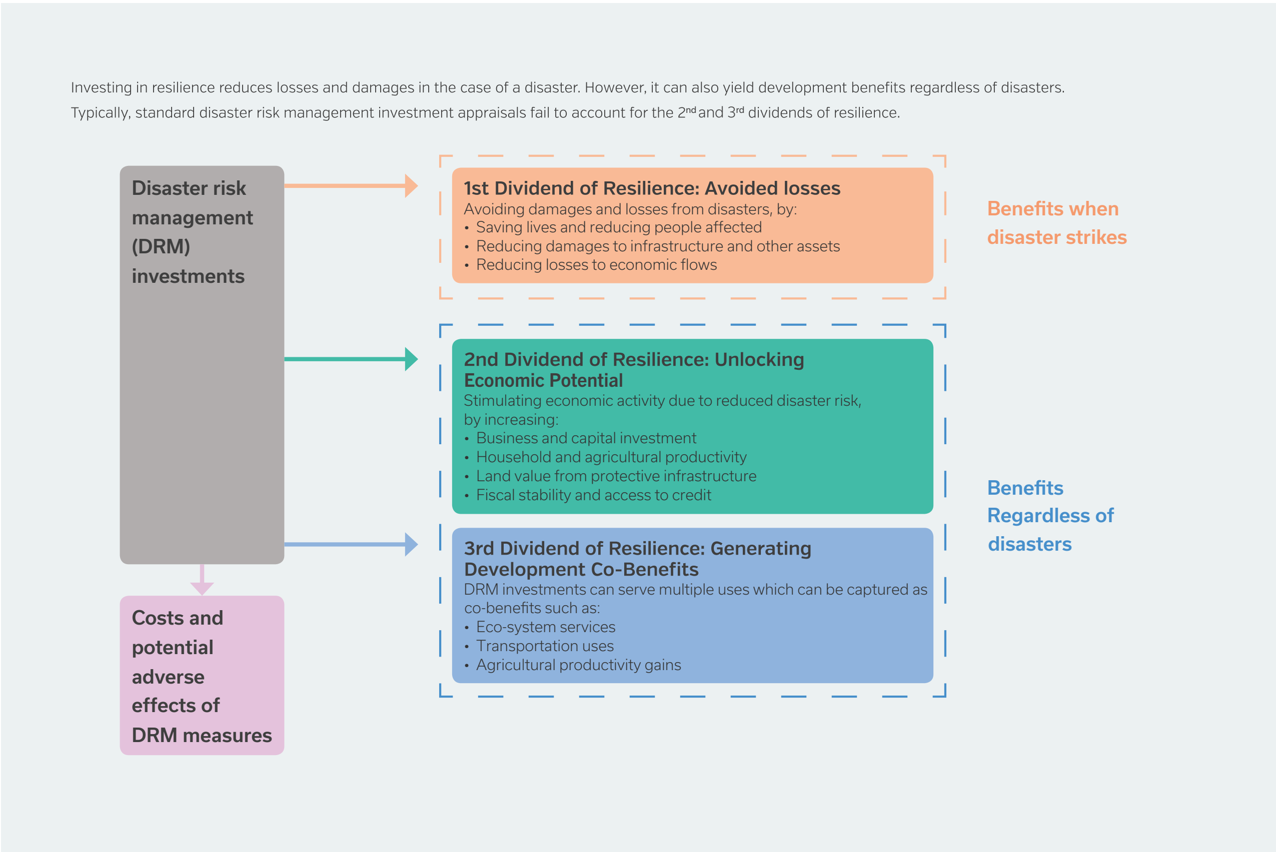
Source: World Bank analysis
Note: BC = benefit-cost; IRR = internal rate of return; NPV = net present value.

Figure 11. The do's and dont's of a BCA to assess DRR investments



Source: World Bank analysis

Figure 12. Triple Dividend of Resilience



Source: Tanner, et al. (2015)

Table 2. Main methodologies used for the economic analysis of disaster risk reduction investments

METHODOLOGY	DESCRIPTION
Cost-effectiveness analysis	Used to identify least-cost options to meet a specific, predefined target or policy objective without necessity of quantifying benefits.
Multi-criteria analysis	Emphasizes low costs and is organized around objectives, criteria, and indicators that can be compared to the performance of different (policy) options over time in achieving stated objectives. One type of multi-criteria analysis is the criticality analysis, which is used in several contexts for the prioritization of infrastructure projects.
Decision-making under deep uncertainty	Uses a process of robust decision- making to enable the best outcomes under a range of futures and world views, given that reliable descriptions of the future are not available. This approach considers mostly the broader welfare perspective with large impacts and necessitates dialogue between various stakeholders, given their differing acceptance of risk and uncertainty. Decision making with uncertainties in Climate Change require additional considerations and should be addressed uniquely from other hazards (Christensen, et al., 2018; Dellink, et al., 2018).
Benefit-cost analysis (BCA)	Generally focuses on immediate benefits that are linked to the project and that can be monetized easily (tangible values). Efforts have been made to use BCAs in a risk-based approach more adapted to the analysis of systemic, integrated, or soft investments.
Triple Dividend framework BCA	Aims to estimate a variety of wider benefits potentially arising from investments. It is a comprehensive approach but has not been widely applied in the literature given its rather recent development.

Source: World Bank analysis

Table 3. Triple Dividend benefit-cost analysis template

	CASE STUDY 1	CASE STUDY 2	
FIRST DIVIDEND			
Lives saved			
Injuries avoided			
Avoided direct stock losses			
Avoided direct flow losses (BI)			
Avoided indirect flow losses (higher-order effects)			
Total first dividend			
SECOND DIVIDEND			
Increased land values			
Entrepreneurship and innovation (economic gains from positive risk taking)			
Higher investment in productive assets (households)			
Extended planning horizons			
Cheaper access to credit/ better ratings			
Total second dividend			
THIRD DIVIDEND			
Economic co-benefits (will depend on specific case)			
Energy efficiency			

Job creation and higher-order economic effects			
Social co-benefits (will depend on specific case)			
Improved and secure livelihood			
Environmental co-benefits (will depend on specific case)			
Total third dividend			
Total dividend			
Total project cost			
BENEFIT-COST RATIO (BCR)			

Source: World Bank analysis
Note: BI = business interruption.

Table 4. Triple Dividend analytical framework: Preliminary summary of data requirements and challenges

DIVIDEND	DATA REQUIREMENTS	CHALLENGES
1. AVOIDED LOSSES (REALIZED WHEN A DISASTER STRIKES)		
Saving lives and reducing number of people affected	Quantification requires disaggregated data on potential number of deaths, injuries, and total affected people to calculate total value of statistical life (VSL) and value of disability-adjusted life years (DALY). It may also be important to consider the lives saved and people who will be less affected beyond the direct investment footprint.	Complete numbers may not be available, meaning that conservative estimates are calculated. Data on VSL and DALY will be another challenge, as these typically are based on national data sets, which reduces comparability. Aggregating disaggregated data may require some weighted conversion.
Reducing damage to infrastructure and other assets	Quantification of direct monetary measure of total insured losses from disaster exposure, such as properties saved and damage to properties avoided, requires data on reconstruction costs and increased insurance premium. However, results might be an underestimation because many losses are not covered by insurance.	Many direct losses may not be insured, and there is the possibility of moral hazard arising from insurance, given the lack of private defensive measures. This situation will make any estimate less precise.
Reducing losses to economic flows	Direct monetary measure includes total insured losses from disaster exposure, such as the avoided losses in labour hours at minimum wage rate.	There can be a moral hazard issue.
2. UNLOCKING ECONOMIC POTENTIAL (REALIZED WITHOUT EXPOSURE TO A DISASTER)		
Business and capital investment	Climate-/disaster-resilient communities will attract more business and capital investments due to greater stability. Quantification requires data on changes in investments before and after DRM and the return from such increased investment.	Comparing data on these investments before and after DRM implementation can reveal the benefit. Specific case studies and project-/region-level data will be necessary. Household-level benefits may not be available—employment generation through those investments may be considered as location choice instead of pure job creation. If that is the case, societal benefits from working locally can be an indirect measure of additional benefit. The quality of employment, i.e., increased return, can be useful in quantifying these benefits.

Household and agricultural productivity	Resilient localities will create opportunities for households to increase their agricultural productivity through the intensification of activities and better functioning of agricultural value chains.	Increased production and value addition due to DRM interventions can be quantified by comparing data from before and after such interventions.
Value from protective infrastructure	The development of DRM measures can increase land value. Quantification requires data on land value before and after DRM investments.	Data may come from the local land registry. Existing studies may also be useful in identifying the impact of DRM on land value.
Fiscal stability and access to credit	DRM measures can increase fiscal stability, and their strategic implementation can increase access to credit, which is a measure of adaptive capacity.	Access to credit can increase adaptive capacity, which may enable businesses and households to build back better. However, such impacts may well be incorporated in other indicators and if not carefully differentiated and accounted for may create a double-counting problem.
3. GENERATING DEVELOPMENT CO-BENEFITS (REALIZED EVEN IF A DISASTER NEVER OCCURS)		
Environmental and ecosystem-based co-benefits	Protecting and preserving ecosystems can be instrumental in reducing the risk and harm of disasters. Examples include the role of Sundarbans (mangrove forests) in Bangladesh and India in protecting coastal lives and livelihoods from tropical storms and cyclones.	It requires adopting a production function methods of valuing ecosystem goods and services. However, most such services have either multiple managements and/or competing uses, making the overall quantification challenging.
Transportation use	Some specific DRM structures can be used as roads and highways that generate additional economic co-benefits.	
Economic co-benefits	Economic co-benefits most commonly emerge from multiple uses of structures built under DRM projects.	
Social co-benefits	Public health and societal co-benefits may emerge from DRM measures.	These co-benefits—such as the mental health impacts on children in disasters or the community impacts associated with loss of cultural heritage—may be difficult to quantify.
Climate co-benefits	Considering additional adaptation and mitigation measures (such as energy efficiency, consideration of future hazards under climate change) at the same time as DRM interventions can significantly increase the benefit without significant cost implications	

Source: World Bank analysis; *based on The Triple Dividend of Resilience: Realising development goals through the multiple benefits of disaster risk management* (Tanner, et al., 2015)

3. | Case Study Selection for This Report

The analysis presented here highlights the costs and benefits of a sample of DRM investments funded through EU programmes, national funds, and international financial institutions. Case studies were selected through a three-step approach to ensure a representation of various hazards, sectors, and countries (*Figure 13*). Through these case studies, the report offers new insights using the Triple Dividend approach, provides an overview of existing benefit-cost analysis, and includes the development of new methodologies, in particular to account for the net benefits of soft investments (capacity building, coordination, etc.).

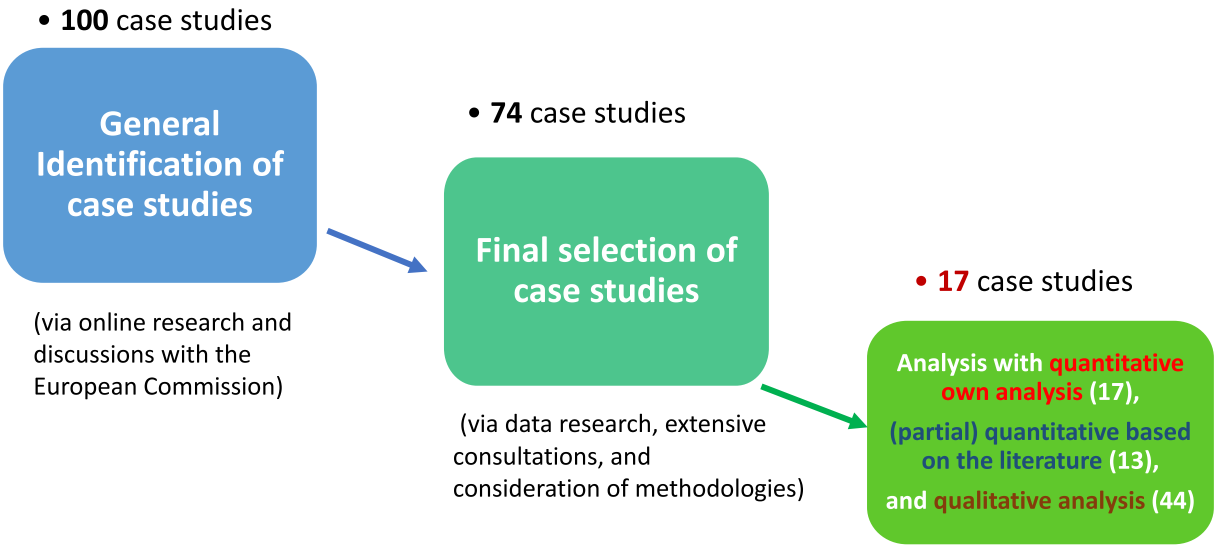
Following an initial review of existing case studies through desk research and extensive consultations with stakeholders from institutions and the European Commission (via virtual meetings, calls, and questionnaires), approximately 100 case studies from a European context were selected. The case studies included a mix of relevant sectors (housing, education, transport, health, emergency response, early warning and lifelines, communication/ICT, energy, and water) and involved both natural hazards (floods, droughts, earthquakes, wildfires, landslides, volcanic eruptions) and technological hazards (oil spills, chemical pollution, and biological, radiological, or nuclear disasters). The case studies focused on Member States and Participating States of the UCPM; on projects funded by national funds, at least partly by EU funds, or by international financial institutions; and on major projects[17] that aimed predominantly at reducing disaster risk and increasing prevention and preparedness. 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.[18] In a third step, analysis was undertaken for the case studies (17 with full quantitative analysis), and relevant international best practices were presented.

The geographic distribution of the case studies collected and analysed is presented in *Figure 14*. Moreover, the distribution of case studies by hazard type is presented in *Figure 15* and a detailed overview is included in *Annex 2*. This figure reveals the greater availability of data and investments for hazards that are more frequently studied (such as flood and earthquake) and highlights the comparative rarity of investments, and associated analysis, for hazards such as volcanic eruption, drought, and landslide. For technological hazards, investments with the potential for economic analysis appeared to be even more scarce and difficult to identify.

17 Major projects in the programming period 2014–2020 are defined as operations where eligible costs exceed €50 million, or €75 million for projects that contribute to the thematic objective under Article 9(7) (Article 100, Regulation 1303/2013 from the European Commission).

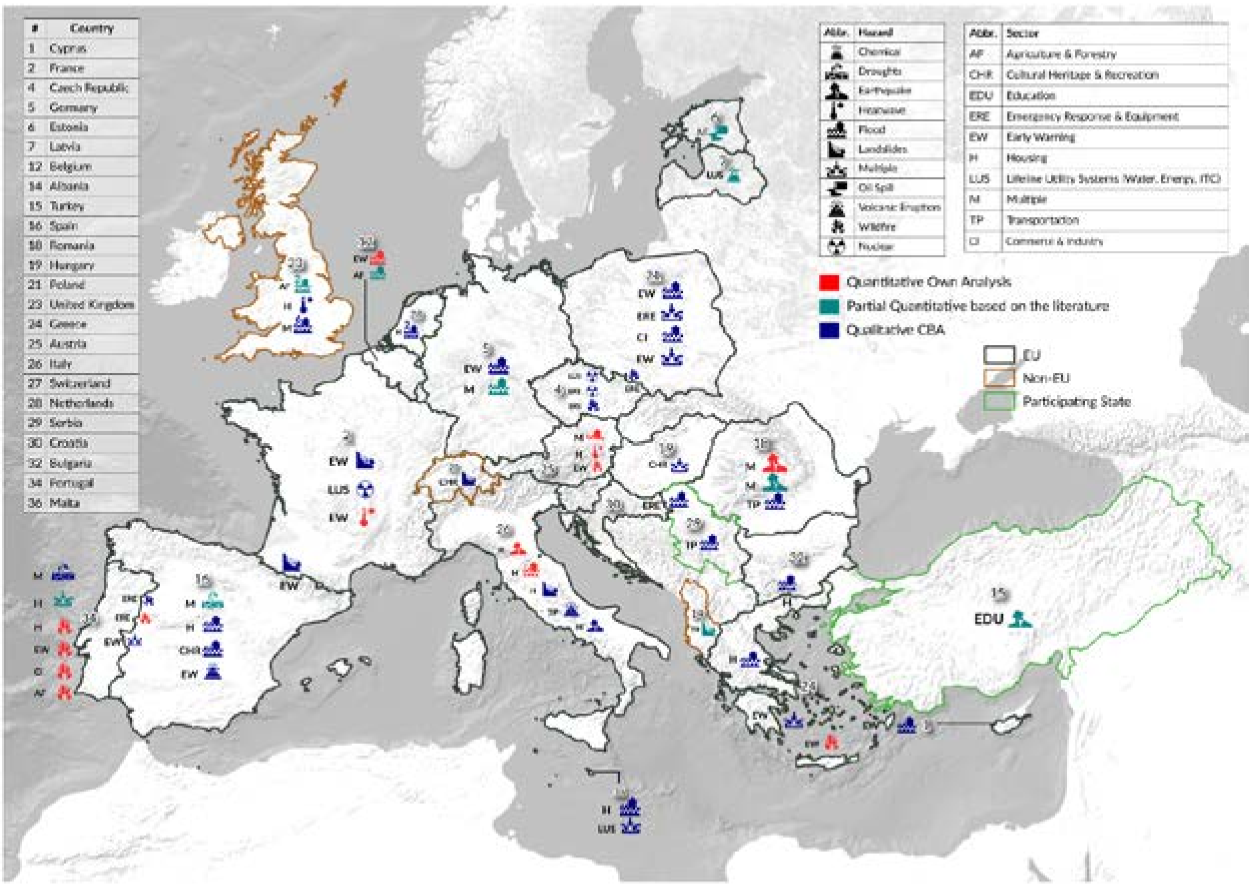
18 The number is higher than the original list of case studies considered, as some case studies were added in the process based on further recommendations from stakeholders.

