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Review

A Review on Connecting Research, Policies and Networking in the Area of Climate-Related Extreme Events in the EU with Highlights of French Case Studies

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Abstract: The increasing severity and frequency of extreme weather and climate events (e.g., floods, heat and cold waves, storms, forest fires) resulting from climate change-compounded vulnerabilities and exposure require a specific research focus. Climate-related extreme events are part of disaster risk reduction policies ruled at international, EU, and national levels, covering various sectors and features such as awareness-raising, prevention, mitigation, preparedness, monitoring and detection, response, and recovery. A wide range of research and technological developments, as well as capacity-building and training projects, has supported the development and implementation of these policies and strategies. In particular, research and innovation actions support the paradigm shift from managing "disasters" to managing "risks" and enhancing resilience needs. In this respect, a huge body of knowledge and technology has been developed in the EU-funded Seventh Framework Programme (2007–2013) and Horizon 2020 (2014–2020), for example in the area of measures and technologies needed to enhance the response capacity to extreme weather and climate events affecting the security of people and assets. In addition, networking initiatives have been developed to connect scientists, policy-makers, practitioners, and industry and civil society representatives in order to boost research uptake, identify gaps, and elaborate research programs at EU level. Research and networking efforts are pursued within the newly starting framework program Horizon Europe (2021–2027), with a focus on supporting civil protection operations. This paper provides a general overview of relevant EU policies and examples of past and developing research in the area of weather and climate extreme events and highlights current networking efforts in this area.

Keywords: climate extreme events; research; science-policy interfacing; networking; EU policies; EU research projects

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1. The EU Policy Landscape

1.1. Introduction

Climate change impacts the frequency and severity of weather/climate extreme events, and the need for proactive management efforts are obviously recognized worldwide. This is reflected in international fora from different angles, namely economic impact forecasting and recommendations expressed by IPCC [1], and disaster risk reduction under the Sendai Framework for Action [2], that are themselves considered in a large span of sectors and EU policies covering secure, safe, and resilient society issues in relation to risks incurred by climate extreme events. Crisis management policies follow an integrated approach for the management of natural (including climate extreme events) and man-made hazards focusing on disaster risk reduction (prevention and preparedness) and disaster response. At EU level, the policy is mainly represented by the EU Civil Protection Mechanism [3]. Climate-related disasters are also directly covered by environmental and climate policies, in particular the Flood Directive [4] and the EU climate change adaptation strategy [5]. Finally, intergovernmental agencies are also involved in climate-related security policies, in particular the European External Action Service (EEAS), which implements the EU Common Foreign and Security Policy (and displacement of population due to climate threats). Complementing this arsenal of policies, the European Green Deal sets a number of policy initiatives with the overarching aim of making Europe climate-neutral by 2050 [6]. This goal has an effect on the policies detailed in the following sections.

As stressed above, international policies are also active in disaster risk and crisis management, and their implementation is largely addressed by a range of EU policies that are described below. It should be recalled that EU policies are adopted by Member States via a co-decision process of the EU Council and Parliament, and that they are transposed (and implemented) in national laws and action plans. The EU framework hence represents an opportunity to discuss coordination among various national approaches and develop a common EU vision. As compared with international conventions with no legally enforceable management framework, the situation in the European Union is developing towards a robust risk-based management system for tackling environmental hazards, including climate-related threats, with legal instruments being in place or in development. This section examines concrete policy steps that are either implemented or being developed in the EU.

1.2. EU Civil Protection Mechanism (UCPM)

The Union Civil Protection Mechanism (UCPM) [3] aims to facilitate reinforced cooperation among EU Member States and to facilitate coordination in the field of civil protection, in order to improve the effectiveness of systems for preventing, preparing for, and responding to natural (including climate extreme events) and manmade disasters. It supports and complements the efforts of the Member States for the protection, primarily of people but also of the environment and property, including cultural heritage. Built upon these policy instruments, the UCPM is about developing an integrated approach to disaster management based on the principles of solidarity. The overall mechanism takes due consideration of laws and international commitments, and exploit synergies with relevant Union initiatives, such as, e.g., the European Earth Observation Programmes (Copernicus). The mechanism recognizes the role of regional and local authorities in disaster management. Outside the Union, disaster response is coordinated with the United Nations (in close interaction with the Sendai Framework for Action) and other relevant international actors concerning humanitarian aid. The UCPM also finances actions related to preventing, preparing for and responding to disasters, including civil protection training programs, large-scale exercises, exchange of experts, prevention and preparedness projects (through annual calls for applications), logistical and transport support for response missions, deployment of coordination, etc.

1.3. Critical Infrastructure Protection

The new approach to the European Programme for Critical Infrastructure Protection (EPCIP) aims to ensure a high degree of protection of EU infrastructures and increase their resilience against all threats and hazards [7], and this includes climate impact-related threats. Within this policy framework, a technical guidance on climate-proofing of infrastructure projects has been recently adopted for the period 2021–2027. It will help mainstream climate considerations in future investment and development of infrastructure projects from buildings and network infrastructure to a range of built systems and assets. That way, institutional and private European investors will be able to make informed decisions on projects deemed compatible with the Paris Agreement [8] and EU climate objectives. The impacts of climate change are already having repercussions for assets and infrastructure with long lifetimes such as railways, bridges, or power stations, and these impacts are set to intensify in the future. It is therefore essential to clearly identify—and consequently to invest in—infrastructure that is prepared for a climate-neutral and climate-resilient future.

