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Resilience of large investments and critical infrastructures in Europe to climate change

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Abstract

Escalating climate risks to critical infrastructures in Europe
Climate hazard damages to critical infrastructures in Europe will escalate as a result of global warming, with an uneven territorial distribution of future impacts and adaptation needs. This calls for (i) an EU commitment to continue supporting adaptation action in Member States (e.g. through Cohesion Policy investments) and to coordinate the exchange of information and best practices; and (ii) further mainstreaming of climate adaptation in a wide range of EU policies and funding instruments, where cross-sectorial consideration of adaptation and climate resilience should be promoted.

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Executive summary

Policy context

One of the three priorities of the EU Adaptation Strategy is to promote better informed decision-making by addressing existing gaps in the knowledge on climate change impacts and adaptation. Critical infrastructures refer to the array of physical assets, functions and systems that are vital to ensuring the EU's health, wealth, and security. The main threats presented by climate change to infrastructures include damage or destruction from extreme events, which climate change may exacerbate.

This report for DG CLIMA Action summarises the key findings of the first comprehensive multi-hazard, multi-sector risk assessment of critical infrastructures under climate change, and identifies the most impacted regions in Europe throughout the 21st century. It significantly contributes to a better understanding and awareness of climate hazard impacts, which is crucial for planning suitable adaptation measures to safeguard and secure the functioning of society.

Key conclusions

This study predicts an upsurge in climate hazard damages to infrastructures in Europe in the coming decades due to global warming, which underpins the recent efforts of the EU to augment the profile of climate change in its budget and policies.

The key findings further provide a better understanding of the regional and sectorial distribution of climate change impacts. They call for the intensified mainstreaming of adaptation in a wide range of EU policies. The benefits of adaptation at EU level are still largely unknown, but there is a vast array of adaptation strategies that can offer impressive prospects to reduce the likelihood of disruptive impacts in the future. Given the high level of interconnectedness of infrastructures, cross-sectorial consideration of adaptation and climate resilience should be promoted.

Substantial resources may be required to increase the resilience of critical infrastructures and key investments to future climate, especially in southern and south-eastern Europe. Further attention will need to be paid to the uneven territorial distribution of future climate hazard impacts and adaptation needs, experience and capacity across the EU. As an instrument that aims to support sustainable territorial development and reduce disparities among the regions, EU Cohesion Policy investments are in a very good position to help address this matter.

A major obstacle to improving our understanding, analysing trends and projecting future impacts is the lack of standard reporting and sharing of disaster damage and loss data in the EU. Recent actions, such as the guidance document[1] for EU Member States on Recording and Sharing Disaster Damage and Loss Data, aim to pave the way for improved disaster loss data collection, and should be further encouraged and supported.

Main findings

This study finds that damages from climate extremes to critical infrastructures and key investments in the energy, transport, industrial and social sector, which at present total to €3.4 billion/year, could triple by the 2020s, multiply six-fold by mid-century, and amount to more than 10 times the present damages by the end of the century (see Figure 1, damages are undiscounted and expressed in 2010 €, assuming no socioeconomic change in future scenarios).

[1] JRC Report EUR 27192 EN, 'Guidance for Recording and Sharing Disaster Damage and Loss Data', EU Expert Working Group on disaster damage and loss data, 2015.

Losses from heat waves, droughts in southern Europe and coastal floods (including the effects of sea level rise) show the most dramatic rise, but the risks of inland flooding, windstorms and forest fires will also increase in Europe, with varying degrees of change across regions. Cold-related impacts will likely disappear in Europe over the coming decades.

Economic losses will be highest for the industry, transport and energy sectors, which are projected to face a 15-fold increase in economic damages. The sharp decrease in the return periods of multiple extreme weather events (e.g., a current 100-year heat wave or 20-year flood that may occur every 1 or 2 years under future climate conditions) sends a strong signal to infrastructure business owners and operators that the current design, construction, operation and maintenance standards and practices should be amended in these sectors.

Future losses will not be incurred equally across Europe. Southern and south-eastern European countries will be most affected. These regions may have to make substantial investments to climate-proof their infrastructures.

As the myriad of climate change impacts go far beyond those of the seven climate hazards to critical infrastructures considered in this study, it should be kept in mind that the damages presented here reflect only a fraction of the potential climate change impacts on society in Europe.

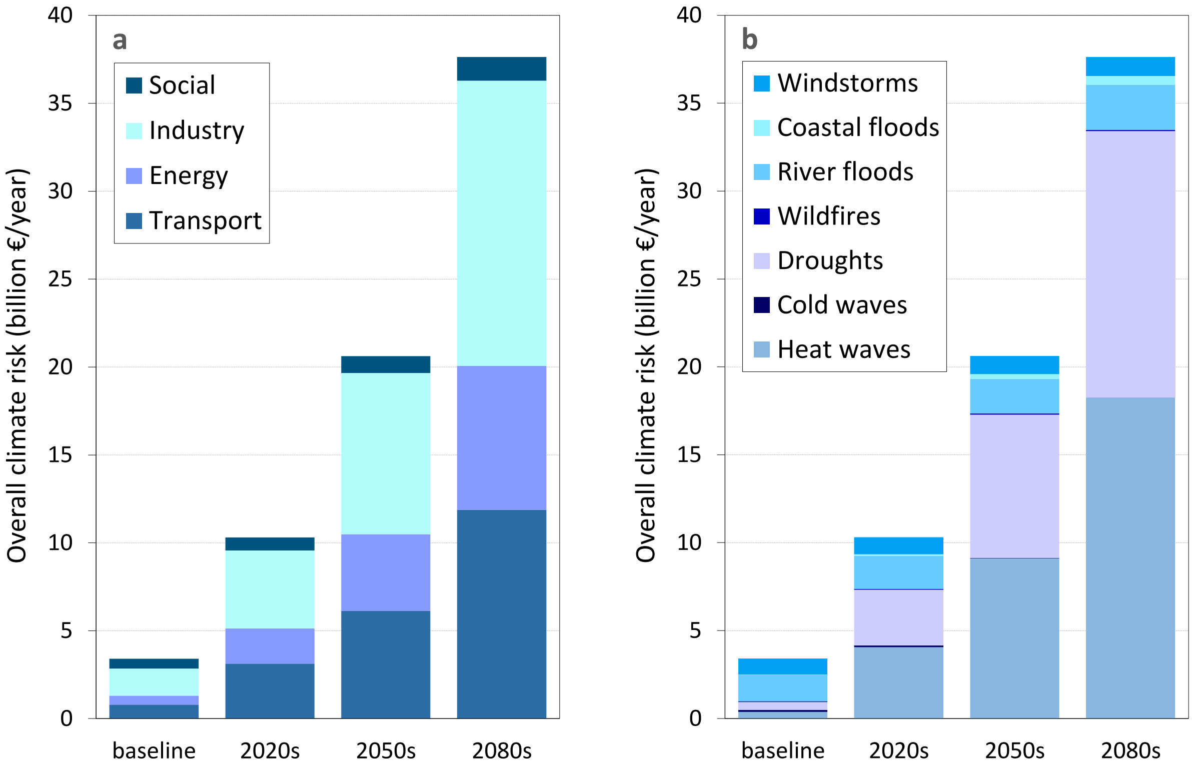

Figure 1 Evolution in the 21st century of climate hazard damages to critical infrastructures in the EU+ (EU28 + Switzerland, Norway and Iceland). Losses are undiscounted and expressed in 2010 €, assuming no socioeconomic change in future scenarios (hence reflect the effects of future climate on current economy).

Related and future JRC work

The JRC performs research on climate impacts across a wide range of sectors in Europe, focusing on the coming decades and on the analysis of adaptation strategies (PESETA3). With these activities, the JRC aims at (i) supporting the implementation of Action 4 of the EU Adaptation Strategy by addressing gaps in knowledge about climate impacts and adaptation in order to promote better informed decision making, and (ii) contributing to the Strategy's implementation report that the Commission will have to present to the European Council and Parliament in 2017. The JRC also hosts several hazard early warning and alert systems, such as the European and Global Flood Awareness Systems, the European and Global Drought Observatories, the European Forest Fire Information System and the Global Disaster Alert and Coordination System, which support disaster risk reduction initiatives at EU and global level.

Quick guide

This study has evaluated how climate hazards in a changing climate would affect the current stock of critical infrastructures in the energy, industry, social and transport sector across Europe.

The dynamics throughout the 21st century of the frequency of occurrence of heat and cold waves, droughts, wild fires, inland and coastal flooding, and windstorms, were analysed using physical models.

These projections were combined with detailed geographic information about infrastructures, their sensitivity to the different hazards, and observed damages from past disasters in order to extrapolate losses to future climate conditions.

Although the findings presented herein are based on state-of-the-art research, they are subject to uncertainty. They are indicative, however, of the massive increase in disaster losses that Europe may face in a warmer world, and of the uneven distribution of the burden across EU Member States.