Figure 13. Process for the selection of case studies



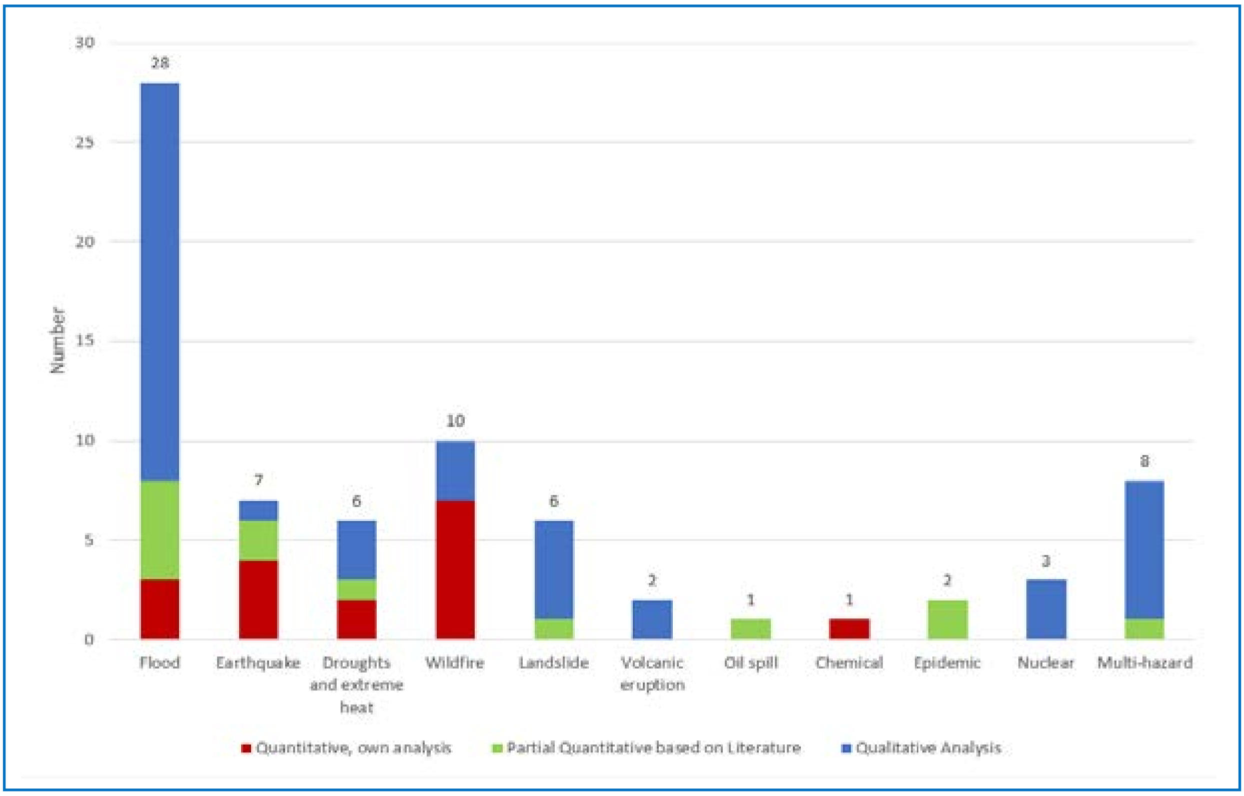
Source: World Bank analysis

Figure 14. Overview of case studies analysed under this report



Source: World Bank analysis

Figure 15. Case studies by hazard and type of analysis



Source: World Bank analysis

4. | Overall Findings

4.1. Overall Results

In most cases and across the range of investments and hazard types, the analysis[19] reveals positive net benefits, with benefit-cost ratios higher than 1, positive net present values, and internal / external rates of return higher than threshold values (shown respectively in *Figure 16*, *Figure 17*, and *Figure 18*). These findings confirm findings from the literature that benefits from targeted preventive investments in DRM generally outweigh the costs. However, determining an average value for a hazard- or sector-specific BCA is not technically sound, as samples were not statistically representative, methodological approaches were not uniform, and investment types/actions varied widely across case studies. However, some key observations were made on the BCRs for different interventions across hazards:

1. There are very clear benefits of investing in flood prevention and preparedness, as the majority of BCRs were found to be greater than 1.5, with a median of 2.6. Investments that integrate nature-based solutions and early warning were found to have the greatest benefits, with median BCRs of 4.9 and 2.8, respectively.

2. For earthquake risk reduction, structural strengthening of existing buildings yielded a BCR of 1.8 for public buildings and a BCR of 5 for private buildings under probable maximum loss (PML) analysis. The analysis of hypothetical investments in seismic strengthening and energy efficiency in education facilities across Europe yielded BCRs ranging from 0.6 to 2.2. Earthquake prevention measures that were accompanied by investments in energy efficiency and building modernization provided the greatest BCRs and provide immediate benefit to beneficiaries even if a disaster does not occur. The application of earthquake EWS to automatically shut off critical systems or provoke rapid action to save lives and assets - such as stopping of trains, energy protection measures, and so forth - was found to have significant benefits with a BCR of 7.

3. Extreme heat prevention and early warning had a wide range of BCRs. BCRs associated with changing the urban landscape through green and white measures ranged from 0.82 to 1.79, depending on the level of green and white measures introduced. Those scenarios that focused only on green measures brought about higher BCRs due to the numerous co-benefits generated by greening of urban space. Heatwave early warnings provide significant benefits, with BCRs from 48 to 246.

4. Wildfire prevention and response was found economically very positive, with BCRs ranging from 1.6 to 39. Measures focused on prevention, such as managing wildland-urban interfaces,

19 Results from this research presented in figures in this report such as boxplots and histograms are presenting results from the 30 case studies (17 own new quantitative analysis and 13 quantitative results from the literature) that have data available for display. In section 4.2. results from own analysis will be indicated by adding a footnote wherever applicable.

were found to have BCRs of 2.1 to 3.1, and addition of fuel breaks in forested areas had BCRs of 12. Decision support tools for climate change adaptation and alerting for wildfire risk reduction yielded BCRs ranging from 5.8 to 39, while cross-border coordination mechanisms had a BCR of 1.6.

5. Case studies on landslides were comparatively few, and the calculated BCRs of 0.1 to 1.1 are expected to be underestimated. The most disruptive landslides affect key highway and transportation routes; if the full disruption can be calculated, and the intervention measures targeted at critical transport areas with limited redundancy, then the returns on investment for such actions will be high.

6. The analysis for volcanic eruptions was significantly limited by the difficulty in finding case studies and determining investments, but based on literature it is clear that monitoring and early warning systems alongside adequate transportation routes are very sound and economically beneficial investments.

7. In managing pandemics and public health, there is a very clear economic argument for preparedness, including stockpiling of equipment and supplies. This is illustrated by the increase in the cost of personal protective equipment (PPE) during the COVID-19 pandemic (*Table 12*); according to SHOPP (2020), prices increased between 200% and 1,500%.[20] Moreover, a recent study by the National Academy of Medicine (2016) determined a BCR of 13.3 for investing in pandemic preparedness globally.[21]

8. For technological hazards and clean-up of environmentally degraded areas, there is a clear economic argument, with BCRs ranging from 1 to 5.8 depending on the nature of the technological hazard and the planned investment.

The collected case studies and analysis conducted here lead to some further conclusions about the benefits and costs of interventions aimed at increasing societal resilience:

- In most investments across the range of hazards, the quantified benefits of investment outweighed the costs. These benefits are still considered to be underestimated, as many benefits are difficult to monetize, such as reduced disruption to societal functions, business continuity and production, rescue and recovery costs, post-traumatic stresses (and accompanying mental health and loss of productivity burdens), protection of cultural heritage, and so forth.

- Large uncertainty in the vulnerability of exposed assets and economic activities to hazards complicates the estimation of the real costs of disasters as well as the benefits of adaptation or DRR measures, a reason why effective use of methodological approaches and communication of results is essential.

- In the case studies where the benefits of investment were assessed as lower, it was generally clear that this was an artefact of data availability rather than a result of sub-optimal investment selection compared to the counterfactual of no investment. For example, in one case study, it was evident that the investment would have been characterised as a positive investment economically had it been possible to quantify all the benefits, such as lower insurance costs, higher property values, stimulated construction and labour during construction and through operations and maintenance, etc. In the case where two investment options for disaster risk reduction would be compared, it would be even more essential to ensure having same type and levels of data and information available to allow for a true comparison.

- Benefits are maximized (or in some cases economic viability is ensured) when comprehensive and integrated investments are undertaken. Examples of such investments are the combination of grey and green infrastructure solutions; support for early warning, capacity building, and coordination mechanisms that can also enhance knowledge and research to inform preventive investments; and low-cost preventive measures that provide incentives to and enhance dialogue with the private sector and civil society. Though these investments may be perceived as more complex to implement

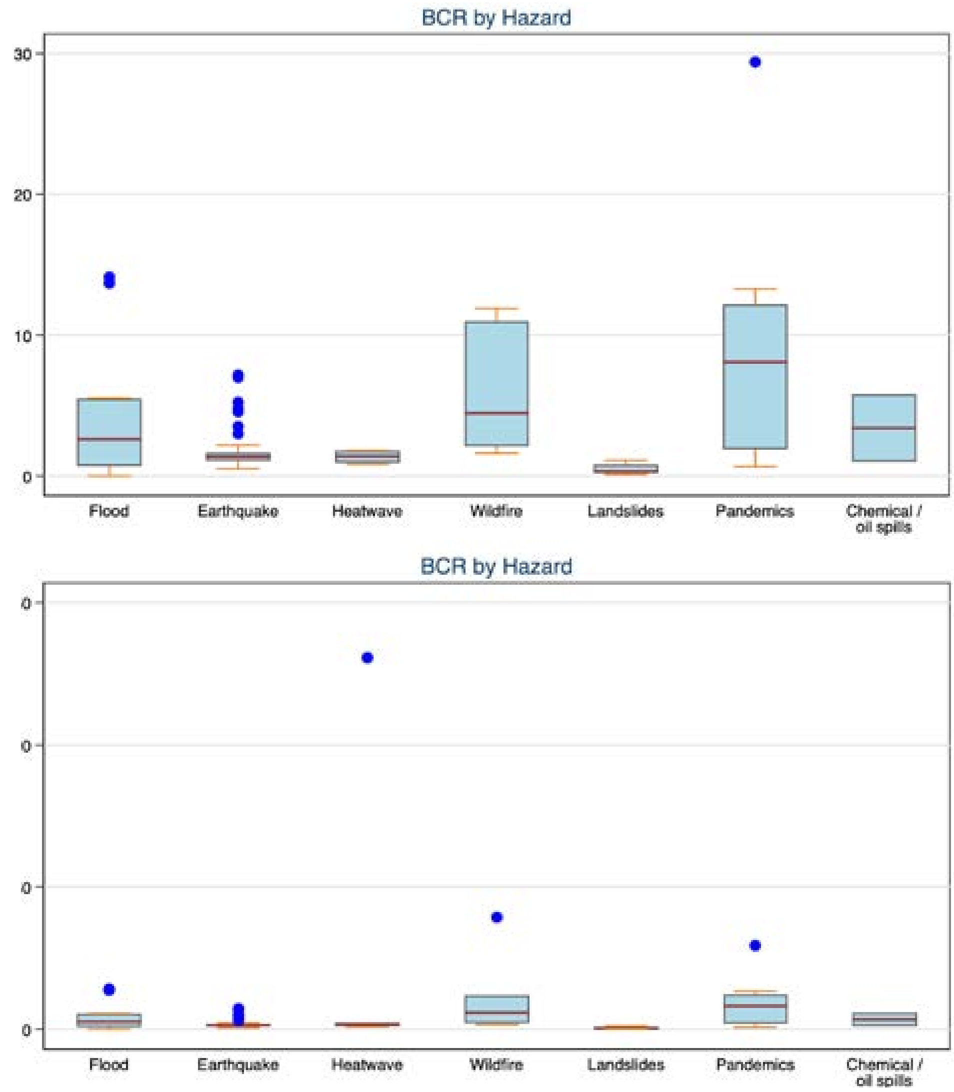
20 Results are for calculations in Euro, original values are in US dollars
21 Results are for calculations in Euro, original values are in US dollars

than hard preventive infrastructures, they can promote many environmental, developmental, and climatic co-benefits.

- Compared to investments for a single hazard, multi-hazard investments for prevention and preparedness are more complex and generally understudied in terms of economic valuation assessments. This report has conducted and presented results for several qualitative case studies where investments in equipment, capacity, coordination mechanisms, or infrastructure could support increased prevention and preparedness, as well as leverage other co-benefits. In general, these effects tend to be mostly observed for cross-border investments, international support mechanisms, or local/urban areas. This result may however be due to economies of scale effects and selection bias for the case studies considered (mostly investments from the EU and Member States). The qualitative studies for cross-border investments present high benefits, while the quantitative case studies shows net benefits that are likely underestimated (European Commission and World Bank, 2021a). Cross-border mechanisms require additional and particular research to estimate the total costs and benefits. However, methodologies to include capacity building and other behavioural effects have been limited for such studies. The methods presented in this study could be used as inspiration to conduct a Triple Dividend benefit analysis for cross-border investments, paying close attention to attribution effects.

Additional observations are illustrated in *Figure 20*, and the following section elaborates on findings further, by hazard and by intervention type.

Figure 16. Findings of benefit-cost analysis by hazard: Benefit-cost ratios, excluding extreme values (above) and including extreme values (below)

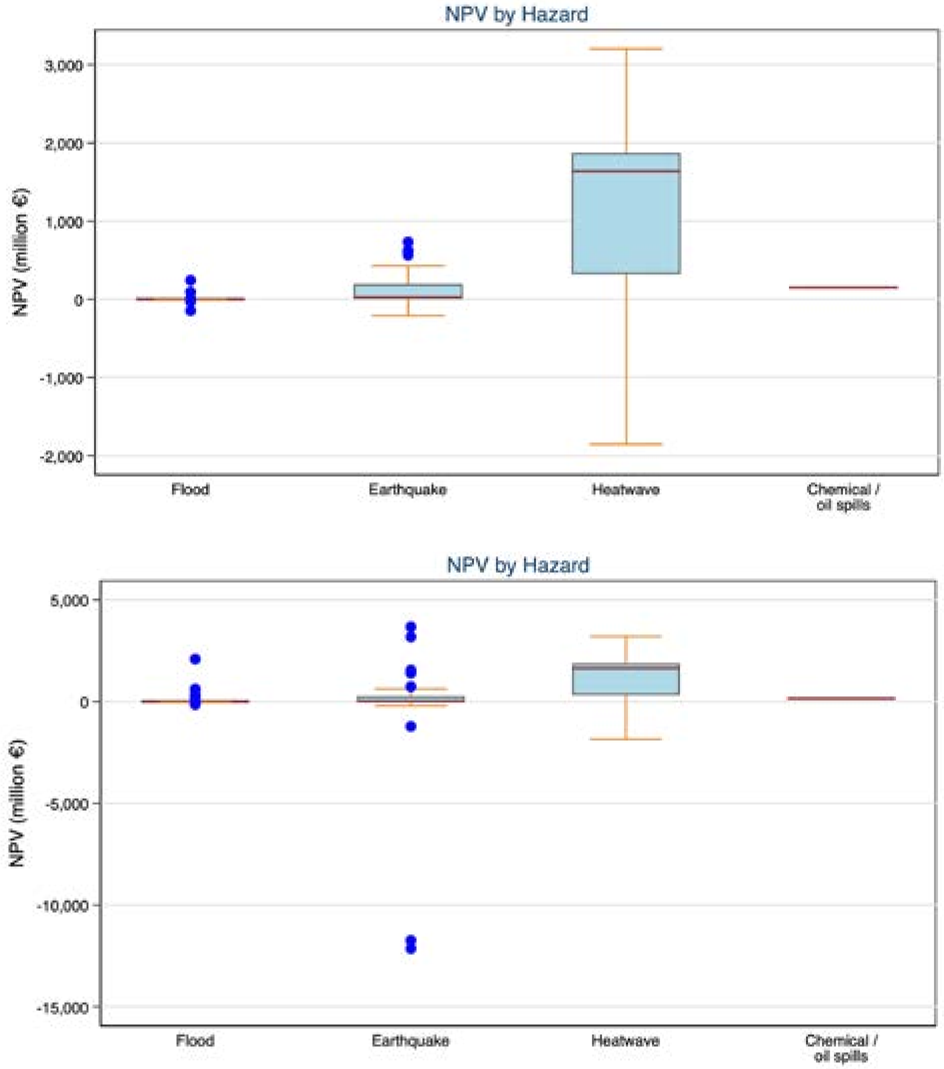


Source: World Bank analysis; *based on external data and information; presenting in part results from literature based on World Bank*

& external reports (4 Flood results from World Bank (2007), Spray (2016), Hölzinger & Haysom (2017), Gauderis, et al. (2005); 2 Earthquake results from World Bank (2018a, 2019c, 2019a, 2019d); 1 Landslide result from Xiong & Alegre (2019); 2 Pandemics/Epidemics results from Master, et al. (2017), GHRF Commission (2016); 1 Oil Spill result from European Commission (2020)).*

Note: The figures show the distribution of benefit-cost ratios (BCRs) for disaster risk management investments by the different types of hazards, 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 figure and included in the bottom figure. Bottom graph: Extreme values are included in this graph.

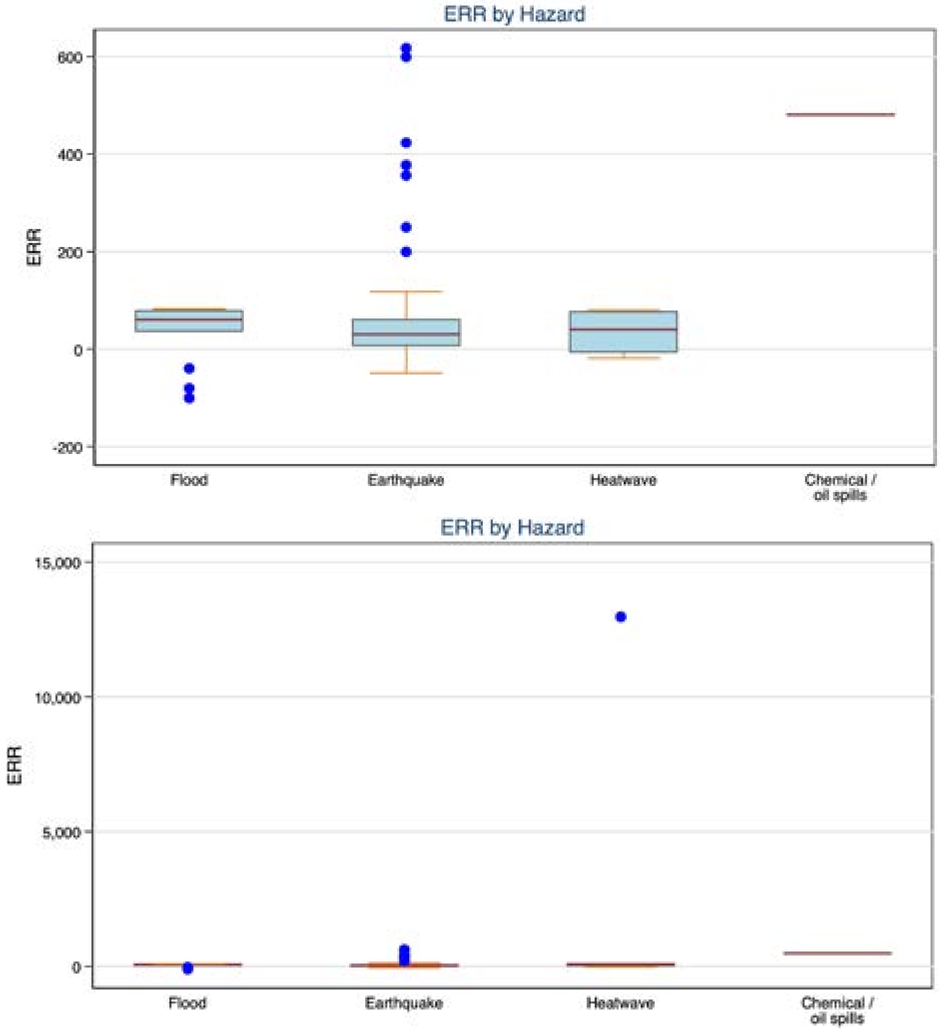
Figure 17. Findings of benefit-cost analysis by hazard: Net present values (million €)



Source: World Bank analysis; *based on external data and information; presenting in part results from literature based on World Bank & external reports (5 Flood results from World Bank (2007), Spray (2016), Grossmann & Hartje (2012), Hölzinger & Haysom (2017), Gauderis, et al. (2005); 2 Earthquake results from World Bank (2018a, 2019c, 2019a, 2019d)).*

Note: The figure shows the distribution of net present value (NPV) for disaster risk management investments by the different types of hazards, 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 this graph.

Figure 18. Findings of benefit-cost analysis by hazard: external rates of return



Source: World Bank analysis; *based on external data and information; presenting in part results from literature based on World Bank & external reports (4 Flood results from World Bank (2007), Spray (2016), Hölzinger & Haysom (2017), Gauderis, et al. (2005); 2 Earthquake results from World Bank (2018a, 2019c, 2019a, 2019d)*

Note: The figure shows the distribution of external rates of return (ERRs) for disaster risk management investments by the different type of hazards, 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 this graph.

Figure 19. Selected lessons learned, by hazard

FLOODS

- Benefits may be underestimated particularly for grey infrastructure given lack of data on real estate.

- Net benefits of NBS tend to arise in the longer term, and accounting for ecosystem services for tourism and recreation can boost these.