In this respect, climate-proofing is a process that integrates climate change mitigation and adaptation measures into the development of infrastructure projects.

1.4. EU Strategy on Adaptation to Climate Change

The EU Strategy on Adaptation to Climate Change [5] highlights the consequences of climate change and the need for adaptation measures. It focuses on early, planned, and coordinated action rather than reactive adaptation. The strategy takes account of global climate change impacts such as disruptions to supply chains or impaired access to raw materials, energy, and food supplies. The overall aim is to contribute to a more climate-resilient Europe by enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national, and EU levels, developing a coherent approach, and improving coordination. This strategy is closely linked to national adaptation strategies, which are considered as recommended instruments by the UN Framework Convention on Climate Change (UNFCCC). A close coordination between climate change adaptation and disaster risk management/policies is also required. The development of guidelines is foreseen on minimum standards for disaster prevention based on good practices. Actions on climate change adaptation must involve all parts of society and all levels of governance, inside and outside the EU. Current work is focusing on improving knowledge of climate impacts and adaptation solutions, stepping up adaptation planning and climate risk assessments, accelerating adaptation action, and helping to strengthen climate resilience globally. Pushing the frontiers of knowledge on adaptation is required to gather more and better data on climate-related risks and losses, making them available to all. This is the aim, in particular, of the European Climate-ADAPT platform for adaptation knowledge, but also naturally of EU-funded programs which are described below. While the Paris Agreement established a global goal on adaptation and highlighted adaptation as a key contributor to sustainable development, the EU will promote sub-national, national, and regional approaches to adaptation.

1.5. EU Water and Marine Policies

Linked to the above, specific policy instruments are in place in sectors related to climate extreme events such as floods and droughts. In the first place, complementing the Water Framework Directive [9], or WFD, flood prevention and management are tackled by the Flood Directive [4], which requires EU Member States to assess and manage flood risks, with the aim of reducing adverse consequences for human health, the environment, cultural heritage, and economic activity associated with floods in Europe. This directive therefore provides a comprehensive mechanism for assessing and monitoring increased risks of flooding, taking into account the possible impacts of climate change, and for developing appropriate adaptation approaches. Finally, while the protection of the (coastal) marine environment is covered by the WFD, environmental objectives for the marine environment are subject to regulations under the EU Marine Strategy Directive [10].

2. Science-Policy Interactions

2.1. Scientific Foundation of Climate-Related Policies

The need to strengthen links among science and policy-making in the overall water-related risk management (including climate threats) has been subject to ongoing debates in the last ten years, in particular in the water and marine sectors [11]. Key policy steps are based upon a scientific foundation and basic technical knowledge that are needed to define protection objectives and related assessment and response measures [12].

2.2. EU Scientific Framework in Support of Climate-Related Policies

EU Research Framework Programmes are established over a 7-year period and serve two main strategic objectives: (1) They provide a scientific and technological basis for industry and encourage its international competitiveness; (2) They promote research activities in support of other EU policies. These programs represent the European Union's main instrument for funding research and development, and in this context, climate change-related research has been ongoing for several years since the beginning of the 2000s. They are implemented through open "calls for proposals", and successful projects are selected after an evaluation procedure carried out with the help of external independent experts. Priority areas reflecting EU research needs are sectors such as health, food and agriculture, information and communication technologies, nanosciences, energy, transport, socioeconomic sciences, space, and security. Environment and climate change are part of these priorities. Examples of EU-funded projects are given in Section 3.

2.3. Identification of Research Needs

The identification of research needs is naturally fed by advances in scientific knowledge but is also directly influenced by the evolution and requirements of policies. The needs for aligning research and policy agendas may depend upon the stage of development of the policy in a given thematic area. Different categories of needs are considered, depending on timing considerations [13]. When identifying research needs, one may ask the basic question: Is our scientific (multidisciplinary) knowledge sufficient to develop a more integrated policy able to efficiently tackle risks of climate/weather extreme events? The ongoing discussions and recent events show that the scientific base is likely still not sufficiently consolidated at this stage, in particular for what concerns governance aspects, but that a tight coordination mechanism and tailormade developments in the H2020 Programme (see Section 3) have enabled some progress to be made regarding the establishment of an operational science–policy interfacing mechanism.

2.4. Governance and Knowledge Transfer

The complexity of the policy framework (described in Section 1) and the wide variety of research, capacity-building, and training initiatives often lead to a lack of awareness about policies and/or project outputs among users, namely policy-makers, scientists, industry/SMEs (small and medium enterprises), and practitioners, e.g., civil protection units, medical emergency services, and police departments. Highly fragmented information often leads to poor awareness of policy requirements by research and industry communities and poor transfer of research results to policy and stakeholder communities. In this respect, several levels of governance need to be considered in areas related to disaster risk management (including climate extreme events): (1) A "horizontal" level in the framework on which interactions among research, industry, policy-makers, and practitioners are established in a coordinated way at different scales, i.e., EU, national, and regional; (2) A "vertical" level which establishes operational links among the EU, national, and regional levels through appropriate information relays, synergies, and demonstration activities.