1. Introduction

Critical infrastructures are the array of physical assets, functions and systems that are vital to ensuring the EU's health, wealth and security[2]. The main threats presented by climate to infrastructural assets include damage or destruction from extreme events, which climate change may exacerbate. Strong efforts have been made to augment the profile of climate change in the EU budget and policies. This is expressed through the following actions:

- The European Council has set a political objective to earmark at least 20% of the entire EU budget for climate-relevant actions in the period 2014-2020[3].
- The current programming period is the first in which climate considerations have been specifically included. Major projects funded by the European and Structural Investment Funds (ESIF) will need to be screened against climate-related vulnerabilities, and appropriate measures undertaken to increase climate resilience should be reported[4].
- For ESIF investments, there is now the specific requirement that adaptation to climate change be part of the horizontal principle of sustainable development[5]. All programmes will need to observe this principle.
- One of the 11 thematic objectives under the new ESIF interventions includes specific measures for adaptation (Thematic Objective 5 – Promoting climate change adaptation, risk prevention and management)[6].
- Large projects that will be part of the trans-European transport (TEN-T) and energy (TEN-E) networks will incorporate considerations on their resilience to climate change[7,8]
- Guidelines and tools have become available on how to take climate change adaptation actions into consideration in EU-funded investments and measures[9,10,11].

Despite the increased attention in the policy debate and recent scientific advances, there is a staggering lack of quantitative information in the literature on the resilience of critical infrastructures and large investments to climate change. In support of the EU Adaptation Strategy[12], the objective of the 'Resilience of large investments in Europe to climate change' (CCMFF) project is to fill this gap by providing insights into the current and future impacts of climate extremes on the present stock of critical infrastructures in Europe, and on regional investments under the EU Cohesion Policy for the 2007-2013 programming period.

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[2] Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection.
[3] Conclusions of the European Council (7/8 February 2013) as regards the multiannual financial framework.
[4] Article 101 of Regulation (EU) No 1303/2013 of the European Parliament and of the Council of 17 December 2013; Commission Implementing Regulation (EU) 2015/207 – Annex II, Section F.8.
[5] Article 8 of Regulation (EU) No 1303/2013 of the European Parliament and of the Council of 17 December 2013.
[6] Article 9 of Regulation (EU) No 1303/2013 of the European Parliament and of the Council of 17 December 2013.
[7] Regulation (EU) No 1315/2013 of the European Parliament and of the Council on Union guidelines for the development of the trans-European transport network
[8] Regulation (EU) No 347/2013 of the European Parliament and of the Council on guidelines for trans-European energy infrastructure
[9] CLIMA.C.3/SER/2011/0011: Methodologies for climate proofing investments and measures under cohesion and regional policy and the common agricultural policy.
[10] ENV/CLIMA.C.3/SER/201l/0037r - Guidelines for project managers: 'Making vulnerable investments climate resilient'.
[11] http://ec.europa.eu/clima/publications/index_en.htm#Mainstreaming
[12] COM (2013) 216 final. An EU Strategy on Adaptation to Climate Change.

This report summarises the key findings, methodological aspects and underlying assumptions and limitations of the research activities undertaken by the JRC in the CCMFF project, which was financed by DG CLIMA Action (Administrative Arrangement 071303/2012/630715//CLIMA.C.3 – JRC 32971-2012 NFP). For a detailed description of the modelling framework and an in-depth discussion of the results, the reader is referred to Forzieri et al. (2015). The CCMFF project provides the first comprehensive multi-hazard, multi-sector risk assessment of critical infrastructural assets under climate change, and identifies the most impacted regions in Europe throughout the 21st century. It significantly contributes to a better understanding and awareness of climate hazard impacts, which is crucial for the management of future climate risks.

2. Methods

The aim of the CCMFF project is to understand to what extent existing infrastructures and new large infrastructure projects funded by EU regional investments are impacted by extreme hazards under current and future climate conditions, and to take stock of the additional expenditures that will be required to make them climate-resilient. In order to answer these questions, the multi-hazard, multi-sector risk assessment framework depicted in Figure 2 was adopted, which builds on the risk concept for extreme events of the Intergovernmental Panel on Climate Change (IPCC) (Lavell et al., 2012). The different building blocks are explained below.

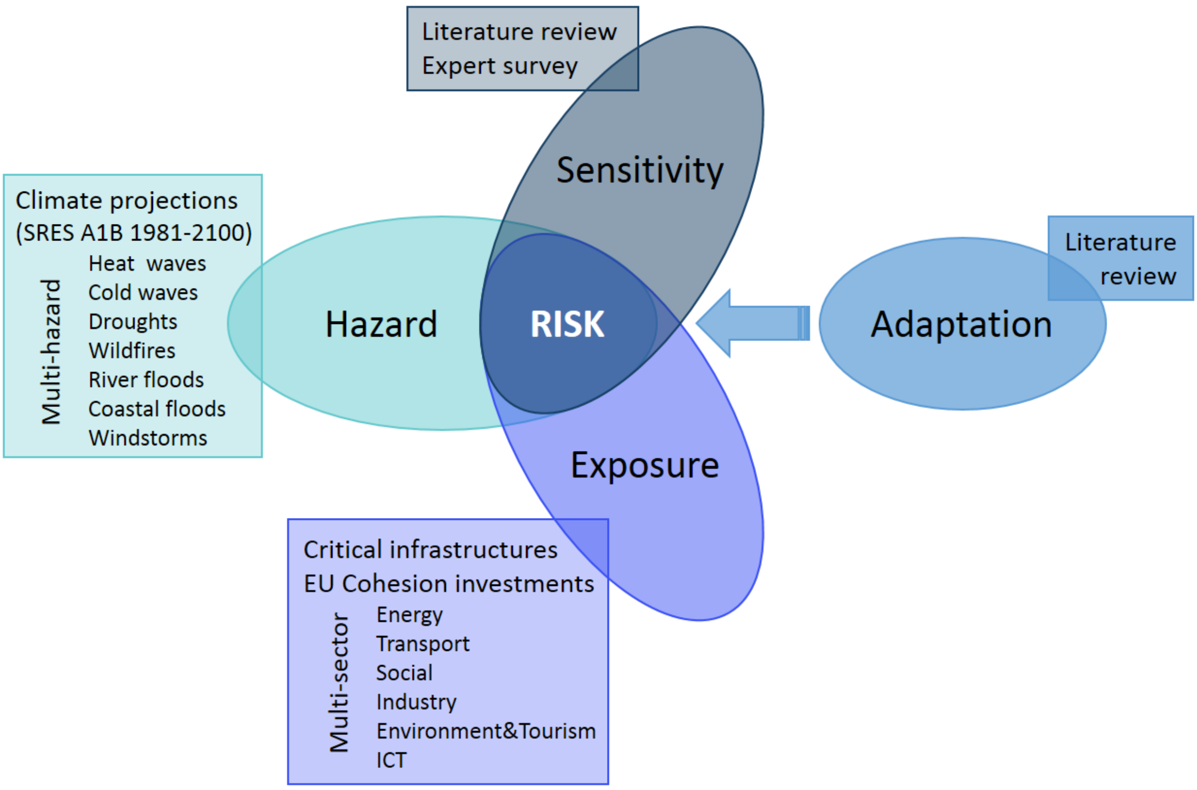


Figure 2 Flow diagram of the CCMFF multi-hazard, multi-sector risk assessment

2.1. Climate hazard

A state-of-the-art multi-hazard framework was used to map the occurrence of seven climate hazards in Europe throughout the 21st century. A baseline (1981-2010) and three future time windows (the 2020s (2011-2040), 2050s (2041-2070, and 2080s (2071-2100)) were used to reflect current, short-, medium- and long-term climate conditions, respectively. Using an ensemble of daily high-resolution climate projections for the IPCC's business-as-usual SRES A1B greenhouse gas emissions scenario, changes in the frequency of heat and cold waves (Russo et al., 2014), river and coastal flooding (Rojas et al., 2012), streamflow droughts (Forzieri et al., 2014), wildfires (Migliavacca et al., 2013) and windstorms (Outten and Esau, 2013) were evaluated. Corresponding variations in areas that are expected to be annually exposed to the hazards allowed for an objective comparison of hazards defined by differing process characteristics and metrics, and for the combination of single hazards within a multi-hazard scheme (Forzieri et al., 2016).

2.2. Exposure

Two types of exposure assets have been considered in this study: EU regional investments and the present stock of critical infrastructures in Europe. The former refer to investments in EU27 regions under the EU Regional Policy during the programming period 2007-2013, comprising the Cohesion Fund (CF), the European Social Fund (ESF), and the European Regional Development Fund (ERDF). The data used has been provided by DG Regional and Urban Policy and consisted of allocated investments in € per NUTS2 regions (271 regions) and per category of expenditure (86 categories). Potentially vulnerable allocations were grouped for the energy, transport, environment and tourism, ICT and social sectors.

The study considered a total of 24 critical infrastructure types, including transport, energy, industry and social infrastructures (see Table 1 and Marín Herrera et al., 2015). Data from various open and proprietary sources were collected to build a geo-database of both the location and key attributes of each infrastructure. The data were 'harmonised' to allow for comparability between infrastructures of the same sector and minimise potential data incompleteness (see Box 1). The harmonised infrastructure layers represent both the location of infrastructures and their 'intensity'. The latter defines the infrastructure's potential usefulness and value to society, and is a function of both the infrastructure's characteristics (e.g., size, productivity) and location.