- More research on Property Level Protection could be useful to provide further evidence on net benefits

EARTHQUAKES

- The infrequent occurrence of earthquakes poses challenges to conduct BCA and interpreting or communicating results.

- Undertaking analysis by building types (including ownership), location of buildings (exposure) and type of intervention considered is essential, as the variability of results is very high.

- More research on earthquake EWS would be beneficial to understand interactions with complementary investments (e.g., public awareness raising).

WILDFIRES

- There is a scarcity of literature on the economic benefits of preventive wildfire investments, while these could be essential for preventive, cross-sectoral decision making on programs

- Wildfire prevention can happen at various scales, from the household level (firebreaks) to a government-led landscape management program, leading to a variety of methodologies and data requirements.

EXTREME HEAT

- An enhanced understanding of urban heat island effects can support effective and economically efficient urban strategies (green, white, blue city measures).

- Other specific parameters have to be used (value of life year instead of value of statistical life).

DROUGHTS

- An enhanced understanding of There are practically no studies on the economic benefits of preventive drought investments

- Droughts are among the most damaging and least understood of all natural hazards given among others their slow-onset nature.

OTHER HAZARDS

- Landslides: Taking into consideration climate change scenarios and seismic risks in assessments improves analysis of preventive investments.

- Volcanic eruptions: Most research has been focusing on assessments of volcanic crisis management.

- Technogenic hazards (oil spills, nuclear, chemical): There is generally a lack of research on the economic benefits of such preventive investments.

- Epidemics/pandemics: Benefits of investing in high-quality public health systems can be considerable and should be further analyzed.

MULTI-HAZARD

- Research on multi-hazard investments should be promoted.

- BCA may not be the best tool to assess these benefits given often substantial intangible benefits and interrelations.

- Capacity building or soft investments can also be assessed quantitatively when understanding real impacts on the ground.

Source: World Bank analysis
Note: BCA = benefit-cost analysis; EWS = early warning systems; NBS = nature-based solutions.

4.2. Key Highlights of Findings by Hazard

MULTI-HAZARD

Disasters are not constrained within borders, nor are regions limited to a single type of hazard. Therefore, 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. A number of investments have been undertaken in Europe to support better decision-making and emergency response in multi-hazard prevention, such as the Aegis Intelligent System in Greece (EC, 2020). Meanwhile, 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 Park (Maksimovic, 2017).

Quantifying the long-term benefits of investments[22] in multi-hazard prevention is essential to fully present the cost-effectiveness of such investments. 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. For instance, no formal benefit-cost analysis 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. On the other hand, participatory methodologies and community-based mitigation approaches serve essential roles in the context of sustainability and climate change adaptation. An analysis of an urban-focused climate adaptation program in Cascais, Portugal, using participatory methodologies reveals the highest BCRs for reforestation (particularly due to long-term benefits), legislation to promote bioclimatic construction norms, and surveillance systems; BCRs are 4.755, 4.74, and 4.34 respectively (Alves, 2015). The following sections will detail the benefits associated with interventions for a single hazard.

FLOOD

Floods cause the largest share of disaster losses in Europe: river flooding results in €7.8 billion of losses per year and impacts more than 170,000 residents, while the annual cost of damage from coastal flooding is €1.4 billion, with around 100,000 people affected (Feyen, et al., 2020). Compared to rural land, cities represent a smaller but increasing share of total flood-prone area; yet their higher density of population and asset value results in higher risk levels (EEA, 2017). Over the past 30 years, the number of devastating flood events in Europe has more than doubled, and there has been a proportional 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).

The European Commission proposed a Directive with the aim of reducing flood risks and the negative impacts of floods by identifying areas at present or future risk of flood and establishing structural protective measures and green infrastructure solutions. The European Commission Directive

22 The analysis comprises the following detailed case studies: - 1 based on results from the literature (Urban-focused participatory climate change adaptation in Cascais , Portugal, ex-post analysis).

2007/60 requires Member States to assess their water courses and coastlines for risk from flooding; to map the flood extent, assets, and humans at risk in these areas; and to take adequate and coordinated measures to reduce the risk, such as implementing retention areas and restoring floodplains (EUR-Lex, 2007). Moreover, sustainable flood risk reduction strategies need to account for the effects of climate change when planning adaptation measures. It is expected that these strategies will reduce the human losses and economic damages of flooding by more than 70% by the end of the century and yield substantial benefits for the environment and ecosystems (Feyen, et al., 2020). International best practices have also shown the benefits of integrated strategies for flood prevention (see *Box 11* for an example from the Netherlands or *Box 12* for the town of Queensland, Australia).

BCAs for flood protection were observed to be highly variable[23], as they depend on the scale and type of investment and on the intersection of localized hazard and exposed assets. This observation aligns with the findings of the PESETA IV project (Dottori, et al., 2020) (*Box 13*). The challenge is that multiple interventions are possible to manage flood, and the benefits can be challenging to capture and monetize. Typical flood interventions fall into four categories:

1. **Structural protection,** which comprises engineered or "hard" defences. These are further classified as permanent engineered structures (e.g., levees, dikes, walls, dams, flood gates) or temporary or de-mountable infrastructure (e.g., temporary barriers). Physical permanent structures have been found in some cases to transmit disaster risk further downstream.

2. **Nature-based solutions or natural floodplain management,** which includes interventions such as floodplain, dune, or wetland restoration; planting of green infrastructure (e.g., hedgerows, woodlands, natural grasslands); and blue elements such as pools, ponds, buffer basins, or water courses. Commonly, several elements are combined in a management plan to create blue-green infrastructure, with the selection determined by the local environment and prevalent flood mechanisms.

3. **Early warning systems,** which rely on meteorological forecasts of intense or sustained rainfall to identify locations with forecast flooding. EWS comprise technical components to detect rainfall in advance, estimate flood conditions, and disseminate warnings to affected communities, but also human/behavioural components regarding decisions to activate warnings and respond to warnings.

4. **Property-level protection,** which comprises protection of individual properties through small-scale interventions such as demountable flood walls and gates at doorways, raising of ground-floor levels, or elevation of door thresholds.

In this study, the BCRs were variable between and within each MS, depending on the intervention (*Figure 20*); however, damage reduction measures at the building level were found to be very positive (BCR ranges from 2.3 to 12.2). In this report, the BCRs associated with EWS and NBS were found to very favourable, although with wide ranges. For example, a landscape restoration project in Scotland aimed at reducing flood yielded a range of BCRs from 1.17 to 17 depending on the assessment and time scale considered. An analysis conducted for Belgium highlighted that a flood EWS could generate BCRs exceeding 5.2 if recipients of early warnings responded and acted in line with the warnings given to ensure the expected reduction in losses (*Table 5*). A third example, a study from Poland, found a BCR of 5.14, where most of the benefits derived from economic opportunities afforded by flood protection and a reduction in physical and mental health impacts on residents within the flood area.

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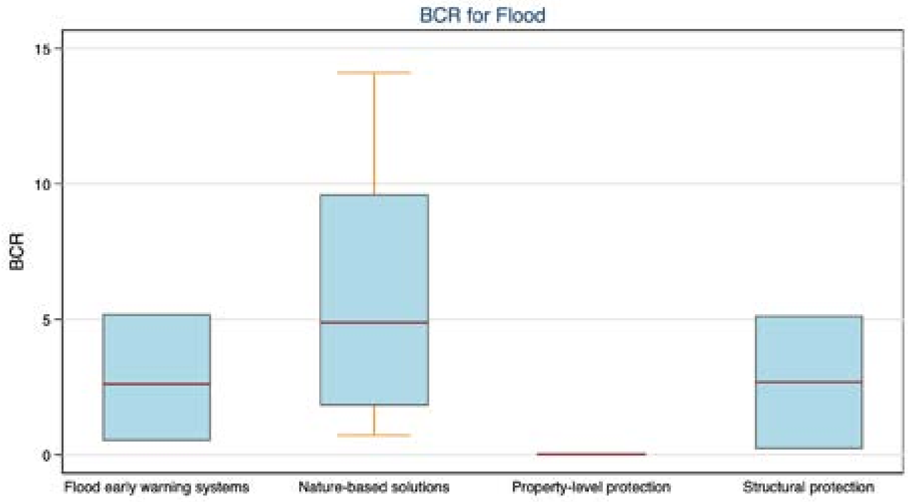
23 The analysis comprises the following detailed case studies: - 3 based on new analysis under this project (1 on structural protection, Machlanddamm, Austria, ex-post analysis; 1 on flood EWS, Belgium Flandres, ex-post analysis; 1 on property level protection, Italy Milan, ex-ante analysis)- 5 based on results from the literature (1 on structural protection, Poland Odra river, ex-ante and ex-post analysis; 3 on natural floodplain management in Scotland, Eddleston water, ex-ante and ex-post, Germany Elbe river ex-post, UK Chimney Meadows ex-post; 1 on nature-based coastal and tidal protection Sigma Plan Belgium, ex-ante).

Figure 20. Findings of benefit-cost analysis for floods (benefit-cost ratios)



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)*

Note: The figure 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).

Table 5. Benefit-cost ratio of implementing early warning systems in Flanders by dividend, over 30 years

	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	€1.5 million	€7.8 million	€15.5 million
Total first dividend (30 years)	€29.1 million	€151.3 million	€300.6 million
COSTS			
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	- €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*

Note: Future benefits and costs are both discounted by 3.5% a year. BCR = benefit-cost ratio; ERR = external rate of return; EWS = early warning systems; IRR = internal rate of return; NPV = net present value.

Box 11. Flood management in the Netherlands

The Netherlands has a wide-ranging history of preventive investments dating back 200 years (Cooper, 2015). Its Room for the River Waal project offers an example of an innovative, preventative investment that promotes both flood deterrence and sustainable urban regeneration (Climate-ADAPT, 2016). This €344 million ($381.6 million) project aims to protect the city of Nijmegen from high-water flooding. The River Waal bends sharply and narrows near Nijmegen, and during times of heavy rain, such as occurred in 1993 and 1995, an upsurge in water levels threatens dike breaches and resident evacuation. To prevent such a flooding catastrophe, the city initiated the Room for the River Waal project in 2013 to move the Waal dikes 350 m inland and construct an ancillary channel in the floodplains, resulting in a unique urban river park island at the heart of the city. To connect the new island to both sides of the river, the city is also building four new bridges. Room for the River Waal is part of the Netherlands' national flood prevention program, Room for the River, in which the Dutch government is investing €2.3 billion. The project addresses more than 30 crucial river locations to protect 4 million people who live on flood-prone territory.

Box 12. Managing flood risk in Roma, Australia

Roma, a town in Queensland, Australia, is an international example of how the implementation of flood protection can reduce an area's flood risk status (The Northern Star, 2012). After the area experienced record-breaking destructive floods in 2010, 2011, and 2012, Suncorp, the only flood insurer left in the area, refused to issue new policies to residents unless action was taken to mitigate Roma's flood risk. According to Suncorp, the average insurance claim following the 2012 floods was €77,376 (AU$96,000).[a]

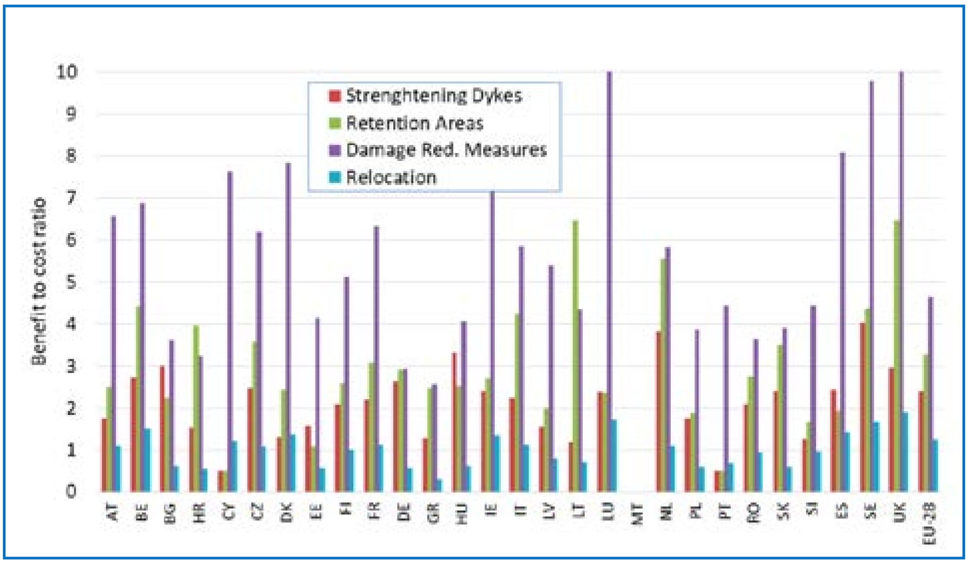
In response Roma undertook a multi-stage €6.69 million (AU$8.3 million) flood mitigation project.[b] The first stage consisted of constructing a levee; after its completion in 2014, Suncorp cut property premiums in the town by an average of 45% (Insurance News, 2019). The following stage of the mitigation scheme involved the construction of a diversion drain and the extension of the levee built in stage 1. In 2019, when the project was completed, the Queensland government announced a downgrade in the flood risk for more than 500 properties (Insurance News, 2019).

a. Original value in Australian dollars.
b. Original value in Australian dollars.

Box 13. Comparison of BCR for different adaptation measures across EU Member States

The PESETA IV project estimated benefits and costs of different measures across Europe by combining hydrological simulations with literature-based information on the costs of measures as well as simulation of avoided damages linked to their implementation. The BCRs for each EU Member State considering the effect of strengthening dikes, establishing retentions areas, implementing property damage reduction measures, and removing buildings at future flood risk are shown in *Figure 21*.

Figure 21. Benefit-cost ratio values for four adaptation measures for the period 2020–2100, under a 2°C warming scenario



Source: (Dottori, et al., 2020)
Note: EU country abbreviations are available on the Eurostat website at https://ec.europa.eu/eurostat/statistics-explained/index.php/ *Glossary: Country_codes*

EARTHQUAKE

After extreme temperatures, earthquakes have been the second deadliest natural disaster in Europe, causing more than 33,000 deaths and €62 billion in losses between 1980 and 2014 (Corbane, 2017). Earthquake risk is highest in the Mediterranean and Balkan regions, due to the high seismic hazard, aging infrastructure, and concentration of populations and assets in high-hazard areas (*Figure 21*). To reduce the damage to infrastructures and save human lives, the Eurocodes were established to provide guidance on the design of structures in seismic zones. They have proven a valuable tool beyond the EU, as many countries are increasingly using Eurocodes as standards (EU, 2018; European Parliament Think Tank, 2016). In addition, as the Green Deal and sustainable development are promoted in Europe, the integration of energy and seismic retrofitting is increasingly being explored (EC, 2020). This approach offers substantial potential benefits with reduced payback periods[24], especially in moderate to high seismicity region compare to separate investments (Pohoryles, et al., 2020). The biggest challenge for EU countries with respect to earthquake is the massive amount of building stock and infrastructure constructed prior to modern earthquake codes.

Co-investment in seismic strengthening and energy efficiency improvements offers a significant co-benefit for EU countries. Large portions of European cities comprise ageing building stock, which often has high social, financial, recreational, and cultural value. Currently, 80% of existing EU buildings were built before the 1990s, and of these 40% were built before the 1960s (EC, 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 heritage. At the same time, the EU's Energy Efficiency Directive

24 The EU is aiming for an emissions reduction target of at least 55% by 2030, with high ambitions for reduction of energy consumption (reduction of 36–37% by 2030), also through energy efficiency measures. Eurocode 8 exists for seismic design.

also set a target of reaching a 20% saving in energy consumption compared to projections for 2020. Retrofitting existing buildings so that they are both seismically resistant and energy efficient usually requires high costs (European Commission, 2020) but international examples such as from New Zealand and Japan show that these investments pay off when implemented effectively (see *Box 14* and *Box 15*).

Benefit-cost ratios for earthquake investments collected and conducted for this report were found to be positive[25], with BCR values generally exceeding 1.5 and exceeding 4 in several case studies related to earthquake structural strengthening and EWS (*Figure 23*). It is important to note that earthquake risk reduction can involve a range of interventions, from simple and low-cost steps like securing furniture and equipment, to full-scale overall strengthening of buildings or building demolition and reconstruction. Most benefits yielded in the economic analysis come from ensuring life safety of building occupants and (where implemented) the benefits associated with integrating energy efficiency measures. The National Plan for Seismic Risk Prevention in Italy (analysed for this report) yielded respective BCRs of 1.65, 1.66, and 3.5 for seismic upgrading, demolition and reconstruction, and local strengthening of public buildings. Benefits were also found to vary across public building type (*Table 6*). Similarly, three projects in Romania focusing on the seismic resilience of first response and emergency buildings had BCRs ranging from 1 to 2, an expected underestimation of the benefits given the challenges associated with quantifying the second and third dividends.

This report also highlights analysis of hypothetical investments in seismic strengthening and energy efficiency in pre-tertiary and tertiary education facilities in earthquake-prone countries in Europe (a map of seismic countries in the EU by the exposed value of education facilities is presented in *Figure 24*). When seismic strengthening was combined with energy efficiency measures and the most vulnerable buildings were prioritized, a higher BCR was yielded, but nonetheless the range for all countries was 0.63 to 2.18 (*Table 7*). Benefits differ across countriesdepending on their seismic risk, climate, and energy profile. This finding aligns with analysis conducted for the retrofitting and reconstruction of 350 schools in Turkey, which yielded a BCR of 1.53.

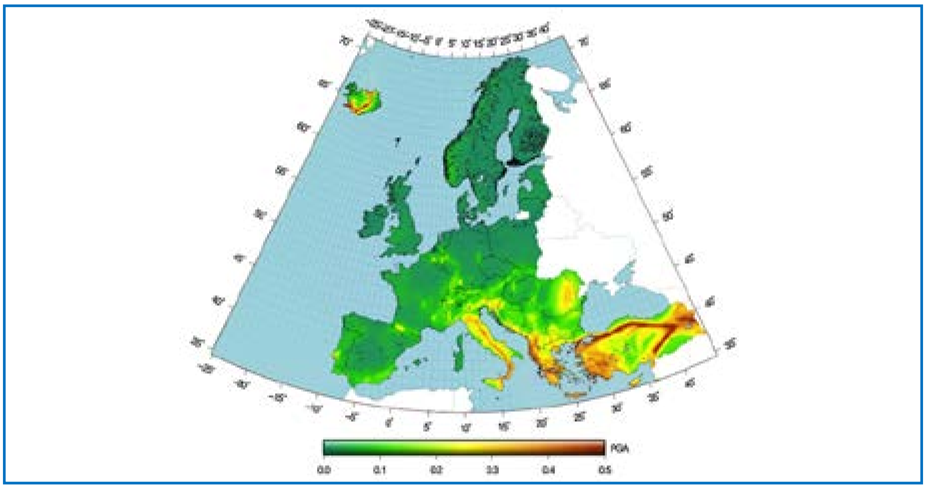
Earthquake early warning systems consist of physical infrastructure and software that can alert stakeholders about an incoming earthquake seconds to minutes before they experience the resulting strong shaking, which allows for actions (moving to a safer location, shutting off gas pipelines, shutting down critical infrastructure, etc.) to decrease detrimental impacts from shaking. As earthquake early warning has a short lead time (as short as 27 seconds in Bucharest, according to Neagoe (Neagoe, 2016)), its main purpose is to prevent loss of life and injuries. For the DACEA (Danube Cross-border system for Earthquakes Alert) program in Romania, with conservative assumptions, a BCR range of 3.4 to 11.1 was determined. Although the benefits are likely to be underestimated given lack of information and data, the actual cost of implementation, especially with respect to efforts to build public awareness on safe actions to take in the event of an earthquake, may also be underestimated.