2.4.1. Horizontally

- Science to science: Sharing information and developing interactions among research projects (and various disciplines) dealing with climate extreme events to develop a critical mass, reduce fragmentation, and bring developed tools/technologies to the market through links with industrial stakeholders. Projects should, in principle, respond to research needs in support of well-defined policies (in this case, mainly climate and related policies). It is hence expected that projects supporting common policy goals will establish synergies. This is, however, rarely the case without a push from research-funding agencies owing to various considerations (intellectual property rights in particular), while sharing information and developing interactions on a regular basis should become a common practice.
- Policy to policy: Policy interactions in the light of implementation needs and establishing links with implementing agencies/ministries. While international and national policies are developed in close consultation among different sectors, in practice, few interactions take place at the implementation level among sectors (e.g., climatologists

working with hydrologists for policy implementation-related actions). This is partly due to insufficient sharing of information and joint actions.
- Science to policy: Formatting/translation of research information in a way that is tailor-made to policy-makers, and ultimately users', needs, responding to well-specified technical challenges. This is obviously directly linked to the above, with the requirement for the scientific community to format/translate research information into a policy-understandable format, basically responding to well-specified technical challenges.
- Policy to science: Identification of research needs from policy-makers, stakeholders, and practitioners in the short to long term, and communication of these needs to be taken into account in research programming, development, and implementation. An essential component of the policy to science interaction is the capacity for policy-makers to identify research needs in the short to long term and communicate these needs in anticipation to the research community so that programming, research development, and implementation can match the policy timeline (e.g., access to the scientific state-of-the-art, short-term research/capacity building, longer term research goals, pre- and co-normative research).

2.4.2. Vertically

- International to National: In the research sector, interactions take place among different project consortia, with increasing efforts to cluster projects. In the policy sector, interactions may occur through policy committees representing national agencies/ministries and stakeholders (e.g., in the European Union), working out appropriate relays to national authorities and stakeholders based on well-formatted information. At international/EU level, policies are elaborated by relevant organizations (e.g., Sendai Framework for Action and European Commission for climate/environment-related EU policies). There is a need to ensure that policy committees are informed on similar grounds about science and policy developments.
- National to Regional/Local: Information relays are needed through interactions with regional research partners and regional authorities, as well as practitioners' networks and associations. Once representatives of national policy committees are duly informed, it is to be expected that appropriate relays with regional/local implementers will then take place under their responsibility. This also requires a level of coordination which depends upon the willingness and capacity of each country. In the European Union, this level of interaction is less well defined at national level because of different settings within the different Member States.
- Regional to National/International: Returns of experiences from either practitioners involved in research or capacity-building projects or practitioners informed via national channels are essential to both fine-tune research programs and provide support for policy implementation.

2.5. Interactions with the Scientific Community

At the start of research projects of potential relevance to (climate and other) policies, there is a need to clarify policy issues by describing the aims, milestones, and technical challenges to the research teams so that they understand the policy expectations over the duration of their project. These exchanges of information/knowledge rarely occurred in the past, but the practice is now progressively changing in the EU within the H2020 Framework Programme and the current Horizon Europe developments. Fields concerned with climate extreme events, including security, safety, and resilience for societies are themselves scattered into different disciplines and sectors. Five main categories of actors may be considered: (a) Policy-makers; (b) Scientists; (c) Industry (including SMEs); (d) Training and Operational units; and (e) NGOs and the citizen dimension. While some of the actors in categories *a*, *b*, and *c* regularly participate in international meetings, this is less frequent for SMEs (in category *c*) and even less for actors in categories *d* and *e*. New ways must hence be found to ensure that information may freely circulate "horizontally" as well as "vertically" in order to fertilize all project deliverables while, at the same time, maturing them to the final operational phase (also called "usefulness and use") by end-users, and integrating them into appropriate policy implementation and development [14].

2.5.1. Networking Needs

Risk management of climate extreme events involves various communities covering research, policy, and operational actors (including industry/SMEs, first responders, civil protection units, decision-makers, etc.), all of which have specificities but also present common features regarding the overall risk management cycle (preparedness/prevention, detection/surveillance, response/recovery). Networking efforts are needed to ensure a proper transfer (and implementation) of research outputs to "users". In this respect, the dissemination and communication of project results should be tailormade to different sectors, while bearing in mind that the common goal is to ensure that "solutions" resulting from research will reach users (often regional implementers, first responders, civil protection units, SMEs, individuals, etc.) in a timely and relevant fashion and be translated into "useful and used operational tools". The high number of research projects and the lack of "interfacing" mechanism make it difficult to efficiently reach this goal without proper networking.