Table 1

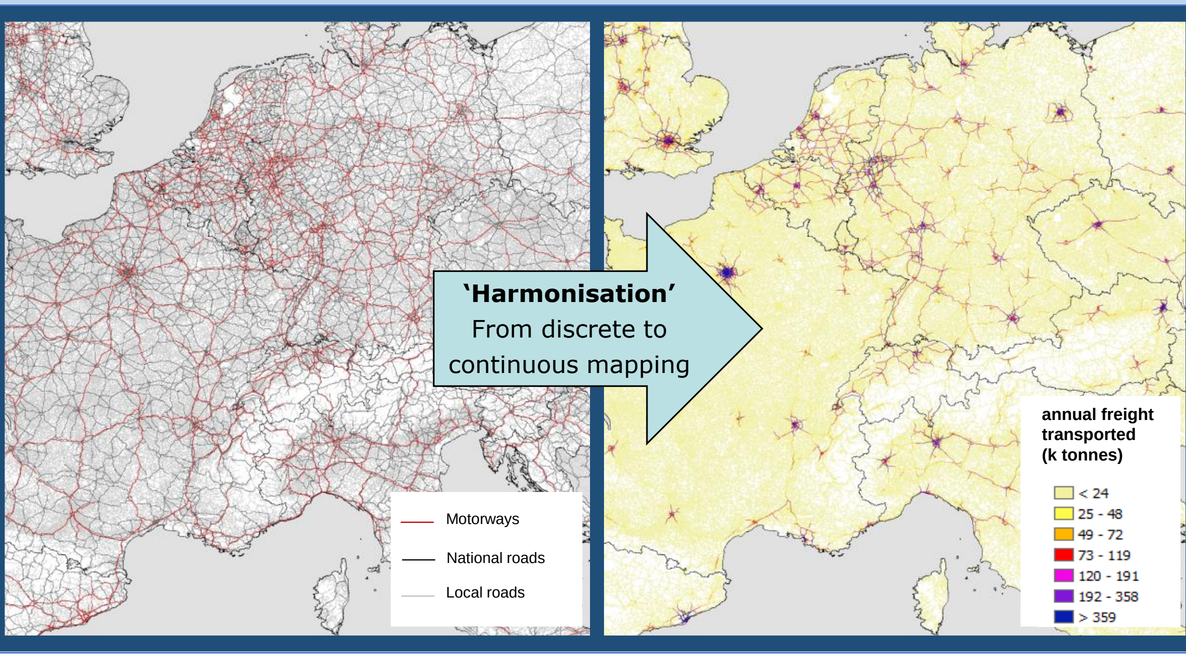
List of critical infrastructures considered in this study, with main source and reference date (see Marín Herrera et al. (2015) for further details).

Sector	Sub-sector	Infrastructure type	Main sources	Reference date
Transport	Roads	Local roads	Open Street Map	2014
		Roads of national importance		
		Motorways		
	Other modes	Railways		
		Inland waterways	GISCO+UNECE	2013
		Ports	CORINE Land Cover + GISCO	2006
		Airports		
Energy	Non-renewable energy production	Coal power plants	PLATTS	2013
		Gas power plants		
		Oil power plants		
		Nuclear power plants		
	Renewable energy production	Biomass and geothermal power plants		
		Hydro power plants		
		Solar power plants		
		Wind power plants		
	Energy transport	Electricity distribution and transmission networks		
		Gas pipelines		
Industry	Heavy industries	Metal industry	EPRTR v7	2013
		Mineral industry		
		Chemical industry		
		Refineries	Global Energy Observatory	2010
	Water/waste treatment	Water and waste treatment facilities	EPRTR v7	2013
Social	Education	Education infrastructure	Open Street Map	2014
	Health	Health infrastructure		

Box 1

Harmonisation of critical infrastructures per sector: from categorical information to a continuous indicator of intensity (based on national data collected by Eurostat).

Sector	Intensity variable	Unit
Transport	Annual freight transported	k tonnes
Energy	Electricity produced/transported	k tonnes of oil equivalent
Industry	Annual turnover	Million €
Social	Annual expenditure	Million €



2.3. Sensitivity

To ensure comparability in the multi-hazard and multi-infrastructure/investment context, qualitative sensitivities to the considered climate hazards were derived for key infrastructures and investments by integrating information from an extended literature review with a survey that was conducted among a pool of experts in the considered sectors. For each sector, 500 experts were asked to complete the survey, including facility operators, authors and editorial boards of peer-reviewed journals in the field of climate change and sector-specific structural engineering. Experts anonymously assigned a degree of vulnerability (high, moderate, low, no) of infrastructures to each of the climate hazards considered. About 10% of the invited experts responded, resulting in a sample size of ~50 per infrastructure type and hazard. The modes of the Likert distributions were considered to be representative of the sensitivities, and where there was low consensus amongst experts and/or strong disagreement with reported impacts adjustments were made based on the literature review.

2.4. Risk

For each infrastructure type, pan-European maps of potential risk levels (very high, high, moderate, low, very low, no) were constructed. These maps indicate how much of the infrastructure type in a particular area is subject to certain levels of risk, which are defined by the hazard magnitude and the sensitivity of the infrastructure to the hazard. Assuming that no damages occur to assets with no or low sensitivity to the hazard and for low magnitude hazard events, only assets exposed to very high and high risk levels are considered to contribute to the impacts. For the baseline period, the accumulated assets under very high and high risk levels for a specific hazard at sector and NUTS2 level were linked to reported damages for that hazard derived from MunichRe (http://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html) and EMDAT (http://www.emdat.be) databases. Reported disaster damages, which are aggregated at country and multi-sector level, were distributed over specific sectors based on the national shares of the monetary value of sector-specific capital stock and gross value added (obtained from Eurostat), and the sensitivity of sector infrastructures to the considered hazard. Sector-specific country damages were further disaggregated to NUTS2 level based on regional GDP. Future damage estimates were based on the projected changes of assets under high risk levels (which are fully defined by the changes in hazard as the exposure layers and the sensitivity are assumed to be constant).

2.5. Adaptation

Only a few studies have reported figures about the benefits and costs of adaptation strategies across Europe, covering different regions, types of hazards, infrastructures, measures, and accounting and appraisal approaches. These studies indicate that there is large uncertainty about the costs and benefits, but that, although capital investments can be large, many adaptation options could have high benefits compared to costs. The studies reviewed provided a range of the benefit-to-cost ratio (BCR) of between 9 and 0.4, with an average value of 2.5. The average BCR value has been used in this report to provide indicative estimates (order of magnitude) of the potential cost of adaptation. It was further assumed that the benefits of adaptation represent 75% of the potentially avoided damages, or that 25% of the increased risk was considered to be the unavoidable or residual damage from climate change that is incurred even with adaptation.

3. Key findings

3.1. Climate hazards under future climate

The frequency of occurrence of the seven most important climate hazards show significant changes in Europe throughout the 21st century due to climate change.

- **Heat waves** show a progressive and highly significant increase in frequency of occurrence all over Europe. By the end of this century, a current 100-year heat wave may occur almost every year in southern Europe, whereas in other regions of Europe such events may occur every 3 to 5 years.
- **Cold waves** show an opposite trend, with current cold extremes tending to disappear from Europe in the more distant future.
- **Streamflow droughts** will become more severe and persistent in southern and western Europe, with current 100-year events occurring approximately every 2 to 5 years by 2080, respectively. In other regions of Europe an opposite trend is expected, with a strong reduction in drought frequency in most areas.
- In most regions of Europe, **wildfires** may occur more frequently in the future, especially in southern, eastern and central Europe, although the signal is not always very strong and is only significant in limited areas.
- **Floods** will become more frequent in western Europe (current 100-year events could manifest every ~30 years by the 2080s). In other regions, projections of river floods show higher spatial and temporal variability, with lower and less significant changes. In southern and eastern Europe, more areas (30%) show a significant decrease (compared to 10% that show an increase) in flood hazard. In northern Europe, areas with a significant increase in flood hazard (24%) balance those with a significant decrease (23%). In central Europe, more areas show a significant increase (26%) than decrease (15%).
- **Coastal floods** along Europe's coastlines show a progressive and pronounced increase in recurrence frequency, mainly due to **sea level rise**, with a current 100-year event that may occur every 2 to 8 years by the end of this century.
- Evidence of changes in the frequency of **windstorms** remains largely elusive. Areas with increases in windstorm hazard are mainly located in western, eastern and northern Europe, while southern regions will likely experience slight reductions in windstorm frequency.

Europe will see a progressive and very strong increase in overall climate hazard, with a prominent spatial gradient towards south-western regions.

- By the end of this century, 76% of the area in southern Europe is expected to be annually exposed to at least one climate hazard with a current 100-year intensity, or more than 15 times the baseline value (see Figure 3). For the other regions in Europe, changes are somewhat less pronounced, but still considerable: by the 2080s, about 50% (10-fold increase), 36% (7-fold increase), 31% (6-fold increase) and 29% (6-fold increase) of the western, central, eastern and northern European territory, respectively, is expected to be annually exposed to at least one hazard that currently occurs once every 100 years.