To analyse benefits and costs for response, a novel analysis was undertaken of investments in training for emergency responders and response coordination through the UCPM in emergency responders and response coordinators through the UCPM's Knowledge Network (*Figure 25*). The analysis focuses on two earthquake disaster interventions, one in Albania (November 2019) and one in Croatia (March 2020). The analysis quantified the investments of DG ECHO and those countries that sent responders (training and deployment costs), and also quantified the benefits due to rescues and damage assessments (*Figure 26*). This approach required quantitative "what-if" analysis, as well as interviews with a range of responders. While the nature of the interventions differed (Albania involved an international deployment, Croatia was managed solely by in-country personnel), the BCRs were positive in both cases. A BCR of 1.9 in Albania was driven by the damage assessments led by the EU CPM (Civil Protection Mechanism), which expedited a return to long-term accommodation and work. A BCR of 1.1 in Croatia was driven by international training of Croatian Civil Protection personnel, showing that

25 The analysis comprises the following detailed case studies: - 4 based on new analysis under this project (2 on seismic strenghtening of buildings including national programme in Italy, ex-post analysis and Europe wide investment in educational buildings, ex-ante analysis; 1 on earthquake EWS in Romania Bucharest, ex-post analysis; 1 on responder capacity of UCPM, ex-post).- 2 based on results from the literature (2 on World Bank comprehensive programs in seismic strengthening of buildings including 1 overall program in Romania involving three projects for public sector buildings, ex-ante analysis, and 1 overall program in Turkey in the educational sector, ex-ante analysis).

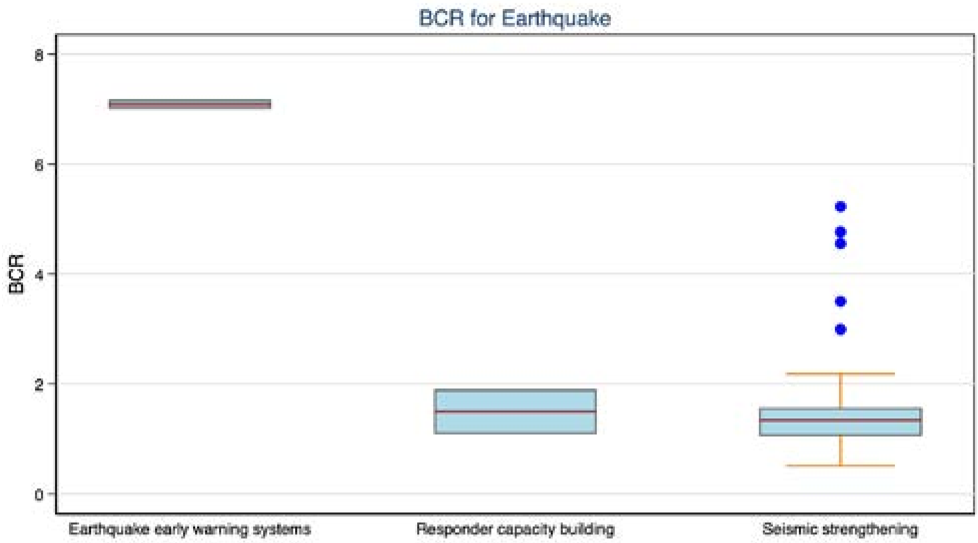
capacity-building benefits can outweigh costs even where no international personnel are deployed. This type of analysis, and the quantification of more intangible benefits of training and coordination, could and should be further developed.

Figure 22. Mean seismic hazard map from ESHM13 for the 475-year return period in terms of peak ground acceleration (PGA)



Source: (Danciu, et al., 2013)
Note: ESHM13 = The 2013 European Seismic Hazard Model.

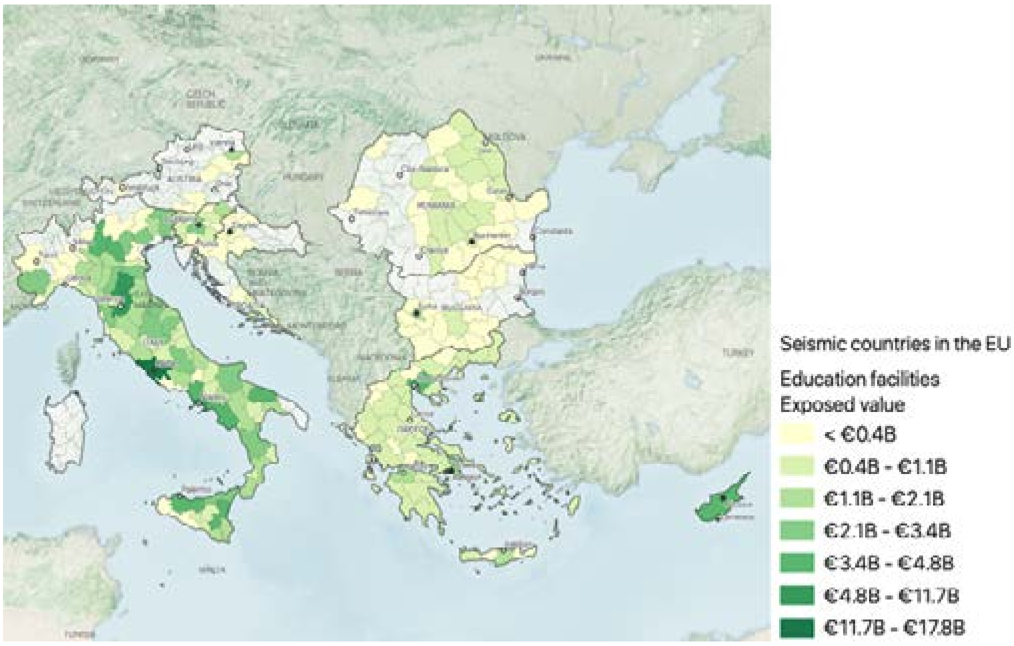
Figure 23. Findings of benefit-cost analysis for earthquakes (benefit-cost ratios)



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))*

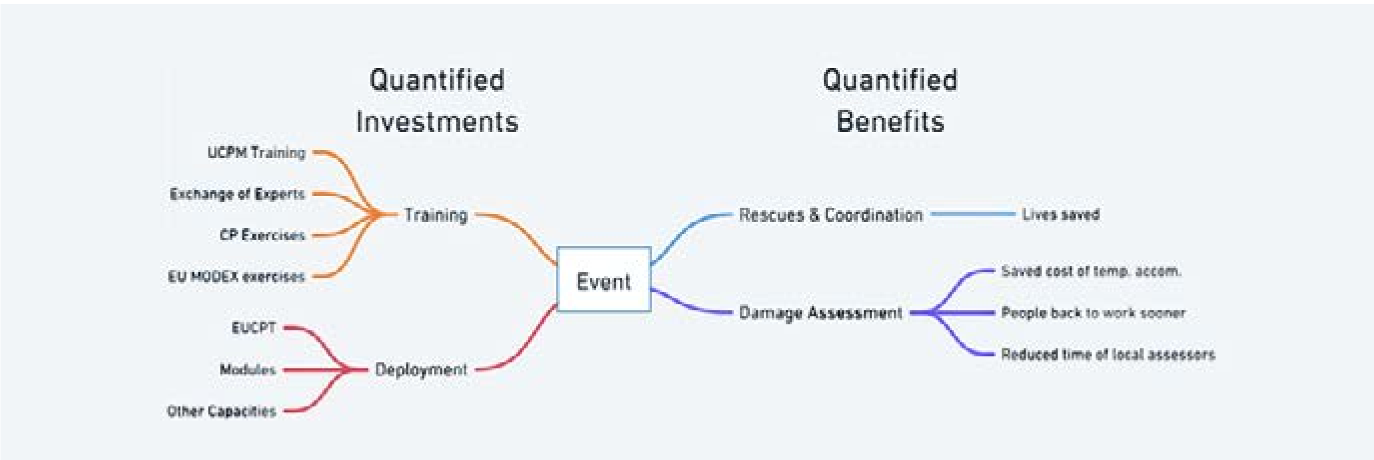
Note: The figure shows the distribution of benefit-cost ratios (BCRs) for earthquake investments based on a five-number summary: minimum (shown in yellow), first quartile, median (shown in red), third quartile, and maximum (shown in yellow). The outliers are shown as dots. Extreme values are excluded from this graph.

Figure 24. Map of seismic countries in the EU by exposed value of education facilities



Source: World Bank analysis

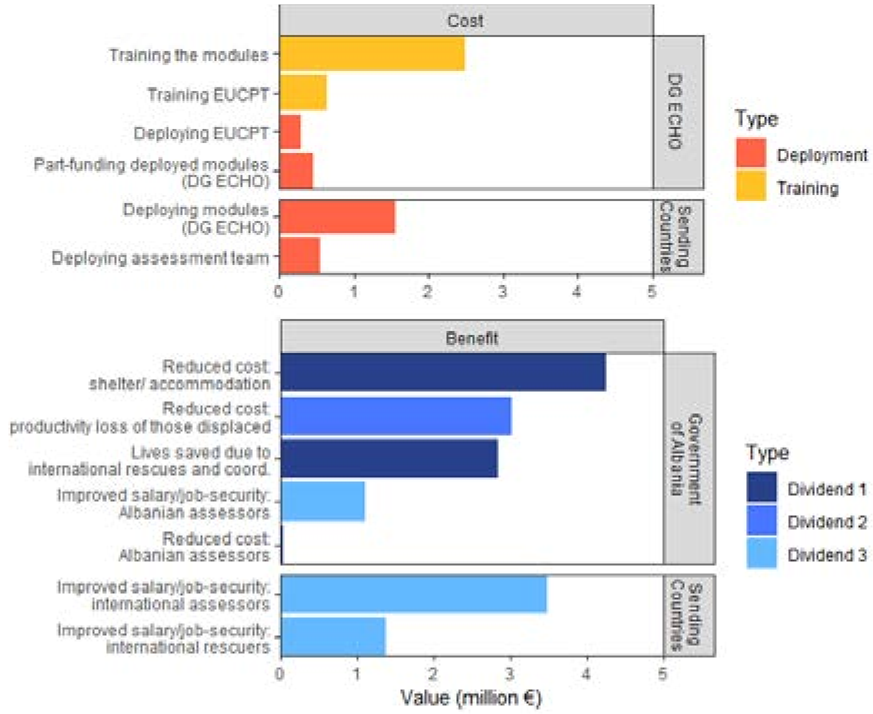
Figure 25. Costs (investments) and benefits considered for quantitative analysis to provide the capacity-building benefit-cost ratio for the Albania (2019) and Croatia (2020) earthquakes



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.

Figure 26. Capacity-building costs and benefits for the Albania earthquake (2019) further broken down and ranked for each actor



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 6. Investment in public buildings in Italy: Probable maximum loss analysis (475-year return period) by facility type

	CIVIL PROTECTION HEAD-QUARTERS	EDUCATION[a]	HEALTH CARE[a]	MILITARY & FIREFIGHTING	RECREATION & SPORTING	PUBLIC AD-MINISTRATION & CIVIC
DIVIDEND 1						
Avoided injuries	€2.0 M	€25.9 M	€6.3 M	€3.7 M	€4.3 M	€24.0 M
Avoided fatalities	€8.6 M	€113.1 M	€35.5 M	€ 17.8 M	€20.6 M	€103.2 M
Decrease in repair cost	€3.7 M	€27.4 M	€14.9 M	€7.5 M	€3.1 M	€66.5 M
Decrease in losses due to interruption of services	€9.2 M	€52.3 M	€60.9 M	€21.0 M	€9.2 M	€167.2 M
Total dividend 1	€23.5 M	€218.7 M	€117.6 M	€49.9 M	€37.2 M	€360.9 M
Total benefits	€23.5 M	€218.7 M	€117.6 M	€49.9 M	€37.2 M	€360.9 M
Total costs	€10.8 M	€119.0 M	€73.9 M	€22.8 M	€11.3 M	€223.3 M
BCR	2.17	1.84	1.59	2.19	3.29	1.62
NPV	€12.7 M	€99.7 M	€43.7 M	€27.1 M	€25.9 M	€137.6 M
ERR	117.59%	83.78%	59.13%	118.86%	229.20%	61.62%

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

Note: ERR = external rate of return; NPV = net present value.
a. service interruption in education does not include the social losses and childcare costs associated with interruption of education; service interruption in the health care sector does not include casualties associated with loss of hospital functionality, only due to casualties caused by earthquake damage

Table 7. Benefit-cost analysis for schools conducted for this report

PML ANALYSIS (475-YEAR RETURN PERIOD)	AUSTRIA	BULGARIA	CROATIA	CYPRUS	GREECE	ITALY	ROMANIA	SLOVENIA
DIVIDEND 1								
Avoided injuries	€1.5 M	€43.2 M	€5.2 M	€27.7 M	€105.5 M	€150.2 M	€35.7 M	€13.7 M
Avoided fatalities	€16.7 M	€486.6 M	€50.6 M	€235.0 M	€1.2 B	€1. 8 B	€188.2 M	€161.7 M
Decrease in repair cost	€12.3 M	€27.6 M	€ 6.1 M	€141.6 M	€478.1 M	€590.0 M	€56.0 M	€67.0 M
Total dividend 1	€30.5 M	€557.5 M	€62.0 M	€404.3 M	€1.8 B	€2.5 B	€280.0 M	€242.4 M
DIVIDEND 3								
Energy savings	€227.7 M	€445.3 M	€139.9 M	€464.5 M	€4.4 B	€13.5 B	€1.4 B	€1.6 B
CO_2 savings	€49.0 M	€334.4 M	€47.6 M	€444.0 M	€7.3 B	€4.2 B	€998.6 M	€380.3 M
Total dividend 3	€276.7 M	€779.7 M	€187.5 M	€908.6 M	€11.7 B	€17.7 B	€2.4 B	€2 B
Total benefits	€307.2 M	€1.3 B	€249.5 M	€1.3 B	€13.5 B	€20.2 B	€2.7 B	€2.2 B
COSTS								
Seismic retrofit costs	€78.0 M	€270.2 M	€60.9 M	€600.9 M	€4.8 B	€15.5 B	€811.8 M	€459.8 M
Energy efficiency improvement costs	€219.5 M	€645.0 M	€165.8 M	€521.6 M	€5.1 B	€16.4 B	€1.3 B	€1 B
Total costs	€297.5 M	€915.2 M	€226.7 M	€1.1 B	€9.9 B	€32 B	€2.1 B	€1.5 B
BCR	1.03	1.46	1.10	1.17	1.37	0.63	1.30	1.49
NPV	€9.7 M	€422.0 M	€22.8 M	€190.4 M	€3.7 B	- €11.7 B	€625 M	€733.9 M
ERR	3.26%	46.1%	10.1%	17%	37.2%	-36.7%	30.2%	48.7%

Source: World Bank *analysis; based on external data and information*
Note: PML = probable maximum loss.

Box 14. Earthquake experience from New Zealand

The 2011 Christchurch earthquake, which caused 39 people to lose their lives, showed the severe failures of unreinforced masonry buildings. Prior to this earthquake, Christchurch was not considered to have a high earthquake risk because it is not located near any of New Zealand's main fault lines. However, Swiss Re, one of the largest reinsurance companies in the world, estimated the economic cost of this disaster at €15.5 billion.[a] Of this, the cost incurred to the insurance sector was €12.4 billion (Grollimund, 2014).[b] Such high costs are due to several factors: the aftershocks that struck close to the city's central business district, soil liquefaction, and the unexpected shock to the insurance sector.

Employing the knowledge gained from this experience and similar ones overseas, New Zealand passed the Buildings (Earthquake-prone Buildings) Amendment Act in 2016 and introduced major changes to the way earthquake-prone buildings are identified and managed. This national system went into effect on July 1, 2017. The country is categorized into three seismic risk areas—high, medium, and low—which allows territorial authorities to determine the time frame for identifying, assessing, and conducting seismic work for earthquake-prone buildings using the EPB methodology (MBIE, 2017). According to Building Performance, an entity of the New Zealand government, a building or part of a building is deemed earthquake-prone if "it will have its ultimate capacity exceeded in a moderate earthquake, and if it were to collapse, would do so in a way that is likely to cause injury or death to persons in or near the building or on any other property, or damage to any other property" (Building Performance - New Zealand Government, 2020). Buildings that are considered earthquake-prone are issued an EPB notice that must be clearly displayed, and information on buildings' seismic risk status is available to the public via the EPB register.

a. Original values in US dollars.

b. Original values in US dollars.

Box 15. Comprehensive earthquake risk prevention in Japan

Japan has had many destructive earthquakes due to its topography. Most notably, Japan experienced a 9.0 magnitude earthquake off the coast of Tōhoku in 2011, nearly one month after the Christchurch Earthquake in New Zealand. This created a series of far-reaching hazardous effects, including a tsunami, which claimed the majority of the 15,848 lives lost as a result of the earthquake, and an accident at the Fukushima nuclear power plant, which was reported as a potential Public Health Emergency of International Concern (WHO, 2011). According to a report published by the Brookings Institution, a Washington, DC–based think tank, this "Triple Disaster" was the most expensive disaster in human history: 138,000 buildings were destroyed and €259 billion in economic losses were incurred (Ferris & Solis, 2013).[a]

In the wake of the 2011 event, known in Japan as the Great East Japan Earthquake and Tsunami, the country improved its already-robust earthquake preparedness and response efforts to prevent future damages. Efforts to promote disaster risk reduction and resilience in Japan include making buildings earthquake-resistant and trains earthquake-ready. Most buildings in Tokyo have been found to be earthquake-resistant during past events and the seismic resistance of public buildings has increased over time (World Bank, 2018); one prominent example of Japanese anti-seismic construction using base isolation is the Tokyo Skytree broadcasting tower. Japan's bullet trains (shinkansen) and electric trains (densha) are equipped with earthquake sensors that can be triggered to freeze every moving train in the country in the event of an earthquake.

a. Original values in US dollars.

EXTREME HEAT

Extreme heat not only has catastrophic effects on our environment, but it can also be detrimental to public health. Extreme heat events can trigger heat stroke, in which the body's temperature rises rapidly and may be unable to regulate and cool down. Without emergency treatment, this condition can lead to death or permanent disability. Marginalized communities and vulnerable people, such as small children, the elderly, people with chronic diseases, low-income populations, and outdoor workers, are more susceptible to developing heat-related illnesses. Higher temperatures also contribute to the build-up of harmful air pollutants, which causes respiratory problems. Intense heatwaves throughout Europe in June and July of 2019 highlighted the growing risk of extreme heat events if no adaptation measures are implemented (*Figure 7*). According to JRC's PESETA IV, by 2050 the number of EU and UK residents exposed to heatwaves will grow from 10 million people per year to over 180 million people per year under a scenario of 2°C global average warming warming (Naumann, et al., 2020). Without adaptation, that could result in about 52,000 fatalities per year, compared to the current statistic of 2,750 deaths per year (*Table 8*). International examples show that preventive measures particularly to support the vulnerable in case of heatwaves can be highly beneficial to reduce fatalities and harmful effects (see the example of Philadelphia, USA in *Box 16*).

The UHI effect is a result of a high coverage by impermeable surfaces, a lack of vegetation, and dense concentration of structures that absorb and re-emit the sun's heat more slowly than natural landscapes such as forests (Oke, 1982). The UHI effect can have detrimental consequences for urban populations, including increased heat-related mortality (Dang, et al., 2018). Several EU initiatives such as LifeMedGreenRoof (EU+Life) and Urban GreenUP project (Horizon 2020) have promoted the research and development of solutions to the UHI effect. Mitigating the impacts of UHI includes solutions such as greening roofs to increase vegetation (green solutions), modifying buildings to have higher reflectivity of sealed surfaces (white solutions), and increasing the coverage by water for cooling effects (blue solutions) (World Bank, 2020d). It is important to take costs and benefits of these solutions into consideration, as city-wide implementation efforts can incur significant sums. However, other solutions can be implemented that are more integrated in other interventions and can therefore yield substantial co-benefits, such as the Life+ Programme co-funded by the EU (LIFE, 2020).