2.5.2. Synthesis Needs

At the end of research projects, the most critical issue is the way the scientific information is "translated" in a language that may be easily caught up by policy end-users and practitioners, and possibly used by them for policy developments and operations. This translation part is certainly the weakest link of the science-policy-practitioner chain. Indeed, only a small percentage of research projects are made known by policy implementers and practitioners, which illustrates the need to improve awareness about research outputs but also to encourage actors to reflect on research needs linked to their portfolios in the short to long term [14]. The communication may be facilitated by synthesis documents in the form of "policy and science briefs", addressing policy and scientific communities as well as practitioners in a tailormade fashion.

2.5.3. Toward a "Science–Policy Interface"

At the present stage, despite clear improvements in the last decade, efforts are still lacking for presenting results of research and demonstration of projects in a form that policy-makers may easily use, i.e., synthetic "science-digested" policy briefs. On the reverse side, the consideration of research results by the policy-making community is not straightforward, mainly for political reasons and difficulties to integrate the latest research developments in legislation. The difficulty is enhanced by the fact that the policy-making community is probably not defining its role as "client" sufficiently well. In other words, the dialogue and communication are far from being what one would hope to ensure an efficient flow of information [15]. In this respect, the different communities have made improvements within the H2020 Framework work with enhanced science–policy interfacing efforts and production of briefing materials taking into consideration views. This interface is facilitated by various components, such as the following:

- Screening with policy-makers to evaluate which type of research is needed (background information or tailormade research and demonstration) in accordance with the policy step of concern (e.g., implementation issues, reviewing).
- Validation of the most promising research projects in support of the policies through demonstration activities, and dissemination at the appropriate level (regional, national, or EU).
- Exchanges among scientists and policy-makers from the very beginning of research projects (in the light of policy agendas) in order to ensure a more structured communication at all appropriate levels of policy formulation, development, implementation, and review.

Science–policy interfacing is further discussed in Section 4 of this paper.

3. Legacy and Research Trends

3.1. Introduction

As mentioned above, a range of EU-funded and national research projects are directly or indirectly supporting climate (and related) policies. Some of these are used as examples in this paper to illustrate various research streams developed in the last ten years. For a more exhaustive list of projects, the reader is invited to consult available project mapping documents produced by the European Commission [16–18]. Projects presented in this paper reflect the legacy of past research in the area of climate extreme events and provide some insight into recent projects.

3.2. EU-Funded Instruments

The European Union is funding research through its Framework Programme for Research and Technological Development. In this context, research initiatives related to climate and weather impacts on extreme events readily started in the 6th Framework Programme (2002–2006) or FP6, in particular, projects funded under the "Global Change and Ecosystems" sub-priority. Research programming in this area was pursued under the 7th Framework Programme (2007–2013) or FP7, in particular, projects funded under the "Environment (including climate change)" theme largely contributed to gathering knowledge relevant to the natural hazards knowledge base, while the "Secure Societies" theme focused on civil protection aspects (also looking at impacts of climate extreme events).

Horizon 2020 (or H2020) has taken over the years 2014 to 2020 with an even stronger emphasis on climate change adaptation and studies of climate-related impacts, including extreme events. The EU research landscape is now ruled by the Horizon Europe Framework Programme (2021–2027), which is pursuing its mission of supporting many research challenges, including climate-related policies, e.g., the EU Strategy on Climate Change Adaptation [5], the Union Civil Protection Mechanism [3], and a range of related environmental policies (see Section 1). In the security area, the primary aim is to enhance the awareness, preparedness, and resilience of our society against natural (including climate) and manmade disasters.

3.3. Climate Change Impacts on the Water Cycle and Ecosystems

3.3.1. Investigating Climate Change Impacts on the Global Water Cycle

Specific research on climate change impacts on the global water cycle has been carried out under the EU F6 funded project, *Water and Climate Change* (WATCH), which produced consistent analyses of components of the terrestrial water cycle (runoff, soil moisture, etc.) for the past and the future (using Global Climate Models outputs) [19]. The WATCH experience has shown that by uniting hydrologists and climate scientists, it is possible to produce robust and consistent estimates of components of the hydrological cycle (river flow, soil moisture, evaporation, etc.). The project identified many research challenges, in particular the need to improve the representations of a range of processes in large-scale hydrological models (to include, for example, groundwater, water extractions, and dams) and to better coordinate the collection of, and access to, hydrological data across Europe (and worldwide) to support water vulnerability assessments [20]. The climate and hydrological modeling was led by a combination of well-established world leading laboratories in the UK, Germany, and France (e.g., Cemagref, Laboratoire de Météorologie Dynamique).

3.3.2. Regional Assessment of Climate Change Impacts in the Mediterranean

The FP6 CIRCE project developed, for the first time, an assessment of climate change impacts in the Mediterranean and their consequences to society and the economy [21]. It involved partners from Europe, the Middle East, and North Africa working together to evaluate strategies of adaptation to the climate change in the Mediterranean region. Beyond research, the role of public engagement in the project was fundamental, especially at local level. To identify the best policies to help Mediterranean communities adapt to the effects of climate change on water supply, a team of CIRCE scientists [22] created a methodology linking science outputs to water management policy options, e.g., social and political changes to ensure water supply and demand to meet the needs of agricultural and urban users as well as ecosystems (see more details in [23]). Several French organizations participated in this large research project, e.g., CIRAD (Centre de Coopération International de Recherche Agronomique pour le Développement) and CNRS (Centre National de la Recherche Scientifique), as well as Météo-France, and case studies were selected in Corsica and in the Var region.