- Due to the increase in the frequency of multiple hazards in many regions of Europe, the expected annual exposure to multiple hazards increases much more sharply than for single hazards (see Figure 3). By the 2080s, 25% of the area in southern Europe could be annually exposed to at least two hazards that currently have a 100-year intensity, or nearly 250 times the baseline value. When considering three hazards, the increase in area exposed is 700-fold. For the other regions, joint annual exposure expectancy by the end of the century for two and three hazards, respectively, will increase 95 and 245-fold in western Europe, 21 and 63-fold in central Europe, 14 and 43-fold in eastern Europe, and in northern Europe 10 and 13-fold.

Key hotspots of future climate hazards emerge particularly along coastlines and in floodplains in southern and western Europe, which are often highly populated and pivotal to the economy.

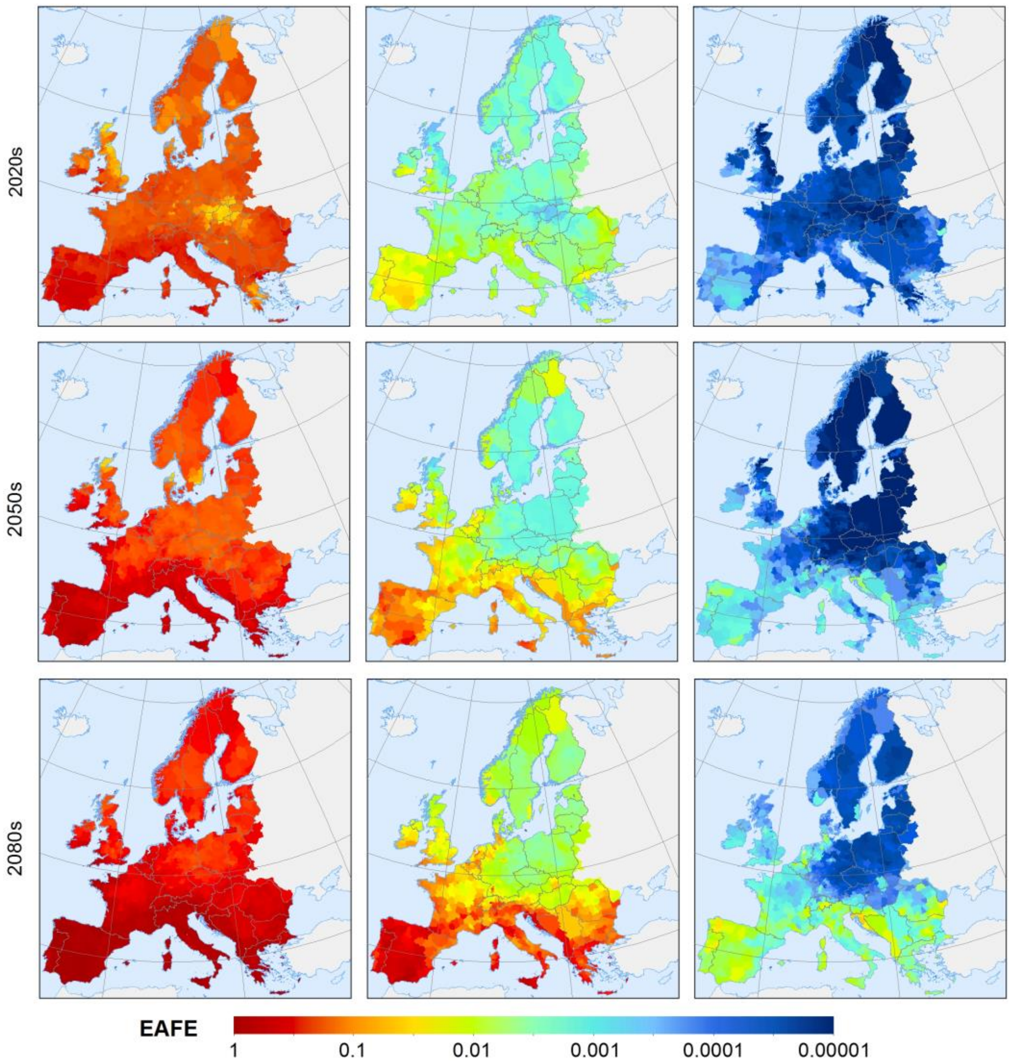


Figure 3 Evolution in time and space of the fraction of a unit area that is expected to be exposed annually (expected annual fraction exposed, EAFE) to at least one (left), two (middle) and three (right) hazards with a current 100-year intensity. At present, approximately 0.05, 0.001, and 10^{-5} of the area in all European regions is expected to be annually exposed to at least one, two and three hazards, respectively.

Box 2

Critical infrastructures and investments are vulnerable to climate hazards in a myriad of ways. Examples of some key vulnerabilities per sector are given below.

	Energy	Transport	Industry	Social
Heat	reduced power plant efficiency due to higher water temperature required for cooling	material degradation and buckling of roads, rails and bridges due to thermal expansion	increased costs for cooling and refrigeration	increased costs for cooling
Cold	structural damage to distribution lines due to ice and snow loads	buckling of roads, rails and bridges due to thermal contraction	water pipes vulnerable to frost/ice	increased cost of heating during cold episodes
Drought	reduction in hydropower potential and biofuel production	reduced navigability of rivers and channels	water quality degradation, reduction in usable water and increase in treatment costs	structural damages due to drought-induced subsidence and permafrost thawing
Wildfire	reduction in biofuel sources	deterioration of roads, railways and power lines	structural damages to industrial sites	destruction of social infrastructures
Flood	structural damages to energy production sites and transport networks	reduction of structural integrity of surface and subgrade material	structural damages to industrial sites, increased costs for water treatment	structural damage to social infrastructures and reduction in operational services
Windstorm	disruption of transmission and distribution networks	structural damages to transport facilities	structural damages to industrial systems equipment	structural damages to social structures and facilities

3.2. Climate risks under future climate

3.2.1. Risks to critical infrastructures

Climate hazard impacts on critical infrastructures may rise significantly in Europe: damages could triple by the 2020s, multiply six-fold by mid-century, and amount to more than 10 times present damages by the end of the century.

- Europe will face a significant increase in multi-hazard, multi-sector damages in the coming decades. The current expected annual damages (EAD) of €3.4 billion/year for the EU+ (the EU28 + Switzerland, Norway and Iceland) are projected to triple by the 2020s, multiply six-fold by mid-century, and increase to €38 billion/year[13] by the 2080s. These figures reflect only the combined damages of the seven climate hazards related to critical infrastructures and their operation in the energy, transport, energy and social sectors, hence they do not reflect the total damages of these hazards to society, which are likely to be even higher.

Projected damages are highest for the industry, transport and energy sectors. The strongest increase in damages is projected for the energy (16-fold increase by the end of the century) and transport (15-fold increase) sectors.

- The strongest increase in multi-hazard damages is projected for the energy sector, for which the baseline EAD of €0.5 billion/year could rise to €2, €4.4, and €8.2 billion/year (or 4, 9 and 16-fold increases in EAD) by the 2020s, 2050s and 2080s, respectively (see Figure 4a).
- A comparable trend can be observed for the transport sector, for which the baseline EAD of €0.8 billion/year is expected to reach nearly €12 billion/year (a 15-fold increase) by the end of this century.
- For industry, which faces the greatest damages of all the sectors considered, the current expected costs of €1.5 billion/year are estimated to surpass €16 billion/year by the 2080s, corresponding to a 10-fold increase.
- For the social sector, the rising trend in damages is less pronounced, but the current impacts of €0.6 billion/year could still more than double by the end of this century due to climate change.

[13] All damages reported herein are undiscounted and expressed in 2010 €. Only the effects of climate change are accounted for, assuming no socioeconomic changes in future scenarios.