BCRs[26] of heat EWS tend to be very high. Recent studies have highlighted BCRs ranging from 23 in London to 1,375 in Madrid (Hunt, et al., 2017) depending on the climate of the city, effects of climate change, socio-demographic change, and the approach to valuing reduced mortality (i.e., premature versus displaced deaths; see (Chiabai, et al., 2018). For mitigating UHI effects, cost-benefit analyses of city-wide application of green and white solutions are rare; the only published study found 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). In the current report, a new analysis for Vienna, Austria, highlighted a positive BCR of 1.8 for green solutions. An analysis was also undertaken considering a national program for heatwave early warning systems in France (*Table 9* and see *Box 17* for more details), which yielded a very high BCR of 131; even with sensitivity analysis the lowest BCR was found to be 48, which demonstrates the significant value of these systems for reducing heat wave mortality and morbidity.

Table 8. Projected changes in exposure and fatalities related to heat and cold extremes: EU and UK

EU+UK		heat exposure	heat fatalities	cold exposure	cold fatalities
	base	9,620,776	2,752	9,620,776	77
Present population	1.5°C	107,821,398	30,194	5,112,878	43
	2.0°C	176,270,043	52,182	2,826,614	25
	3.0°C	307,144,027	95,337	1,226,096	11
Population 2050	1.5°C	112,455,255	30,650	5,338,071	41
	2.0°C	183,068,319	52,666	2,924,151	24
Population 2100	1.5°C	103,363,515	28,810	4,964,788	33
	2.0°C	167,987,746	49,375	2,688,268	19
	3.0°C	288,578,248	89,644	1,189,432	8

Source: Naumann, et al. (2020)

26 The analysis comprises the following detailed case studies: - 2 based on new analysis under this project (1 on interventions tackling Urban Heat Island effects in Vienna Austria, ex-ante analysis and 1 on heatwave EWS with a national program in France, ex-post analysis).

Table 9. Benefit-cost ratio for heatwave early warning systems in France, by dividend

HEAT EARLY WARNING SYSTEMS	
FIRST DIVIDEND	
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 M
THIRD DIVIDEND	
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 for both dividends	€1.9 B
Total cost	€14.4 M
BCR	131
NPV	€1.9 B
ERR	12,967%

Source: World Bank analysis; *based on external data and information*
Note: BCR = benefit-cost ratio; ERR = external rate of return; NPV = net present value.

Box 16. Heatwave impact prevention in the US

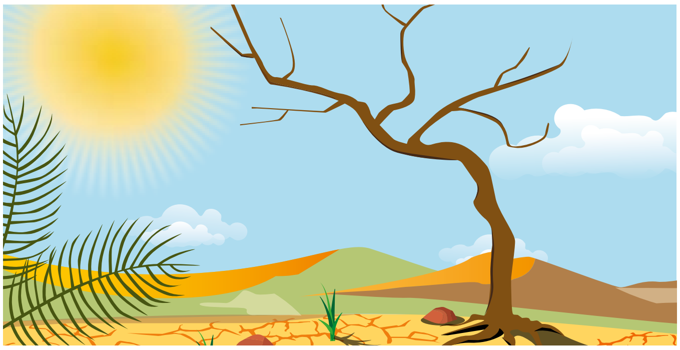
In regions that are unprepared to deal with sustained episodes of summer heat, the death toll can be substantial. This was the case in the eastern part of the United States during the first half of July 1993: between July 6 and 14, the Medical Examiner's Office in Philadelphia, Pennsylvania, determined that 118 deaths were heat related. However, this is considered to be an underestimate because heat can cause an onslaught of fatal and nonfatal conditions, such as cardiovascular diseases, cerebrovascular diseases, and respiratory diseases. These diseases respectively account for 13–90%, 6–52%, and 0–14% of the increase in overall morbidity. In 2005, partly in response to the heat waves in 1993 and 1994, the Philadelphia Hot Weather Health Watch/Warning System (PWWS) was developed to alert the city's population when weather conditions, such as abnormally high temperatures, pose risks to health. Through this system, radio and TV announcements warn the public about risks and suggest that residents check on vulnerable neighbours; hours of operation in senior centres with air conditioning are extended; and emergency medical teams' shifts are lengthened.

During the summer months of 1995–1998, warnings were issued for 45 days; considering the effect of warnings over the three-day lag after the initial warning was released, the estimated total number of lives saved was 117. Assuming a value of statistical life (VSL) of $4 million (i.e., €3.6 million in 1998) among people who are 65 years of age or older in Philadelphia, Ebi et al. (2004) found that the gross benefits of the PWWS totalled $468 million over the three-year period, which is equivalent to €417 million. On the costs side, if the direct wage costs of the Heatline (i.e., a service in Philadelphia providing information and counselling on avoiding heat stress) and additional emergency medical service crews do not exceed €8,920 per day, the total cost of implementing this system for the 21 days that a heatwave warning was issued during the three-year period was €187,316. Thus the benefits of lives saved by this system far outweigh its costs. Because of how effective this system was, it has become the blueprint for more than 20 other heat-health warning systems instituted in cities around the world.

Box 17. Heatwave impact prevention in France

The 2003 heatwave that swept across Europe was estimated to have claimed the lives of around 30,000 people people (UNEP, 2003). In just one hospital in Paris, 2400 additional emergency care visits and 1900 excess hospital emissions were recorded during the heatwave (Åström, et al., 2013), and it has been estimated that the number of excess deaths that occurred in due to the 2003 heatwave in France to total 14,800 (Bouchama, 2003). Given that numerous heatwaves in the past have led to considerable excess mortality in France, 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).

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 a heat early warning system (HEWS) to alert vulnerable groups of the ensuing high temperatures in order to have better preparedness. The aim was to provide a system of alerting authorities of ensuing extreme heat events in order 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 1st and August 31st. In the event that the 3-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 (e.g., schools, hospitals, and businesses). Studies have shown that the France HEWS has provided positive effects of HEWS in reducing (Bouchama, 2003) heat-related mortality since its inception and implementation (Bassil & Cole, 2010).



DROUGHT

Drought, commonly defined as an extended period during which a region is affected by a deficiency in water supply, negatively affects the economy by causing agricultural failure, reducing power supply, and causing shipping interruptions (Cammalleri, et al., 2020). The drought sensitivity of an area is determined by two important factors: (i) the population living in the area and the number of activities undertaken in the area that rely on the land (e.g., livestock farming); and (ii) the health status, amount of poverty, and economic conditions of the area. The damage caused by droughts in the European Union is estimated to be between €7.4 and €14.2 billion per year (Cammalleri, et al., 2020). Drought conditions often remain unnoticed until water shortages become severe and impose adverse impacts on the environment, and therefore the consequences to ecosystems, such as limited public water supplies, agricultural losses, and damage to buildings and infrastructure due to soil subsidence, are not monetized.

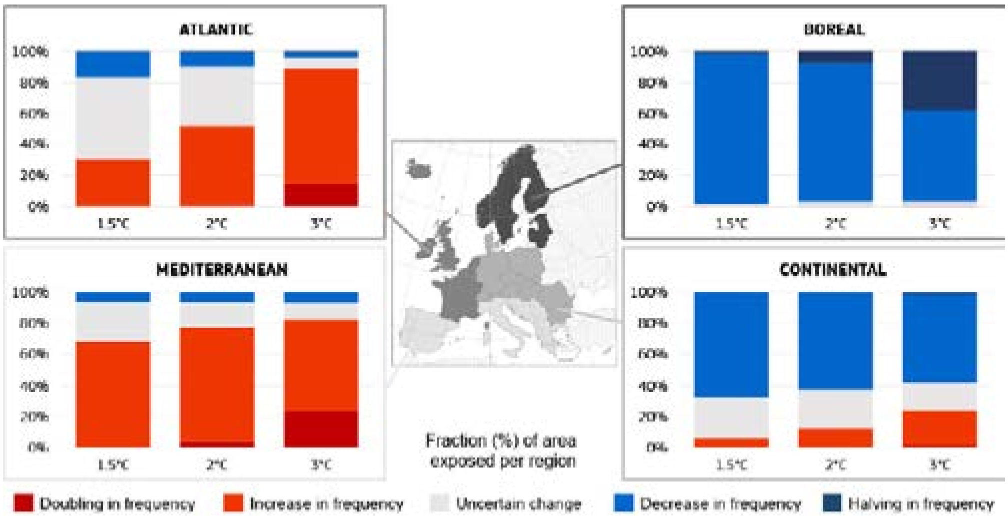
With the effect of climate change and global warming, the negative impact and damages of droughts are expected to increase dramatically, according to the PESETA IV report on droughts. Under the scenario with 3 °C global warming, the annual economic losses from droughts would increase from €9.4 billion to €45 billion. The Mediterranean and Atlantic regions of Europe will be more vulnerable to droughts because of the increase in droughts' duration, frequency, and intensity (see *Figure 27*). With climate change mitigation, however, the damage caused by droughts is expected to be only half in comparison to the scenarios with no mitigation (Cammalleri, et al., 2020).

Benefit-cost ratios[27] have generally not been calculated for this type of disaster. Droughts are among the least understood and quantified of all natural hazards due to their multi-faceted nature, which makes the economic analysis of preventive investments inherently difficult (Pulwarty & Sivakumar, 2014). In addition, 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. Irrigation and water provision systems

27 The analysis comprises the following detailed case studies: - 1 based on results from the literature (Drought prevention program in the Jucar River Basin in Spain, ex-post analysis).

constitute preventive investments against droughts. These investments include structural improvements and interventions in 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 saving lives and preserving health and productivity. Examples include the large-scale water project Ligação Pisão-Roxo in south Portugal, which systematically improved the water supply system (EC, 2011) and see Box 18, or early warning systems such as the DriDanube project (Interreg Danube, 2020) (see Box 19).

Figure 27. Fractions of area expose to drought risks under three global warming scenarios (1.5°C, 2 °C, and 3°C)



Source: Cammalleri, et al. (2020)

Box 18. Improving water security in Portugal

Structural improvements to the water security system can directly benefit civilians and lead to positive economic impacts (EC, 2011). In southern Portugal, a large-scale water project called Ligação Pisão-Roxo was launched with the objective to improve the water supply system of the Guadiana River. As a part of the Alqueva Dam Project, the Ligação Pisão-Roxo included investments in construction of a new dam to form part of a larger water network with a canal extension of 23.13 km. The project was implemented at a total cost of €65,181,300, and it was expected to provide increased supplies of water for the region and its residents. An analysis of the project's benefits and impacts shows that the improved water system benefits an estimated 44,486 people and also generates economic benefits through the creation of 40 new jobs.

Box 19. Early warning and preparedness in the Danube

Early warning and monitoring systems can yield benefits in terms of disaster risk reduction (Interreg Danube, 2020). With the objective of increasing the capacity to manage drought-related risks, the DriDanube project 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. The DriDanube project helps all stakeholders involved in drought management to be better prepared and more efficient in responding to drought emergencies. At a cost of €1,974,750, the project accomplished its goal with the output Drought User Service, which allows efficient and accurate monitoring and early warnings of droughts. This in turn enables better cooperation between agencies and improves emergency responses to droughts, which decrease the loss of life and damage when a drought occurs.

WILDFIRE

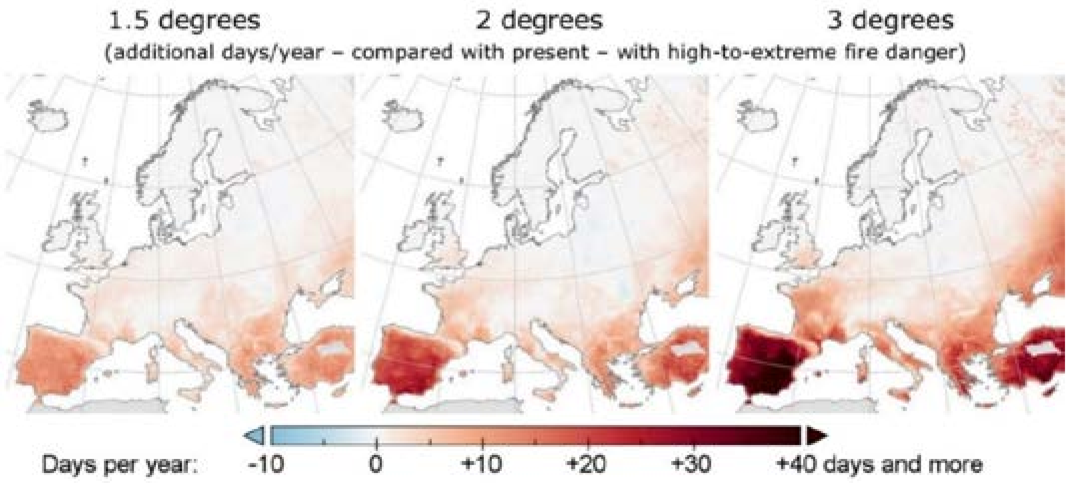
Globally, the impacts of wildfires on humans, the environment, and the economy are extensive. In the past few years, there has been an unprecedented number of severe wildfires globally, in places such as Portugal, Greece, and Sweden, along with the United States, Australia, the Amazon, and parts of the Arctic. Climate change is causing the increase in the weather conditions that can trigger and amplify wildfires, and these effects are only anticipated to get worse without proper environmental conservation efforts so that some governments have taken extensive measures for wildfire prevention (see Box 20 for more information about programs in Australia). Research has also found that wildfires are a major driver of greenhouse gas emissions and are also responsible for 5–8% of the 3.3 million annual premature deaths (i.e., 165,000 to 264,000 deaths) due to poor air quality (Lelieveld, et al., 2015). Factors that contribute to forest fire occurrence include the moisture content of the forest surface and climate variables, such as wind speed. Increased moisture impedes potential spreading of a fire and the ease of ignition, while wind speed can affect the rate of 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, part of central and southern Italy, Mediterranean France, and the coastal region of the Balkans are also susceptible to increased danger.

There are initiatives at the European supranational level to understand the impacts of forest fires. For example, 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. In addition, 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) (See *Figure 28*). Under the 3°C warming scenario, it is estimated that the number of people exposed to high-to-extreme fire danger levels for at least 10 days annually would increase by 24% from now. Southern European countries would experience the most fire risks as those countries have already experienced severe and frequent wildfires in the present (Costa, et al., 2020).

Benefit-costs assessments[28] of wildfire risk reduction investments yield net benefits (*Figure 29*); median BCRs exceeding 10 are found for decision support tools, alerting systems, and fuel management. Cross-border collaboration tools and management of the wildland-urban interface also yield positive benefits. Two case studies on the management of wildland-urban interface in Portugal were undertaken for this report and produced BCRs of 2.1 and 3.1, and a third study on fuel management in Portugal that focused on the addition of fuel breaks yielded a BCR of 11.9 (*Table 10*). A forest decision support system for small forest owners in Austria was assessed with a BCR of 5.8. Two hypothetical warning systems and public preparedness programs were considered for Portugal and Greece, yielding BCRs of 11 and 39.3, respectively. Finally, a BCR of 1.6 was found for an investment in an information exchange system designed to reduce forest fire risks in the border area between Portugal and Spain. More generally cross-border cooperation programs to enhance common response to wildfire and build capacity have appeared beneficial (see *Box 21*).

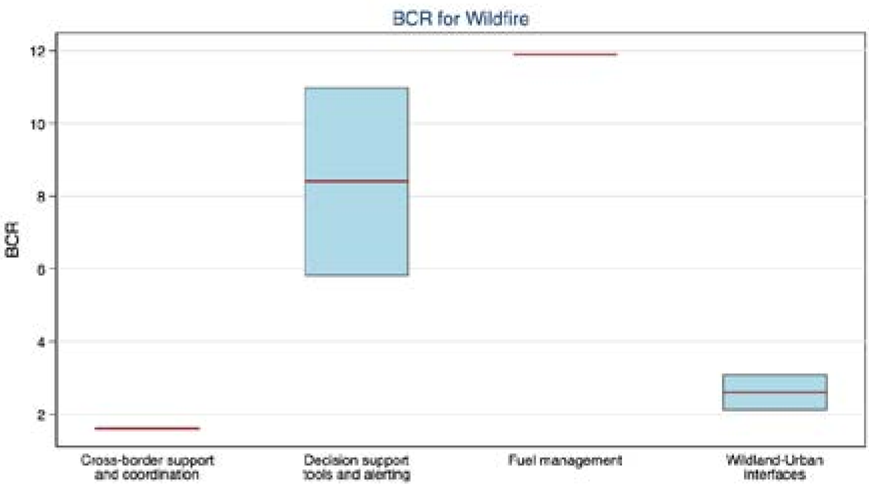
28 The analysis comprises the following detailed case studies: - 7 based on new analysis under this project (2 on Wildlife Urban Interface investments in Pedrógão Grande Portugal, ex-ante analysis and Oliveira de Hospital Portugal, ex-ante analysis; 1 on Fuel Management in the Central region of Portugal, ex-post analysis; 1 on a Decision Support System in Carinthia region Austria, ex-post analysis; 2 on Wildfire EWS in Centro region Portugal, ex-ante and Attica region, Greece ex-ante respectively for firms and households to inform fuel management; 1 on corodination mechanism cross-border with the Spitfire tool, ex-ante analysis).

Figure 28. 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.

Figure 29. Findings of benefit-cost analysis for wildfires (benefit-cost ratios)



Source: World Bank analysis; *based on external data and information*
Note: The figure shows the distribution of benefit-cost ratios (BCRs) for wildfire investments.
Extreme values are excluded from this graph.