3.3.3. Assessing Climate Impacts on the Quantity and Quality of Water in Vulnerable Mountain Environments

The FP7 ACQWA project investigated the vulnerability of water resources in mountain regions, such as the European Alps, the Central Andes, or the Tien Shan range of Central Asia, where declining snow and ice are likely to strongly affect hydrological regimes in a warmer climate. State-of-the-art models were applied to various interacting elements of the climate system, namely, regional atmospheric processes in complex terrain, snow, and ice, vegetation, and hydrology in order to project shifts in water regimes in a warmer climate in these mountains (e.g., [24]). Observations, targeted models, and methodologies from the social sciences were then used to analyze the impacts of changing water availability and seasonality on economic activities, in particular tourism, agriculture, hydropower, or the mining sector (see more details in [23]). Several French organizations participated in this research project, e.g., CNRS (Centre National de la Recherche Scientifique), CEN (Centre d'Étude de la Neige) of Météo-France, LSCE (Laboratoire des Sciences du Climat et de l'Environnement), and case studies were selected in the French Alps with a comparison of situations in the Andes Mountains in Chile.

3.4. Climate Change Impacts on Water and Security

As a preamble, let us note that the word "security" in this context refers to availability of resources and not to (criminal or terrorist) intentional threats.

The FP7 WASSERMed project (*Water Availability and Security in Southern Europe and the Mediterranean*) was built on existing climate projections in order to address uncertainties in hydrological budgets in the Mediterranean area. It entailed high-level interdisciplinary research, combining climatic/hydrologic scenario building, water system modeling, and macroeconomic analysis. Emphasis was placed on the most significant and at-risk sectors, namely, agriculture and tourism, in order to assess impacts and propose technological solutions and management practices towards their mitigation. The project explored potential security threats, infrastructure requirements, and integrated adaptation strategies in five areas in the Mediterranean, taking into account diverse drivers of change and anticipated environmental and socioeconomic implications. The IRD (Institut de Recherche pour le Dévelopment) participated in this project but there were no French case studies considered.

Complementing this project, the FP7 CLIMB project (*Reducing Uncertainty and Quantifying Risk through an Integrated Monitoring and Modeling System*) improved modeling capabilities and developed appropriate tools to advance the capacity to assess climate effects on water resources and uses [25]. The research was based on a combination of novel field monitoring concepts, remote sensing techniques, integrated hydrological modeling, and socioeconomic factor analyses to reduce existing uncertainties in climate change impact analysis and to create an integrated quantitative risk and vulnerability assessment tool. Together, these provided the necessary information to design appropriate adaptive water resources management instruments and select suitable agricultural practices under climate change conditions. An important output of the research in the individual study sites was to develop a set of recommendations for an improved monitoring and modeling strategy for climate change impact assessment, including projections on future hydrological budgets and extremes (see more details on both projects in [23]). The Cemagref and the University of Angers (France) participated in this project with a focus on the Mediterranean region.

3.5. Climate Change Impacts on Droughts

The FP7 Support Action XEROCHORE (*An Exercise to Assess Research Needs and Policy Choices in Areas of Drought*) synthesized the knowledge base on past, current, and future drought, including hydroclimatic drivers of the natural hazard, environmental and socioeconomic impacts, management, and policy responses [26]. Besides the overall vulnerability of global water resources to climate change, the abovementioned WATCH project also investigated spatiotemporal characteristics of past and future drought. An important outcome was the Drought Catalogue [27,28] that proved to be a good basis for (i) the spatiotemporal analysis of observed hydrological drought, (ii) comparison with large-scale climate drivers, to examine the causes behind major European events, and (iii) a benchmark against which historic drought of global hydrological models could be tested. These research trends were pursued by the FP7 project DROUGHT-R&SPI (*Fostering European Drought Research and Science-Policy Interfacing*), which investigated drought occurrences and impacts in six case study areas in water-stressed regions (e.g., Mediterranean, the Netherlands) [29,30]. The collated state-of-the-art drought information was used as a basis for an intercalibration experiment with national, EU, and other international projects (see more details in [23]). The study created a better understanding of past droughts (e.g., underlying processes, occurrences, environmental and socioeconomic impacts, past responses), which then contributed to the exploration of assessment of drought hazards, impacts, potential vulnerabilities, and promising management and policy option in the light of EU policy developments [31]. In particular, this supported the development or further improvement of drought management planning in the framework of the second cycle of WFD River Basin Management Plans (2015). There were no specific case studies carried out in France in this project, but data and background knowledge were provided by representatives of the French Water Basin Agencies.