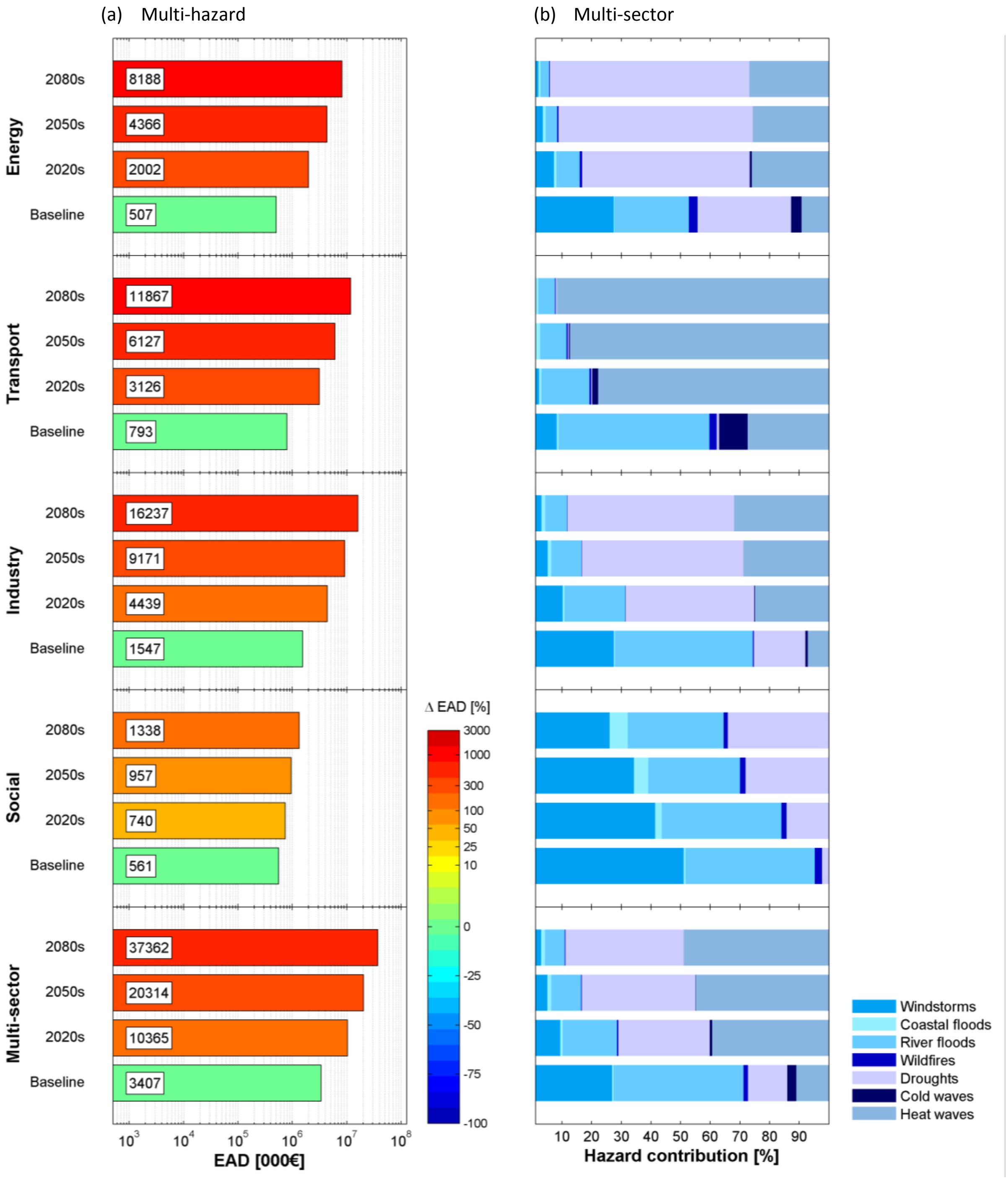


Figure 4 Risk to critical economic infrastructures aggregated at the European level for each time period and sector: (a) Multi-hazard expected annual damage (EAD): Bar length (on logarithmic scale) indicates the ensemble median – also reported in numerical labels in million € – where colours reflect the relative change in EAD with respect to the baseline; (b) distribution of multi-sector damages over the seven hazards.

Present overall climate hazard damages relate mostly to river floods (44%) and windstorms (27%). In the future, droughts and heat waves may become the most damaging hazards.

- Aggregated over the four sectors, current climate hazard damages relate mostly to river floods (44%) and windstorms (27%). Their relative contribution to total damages diminishes rapidly over time. The shares of drought and heat will increase strongly, accounting for more than 70% of climate hazard damages by the end of the century (compared to 12% at present, see Figure 4(b)).
- The contribution of wildfires, coastal floods and cold waves to the total damage is low, despite the fact that coastal flood damages are projected to increase strongly in the coming century. On the other hand, cold-related impacts in Europe could completely disappear with global warming.

Hazard impacts in the different sectors vary depending on infrastructure-specific vulnerabilities to the different hazards and the rate and magnitude of change in the latter in view of global warming.

- The largest rise in damages for the **energy sector** relates to energy production – fossil fuel, nuclear and renewable – as a result of the sensitivity to droughts and heat waves (see Figure 5) and the pronounced changes therein over the coming decades. By the end of this century drought and heat damages in Europe will comprise 67% and 27%, respectively, of all hazard impacts to the energy sector (vs 31% and 9% now, respectively). The other hazards mainly affect energy transport systems, and with time the hazard impacts either show less distinct increases (wildfires, inland flooding and wind storms), drastically increase but remain lower in magnitude (coastal flooding), or decline sharply (cold waves).
- For the **transport sector** heat waves will largely dominate future damages (92% of total hazard damages by 2080s), mainly by impacting roads and rails. These modes of transport also suffer losses from inland (>50% current road and rail damage) and coastal flooding, which will moderately and drastically increase over time, respectively, as well as from cold waves (~10% current road and rail damage) but with a strongly declining trend. Inland waterway transport will increasingly be impacted by droughts, whereas windstorm damages to river navigation show a slight increase. Sea level rise and increased storm surges will lead to strong increases in damages to ports in the coming century.
- Floods and windstorms currently dominate hazard losses in the **industry sector**, mainly through structural damages to infrastructures, machinery and equipment. Despite the fact that flood and windstorm damages are on the rise, their contribution will be quickly outweighed by those of droughts and heat waves in the coming decades. The impacts relate mostly to reduced operability and productivity of water and waste management systems with corresponding higher costs for water and its treatment.
- For the **social sector**, structural damages from flooding and windstorms will rise and remain important, whereas drought-induced subsidence damages could considerably rise. No damages are obtained for heat and cold waves, as the sensitivity (derived from the survey and literature) of education and health infrastructures to the considered hazards is low.

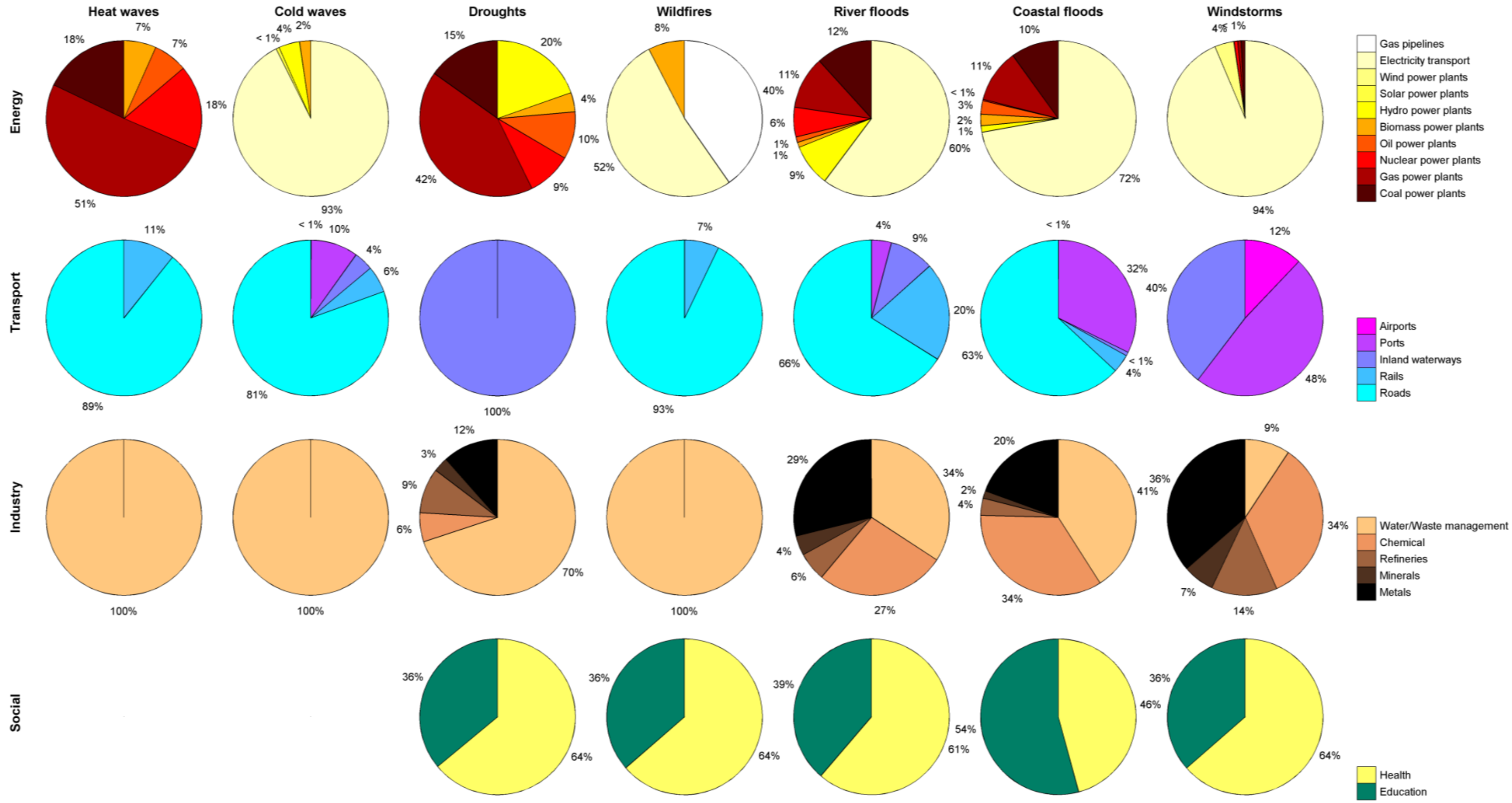


Figure 5 Distribution of hazard impacts over infrastructure types by sector, calculated for 2011-2100.

Southern European countries will be most impacted.