Table 10. Expanded triple dividend cost-benefit ratio calculation of fuel management for wildfire risk reduction in central region of Portugal

FUEL MANAGEMENT	
FIRST DIVIDEND	
Reduction of lives lost	€5 M
Reduction of injuries	€0.55 M
Fire damage prevented (industries)	€0.23 M
Losses of timber production (trees not planted in the fuel break)	(–) €0.88 M
Reduction of losses to forestry	€8.8 M
Reduction in deaths related to cardiorespiratory problems	€2.6 M
Reduction in treatment costs related to cardiorespiratory problems	€0.032 M
Cost of CO_2 avoided	€0.87 M
Avoided loss of property values	€0.63 M
Avoided loss of tourism income	€2.8 M
Cost of sheltering/displacement avoided—lodging	€0.0033 M
Cost of sheltering/displacement avoided—productivity	€0.0042 M
Soil erosion costs avoided	€0.035 M
Fire suppression, operational costs, lowered with fuel breaks	€2.8 M
Total first dividend	€23.3 M
SECOND DIVIDEND	
Economic value-add from sale of cork (indirect/induced)	€0.088 M
Security/reduced volatility from mitigation/risk perception	€2.4 M
Increase in land purchases	€0.13 M
Total second dividend	€2.7 M
THIRD DIVIDEND	
Economic co-benefits	
Fire suppression, fixed costs, lowered with wildland-urban interface management	€0.049 M
Carbon sequestration	€0.11 M
Sale of cork	€0.19 M
Total third dividend	€0.35 M
TOTAL DIVIDEND	€26.3 M
Total cost	€2.2 M
BCR	11.9

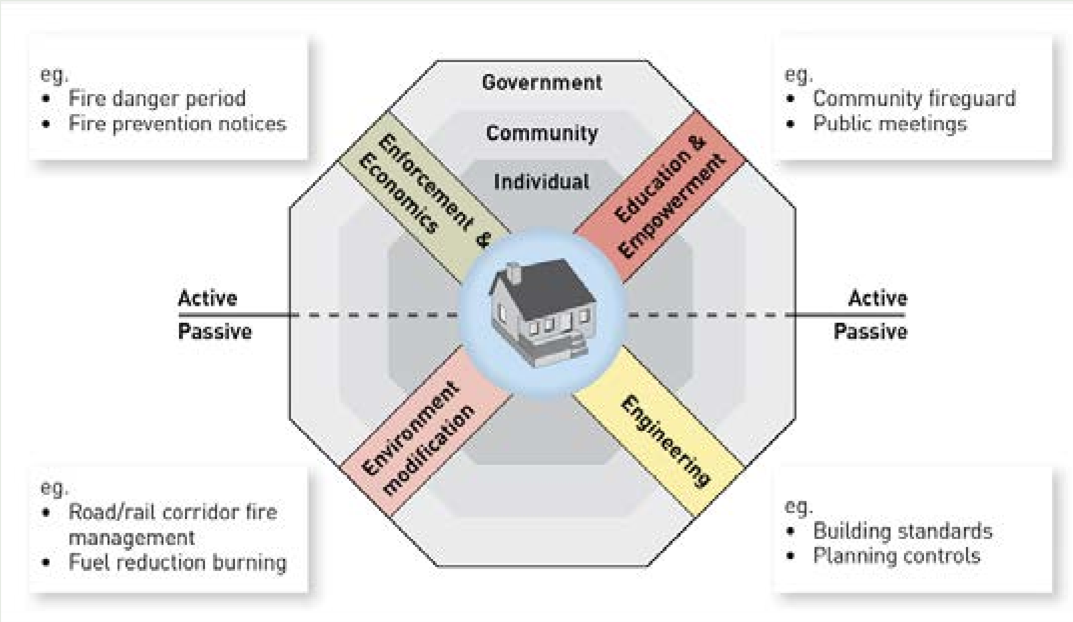
Source: World Bank analysis; *based on external data and information*

Box 20. Wildfire prevention in Australia

In Australia, wildfires—or "bushfires" as they are called—are a common occurrence. Nonetheless, the 2019–2020 bushfire season wreaked significantly more havoc than a typical season due to increased temperatures and a prolonged drought. By the time all the fires were contained in March 2020, they had burned more than 46 million acres, destroyed thousands of homes and buildings, and killed 34 people (Center for Disaster Philanthropy, 2019). Insured claims of bushfire losses between November 2019 and February 2020 are estimated at €1.18 billion according to Aon (Martin, 2020).[a] Fully calculating the overall economic impact of these wildfire incidents, however, is difficult because the evaluation of intangible losses (e.g., loss of income and productivity) is not standardized, and because the COVID-19 pandemic overlapped with the fires. Despite this, some estimates state that the economic impact may be greater than the 2009 Black Saturday fires, which cost €2.73 billion.[b]

Without the wildfire management policies implemented by the Australian government in the wake of the Black Saturday fires, the impacts of the 2019–2020 bushfires could have been a lot worse. The Country Fire Authority (CFA) in Victoria developed the Bushfire Safety System to address issues within its community preparedness programs (see *Figure 30*). This structure was the first of its kind, and it emphasized two things: (i) there is no one-size-fits-all solution to creating safer communities, and (ii) building a safer environment requires a strong relationship between government, community, and individuals.

Figure 30. Bushfire Safety System in Victoria, Australia



Source: (Sturzenegger, et al., 2010); cited in (Sturzenegger & Hayes, 2011)

a. Original values in Australian dollars.
b. Original values in Australian dollars.

Box 21. Enhanced wildfire response in Europe

A review of investments in capacity building for wildfire prevention and response across Europe provided several lessons and inspiring achievements. A common theme is that a combination of equipment, coordinated trainings, and peer learning, along with the human resources to address fires and other disasters, seems to ensure the greatest benefits in terms of effectiveness of response during disasters.

In the Czech Republic, wildfires caused 155 injuries and 12 fatalities over the past decade (Velinger, 2015), and economic costs could be substantial given that 34% of the country is covered by forests (Baranovskiy, 2019). A €58 million project (€50 million financed by the EU) was carried out from 2007 to 2013 with the goal of enhancing the capacity of the Fire Services to engage in activities for flooding situations, including intervention management, rescue operations, emergency survival for the population, and salvage operations—in all parts of the country.

Another project, called Safe Borderlands (EU, 2021), has aimed to strengthen the cooperation between fire and rescue services and other emergency response units (police, medical rescue, public health authorities, etc.) on the shared border of the Czech Republic and Poland, where more than 7 million people live. Firefighters and other emergency response personnel hold organized conferences and trainings, take language courses, purchase special equipment, and exchange data with each other in order to maintain smooth 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 important given the possibility for these to occur more frequently due to climate change.

The EU supported the establishment of a defence centre to fight forest fires in in Andalusia, Spain (EC, 2016), 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 enhance forest management, training, and awareness raising. Another project, the Interreg España-Portugal project, facilitates collaboration between over 15 institutions located in the cross-border regions of Spain and Portugal, promoting exchanges of knowledge and good practices. Both Spain and Portugal are highly vulnerable to wildfire hazards, and there is a long history of institutions fighting forest fires along the cross-border area. 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 model in the fight against forest fires, increase response capacity to forest fires, and reduce the economic cost of fires (CILIFO, 2020). While it may be difficult to measure the impacts of this investment using a benefit-cost analysis, it is important to reference qualitatively because this case study exemplifies the impacts of improving capacity.

MASS MOVEMENT/LANDSLIDE

Landslides—including rockfalls, debris avalanche, debris flows, creep, and snow avalanches—pose risk to life, property, and infrastructure in mountainous regions of Europe (EC, 2020). Steep coastal areas are also subject to unstable slopes, putting coastal properties and infrastructure at risk of slope creep and cliff collapse. A variety of mitigation options is available to manage landslide risk, including engineered and natural slope stabilization, control of flooding or runoff that destabilizes slopes, and debris capture or diversion.

Results of the benefit-cost analysis[29] indicate potential economic benefits of preventive investments, with prioritization of infrastructure such as road assets critical to maximise returns. Low-cost land management solutions seem to be quite effective. Although BCRs found were small or close to 1, it is expected that societal benefits were underestimated. A study in Albania on reducing transport disruptions from landslide found BCRs of between 0.1 and 1.1, with the highest returns on investment in main transport corridors (Xiong & Alegre, 2019); see *Figure 31* for a map showing the primary network considered for the project and *Table 11* for the BCR results. However, it is very likely that BCRs are underestimated, given the full cost of disruption to critical transport networks where there is limited redundancy. Other studies on landslides and avalanches prevention using drainage and landscape management approaches show some potential net benefits of such interventions (see *Box 22* and *Box 23* for examples from Italy and Switzerland respectively).

29 The analysis comprises the following detailed case studies: - 1 based on results from the literature (1 on World Bank investment in Alabania in road retrofitting, ex-ante analysis.

Figure 31. Primary network considered in Albania study on reducing transport disruptions from landslide

Source: Xiong & Espinet Alegre (2019)
Note: The colours indicate the various corridors within the primary road network.

Table 11. Benefit-cost ratio for landslide measures implemented, by corridor

CORRIDOR NUMBER AND NAME	INVESTMENT (MILLION €)	BENEFITS (MILLION €)	BENEFIT-COST RATIO
1 Milot–Morine New	15.0	4.2	0.3
5 Durres–Vlore	6.3	6.7	1.1
6 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

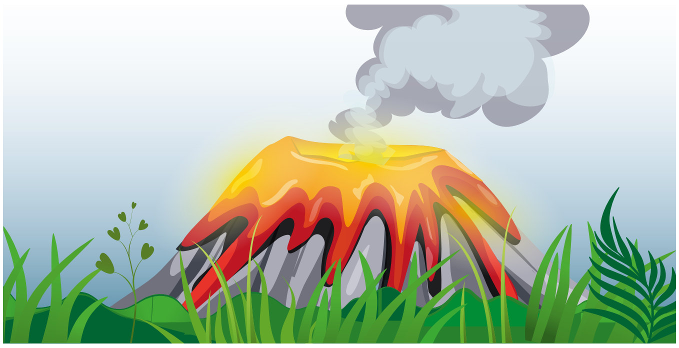
Source: Xiong & Alegre (2019)

Box 22. Economics of prevention versus response for landslides in Italy

A study on the costs and benefits 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 2010 in Vicenza, located in Italy's Veneto region (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 €57,000 in remediation costs, installing a drainage channel and maintaining it over 20 years would have saved 30% of the remediation cost, leading to a benefit of €17,000 (Salbego, et al., 2015b).

Box 23. Economics of prevention versus response for landslides in Switzerland

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, 2020). 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 for direct costs, the most cost-effective risk reduction measures are interventions with snow fences and land use planning, though for avalanche mitigation the scale of benefit is highly dependent on the number of snow fences deployed.



VOLCANIC ERUPTION

Volcanic hazards can lead to fatalities and widespread homelessness, while volcanic ash fall has a negative impact on health, infrastructure, transportation networks, and agriculture. It is estimated that in the 20th century, volcanic eruptions caused more than 90,000 fatalities and affected around 5.6 million people (Loughlin, 2013). The 2010 eruption of Eyjafjallajökull in Iceland, a small-moderate volcanic hazard, caused disruption for around 10 million people and total loss of €3.9 billion (EC, 2014b). In recent years, the number of people exposed to volcanic risk has increased as a result of increasing global population and urban area expansions.

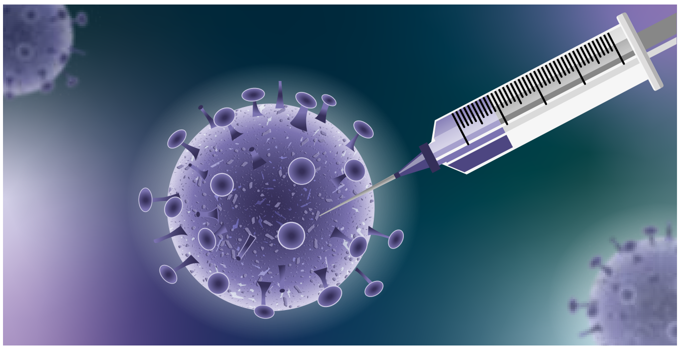
The European Commission has made attempts to reduce volcanic risks by monitoring volcanic activity and enhancing preparedness and response. The European Spatial Planning Observation Network (ESPON) provides a digital volcanic hazard map that traces dangerous volcanoes and eruption activities during the last 10,000 years and that identifies countries vulnerable to volcanic risks (ESPON, 2003). In 2012, the EU-funded project FUTUREVOLC was launched, with the goal to create an integrated monitoring system for volcanic activity through European collaboration and to enhance understanding of and preparedness for volcanic eruptions (FUTUREVOLC, 2016). In Italy, EU-funded investments have been made to establish resilient/escape routes in the case of volcanic eruptions (see *Box 24*).

As a quantitative method, benefit-cost analysis of volcanic hazard assists authorities in making key decisions that reduce the risks and impact of volcanic eruptions. A study that examined four volcanic hazards (Wilson, et al., 2014) and their damages to infrastructures stresses that it is crucial to have quantitative vulnerability assessments for under-standing the risks and economic impacts of volcanic hazards . Another analysis of volcanic risk suggests the importance of BCA in decision-making as a way to segment affected populations according to the cost of evacuation during a volcanic crisis (Woo, 2015).

During a volcanic eruption, effective roads and transportation networks are crucial for rescuing and evacuation. However, transportation networks are vulnerable to volcanic activity, as they can be damaged or blocked during eruptions and also disturbed by volcanic ash, which can cover road markings and reduce visibility and skid resistance (Blake, et al., 2017). Hence, investments in improving road resilience and advance planning of escape routes can enhance the efficiency of evacuation when an eruption occurs, leading to fewer fatalities and injuries. In Europe, economic assessments have been undertaken to quantify the impacts and losses due to volcanic eruptions and identify the direct and indirect benefits of investing in evacuation and escape routes.

Box 24. Evacuation routes in volcanic areas of Italy

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. In the past few decades, vulnerability has increased because of rising population density in cities and related complex infrastructure. Scientists warn that the impacts of a Vesuvius eruption (Hofmann, 2010) 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 is also in close proximity, with an estimated likelihood of medium-term eruption (De Natale, et al., 2017). Because of the imminent—and unpredictable—threat, the Italian government has devised a plan to evacuate a defined "red zone" 72 hours ahead of an impending eruption, has proposed compensation for people to relocate (Pasha-Robinson, 2016), and has created a national park around the volcano to avoid illegal building. However, the plan to evacuate has received slow uptake and been met with limited enthusiasm, given that the region is a considerable tourist attraction with related economic opportunities. Under the Redeveloped Road to Upgrade Volcano Escape Route project financed by the EU during the programming period 2007–2013 (EC, 2013), works were carried out 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 volcanic eruption or earthquake. Total investment was €53.4 million, of which €26.7 million was financed by the EU. This can be seen as a no-regret investment, as it enhances both connectivity and disaster prevention.

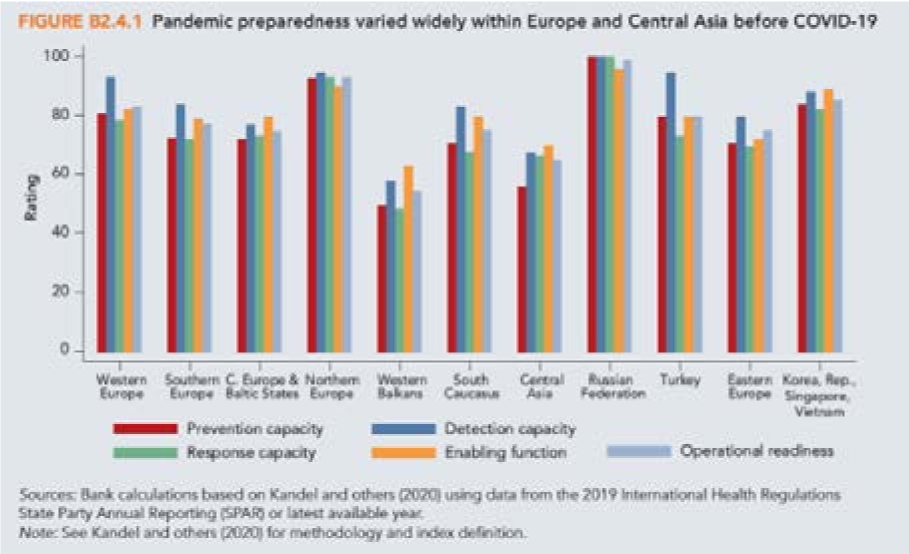


EPIDEMIC AND DISASTER HEALTH PREPAREDNESS

The COVID-19 pandemic has shown the consequences of systematically underinvesting in pandemic preparedness (the different levels of pandemic preparedness for countries in Europe and Central Asia are shown in *Figure 32*). Suk et al. (2020) found that the cascading effect of disasters, such as earthquakes and floods in the EU, have led to the outbreak of infectious diseases. 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. Given such studies and ongoing lessons from the pandemic, it is clear that preparedness planning and supply chain stockpiling and management are essential to reduce the negative impacts of epidemics and natural hazards on health and well-being, and that these steps are most effective when carried out well ahead of any slow- or fast-onset event. Benefit-cost ratios[30] for investments in public health systems and preparedness planning at local and national levels reveal that such investments generate significant benefits in reducing negative health outcomes, with a median BCR of 8.3 found for public health interventions (Masters, et al., 2017). Moreover, it has been documented that essential personal protective equipment (PPE) and other required equipment rose dramatically in price due to supply shortages during the COVID-19 pandemic, with increases ranging from 184% to 2,000% (SHOPP 2020); see *Table 12*. A study by the National Academy of Medicine (2016) determined a BCR of 13.3 for investing in pandemic preparedness globally.

30 The analysis comprises the following detailed case studies: - 2 based on results from the literature (1 on public health interventions in high-income countries, ex-post; 1 on pandemic preparedness interventions in the EU, ex-post).

Figure 32. Pandemic preparedness: Preparation of countries in Europe and select other regions for infectious disease before COVID-19



Source: World Bank (2020a), drawing on Kandel, et al. (2020)
Note: Details on the methodology and index definition are in Kandel, et al. (2020).

Table 12. Cost of PPE supplies in the United States: Before and during COVID19

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	€0.03	€0.07	€0.05	267%
Nitryl gloves	€0.05	€0.09	€0.05	200%
Three-ply masks	€0.05	€0.68	€0.63	1500%
K95 masks	Not applicable	€3.60	Not applicable	Not applicable
N95 masks	€0.34	€5.18	€4.83	1513%
3M N95 masks	€0.10	€6.08	€5.98	6136%
Hand sanitizer	€0.23	€0.50	€0.27	215%
Isolation gowns	€0.23	€4.50	€4.28	2000%
Face shields	€0.45	€4.05	€3.60	900%
Soap	€0.17	€0.32	€0.14	188%

Source: SHOPP 2020
Note: Values are as of April 7, 2020. Original values in US dollars.

OIL SPILLS AND NUCLEAR AND CHEMICAL RISKS[31]

International seaborne oil trade has grown steadily since the 1970s (Holleman, 2004), and the risk of oil spills has increased, leading to damage to the marine environment and coastal areas as well as huge economic losses in industries like fisheries and tourism. In Spain, the 2002 Prestige oil spill was estimated to have caused a loss of €770.58 million, including cleaning and recovery costs, losses in economic sectors affected, and environmental losses (Loureiro, et al., 2006). The benefits of preventing oil spills can be analysed through the modelling of the effect of a catastrophic oil spill. The frequency and spill size volume of hypothesized oil spills are often taken into consideration as essential factors that affect the modelling and the result. However, the quantification of the avoided costs is often 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 ecosystems - usually do not have common standards and are thus difficult to quantify . Typically estimates of BCRs for oil spill prevention and preparedness are positive but low, but the benefits are typically viewed as underestimates. An ex ante analysis of a preventive investment against oil spills in Estonia reveals a BCR of 1, yet this is likely an underestimate since it does not include the quantification of benefits of reducing potential oil spills and other co-benefits for the ecosystem.

Nuclear safety and liability have been important concerns in Europe since the Chernobyl accident, as people became aware of the tremendous damage and losses that nuclear accidents can cause (PACE, 2018). A nuclear accident causes considerable short- and long-term impacts on human health, including radiation sickness, thyroid cancer, and leukaemia (European Parliament Think Tank 2016), and also affects ecosystems (especially forests and freshwater bodies). It also negatively affects the economy, in particular by disturbing the agricultural sector and generating market losses due to food product contamination. Benefit-cost 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 benefit-cost analysis for such projects. Nonetheless, qualitative analysis has 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.

A chemical incident is defined as the "uncontrollable release of a toxic substance, potentially resulting in harm to public health and the environment" (World Health Organization, 2020). This term encompasses a variety of anthropogenic and technogenic events, such as an oil spill, a factory explosion, a disease outbreak associated with chemical exposure, and even a storage unit leak during transportation. Calculating the BCA or conducting economic analysis for the risk of chemical incidents is important because chemical incidents often have a multitude of domino effects and may spawn serious consequences, including mass casualties, health impacts, property losses, and environmental pollution. These incidents also have major direct economic consequences, such as property damage that requires facility repair and replacement, lost wages, business interruption, clean-up costs, and chemical supply chain disruption. Under this report, new analysis was conducted for a remediation investment in Latvia aimed at cleaning up sulphuric acid tar lagoons that once operated as waste dump sites. This investment yielded positive net benefits (BCR of 5.8) where the direct impacts could be calculated (particularly on the environment), and also unlocked economic potential through increased land value, construction investments, and linked jobs created (*Table 13*). Future case studies could take this analysis further by considering the long-term impacts

31 The analysis comprises the following detailed case studies: - 1 based on new analysis under this project (Environmental remediation against acid tar lagoons in Latvia, ex-post analysis).- 1 based on results from the literature (Multi-functional ship against oil spills in Estonia, ex-ante analysis).

on human health, productivity losses from agriculture avoided, or CO_2 emissions avoided, among other effects.

