# Storylines development and description for the financial sector

Deliverable D4.1



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| Lead beneficiary | University of Bern |
| Authors | Alessio Ciullo, Olivia Martius |
| Contributors | David N. Bresch, Eric Strobl, Stefan Hochrainer-Stigler, Jonas Peisker, Reinhard Mechler, Max Tesselaar, Fujin Zhou, Onno Kuik |
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# 1. Introduction

This report summarizes the progresses in developing climate storylines of Work Package 4 (WP4) of the *REmote Climate Effects and their Impact on European sustainability, Policy and Trade (RECEIPT)* project. The main goal of RECEIPT is to develop plausible *storylines* of Europe's vulnerability to remote climate risks by connecting climate risks outside Europe with potential consequences for key European socio-economic sectors. The goal of WP4 is to focus on the financial sector, both public and private.

In the context of WP4, *storylines* are defined after Shepherd et al. (2018) as *a physically self-consistent unfolding of past events, or of plausible future events or pathways* and, specifically, they are developed through a *downward counterfactual* approach, which aims at finding *alternative past events where the outcome could have been worse than what actually happened* (Woo, 2019, Woo et al. (2017)). In other words, the attempt of a storyline approach using downward counterfactuals is to generate alternative plausible realizations of historic events and to explore and assess critical impacts to the European private and public finance had things turned to the worse. Identifying these critical impacts allows to untangle the underlying causal relationships and, once these are identified, to develop a storyline of a causal chain of events under future climatic and socio-economic changes.

The aim of this report is threefold. First, to introduce the four research problems related to private and public European finance which are deemed most relevant by WP4 members and involved stakeholders. This entails a detailed description of the climatic events of interest, the affected remote areas, and the reason why these are deemed relevant for Europe. Second, to introduce - in general terms - the storyline development framework that will be applied to address the four identified research problems. Third, to provide an application of the framework to one of the identified problems, based on preliminary results.

The report is structured as follows. Section 2 introduces the four identified research problems and the process which led to their identification throughout the first year of work; Section 3 describes the proposed framework for developing storylines; Section 4 applies the framework to the problem of assessing the effect of remote climate events to the capital availability of the European Union Solidarity Fund, i.e. a fund which provides financial aid to EU countries affected by natural disasters; finally, Section 5 provides conclusions and planning of future work.


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# 2. The identified climatic events, hotspot areas and remote causal links

The first steps toward building climate storylines involve the identification of (1) relevant climate events, (2) the remote areas affected by such climate events and (3) the causal links between remote impacts and the European economy. In order to identify these three key elements, WP4 members engaged in a series of internal and stakeholder discussions throughout the first year of the project. The goal of the discussions was to select climate events and remote areas of interest, investigate the causal links with the European public and private financial sectors and, finally, test and refine the appropriateness of the choices made. A summary of this process is provided in Table 1.

The first months (M1 – M4) were dedicated to a first tentative selection of what climatic events, remote areas, and causal links to consider as well as on reaching a common understanding on how to interpret and operationalize the concept of *climate risk storylines*. More details on the latter are provided in Section 3. Since the beginning, a clear distinction was made between public and private finance. This distinction mostly pertains to the causal links and spill-over mechanisms of remote impacts to the EU financial sector and plays a role in the identification of relevant stakeholders. In terms of climatic events and remote areas, however, ideally the effects on both public and private finance are explored given the *same* climatic events and remote areas. This would enhance and enrich the overall relevance of the identified causal chain of events and guarantee comparability both across work-packages as well in a wider context. Thus, an effort was made to maintain consistency between the two sectors as much as possible. With this in mind, a choice was made to investigate the effects of the same type of climatic events, i.e. tropical cyclones, affecting remote areas such as the East Coast of the United States as well as small islands in the Caribbean, the North Atlantic and the Pacific. The choice of tropical cyclones is due to two main reasons.