- Detailed space-time variations in multi-hazard multi-sector impacts visualised in Figure 6 show that all regions of Europe are projected to experience a progressive increase in multi-hazard losses, but a noticeable pattern emerging from climate change is the strong increase in damage load in southern Europe in the coming decades, with the most southern regions progressively much stronger affected by future climate extremes compared to the rest of Europe.
- For Europe as a whole, the damages to the considered infrastructures by the seven hazards expressed as a share of the gross fixed capital formation (GFCF, a measure of the annual investments in fixed assets) at risk rises progressively from 0.12% at present to 1.37% by the end of this century (Table 2). The regional imbalance in impacts is reflected by the strong variations in the shares of GFCF at risk within Europe. Whereas in northern Europe the damages under climate conditions by the end of this century represent less than 1% of annual investments, in southern European countries these damages correspond to much higher shares of annual fixed capital formation, especially for Italy (2.43%), Slovenia (2.63%), Portugal (3.74%), Spain (3.77%), Greece (3.86%) and Croatia (4.54%).

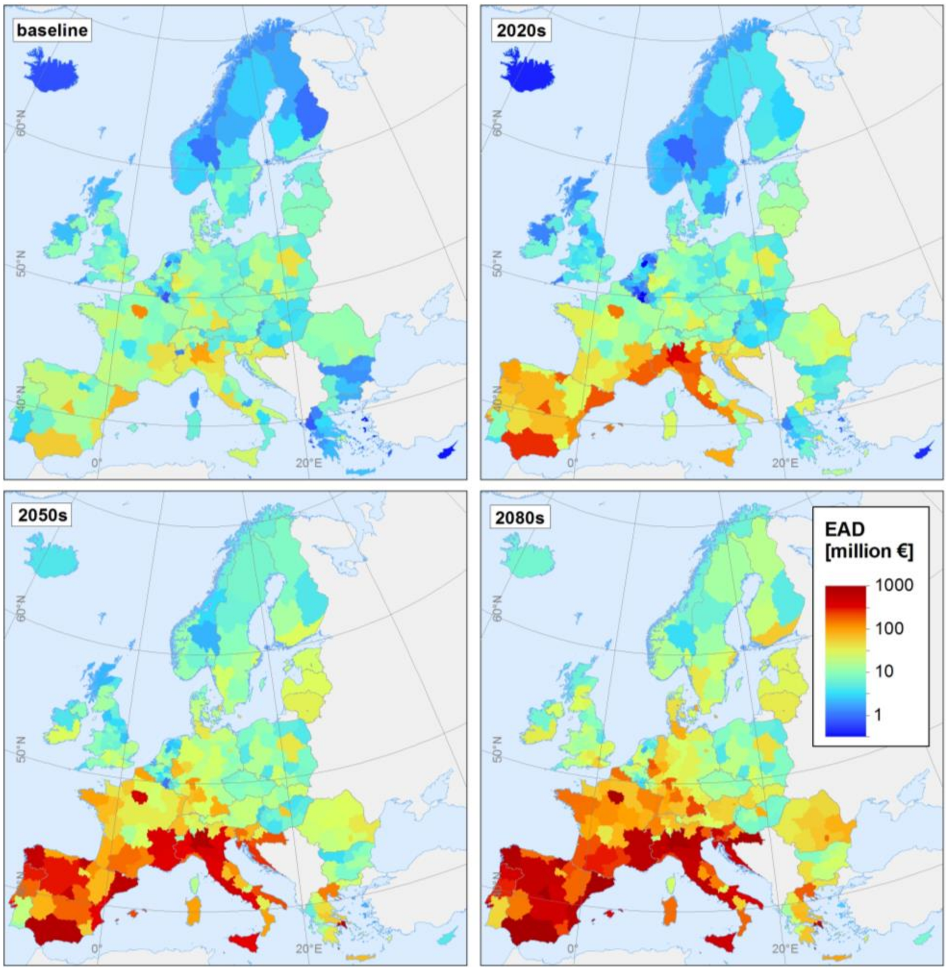


Figure 6 Evolution in time and space of expected annual multi-hazard impacts on critical infrastructures in the energy, transport, industry and social sectors. Damages are expressed as expected annual damage (EAD) in million €. Note that for Cyprus (coastal and inland floods, and droughts) and Malta (floods and droughts) some hazards are not modelled, hence no damages are included for these hazards in these countries.

Table 2

Percentage of gross fixed capital formation (GFCF, a measure of annual investments in fixed assets) at risk expressed by multi-hazard damage normalised by country GFCF. Note that for Cyprus (coastal and inland floods, and droughts) and Malta (floods and droughts) some hazards are not modelled, hence no damages are included for these hazards in these countries.

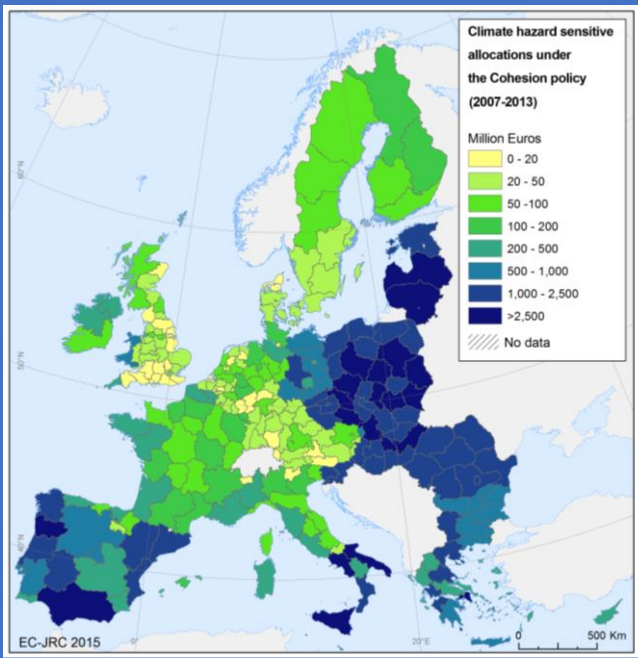
Country	baseline	2020s	2050s	2080s
AT	0.11%	0.15%	0.32%	0.66%
BE	0.07%	0.07%	0.15%	0.26%
BG	0.18%	0.47%	0.73%	1.74%
CH	0.13%	0.19%	0.48%	0.79%
CY*	0.01%	0.01%	0.12%	0.19%
CZ	0.20%	0.21%	0.22%	0.29%
DE	0.11%	0.15%	0.32%	0.51%
DK	0.14%	0.21%	0.38%	0.58%
EE	0.20%	0.34%	0.93%	1.17%
ES	0.15%	0.67%	1.94%	3.77%
FI	0.04%	0.07%	0.16%	0.27%
FR	0.09%	0.23%	0.59%	1.06%
GR	0.11%	0.41%	2.90%	3.86%
HR	0.21%	0.42%	1.54%	4.54%
HU	0.23%	0.21%	0.51%	0.74%
IE	0.04%	0.05%	0.15%	0.16%
IS	0.05%	0.05%	0.34%	0.52%
IT	0.14%	0.60%	1.39%	2.43%
LT	0.19%	0.40%	0.80%	0.90%
LU	0.08%	0.09%	0.14%	0.25%
LV	0.24%	0.47%	1.04%	1.05%
MT*	0.01%	0.54%	0.57%	0.64%
NL	0.06%	0.06%	0.11%	0.14%
NO	0.03%	0.03%	0.09%	0.15%
PL	0.27%	0.28%	0.30%	0.31%
PT	0.13%	0.75%	2.21%	3.74%
RO	0.30%	0.58%	0.80%	1.75%
SE	0.06%	0.08%	0.20%	0.25%
SI	0.22%	0.37%	0.85%	2.63%
SK	0.12%	0.13%	0.50%	1.21%
UK	0.13%	0.14%	0.21%	0.32%
EU+	**0.12%**	**0.38%**	**0.75%**	**1.37%**

3.2.2. Risks to EU regional investments

Box 3

Distribution of potentially vulnerable EU regional investments under the European Cohesion Policy 2007-2013.

A total of 50 categories of expenditure were considered to be potentially vulnerable to climate hazards, which accounts for 53% of the 2007-2013 investment programme, or roughly €185 billion. Investments in the transport, environment and tourism sectors account for more than 75% of all vulnerable investment categories. Regions in the southern and eastern parts of Europe are the main beneficiaries.



EU regional investments may be increasingly at risk from climate hazards, with expected overall impacts projected to nearly quadruple by 2040, and to increase 12-fold by the end of the century.

- Annual damages to EU regional investments will rise rapidly from €146 million/year (0.04% of the total 2007-2013 regional investments), to €556 million/year (3.8 times the baseline EAD, or 0.16% of total 2007-2013 regional investments) by the 2020s. By the 2050s, damages will climb further to €1 109 million/year (7.6 times the baseline EAD, or 0.32% of total 2007-2013 regional investments), and by the end of this century the annual risk amounts to €1 703 million/year (12 times the baseline EAD, or 0.49% of total 2007-2013 regional investments).

Floods currently account for half (51%) of climate hazard damages to EU regional investments, followed by droughts (26%) and heat waves (10%). By the end of the century, 92% of damages could be due to droughts (52%) and heat waves (40%).