3.6. Research on Floods

The project most relevant to flood research carried out within the years 2004–2009 at EU level in support of the Flood Directive is certainly the FP6 FLOODsite project (*Integrated flood risk analysis and management methodologies*), which gathered interdisciplinary knowledge, integrating expertise from across the environmental and social sciences, as well as technology, spatial planning, and management to develop robust methods of flood risk assessment and management and decision support systems, which were largely tested in pilot sites

Complementing this large project, the FP7 IMPRINTS project developed methods and tools to be used by emergency agencies for improving the preparedness and the operational risk management for flash floods and debris flow-generating events, as well as contributing to sustainable development through reducing damages to the environment. Impacts of future changes, including climatic, land use, and socioeconomic, were analyzed in order to provide guidelines for mitigation and adaptation measures. Systems were tested on five selected flash flood-prone areas supervised by risk management authorities and utility company managers in duty of emergency management (see more details on both projects in [14]). The French Ministry of Ecology participated in the studies through the SCHAPI (Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations). Among other European cases, one of the key case studies considered in the project was the Gardon d'Anduze (France).

With a focus on urban environments and through a series of case studies in Europe and Asia, the CORFU project (*Flood resilience in urban areas*) looked at drivers impacting urban flooding with the objective to develop a consistent framework for analysis of sustainable long-term urban flood management and the development of flood-resilient cities [32]. In conjunction with climate change projections, these drivers fed into development scenarios that were used for prediction of flood impacts (see more details in [23]). The University of Nice Sophia Antipolis has been active in this project, in particular providing expertise from the Var Region (France).

3.7. Research on Coastal Risks Induced by Storm or Flooding

Coastal risks have been prone to research projects funded by several projects. The FP7 MICORE project (*Morphological Impacts and COastal Risks induced by Extreme Storm events*) developed probabilistic mapping of the morphological impact of marine storms and produced early warning and information systems to support long-term disaster reduction. A review was carried out of historical storms that had a significant impact on nine representative sensitive European sites according to wave exposure, tidal regime, and socioeconomical pressures. One-year monitoring to collect new datasets enabled the researchers to develop and test numerical models of storm-induced morphological changes, linking wave and surge forecasting models to set up a real-time warning system and to implement its usage within Civil Protection agencies. Among nine selected case studies, the project considered the Lido beach in Sète (France).

Catastrophic events, such as the Xynthia event in France (February 2010), led to identifying research needs in the prevention/preparedness of such extreme events. These were prone to EU calls for proposals in the FP7 Programme, which resulted in two major projects (quoted in [14]), namely, the FP7 PEARL project (*Preparing for Extreme And Rare events in coastal regions*) which developed sustainable risk management solutions for coastal communities, focusing on present and projected extreme hydrometeorological events. Seven case studies from across the EU were designed, one of which was located in France (Les Boucholeurs), to develop a holistic risk-reduction framework to identify multistressor risk assessment, risk-cascading processes, and strengthen risk governance by enabling an active role for key actors based on the real case studies and demonstrations of best practice across the EU. In addition, the FP7 RISC-KIT (*Resilience-Increasing Strategies for Coasts*) developed ready-to-use methods, tools, and management approaches to reduce risk and increase resilience to low-frequency, high-impact hydrometeorological events. Open-source ware and freeware were developed to assess present and future hot-spot areas of coastal risk due to multihazards, as well as high-resolution early warning and decision support systems (EWS/DSS). With the participation of the University of Caen (France), one of the ten case studies focused on historical records of coastal storms in the area hit by the Xynthia event.

3.8. Examples of Research Trends

The H2020 ANYWHERE project (*EnhANcing emergencY management and response to extreme WeatHER and climate Events*) aimed to empower exposed responder institutions and citizens to enhance their anticipation and proactive capacity of response to face extreme and high-impact weather and climate events. This was achieved through the operational implementation of cutting-edge innovative technology as the best way to enhance citizen protection and save lives. The project developed and implemented a pan-European multi-hazard platform, which provides a better identification of the expected weather-induced impacts and their location in time and space before they occur. This platform will support a faster analysis and anticipation of risks prior to the event occurrence, an improved coordination of emergency reactions in the field, and help to raise the self-preparedness of the population at risk. This platform is adapted to provide early warning products and locally customizable decision support services proactively targeted to the needs and requirements of the regional and local authorities, as well as public and private operators of critical infrastructures and networks. The platform prototype has been demonstrated in pilot case studies. Its market uptake will be ensured by the cooperation of an SME and Industry Collaborative Network, covering a wide range of sectors and stakeholders in Europe, and ultimately worldwide.

The H2020 I-REACT project (*Improving Resilience to Emergencies through Advanced Cyber Technologies*) developed a big data platform for natural hazard resilience. Climate change is estimated to increase the likelihood of events such as floods, due to extreme rainfall and rapid snow melting, and also wildfires because of longer dry and hot seasons. To better adapt to such adverse climate change effects and meet sustainable development goals, the I-REACT project developed a big data system to improve the resilience to natural hazards at the prevention, preparedness, and response phases. I-REACT grouped together several information sources, including Copernicus-EMS maps, early warnings from EFAS and EFFIS, satellite data (Sentinel), open data, UAV images and videos, social media and crowdsourced information (i.e., real-time reports from the ground coming from emergency responders and citizens). All this information was merged and processed to provide added-value services and products, such as a decision support system for authorities and a mobile application for citizens. Wearable devices and smart glasses can be provided to first responders, who benefit from high-precision Galileo positioning and augmented reality to make hands-free reports.