Table 13. Expanded Triple Dividend cost-benefit ratio calculation for cleaning up hazardous waste in Latvia

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 loss avoided	€0.12 M
Total first dividend	€119.75 M
SECOND DIVIDEND	
Reduction in land value avoided	€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*
Note: BCR = benefit-cost analysis; ERR = external rate of return; NPV = net present value.

4.3. Conclusions

This study and its preparation have reinforced the economic case for disaster preparedness and prevention in Europe, with findings in line with global research. Investments in disaster and climate resilience are almost always no-regret from an economic perspective and offer many co-benefits to society beyond disaster risk management. There are many findings relevant to specific stakeholder groups or for specific hazards within this report and its background papers, but the major conclusions for a wide range of stakeholders are presented here:

1. **The physical, financial, and social impacts of disasters are growing and will continue to grow unless urgent actions are taken.[32]** The impacts of flood, wildfire, and extreme heat in Europe are increasing rapidly, and climate damages could reach €170 billion per year according to conservative estimates for a 3° scenario (Szewczyk, et al., 2020) unless urgent action is taken now. Earthquakes, while rare, have a devastating impact on the ageing and pre-code buildings and infrastructure of Europe. However, disasters do not affect everyone equally: poor, elderly, very young, and marginalized populations are most affected and least able to recover, and municipalities in the poorer and more disadvantaged areas have the least capacity to design and implement resilience investments.

2. **The positive economic case for investing in resilience in Europe is mirrored by research internationally.** This report showed benefit-cost ratios that almost always exceeded 1, and typically ranged from 2 to 10, for resilience investments in Europe, with BCRs often exceeding 20. The World Bank's *Lifelines* report concluded that roughly €4 in benefits accrued for every €1 invested in critical infrastructure, and in 96% of scenarios analysed, BCRs greater than 1 were achieved (Hallegatte, et al., 2019). Similarly, a global report on hydro-meteorological early warning systems found BCRs of 4 to 35, depending on the co-benefits and assumptions used (Hallegatte, 2012). Finally, review of disaster risk reduction investments in the US found BCRs of between 2 and 12, with the highest BCRs attributed to ensuring that all buildings met the current building codes (NIBS, 2019).

3. **Integrated investments aimed at achieving multiple objectives make technical, financial, and social sense.** Many examples showcased in this report have highlighted the societal value of achieving multiple benefits with a single integrated investment. Achieving reductions in GHG emissions through energy efficiency savings in buildings also typically requires a complementary structural strengthening to ensure that buildings constructed prior to modern codes—the majority of the European built environment—are resilient to snow, wind, and seismic loading, meet modern fire safety standards, and ensure inclusion for people with disabilities. Integration of these objectives saves money, reduces disruption, and is more sustainable over the short and long term. This study also highlighted the higher returns on investment that result from combining EWS with efforts to ensure public preparedness and readiness for action and promote coordination.

4. **Reduction in disaster and climate risks requires action across a wide range of authorities at national and subnational level.** Many of the case studies included in this report looked at investments undertaken by national authorities and civil protection agencies; but the management of disaster and climate risk is often a municipal responsibility. Even if municipal authorities are aware of the potential risks, they face many obstacles to reducing risks - related to prioritization issues, limited access to capital, limited capacity to prepare technical and economic assessments, and issues with permitting, procurement, and project management. Even at the national level, line ministries in transport, energy, health, education, and so forth may not be sufficiently aware of potential disaster risks and their responsibility and mandate for action.

32 Several case studies present impact results in both absolute and relative terms, depending on the methodology applied. In general, relative losses (with respect GDP, for example) can be estimated with a financial growth model which has not been included in the scope of this Component.

5. **Targeting investments in resilience to the areas and assets under the highest risk vastly reduces costs and increases benefits.** Access to high-resolution and up-to-date data and information on disaster and climate risks, and on the assets exposed to these risks, requires investment of public funds. However, the returns on this relatively modest investment are significant, given the savings they make possible by more accurate targeting of resilience investments to the criteria mentioned above. The *Lifelines* report noted that the savings from targeting infrastructure assets that are most exposed to hazards appear to be orders of magnitude larger than the costs of data collection and modelling that would be required to improve knowledge of current and future hazards. The report also shows that building more resilient infrastructure assets may be costlier, but the incremental cost is small especially if countries use data and criticality analysis to prioritize investments (Hallegatte, et al., 2019). Similarly, analysis conducted for this report showed that targeting education facilities with the highest vulnerability to damage or collapse in earthquake resulted in significantly higher BCRs, at a portfolio level.

6. **The economic co-benefits of resilience measures are regularly and significantly underestimated.** Economic analysis often focuses on the reduction in direct damage, such as the reduction in damage to buildings and infrastructure protected from flood; but such an approach is insufficient to capture measures' full benefits. The Triple Dividend of Resilience approach used in this report aims to capture avoided losses and lives saved, unlocked economic potential, and the social, environmental, and economic co-benefits that are generated even in the absence of a disaster. Unfortunately, data on these types of co-benefits are rarely captured, and it can be difficult to find data on co-benefits such as the increase in property prices or reduction in insurance premiums after flood protection, the employment provided during construction and subsequently through operations and maintenance, biodiversity and amenity improvements, enhanced mental and physical health of beneficiaries, protection of cultural heritage, increased investments due to (actual and perceived) reduced disaster volatility, and so forth. Applied research is critical to develop the data and approaches to monetize these crucial co-benefits for inclusion in future economic analyses.

7. **Ensuring that authorities can make the economic case for prevention and preparedness itself requires investment.** Undertaking benefit-cost analysis for different types of investments is a significant undertaking, involving data collection, modelling and analysis, and reporting and communication of findings. Unfortunately, there are significant gaps in data availability, especially for less studied hazards such as wildfire, drought, volcanic eruption, and technological hazards, and for calculation of co-benefits (as noted above). Moreover, authorities responsible for undertaking such analysis at national or subnational levels rarely have the needed expertise or experience, and in this regard significant capacity development is needed.

8. **There is insufficient research and reporting that captures the benefits of preparedness and prevention, either prospectively or retro-spectively, also linked to underreporting of disaster damages.** At the onset of this study, an extensive review of literature (published and unpublished) was undertaken, and consultations were held with many stakeholders at commission and national levels. Ultimately only about 100 cases were found for which there was a modicum of information available for economic analysis. Of these, only a third of cases had enough data for quantitative or semi-quantitative analysis. The benefits of "softer" measures around human capacity to respond and coordinate during disasters are even less well understood and less likely to be quantified, but this report conclusively demonstrates the value and positive economic case for activities provided under UCPM. Given the difficulty faced by authorities seeking to advocate for investment in preparedness and prevention for the disaster that has not yet happened (*Figure 33*), it is even more critical to develop a solid evidence base.

Figure 33. Difficulty of funding investments in disaster risk reduction

Source: Paul Bisca *(Carton Collections)*

5. | Recommendations Moving Forward

This report has made the economic case to invest in preparation and preparedness in Europe to halt the steep increase in the physical, social, and economic losses from disasters and climate change. Ultimately, however, to build a resilient Europe it is critical to achieve the following:

1. **A substantial increase in the financing targeted for disaster and climate resilience, along with ways to ensure that potential beneficiaries can access it.** It is expected that the financing available for disaster and climate resilience will increase in Europe in coming years through a variety of funding sources. However, it should be noted that authorities responsible for disaster risk management may need additional support to advocate for increased allocations within national budgets, since sectoral ministries may not prioritize funding for disaster prevention and preparedness over other more immediate needs. Moreover, as noted during consultations with civil protection authorities, there is a lack of clarity around different potential funding sources, and hence a need for support in identifying and targeting different funds.

2. **Systems to track, monitor, and evaluate disaster and climate resilience financing.** It is difficult to track how much funding has been spent, or will be spent, for disaster and climate resilience without systems in place to follow investment in this area. Currently it would be difficult or potentially impossible to track how much funding has been used for modernizing fire coordination and response in the last decade, or how much is planned in the coming decade, or the how much has been spent on awareness and preparedness campaigns. Tracking these funds into the future would be very helpful to identify gaps (e.g., pandemic preparedness) and target awareness, capacity development, and ultimately financing in these areas.

3. **Wide promotion and uptake of integrated and novel approaches to build resilience and maximize co-benefits.** This point has been reiterated many times in this report, but it is important and bears repeating. While such approaches are perhaps more complicated to implement than traditional approaches, they often provide significantly higher co-benefits. For example, nature-based solutions yield greater co-benefits than traditional grey flood protection solutions. Similarly, investing in green, white, and/or blue solutions in cities is proven to reduce extreme heat and also brings enormous benefits in air quality, amenities, and liveability for residents. Finally, promoting a single investment with multiple objectives—for example, combining energy efficiency measures with structural strengthening (if needed) to create resilient, inclusive, and sustainable schools—can save time and money and minimize disruption.

4. **Policy reforms to address the asymmetry in preparedness and prevention across types of hazards.** There was a clear asymmetry observed in the availability of case studies and investments for hazards such as flood, as compared to wildfire, drought management, extreme heat, and others. The EU Floods Directive has been incredibly effective at focusing government attention on the

need to understand, quantify, and manage flood risks. Unfortunately, similar directives are lacking for other hazards, and perhaps as a result, awareness of these risks and prevention and preparedness actions are also lacking. For example, it may be appropriate to consider appropriate legislation for prevention and preparedness that is operationalized and enforceable. This is critical for uniform risk reduction, such as fire breaks to reduce wildfire or steps to move beyond emergency management towards disaster prevention and preparedness.

5. **Scaled-up availability of, and access to, data, information, and knowledge on disaster and climate risks.** Compared to other regions of the world, Europe is fortunate to have a range of data and information on disaster and climate risks. As noted by all stakeholders during consultations, however, there are issues associated with accessing a range of data, including open, high-quality, and high-resolution data on historical disaster damages and losses, maps and data on the probability and potential impact of the full range of hazards (and how they may change with climate change), data on exposed assets and populations (and their expected change into the future), replacement costs, typical costs for different prevention and preparedness measures, and of course the multitude of co-benefits of resilience. The costs of investment to ensure that these data are open and available to all users and stakeholders pales in comparison to costs of mis-targeting investments away from the highest-risk areas and assets.

6. **Increased human capacity to assess, prioritize, design, and implement measures aimed at prevention and preparedness.** There is a clear and urgent need to build the capacity of experts and authorities to undertake a range of prevention and preparedness measures: collection of data on assets and infrastructure that may be at risk; development of objective and transparent prioritization to ensure targeting of scarce financing to areas of the greatest vulnerability; conduct of technical, financial, and economic studies; steps to ensure that procurement, permitting, stakeholder consultations, etc. are completed on time; management and supervision of works; and long-term operations and maintenance. Expertise and experience in these areas are often limited within civil protection agencies, line ministries, and especially subnational authorities. This capacity can be built through a combination of training, workshops, guides/handbooks, hands-on implementation, and just-in-time support.

All these proposed measures are aligned with some objectives of the EU Green Deal, in particular its initiatives related to DRM such as the recent EU Adaptation Strategy from 2021 or the Renovation Wave (EC, 2016). The analysis of this report highlights the need to build physical resilience to natural disasters. However, as demonstrated in the Component 2 report (European Commission and World Bank, 2021b), there is a complementary need to build financial resilience at household, sovereign, and regional levels—in particular through improving access to, and uptake of, insurance for private and public assets. A holistic approach should be developed to foster physical and financial resilience to disaster risk, such as was presented in *The Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience* (Hallegatte, et al., 2020). Component 3 (European Commission and World Bank, 2021c) also highlighted the challenges of securing financial resources and building human capacity for mitigation, adaptation, and response to large-scale events. By developing a combined approach and "greening the EU", the European Commission could send a clear message that this is a priority and that resources will be dedicated to the holistic approach for its implementation.

6. | References

Alves, F., 2015. Benefit-Cost Analysis in Climate Change Adaptation: The Use of Participatory Methodologies, s.l.: Universidade NOVA de Lisboa.

Åström, C. et al., 2013. Heat-related respiratory hospital admissions in Europe in a changing climate: a health impact assessment. BMJ Open.

Baranovskiy, N. V., 2019. Predicting, Monitoring, and Assessing Forest Fire Dangers and Risks. s.l.:IGI Global.

Barbier, E., 2007. Valuing Ecosystem Services as Productive Inputs. Economic Policy, Volume 49, p. 178–229.

Barbier, E., 2009. Ecosystems as Natural Assets. Foundations and Trends in Microeconomics, Volume 4 (8), p. 611–81.

Bassil, K. L. & Cole, D. C., 2010. Effectiveness of Public Health Interventions in Reducing Morbidity and Mortality during Heat Episodes: a Structured Review. International Journal of Environmental Research and Public Health, 7(3), pp. 991-1001.

Blake, D. et al., 2017. Impact of Volcanic Ash on Road and Airfield Surface Skid Resistance, s.l.: Sustainability. 9. 1389. 10.3390/su9081389.

BMLFUW, 2009. Untersuchungen im Schutzwasserbau Richtlinie, KNU gemäß § 3 Abs. 2 Ziffer 3 Wasserbautenförderungsgesetz, BMLFUW (Federal Ministry of Agriculture, Forestry, Environment and Water Management), s.l.: s.n.

Bos, F. & Zwaneveld, P., 2017. Cost-Benefit Analysis for Flood Risk Management and Water Governance in the Netherlands: An Overview of One Century. SSRN Electronic Journal.

Botzen, W. J., Deschenes, O. & Sanders, M., 2019. The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies. Review of Environmental Economics and Policy, Volume 13(2), p. 167–88.

Bouchama, A., 2003. The 2003 European heat wave. Intensive Care Medicine, 30(1).

Browder, G. et al., 2019. Integrating Green and Gray : Creating Next Generation Infrastructure, Washington, DC: World Bank and World Resources Institute.

Building Performance - New Zealand Government, 2020. Managing Earthquake Prone Buildings. [Online] Available at: *https://www.building.govt.nz/managing-buildings/managing-earthquake-prone-buildings/*

Bureau of Ocean Energy Management, 2016. Economic Analysis Methodology for the 2017-2022 Outer Continental Shelf Oil and Gas Leasing Program. [Online]
Available at: *https://www.boem.gov/sites/default/files/oil-and-gas-energy-program/Leasing/Five-Year-Program/2017-2022/Economic-Analysis-Methodology.pdf*

Buss, I., 2010. Best Practices in Capacity Building Approaches: Recommendations for the Design of a Long-Term Capacity Building Strategy for the Wind and Solar Sectors by the MEF Working Group, s.l.: Frankfurt, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Cammalleri, C. et al., 2020. Global Warming and Drought Impacts in the EU, Luxembourg: Publications Office of the European Union.

Center for Disaster Philanthropy, 2019. 2019-2020 Australian Bushfires. [Online]
Available at: *https://disasterphilanthropy.org/disaster/2019-australian-wildfires/*

Chiabai, A. S., Spadaro, J. V. & Neumann, M. B., 2018. Valuing Deaths or Years of Life Lost? Economic Benefits of Avoided Mortality from Early Heat Warning SYstems. Mitigation and Adaptation Strategies for Global CHange, 23(7), pp. 1159-76.

Christensen, P., Gillingham, K. & Nordhaus, W., 2018. Uncertainty in forecasts of long-run economic growth. Proceedings of the National Academy of Sciences, Volume 115(21), pp. 5409-5414.

CILIFO, 2020. CILIFO website, s.l.: s.n.

Climate Change Post, 2020. Avalanches, Landslides and Rock Fall Switzerland, s.l.: s.n.

Climate-ADAPT, 2016. Room for the River Waal: Protecting the City of Nijmegen. [Online] Available at: *https://climate-adapt.eea.europa.eu/metadata/case-studies/room-for-the-river-waal-2013-protecting-the-city-of-nijmegen*

COACCH, 2019. The Economic Cost of Climate Change in Europe: Synthesis Report on COACCH Interim Results, s.l.: s.n.

Cooper, K., 2015. Flood Prevention Scheme in the Netherlands Creates Unique Byproduct: An Urban River Park Island. The Architect's Newspaper.

Corbane, C., 2017. Pan-European seismic risk assessment: a proof of concept using the Earthquake Loss Estimation Routine (ELER). Bulletin of Earthquake Engineering, Volume 15(3), pp. 1057-1083.

Costa, H. et al., 2020. European wildfire danger and vulnerability in a changing climate: towards integrating risk dimensions, Luxembourg: Publications Office of the European Union, Luxembourg.

Danciu, L., Woessner, J. & Giardini, D., 2013. A community-based probabilistic seismic hazard maps for the Euro- Mediterranean Region. Congress on Recent Advances in Earthquake Engineering and Structural Dynamics, Vienna, Austria; SHARE Consortium.

Dang, T. V. et al., 2018. Green Space and Deaths Attributable to the Urban Heat Island Effect in Ho Chi Minh City. American Journal of Public Health, 108(S2), pp. S137-S143.

De Natale, G. et al., 2017. Understanding Volcanic Hazard at the Most Populated Caldera in the World: Campi Flegrei Southern Italy. Geochemsitry, Geophysics, Geosystems, 18(5), pp. 2004-08.

Dellink, R., Chateau, J., Lanzi, E. & Magné, B., 2018. Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change, Volume 42, pp. 200-214.

Dottori, F. et al., 2020. Adapting to Rising River Flood Risk in the EU under Climate Change, Luxembourg: Publications Office of the European Union.

Ebi, K. L. et al., 2004. Hest Watch/Warning Systems Save Lives: Estimated Costs and Benefits for Philadelphia 1995-98. American Meteorological Society, 85(8), pp. 1067-1074.

EC, 2011. Capturing River Flows to Improve Water Supplies, EC (European Commission). [Online] Available at: *https://ec.europa.eu/regional_policy/en/projects/major/portugal/capturing-river-flows-to-improve-water-supplies*

EC, 2013. Redeveloped Road to Upgrade Volcano Escape Route, EC (European Commission), s.l.: s.n.

EC, 2014b. Increasing our Understanding of Volcanic Eruoptions. European Commission. [Online] Available at: *https://ec.europa.eu/programmes/horizon2020/en/news/increasing-our-understanding-volcanic-eruptions*

EC, 2014. Guide to Benefit-Cost Analysis of Investment Projects, Economic Appraisal Tool For Cohesion Policy 2014–2020, EC (European Commission), Luxembourg: Publications Office of the European Union.

EC, 2016. Climate Change and Major Projects. European Commission, EC (European Commission), s.l.: s.n.

EC, 2016. EU Adaptation Strategy - Climate Strategy, EC (European Commission). [Online] Available at: *https://ec.europa.eu/clima/policies/adaptation/what_en*

EC, 2016. Funding Opportunities to Support Disaster Risk Prevention in the Cohesion Policy 2014-2020 Period, EC (European Commission). [Online] Available at: *https://ec.europa.eu/regional_policy/sources/docgener/informat/factsheet_disaster_risk_prevention_03.pdf*

EC, 2019. iRESIST+ - innovative seismic and energy retrofitting of the existing building stock, EC (European

Commission). [Online]
Available at: *https://ec.europa.eu/jrc/en/research-topic/improving-safety-construction/i-resist-plus.*

EC, 2020. Greek Project Develops Intelligent System for Better Disaster Responses, EC (European Commission). [Online]
Available at: *https://ec.europa.eu/regional_policy/en/projects/Greece/Greek-project-develops-intelligent-system-for-better-disaster-response*

EC, 2020. Integrated Techniques for the Seismic Strengthening and Energy Efficiency of Existing Buildings, EC (European Commission). [Online]
Available at: *https://ec.europa.eu/jrc/en/event/webinar/integrated-techniques-seismic-strengthening-and-energy-efficiency-existing-buildings*

EC, 2020. Landslides, EC (European Commission): Joint Research Centre—European Soil Data Centre (ESDAC). [Online] Available at: *https://esdac.jrc.ec.europa.eu/themes/landslides*

EEA, 2015. Exploring Nature-Based Solutions: The Role of Green Infrastructure in Mitigating the Impacts of Weather- and Climate Change—Related Natural Hazards, s.l.: European Environment Agency.