- Floods are currently the most damaging hazard to EU regional investments, accounting for about half (51%) of total impacts, followed by drought (26%) and heat waves (10%).
- Drought damages will increase significantly, from the current €38 million/year to €888 million/year by the 2080s (23 times the baseline EAD), and will make up the greatest share of future damages (52% by the end of the century).
- The strongest relative increase in damages, however, is projected for heat waves and coastal flooding (which are both expected to increase by around 45 times). As a result, heat waves will become the second most damaging hazard to EU regional investments (40% of total damages by 2080s).
- Damages due to cold waves will gradually die out in the coming decades, whereas damages due to wind, floods and fires show more moderate increases, with absolute damages rising this century by 10%, 30% and 50%, respectively.

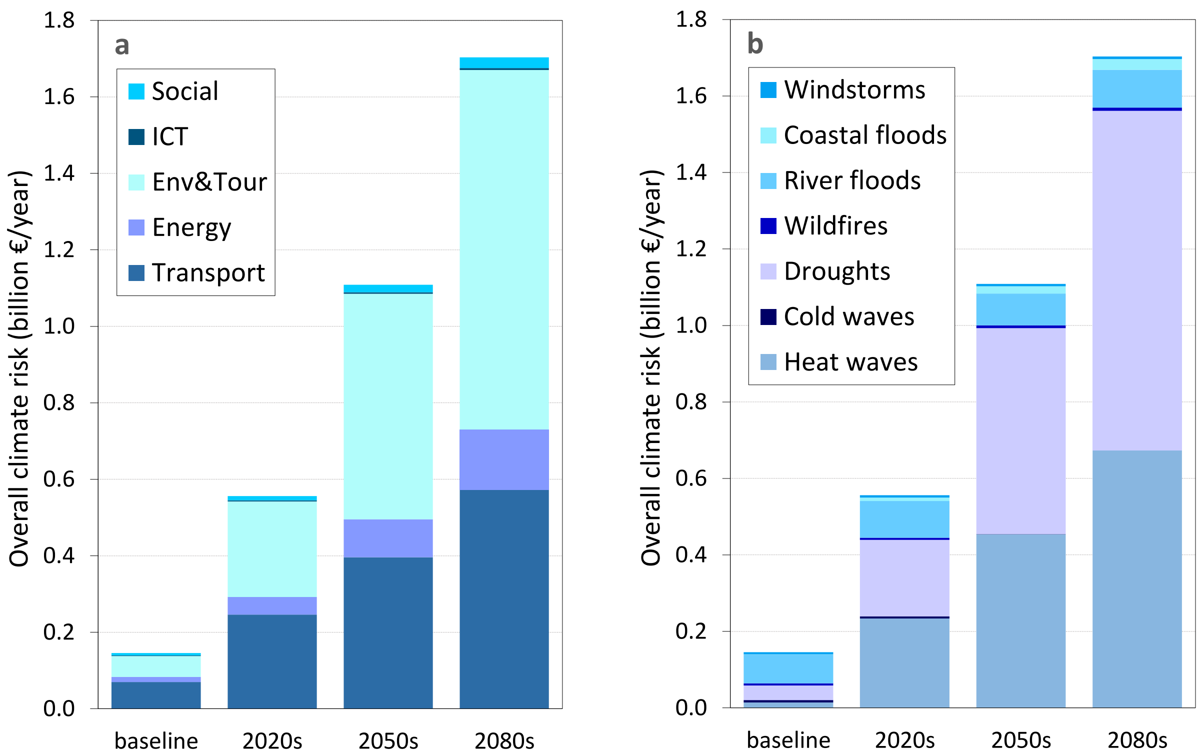


Figure 7 Overall climate risk of the 2007-2013 EU27 Structural Investments: breakdown of total climate risk in (a) multi-sector EAD per hazard, and (b) multi-hazard EAD per sector.

Currently, 48% of hazard impacts are incurred by the transport sector and 37% by the environment and tourism sector. By the 2080s, damages to environment and tourism investments may increase 16 fold and account for more than half of the total hazard damages (55%), while 34% of hazard impacts will be incurred by the transport sector.

- At present, 48% of hazard impacts relate to transport investments, and 37% to the environment and tourism sector. Annual damages in the transport sector are predicted to rise 7 fold, from €70 million/year in the baseline to €573 million/year by the 2080s. For the environment and tourism sector, damages will increase at double the rate (16 fold rise), from €55 million/year now to €940 million/year by the end of the century. Hence, this sector will account for more than half of the total hazard damages (55% compared to 34% for the transport sector) to EU investments under future climate.
- Damages in the energy sector will increase more than 10-fold from €13 million/year in the baseline to €157 million/year by the 2080s.
- The impacts of future climate on the ICT and social sectors will be smaller and show less pronounced increases. While damages to ICT investments are expected to rise from €1.9 now to €5 million/year by the 2080s, an increase from €6 to €28 million/year is projected for the social sector.

For the energy, and environment and tourism sectors, expected yearly losses by the 2080s may increase to (and locally exceed) 10% of the total sector investment in south-western and south-eastern regions of the EU.

- Multi-hazard, multi-sector expected annual losses, which for the whole EU27 correspond to 0.49% of total investments, can reach up to 3% in isolated regions of the Iberian and Balkan Peninsulas.
- The relative impacts at the sector level can even be substantially higher in some parts of Europe. By the end of the century, annual losses incurred by investments in the transport sector are expected to increase to about 5% for Latvia, Romania, Bulgaria and regions of Spain. For the energy and the environment and tourism sectors, expected yearly losses may exceed 10% of the total sector investment in south-west and south-east regions of the EU. For the social and ICT sectors expected annual losses at regional scale remain mostly below 1% and 0.5% of sector investments, respectively.

3.3. Indicative costs and benefits of adaptation

Adaptation strategies can offer impressive prospects for increasing the resilience of critical infrastructures to future climate, but substantial resources may be required, spread unevenly across Europe.

- Indicative estimates based on average benefit to cost ratios from literature show that, for the EU+, the total accumulated benefits (or avoided damages) of adapting critical infrastructures to short-term climate changes (up to 2040) amount to €100 billion, with an accumulated cost of adaptation of €39 billion. Costs incurred now to put adaptation measures in place (i.e., capital costs) could amount to €12 billion, or 0.4% of annual investments in fixed assets in EU+ (the latter defined by 2010 GFCF for EU+), plus a yearly operational and maintenance (O&M) cost of nearly €1 billion. The expected annual benefits of these investments amount to €3.3 billion.
- The investments to be made in order to adapt to changes in climate in the medium term (including the 2050s) would amount to an upfront capital cost of €54 billion (or 1.9% of EU+ 2010 GFCF) and an annual O&M cost of €2.1 billion, with expected annual benefits growing to €11.9 billion by the 2050s.
- The total cost of making infrastructures climate-resilient up to the end of the century rises to €461 billion, which includes a capital cost of €138 billion to be incurred now (about 4.8% of EU+ 2010 GFCF), and O&M costs of nearly €3.6 billion/year. This would yield total accumulated benefits (or avoided damages) of €1 152 billion between now and the end of this century, with expected annual benefits reaching €23 billion by the 2080s.
- Adaptation costs will not fall equally across Europe. Some countries in Europe will potentially have to direct a significant share of their GFCF or investments in fixed assets to adaptation in order to abate the future impacts of climate hazards on critical infrastructures – notably Greece, Portugal, Spain and Croatia.

Adaptation requirements for making EU regional investments resilient to climate up to 2040 show considerable variations across sectors and regions, but for some regions may amount to 10% of total sectorial investments.

- The cost of making EU regional investments resilient to climate up to 2040 may amount to 1.1% of total allocations, which grows to 6.2% and 10.4% for adapting to medium- and long-term climate change, respectively.
- There are considerable variations in adaptation requirements for different sectors, both in terms of overall magnitude and distribution across regions.
- The sectors with the highest relative adaptation costs are the transport, energy, and environment and tourism sectors. For these sectors, several regions in southern and south-eastern Europe, including some in France, may face short-term adaptation costs of up to 10% of the sector investments, and even up to 25% and more in localised regions of the Iberian and Balkan Peninsulas.

4. Main limitations

Although the findings presented herein are based on state-of-the-art research, they are subject to uncertainty due to the following:

- There is uncertainty in the climate projections and extreme value analysis of hazards that is translated into the damage estimates.
- Hazard interrelations, which may affect the overall hazard level and vulnerability of assets, have not been explicitly accounted for.
- Potential data incompleteness regarding exposed assets was partially addressed at country level by the harmonisation procedure, but this does not prevent the underestimation of exposure at the site-specific level in cases where infrastructure data were missing.
- EU regional investments were assumed to be homogeneously distributed within NUTS2 regions. In reality, investments in regions may have marked spatial patterns, or target very specific locations within regions, depending on the type of investment.
- The derived sensitivity classes are subject to exposure, information and individual bias. Furthermore, there can be large variation in infrastructure-specific vulnerability, depending on the institutional, economic, and technological context.
- Estimates of baseline and future climate damages are fully conditional on those reported by EMDAT and Munich Re, and any deviations therein from the true impacts are inherently translated into the damage estimates.
- Disaster risk databases typically poorly reflect indirect, inter-sectorial effects and intangible damages, which may considerably amplify the impacts of hazards. This may lead to potential underestimation of the impacts of climate extremes on the investigated sectors.
- Coastal damages are likely to be underestimated in this study because in the disaster risk databases they are reported under the headings of floods and storms.
- The proposed disaggregation of losses across sectors and regions may not reflect the true sector-specific regional impacts.
- Changes in the frequency distribution that were considered to be linked to the damages may not be fully representative of the true changes in the frequency of damaging events.
- The relationship between the benefits and costs of adaptation measures in a specific setting and the residual damage from climate change that is incurred even with adaptation may deviate strongly from the average literature-derived values used herein.