Another key H2020 project was the beAWARE project (*Enhancing decision support and management services in extreme weather climate events*), which studied how to enhance support in all the phases of an emergency incident. More specifically, beAWARE introduced a novel framework for every aspect of crisis management that integrates weather forecasting, early warnings, transmission of the emergency data, and aggregated analysis of multimodal data, and manages the coordination between the first responders and the authorities. The overall context for the project lay in the domain of situational awareness and command and control. The first phase concerned the forecast of the extreme condition and the relevant preparations. Situational awareness means being able to accurately determine what has happened, what is happening now, and what will come next, all in order to plan and coordinate the most effective response possible with the resources available. The observation phase led to an orientation phase, suggesting both an individual as well as a collective "cognition" orientation to data that is sensed and communicated. Once orientation to the data is in place, then a decision is made, ultimately resulting in the final step, which is "act".

4. Interfacing Multi-Actors and Disciplines

The large span of (research and capacity-building) projects leads to a huge dispersion of resources, as no mechanism is presently in place to establish a common platform to exchange information of public characters, boost awareness, transfer relevant research projects to relevant users (and to industrial/SMEs share- and stake-holders), and make them "useful and used". In addition, efforts have to be made to better address users' needs, which will be reflected into possible inputs to (EU and national) research programming [14]. In this respect, an initiative has been launched by the European Commission DG HOME (DG Migration and Home Affairs) since 2013 to boost transfer of research outputs to relevant users and facilitate sharing of information among different actors [16]. Originally, this dialogue setting among policy-makers, scientists, practitioners, and SME/industry was focused on disaster risk management, including discussions on climate extreme events. It was later enlarged to a wider security-related scope, embedding sectors related to fighting crime and terrorism, protection of critical infrastructures, and border security.

Something at stake with such community-building is the creation of a mechanism involving different levels (EU, national, and regional) by which the different actors, and primarily the "users", will be able to rapidly trace back information and experiences issued from research, capacity-building, and training projects, giving them the possibility to identify and contact the right persons at the right time to obtain the feedback that they are looking for via a dedicated website. Regular information exchanges and debates orchestrated by the Community of Users enables better channeling of the information to the "users", which has a direct effect on research programming, policy implementation, and update. It also has an effect on the involvement of end-users at various levels, and caters links between research projects and capacity-building/training initiatives, e.g., making links with training programs and centers, modules exercises, etc.

Since 2014, the Community of Users (CoU), along with a related initiative, namely, the Disaster Risk Management Knowledge Centre (DRMKC) coordinated by the EC Joint Research Centre, enabled to better visualize/identify research (and in the long-term capacity-building and education) projects related to different themes relevant to safety, security, and resilience.

The CoU informal platform enabled to gather policy-makers, scientists, practitioners, industry/SMEs, and civil society organizations at international and regional level, creating dialogues around research in various thematic areas and building "bridges" among different sectors (areas, disciplines, and actors), which was an essential step forward. Dialogues and events had a clear effect on enhancing the participation of practitioners in research projects, in particular by promoting research results that are relevant to them, including the most promising tools that might have the potential to be taken up by them, and ensuring that their expertise is made available to policy-makers. Synergies were also stimulated between research and capacity-building projects. In the light of the positive impacts of this community-building, the initiative has grown up into a more ambitious network in support of the Horizon Europe Framework Programme: the so-called Community for European Research and Innovation for Security (CERIS). This forum has a large scope with various thematic areas, with the following objectives:

- Raising awareness on major updates in relevant policy sectors and on results achieved by related research and nonresearch initiatives, analyze impacts, and provide policy recommendations.
- Analyzing identified capability needs and gaps in the corresponding thematic areas (within thematic working groups and other networks) and prioritization of related research orientations based, at least, on criticality and urgency, in order to produce recommendations for a civil security research agenda.
- Identifying solutions available to address the gaps, differentiating state-of-the-art technologies (off-the-shelf and development and integration products) and security research trends. It will also take into account other considerations, such as technological maturity, operational relevance, societal acceptance, cost-effectiveness, etc.
- Translating capability gaps and potential solutions into research needs (including scenarios linking research needs to capabilities and societal appropriation, technology readiness levels, development roadmaps, research action types, perspectives of research uptake, etc.) and obtain feedback from practitioners about prioritization of the needs, inputs to research programming, and involvement in research activities.
- Identifying funding opportunities and synergies between different funding instruments and propose measures to facilitate them.
- Identifying standardization needs through existing networks/platforms and prioritize them in close consultations with policy-makers and practitioners.
- Integrating the views of citizens so as to promote responsible research and innovation which respects ethical considerations and civil liberties.