EEA, 2017. Green Infrastructure and Flood Management: Promoting Cost-Efficient Flood Risk Reduction via Green Infrastructure Solutions, s.l.: EEA Report 14/2017.

EEA, 2020. Economic Losses from Climate-Related Extremes in Europe. [Online]
Available at: *https://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-3/assessment-2.*

ESPON, 2003. Europe Volcanic Hazard Map, European Spatial Planning Observation Network. [Online]
Available at: *https://www.preventionweb.net/english/professional/maps/v.php?id=3832*

Estrada, F., Botzen, W. & Tol, R., 2017. A global economic assessment of city policies to reduce climate change impacts. Nature Clim Change, Volume 7, pp. 403-406.

EU, 2018. The Eurocode Map, EU (European Union). [Online]
Available at: *https://www.preventionweb.net/english/professional/maps/v.php?id=67979*

EU, 2019. GRETA - GReen infrastructure: Enhancing biodiversity and ecosysTem services for territoriAl development. Final Report 08/08/2019. *https://www.espon.eu/green-infrastructure*

EU, 2021. Safe Borderland, Keep EU, s.l.: s.n.

EUR-Lex, 2007. Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance) OJ L 288, s.l.: s.n.

European Commission, 2019. A European Green Deal: Striving to be the first climate-neutral continent.
Available at: *https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#policy-areas*

European Commission and World Bank, 2021a. Economic of prevention and preparedness: investment in disaster risk management in Europe makes economic sense – Background Report, s.l.: European Commission and World Bank.

European Commission and World Bank, 2021b. Financial RIsk and Opportunities to Build Resilience - Economic Analysis of Prevention and Preparedness in European Union Member States and Countries under EU Civil Protection Mechanism, s.l.: s.n.

European Commission and World Bank, 2021c. Understanding the Needs of Civil Protection Agencies and Opportunities to Support Scaling up of Investments in Disaster Prevention and Preparedness, s.l.: s.n.

European Parliament Think Tank, 2016. Chernobyl 30 Years On: Environmental and Health Effects. [Online]
Available at: *https://assembly.coe.int/nw/xml/XRef/Xref-XML2HTML-en.asp?fileid=25050&lang=en*

Eurostat Database, 2021. Exchange and interest rates. [Online]
Available at: *https://ec.europa.eu/eurostat/web/exchange-and-interest-rates*

Ferris, E. & Solis, M., 2013. Earthquake, Tsunami, Meltdown: The Triple Disaster's Impact on Japan, Impact on the World – Brookings Institution. [Online]
Available at: *https://www.brookings.edu/blog/up-front/2013/03/11/earthquake-tsunami-meltdown-the-triple-disasters-impact-on-japan-impact-on-the-world/*

Feyen, L. et al., 2020. Climate Change Impacts and Adaptation in Europe: JRC PESETA IV Final Report, Luxembourg: Publications Office of the European Union.

Forzieri, G. et al., 2018. Escalating impacts of climate extremes on critical infrastructures in Europe. Global Environmental Change, Volume 48, pp. 97-107.

Fuchs, S., Thoeni, M. & McAlpin, M. C., 2007. Avalanche Hazard Mitigation Strategies Assessed by Cost Effectiveness Analyses and COst Benefit Analyses–Evidence from Davos, Switzerland. Natural Hazards, Volume 41, pp. 113-29.

FUTUREVOLC, 2016. Final report, s.l.: s.n.

Gasparrini, A. et al., 2017. Projections of temperature-related excess mortality under climate change scenarios. The Lancet Planetary Health, 1(9), pp. 360-367.

GFDRR, 2014. Understanding Risk in an Evolving World: Emerging Best Practices in Natural Disaster Risk Assessment, GFDRR (Global Facility for Disaster Reduction and Recovery), Washington, DC: World Bank.

GFDRR, 2019. The Making of a Riskier Future: How Our Decisions Are Shaping Future Disaster Risk, GFDRR (Global Facility for Disaster Reduction and Recovery), Washington, DC: GFDRR.

Ghesquiere, F. M., Mahul, O. & Jamin, L., 2006. Earthquake Vulnerability Reduction Program in Colombia: A Probabilistic Benefit-Cost Analysis. Policy Research Working Paper, p. 3939.

Gollier, C. & Hammitt, J., 2014. The Long-Run Discount Rate Controversy. Annual Review of Resource Economics, Volume 6, pp. 273-295.

Grollimund, B., 2014. Small Quakes, Big Impact: Lessons Learned from Christchurch, s.l.: Swiss Re.

Hallegatte, S., 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation. Policy Research Working Paper, p. 6058.

Hallegatte, S., Rentschler, J. & Rozenberg, J., 2019. Lifelines: The Resilient Infrastructure Opportunity, Washington, DC: World Bank.

Hallegatte, S., Rentschler, J. & Rozenberg, J., 2020. Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience, Washington D.C.: World Bank.

Hallegatte, S. et al., 2020. From Poverty to Disaster and Back: A Review of the Literature. Economics of Disasters and Climate Change, pp. 223-47.

Hoeppner, E., 2019. Surface Water Flooding: A Growing Risk in Europe – JBA Risk Management. [Online]
Available at: *https://www.jbarisk.com/news-blogs/surface-water-flooding-a-growing-risk-in-europe/*

Hofmann, M., 2010. Mount Vesuvius Europe's most dangerous volcano: Study, s.l.: s.n.

Holleman, M. A., 2004. Lingering Lessons of the Exxon Valdez Oil Spill, Seattle, WA: Seattle Times.

Hunt, A. F. et al., 2017. Climate and Weather Service Provision: Economic Appraisal of Adaptation to Health Impacts. Climate Services, Volume 7, pp. 78-86.

Insurance News, 2019. Roma Gets a Flood Risk Tick after Mitigation Works. [Online]
Available at: *https://insurancenews.com.au/daily/roma-gets-a-flood-risk-tick-after-mitigation-works*

Interreg Danube, 2020. DRIDANUBE–Drought Risk in the Danube Region. [Online]
Available at: http://www.interreg-danube.eu/approved-projects/dridanube

Johnson, D. S. et al., 2020. A Cost-Benefit Analysis of Implementing Urban Heat Island Adaptation Measures in Small and Medium-Sized Cities in Austria. Environment and Planning B: Urban Analytics and City

Science.

Kandel, N., Chungong, S., Omaar, A. & Xing, J., 2020. Health Security Capacities in the Context of COVID-19 Outbreak: An Analysis of International Health Regulations Annual Report Data from 192 Countries. The Lancet, Volume 395, pp. 1047-53.

Kestrel Group, 2011. Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience: Independent Report, Wellington: Kestrel Group.

Lelieveld, J. E. et al., 2015. The Contribution of Outdoor Air Polution Sources to Premature Mortality on a Global Scale. Nature, Volume 525, pp. 367-71.

LIFE, 2015. LIFE+ Climate-Proofing Social Housing Landscapes. [Online]
Available at: *https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE12_ENV_UK_001133_LAYMAN.pdf*

Loughlin, S. C., 2013. Volcanoes and Volcanic Eruptions. In: P. T. Bobrowsky, ed. Encyclopedia of Natural Hazards. s.l.:s.n.

Loureiro, M. L., Ribas, A., Lopez, E. & Ojea, E., 2006. Estimated Costs and Admissible Claims Linked to the Prestige Oil SPill. Ecological Economies, 59(1), pp. 48-63.

Madajewicz, M., Tsegay, A. & Norton, M., 2013. Managing Risks to Agricultural Livelihoods: Impact Evaluation of the Harita Program in Tigray, Ethiopia, 2009–2012, London: Oxfam: s.n.

Maksimovic, C., 2017. Blue Green Solution: A Systems Approach to Sustainable, Resilent, and Cost-Efficient Urban Development, s.l.: Climate-KIC.

Martin, M., 2020. Aon Reveals Impact of the Australia Fires on Reinsurance – Insurance Business Australia. [Online]
Available at: *https://www.insurancebusinessmag.com/au/news/breaking-news/aon-reveals-impact-of-the-australia-fires-on-reinsurance-210475.aspx.*

Masters, R. et al., 2017. Return on Investment of Public Health Interventions: A Systematic Review. Journal of Epidemiological Community Health, Volume 71, pp. 827-34.

MBIE, 2017. EPB Methodology: The Methodology to Identify Earthquake-Prone Buildings, MBIE (Ministry of Business, Innovation, and Employment). [Online]
Available at: *https://www.building.govt.nz/assets/Uploads/building-code-compliance/b-stability/b1-structure/epb-methodology.pdf*

Mechler, R., 2016. Reviewing Estimates of the Economic Efficiency of Disaster Risk Management: Opportunities and Limitations of Using Risk-Based Cost-Benefit Analysis. Natural Hazards, Volume 81, p. 2121–47.

National Academy of Medicine, 2016. The Case for Investing in Pandemic Preparedness. In: The Neglected Dimension of Global Security: A Framework to Counter Infectious Disease Crises. Washington, DC: National Academies Press.

Naumann, G. et al., 2020. Global Warming and Human Impacts of Heat and Cold Extremes in the EU, Luxembourg: Publications Office of the European Union.

Neagoe, C., 2016. Romanian Seismic Network. Dubrovnik, Croatia, October 25-28 2016.

NIBS, 2019. Natural Hazard Mitigation Saves: 2019 Report, NIBS (National Institute of Building Sciences), Washington, DC: National Institute of Building Sciences.

ODI, 2015. Why All Development Finance Should Be Risk-Informed, ODI (Overseas Development Institute), s.l.: s.n.

Oke, T., 1982. "The Energetic Basis of the Urban Heat Island.". Quarterly Journal of the Royal Meteorological Society 108, 455(1-24).

PACE, 2018. Nuclear Safety and Security in Europe, Doc. 14622. September 24, 2018: Committee on Social Affairs, Health and Sustainable Development, PACE (Parliamentary Assembly of the Council of Europe).

Paprotny, D., Sebastian, A., O., M.-N. & Jonkman, S. N., 2018. Trends in flood losses in Europe over the past 150 years. Nature Communications, Volume 9 (1985), pp. 1 - 12.

Parker, C., Persson, T. & Widmalm, S., 2019. The effectiveness of national and EU-level civil protection systems: evidence from 17 member states. Journal of European Public Policy, Volume 26(9), pp. 1312-1334.

Pasha-Robinson, L., 2016. Mount Vesuvius Eruption Risk: Emergency Plans to Evacuate 700,000 Finalised, October 14, 2016: Independent.

Pohoryles, D. A., Madutab, C., Bournasa, D. A. & Kourisa, L. A., 2020. Energy Performance of Existing Residential Buildings in Europe: A Novel Approach Combining Energy with Seismic Retrofitting, Energy and Buildings 223: s.n.,

Prevention Web, 2020. “Europe - Disaster Statistics.”, s.l.: s.n.

Pulwarty, R. S. & Sivakumar, M. V. K., 2014. Information Systems in a Changing Climate: Early Warnings and Drought Risk Management, s.l.: Weather and Climate Extremes 3.

Rose, A., 2007. Economic Resilience to Disasters: Multidisciplinary Origins and Contextual Dimensions. Environmental Hazards: Human and Social Dimensions, Volume 4, p. 383–98.

Rose, A., 2016. Capturing the Co-benefits of Disaster Risk Management in the Private Sector. In: S. S. & T. Tanner, eds. Realising the ‚Triple Dividend of Resilience‘: A New Business Case for Disaster Risk Management. s.l.:s.n., p. 105–27.

Salbego, G., Floris, M., Busnardo, E. & Toaldo, M., 2015a. A Multi-scale Approach to Cost/Benefit Analyses of Landslide Prevention, s.l.: Natural Hazards and Earth System Sciences 3: 1329–55.

Salbego, G. et al., 2015b. Detailed and Large-Scale Cost/Benefit Analyses of Landslide Prevention vs. Post-Event Actions, s.l.: Natural Hazards Earth System Sciences 15: 2461–72.

SHOPP, 2020. SHOPP COVID PPD Cost Analysis, s.l.: Society for Healthcare Organization Procurement Professionals.

Shreve, C. & Kelman, I., 2014. Does Mitigation Save? Reviewing Cost-Benefit Analyses of Disaster Risk Reduction. International Journal of Disaster Risk Reduction, Volume 10(A), p. 213–235.

Simpson, A. & Markhvida, M., 2020. Earthquake Risk in Multifamily Residential Buildings: Europe and Central Asia Region, Washington, DC: World Bank.

Sturzenegger, L., Hayes, T., Brennan, G. & Holland, M., 2010. Bushfire Safety System.” Abstract presented at the International Association of Wildland Fire on Human Dimensions, San Antonio, Texas, April 27, 2010.: s.n.

Sturzenegger, L. & Hayes, T., 2011. Post Black Saturday: Development of a Bushfire Safety System, Australian Institute for Disaster Resilience, s.l.: s.n.

Surminski, S., 2020. A new mindset for resilience in the face of concurrent climate and health risks, s.l.: San Antonio, Texas,.

Szewczyk, W. et al., 2020. Economic analysis of selected climate impacts JRC PESETA IV project – Task 14, Luxembourg: Publications Office of the European Union.

Tanner, T. et al., 2015. The Triple Dividend of Resilience: Realizing Development Goals through the Multiple Benefits of Disaster Risk Management, London and Washington, DC:: Overseas Development Institute and World Bank.

The Northern Star, 2012. Roma and Mitchell Hardest Hit by Flood Insurance Claim Costs, s.l.: s.n.

UNEP, 2003. Environment Alert Bulletin. [Online]
Available at: *https://www.unisdr.org/files/1145_ewheatwave.en.pdf*

UrbanGreenUp, 2020. Need a Hand With Finding the Right Green Solutions for Your City?, s.l.: s.n.

Velinger, J., 2015. More Than 100 Died Due to Fires in the Czech Republic Last Year." Czech Radio, s.l.: s.n.

Weitzman, M. L., 2011. Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change. Review of Environmental Economics and Policy, Volume 5(2), pp. 275-292.

WHO, 2011. Great East Japan Earthquake, s.l.: s.n.

Wilson, G., Wilson, T. M., Deligne, N. I. & Cole, J. W., 2014. Volcanic Hazard Impacts to Critical Infrastructure: A Review, s.l.: Journal of Volcanology and Geothermal Research 286: 148–82.

Woo, G., 2015. Cost–Benefit Analysis in Volcanic Risk, s.l.: In Volcanic Hazards, Risks and Disasters, edited by John F. Shroder and Paolo Papale, 289–300. Elsevier.

World Bank, 2013. World Development Report 2014 : Risk and Opportunity—Managing Risk for Development, Washington, D.C.: World Bank.

World Bank, 2016. Discounting Costs and Benefits in Economic Analysis of World Bank Projects, Washington D.C.: World Bank.

World Bank, 2018. Converting disaster experience into a safer built environment: the case of Japan, Washington, D.C.: The World Bank.

World Bank, 2019. Nature-Based Solutions: A Cost-Effective Approach for Disaster Risk and Water Resource Management, Washington D.C.: World Bank.

World Bank, 2020a. COVID-19 and Human Capital." Europe and Central Asia Economic Update (Fall), Washington, DC: World Bank. doi: 10.1596/978-1-4648-1643-7.

World Bank, 2020b. Overlooked: Examining the Impact of Disasters and Climate Shocks on Poverty in the Europe and Central Asia Region, Washington, DC:: World Bank.

World Bank, 2020c. Seismic Resilience and Energy Efficiency in Public Buildings Project Information Document, Washington, DC: World Bank.

World Bank. 2020d. Analysis of Heat Waves and Urban Heat Island Effects in Central European Cities and Implications for Urban Planning. World Bank, Washington, DC. *https://openknowledge.worldbank.org/handle/10986/34335*

World Health Organization, 2020. Chemical Incidents, s.l.: s.n.

WSL, 2020. Long-Term Statistics, s.l.: WSL Institute for Snow and Avalanche Research.

Xiong, J. & Alegre, E. X., 2019. Climate Resilient Road Assets in Albania, Washington, DC.: World Bank.

7. | Annexes

7.1. Annex 1: 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 and Hammitt 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

$$P_t = \frac{F_{t+\tau}}{(1+r)^{\tau}}$$

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 (B_t) and costs (C_t) from all the future years. When all the economic benefits are accounted for, a project is economically/socially beneficial if 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.

7.2. Annex 2: Overview of case studies reviewed as part of background research

HAZARD[35]	CASE STUDIES	COUNTRIES (INCL. CROSS-BORDER AND AREAS)	TYPES OF INVESTMENTS	SECTORS COVERED	TOTAL VALUE OF PROJECTS (EUR)	FUNDING SOURCES	IMPLE-MENTATION PERIOD	TYPE OF ANALYSIS
NATURAL HAZARDS								
Floods	28	United Kingdom, Portugal, Spain, Greece, Cyprus, Poland, Netherlands, Austria, Croatia, Serbia, Malta, Spain, Bulgaria, Denmark, Belgium, Germany, Italy, Europe	Structural protection (8); Nature based solutions (14); Early Warning (5); Property Level Protection (1)	Industry, Early Warning, Water, Agriculture, Housing and public buildings, Water, response & equipment, Recreation	8.965 billion	EU, World Bank, National	2006-2023	Quantitative, own analysis (3); Partial Quantitative / literature (5); Qualitative (20)
Droughts and extreme heat	6	United Kingdom, France, Spain, Portugal, Austria	Urban Heat Island 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	100.18 million	EU, National	2013 - 2022	Quantitative, own analysis (2); Partial Quantitative / literature (1); Qualitative (3)
Earthquake	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	59.22 billion	EIB, National, EU, World Bank	2015 - 2025	Quantitative, own analysis (4); Partial Quantitative / literature (2); Qualitative (1)
Wildfires	10	Czech Republic, Poland, Spain, Portugal, Greece	Wildland-urban interfaces (2); Fuel Management for wildfire prevention (1); Early Warning (3); Cross-border support, coordination mechanisms and capacity building (4)	Emergency response, Early warning, Forestry	149.24 million	EU, National	2013 - 2022	Quantitative, own analysis (7); Qualitative (3)

Mass movement / landslides/ avalanches	6	Switzerland, Croatia, BiH, 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	20.6 million	EU, National, World Bank	2019 - 2020	Partial Quantitative / literature (1); Qualitative (5)
Volcanic	2	Italy, Spain	Preventive Investment (2)	Transport, Early warning	55 million	EU, National	2013 - 2020	Qualitative (2)
TECHNOLOGICAL HAZARDS AND CROSS-CUTTING								
Oil spills	1	Estonia	Oil Spills Prevention (1)	Water, Fishery	33 million	EU, National	2013	Partial Quantitative / literature (1)
Chemical	1	Latvia	Cleaning up hazardous waste (1)	Water	29 million	EU, National	2013	Quantitative, own analysis (1)
Epidemic	2	Italy, United Kingdom, Sweden, Netherlands, Europe	Return on Investment of National Public Health Program (1); Equipment for health-related disasters (1)	Health	4.5 billion	EU, National	2021	Partial Quantitative / literature (2)
Nuclear/ Radiological	3	Czech Republic, France	Security of nuclear power plant (2); Cleaning up Uranium (1)	Energy, Emergency response & equipment, Water	24.34 billion	EU, National	2018 and on-going	Qualitive (3)
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	730.93 million	World Bank, EU, National	2006 - 2020	Partial Quantitative / literature (1); Qualitative (7)

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