The abovementioned limitations reflect current knowledge gaps and should be taken into consideration when interpreting the hazard, impact and adaptation results for current and future time windows presented in this report.

5. Conclusions

One of the three pillars of the EU Adaptation Strategy is to address gaps in knowledge about climate impacts and adaptation in order to promote better informed decision-making. Little is known about how critical infrastructures and large investments, often with lifetimes spanning several decades, will be affected by extremes in a changing climate. Although various impacts of climate extremes on infrastructures are acknowledged in the literature, they are primarily presented in qualitative, descriptive terms. In support of DG Climate Action of the European Commission, this study breaks new ground by providing a first comprehensive quantitative assessment of the impacts of current and future climate extremes on the present stock of critical infrastructures in Europe, and on regional investments under the EU Cohesion Policy for the 2007-2013 programming period.

This study considered seven of the most damaging climate hazards: heat and cold waves, droughts, forest fires, inland and coastal flooding (including sea level rise), and windstorms. Other hazards, such as landslides, avalanches and hailstorms, may also impact critical infrastructures but have not been considered. The dynamics of the seven climate hazards throughout the 21st century were analysed using state-of-the-art physical models. Results show that Europe will see a progressive and very strong increase in overall climate hazards, with a prominent spatial gradient towards south-western regions. Key hotspots emerge particularly along coastlines and in floodplains. While the projections for climate hazards are prone to uncertainty, they reflect the current understanding about how and why specific climate extremes are expected to change across Europe. It has further been assumed that in areas where the future signal in climate extremes amongst the different climate projections is too noisy (i.e., the changes are statistically insignificant), hazard occurrences (and consequently their impacts) remain as under present climate conditions.

Regarding the implications of climate change for infrastructures in Europe, results indicate that damages from climate extremes could triple by the 2020s, multiply six-fold by mid-century, and amount to more than 10 times the present damages of €3.4 billion/year by the end of the century. Economic losses are highest for the industry, transport and energy sectors. The strongest increase in damage (>1500% by the end of the century) is projected for the energy and transport sectors, and for EU investments in environment and tourism. Whereas floods currently account for approximately half of climate hazard damages, drought and heat waves will become the most damaging hazards in the future. Future losses will not be incurred equally across Europe. Southern and south-eastern European countries will be most affected.

The impacts of climate extremes may go far beyond the physical assets themselves. Wider economic, social, and environmental effects depend on the institutional and economic environment, especially on the upward and downward side of the production chain and thus on the dependency networks of critical infrastructures, which are complex systems. Interdependencies, cascading effects and the risk of failures were not explicitly modelled in this study due to the lack of metrics or models that satisfactorily capture these aspects for highly interconnected infrastructures, especially for application at the continental scale. Rather, it has been assumed that such wider consequences are implicit in the reported damages. Disaster risk databases, however, typically poorly reflect indirect, inter-sectorial effects and intangible damages. Hence, the numbers reported herein may potentially underestimate the full impacts of climate extremes on the investigated sectors.

There is a wide range of adaptation strategies that can offer impressive prospects to reduce the likelihood of disruptive impacts in the future. However, substantial resources may be required to increase the resilience of critical infrastructures and EU regional investments against future climate hazards, especially in southern and south-eastern

Europe. Given the high level of interconnectedness of infrastructures, cross-sectorial consideration of adaptation and climate resilience should be promoted.

The figures presented herein should be interpreted taking full cognisance of the assumptions and limitations that are inherent to a large-scale continental assessment. The findings should be complemented by detailed regional- to local-scale analyses that are better able to capture site-specific vulnerabilities, interdependencies and operational interactions. A major obstacle to improving our understanding, validating approaches, analysing trends and projecting future impacts is the lack of standard reporting and sharing of disaster damage and loss data. Recent developments, such as the report 'Guidance for Recording and Sharing Disaster Damage and Loss Data' for EU Member States (EU Expert Working Group on disaster damage and loss data, 2015), aim to pave the way for improved disaster loss data collection, and should be further encouraged and supported.

It should be further stressed that the myriad of climate change impacts go far beyond those of the seven climate hazards considered in this study; hence, it should be kept in mind that the damages presented here only reflect a fraction of the potential impacts of climate change on society in Europe.

While the estimates herein are only indicative, they do highlight some important issues. The geographical and sectorial distribution of costs provides an indication of the regions and sectors that may require substantial interventions to make present and planned critical infrastructures resilient to future climate hazards. As economic costs are disproportionately spread across the EU, a better understanding of the regional and sector distribution of climate impacts could help in orienting EU Cohesion Policy investments towards addressing the unequal burden of required efforts across Europe. The latter, combined with varying experiences and capacities related to climate change adaptation across Europe calls for:

(i) an EU commitment to continue supporting adaptation actions in Member States (e.g., through Cohesion Policy investments), as well as to promote and coordinate the exchange of information and best practices; and

(ii) further mainstreaming of climate adaptation in a wide range of EU policies and funding instruments, where cross-sectorial consideration of adaptation and climate resilience should be promoted.

References

1. Forzieri, G., Bianchi A., Marín Herrera M., Batista e Silva, F., Feyen, L. and Lavalle, C., 2015. Resilience of large investments and critical infrastructures in Europe to climate change. EUR 27598. Luxembourg (Luxembourg): Publications Office of the European Union. JRC Technical Report, JRC98159.
2. Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R., and Myeong, S., 2012: Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M. (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 25-64.
3. Russo, S., Dosio, A., Graversen, R.G., Sillmann, J., Carrao, H., Dunbar, M.B., Singleton, A., Montagna, P., Barbola, P. and Vogt, J.V., 2014. Magnitude of extreme heat waves in present climate and their projection in a warming world. J. Geophys. Res. Atmospheres 119, 12,500–12,512. doi:10.1002/2014JD022098.
4. Rojas, R., Feyen, L., Bianchi, A. and Dosio, A., 2012. Assessment of future flood hazard in Europe using a large ensemble of bias-corrected regional climate simulations. J. Geophys. Res. Atmospheres 117, D17109. doi:10.1029/2012JD017461.
5. Forzieri, G., Feyen, L., Rojas, R., Flörke, M., Wimmer, F. and Bianchi, A., 2014. Ensemble projections of future streamflow droughts in Europe. Hydrol Earth Syst Sci 18, 85–108. doi:10.5194/hess-18-85-2014.
6. Migliavacca, M., Dosio, A., Camia, A., Hobourg, R., Houston-Durrant, T., Kaiser, J.W., Khabarov, N., Krasovskii, A.A., Marcolla, B., San Miguel-Ayanz, J., Ward, D.S. and Cescatti, A., 2013. Modeling biomass burning and related carbon emissions during the 21st century in Europe. J. Geophys. Res. Biogeosciences 118, 2013JG002444. doi:10.1002/2013JG002444.
7. Outten, S.D. and Esau, I., 2013. Extreme winds over Europe in the ENSEMBLES regional climate models. Atmos. Chem. Phys. 13, 5163–5172. doi:10.5194/acp-13-5163-2013.
8. Forzieri, G., Feyen, L., Russo, S., Vousdoukas, M., Alfieri, L., Outten, S., Migliavacca, M., Bianchi, A., Rojas, R. and Cid., A., 2016. Multi-hazard assessment in Europe under climate change. Climatic Change, doi:10.1007/s10584-016-1661-x.
9. Marín Herrera, M., Batista e Silva, F., Bianchi, A., Barranco, R. and Lavalle, C., 2015. A geographical database of infrastructures in Europe. JRC Technical Report, JRC99274.
10. EU Expert Working Group on disaster damage and loss data, 2015. Guidance for Recording and Sharing Disaster Damage and Loss Data. Towards the development of operational indicators to translate the Sendai Framework into action. EUR 27192. Luxembourg (Luxembourg): Publications Office of the European Union. JRC Technical Report, JRC95505.

List of abbreviations and definitions

BCR: Benefit-to-cost ratio
CCMFF: Climate Change Multiannual Financial Framework, acronym for the project 'Resilience of large investments in Europe to climate change'
CF: Cohesion Fund
EAFE: expected annual fraction exposed
EAD: expected annual damage
ESF: European Social Fund
ESIF: European and Structural Investment Funds
ERDF: European Regional Development Fund
EU: European Union
EU27: European Union with 27 Member States (Croatia not included)
EU28: European Union with 28 Member States
EU+: EU28 + Iceland, Norway and Switzerland
ICT: Information, communication and technology
GDP: Gross domestic product
GFCF: Gross fixed capital formation
IPCC: Intergovernmental Panel on Climate Change
NUTS2: Second level of Nomenclature of Territorial Units for Statistics
O&M: Operational and maintenance
SRES: Special Report on Emissions Scenarios
TEN-T: Trans-European transport network
TEN-E: Trans-European energy network

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