The need for "vertical" transfer of information from the EU to the national and the regional levels could be fulfilled by connecting CERIS thematic discussions (including in the area of climate extreme events) to appropriate expert networks or communities, either existing or to be developed. This would play the role of knowledge integrating and "translating" bodies at European levels, with the mission—in support and in connection with national authorities—to effectively relay research outputs (e.g., new tools or technologies, methods, etc.) to appropriate users at national, regional, and even local levels. This process of pulling EU research outputs to users, i.e., transforming these outputs into outcome, can only be made possible through an effective partnership with users. In other words, if CERIS provides, on a regular basis, information on new tools/technologies or other research information, different thematic groups might format this information to address different categories of users (policy-makers, scientists, industry/SMEs, practitioners, civil society) and undertake ad hoc actions to ensure that potentials of EU research developments are known and possibly implemented by them. This flow of information would enable that we do not miss opportunities (or duplicate work) and would also create effective bridges among the EU down to the citizen's level with possible feedback received and contributing to further research programming.

In the climate extreme events area, CERIS will continue its efforts in identifying relevant projects funded by different (research, capacity-building) programs with the aims to propose clustering initiatives through platforms of information exchanges. Stakeholders will continue to interact with these programs to help interfacing with relevant policies. CERIS is naturally not interfering with policy development and implementation, but contacts are readily established with different policy bodies, enabling to inform users about possible updates and helping research information to be efficiently disseminated to policy actors.

In conclusion, the CERIS platform and its different thematic areas has the vocation to act as a facilitating environment, creating links and dialogues among different actors/disciplines (the "horizontal level") and among different levels (from EU to local). Based on regular mapping of EU-funded projects, a similar architecture has been used to develop a website which facilitates information searches (not repeating what is readily in place but rather providing paths helping users to more easily find information per themes/areas). Such a mapping was initiated in 2014 and is now complemented on an annual basis since 2019 [16–18]. It contributes and complements the work of the Commission's Disaster Risk Management Knowledge Centre (DRMKC), which intends to improve science-based services and analysis, the use and uptake of research and operational knowledge, as well as to advance science and technology in DRM.

5. Conclusions and Perspectives

Issues related to climate extreme events are tackled by a high number of international organizations, national, international, regional, and, sometimes, global research programs, regulations, and conventions, some of which have been running for many years or even decades. Whereas policy tends to focus the short-term perspective, science envisages a long-term perspective. Moreover, while policy tries to involve the development of acceptable compromises, the scientific community aims to work towards the gathering of objective scientific facts. Our conception and perception of risks continue to evolve, notably under the particular pressure of multiple and multidimensional risks generated by climate change [33]. Nevertheless, there is so far no structured and concerted reflection at a global level about the process of building up and transmission of a "culture of risk" which would permit to prepare our societies to sometimes-imminent threats and to their social, economic, environmental, and political consequences.

Most policies dealing with disaster risk and crisis management, including those dealing specifically with climate extreme events, have established operational links with research. While interactions among research and policies are high on the policy agenda, much remains to be actioned to improve the way information flows from the different communities involved in implementation of both research outputs and policies. This includes capitalizing on past research and enhancing cooperation among EU Member States organizations. The complexity of achieving this stems from the wide variety of actors involved and the lack of coordination mechanism at EU and national level regarding the transfer of information and their actual use by implementers and decision-makers. The need for enhanced coordination and information sharing form the basis of CERIS described above.

What is the way ahead? Several objectives will be pursued, for the short to the long term, in both research programming and community building. The CERIS forum has, in the long term, the capacity to gather experiences among different actors involved in disaster risk and crisis management (including climate extreme events-related risks), with possible initiatives leading to synergies in the EU and beyond. In the research-related area, transdisciplinary and participatory (citizens, authorities, practitioners, and various stakeholders) research is required to develop solutions and investigate pathways to implementation. Complementing solution-oriented research developments described in this paper, ongoing trends within Horizon Europe [34] are developed within the Civil Security for Society's Disaster-Resilient Societies area (DRS): They focus on designing preparedness actions that would enable an empowerment of citizens (including particularly vulnerable groups), their communities, and NGOs through bottom-up participatory and learning processes. Improved disaster risk management and governance is another important feature requiring research support. In this area, a focus is made on integrated disaster risk reduction for extreme climate events, which includes some relevant components for climate extreme events, in particular in addressing the capacity of communities and governments to manage expected and/or unexpected events. In the societal resilience domain, efforts are made to better understand citizens' behavioral and psychological reactions in the event of a disaster or crisis situation [34]. Enhanced risks related to hydrometeorological extreme events also call for enhanced operational capacities, including instruments for better prevention and preparedness, technologies for practitioners, and, where relevant, for citizens.

As a concluding remark, let us underline once more that policy orientations rely on scientific evidence. In this respect, the efficient research programming and implementation of science outputs represent an increasing challenge for the scientific and policy-making community, the private sector, NGOs, citizens' associations, and professional organizations. The need to improve the role that science plays in environmental and climate policy-making and overall (climate) disaster risk management has been highlighted by recent events (e.g., in Belgium and Germany during the July 2021 flash flood event). The need to better link policy needs and research programs and to operate mechanisms for knowledge transfer is an essential feature of disaster risk management. This has been discussed in depth in the water sector at the European Union level for more than fifteen years, underlining the need to develop a conceptual framework for a science–policy interface related to water which would gather together various initiatives and knowledge [11,35,36].

For further reading, the reader is invited to consult volumes of Wiley Blackwell's Hydrometeorological Extreme Events Series [33,37–40].

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