First, Mahalingam et al. (2018) show that natural hazards causing losses for 1 trillion dollars or more can have an impact on the global financial market. Although such an event never occurred in the past, the authors identified six plausible scenarios that may lead to such a degree of damage and have relevant impacts on the market including the devaluation of investment assets, changes in interest rates, changes in currency exchange rates and sovereign credit ratings. Two of the analysed scenarios are climate driven and pertain to tropical cyclones





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affecting the USA. One scenario regards a superstorm affecting New Jersey Coast including the New York Metropolitan area reaching peaks of 146 mph winds, with total losses of 1.15 trillion dollars. Another scenario involves a hurricane making a first landfall in Florida with winds over 147 mph into Florida Bay and then a second landfall near Pensacola at sustained winds of 127 mph, with total losses of 1.35 trillion. A choice was therefore made to focus on tropical cyclones hitting the East Coast of the USA.

***Table 1*** *Overview of the process undertaken in WP4 for the selection of climate events, remote areas and causal links.*

| Months | Main Activity | Status |
|---|---|---|
| M1 – M4<br>(September – December) | Kick-off meeting | • Initial proposal of climatic events and affected remote areas. A choice is made for tropical cyclones affecting small islands (in the Caribbean, North Atlantic and Pacific) and the East Coast of the United States.<br>• Investigation of causal links. These pertain (1) the possibility of inducing a "hard market" in Europe due to catastrophic events affecting highly exposed areas like Florida or New York, (2) the EU remote exposure via the European Solidarity Fund through the EU outermost regions and (3) the EU monetary contribution in establishing the Caribbean Catastrophe Risk Insurance Facility. |
| M5 – M7<br>(January – March) | Workshop with stakeholders | After a fruitful interaction with the stakeholders, the identified climatic events, remote areas and causal links did not change substantially. Interest was shown regarding the innovative approach followed in the project. |
| M8 – M11<br>(April – June) | First General Assembly | One causal link previously considered is better characterized, i.e. the risks on foreign direct investments (FDI) of private EU investors due to tropical cyclones in the USA. |





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Second, two significant links of the EU public finance to remote areas are identified. One link is the European Union Solidarity Fund (EUSF), which the EU outermost regions (i.e. territories of some EU member states located outside Europe) are eligible to. The other link stems from the fact that the European Union and some member states provided financial support to the Caribbean Catastrophe Risk Insurance Facility (CCRIF) which, should it go bust because of large pay-outs, would need to be recapitalized. The EU outermost regions are islands in the Pacific, Caribbean and North Atlantic. Countries in the CCRIF are, obviously, Caribbean countries, and, more recently, some central American countries. For all these territories, tropical cyclones are the most impactful and frequent natural hazards, and, thus, the choice to focus on this peril.

After a first selection of climate events, remote areas and causal links, months M5-M7 were dedicated to the evaluation of the quality of these choices and, most importantly, to start selecting and initiating a discussion with relevant stakeholders. Engaging with stakeholders with the aim of co-selecting what factors are more relevant and interesting for research and practice is a core aspect of the project. A broad range of stakeholders was selected, belonging to both the public and private financial sectors. The discussion was fruitful and led to several considerations. First and foremost, interest was shown in the approach of building *climate risk storylines*. Second, the initial decision of focusing on tropical cyclones affecting the US East Coast and several small islands was deemed of interest and appropriate. Third, various relevant aspects emerged related to possible remote impacts to the European economy and society, spanning from humanitarian aid to food security to impacts through the supply chain. Although these are all relevant aspects, they are related but not central to the WP activities and, more importantly, they are dealt with in more details by other WPs within RECEIPT. Thus, a choice was made to maintain the initial selection at this stage of the project. The discussion with both stakeholders and other WP members is open and will go on with the aim of selecting new remote connections for future climate risk storylines to be explored.

The last months, M8-M11, were dedicated to developing preliminary numerical analyses, particularly regarding the impact on public finance relative to the EUSF and CCRIF. Furthermore, another remote impact pertaining private finance was proposed, i.e. the risks on foreign direct investments (FDI) of private EU investors due to tropical cyclones in the USA.


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Table 2 provides an overview of the four causal chains currently under consideration. Each of them is also discussed in the section sub-sections in further detail.

***Table 2*** *Overview of the selected research problems, in terms of climatic events, remote area of interest, its relevance and the adopted method of investigation.*

| Climate Event | Remote Area | Problem | Relevance | Methods and Models |
|---|---|---|---|---|
| Tropical cyclone | Outermost regions of the European Union | Can pay-outs to the outermost regions compromise the stability of the fund? | There might be the need to recapitalize or even redesign the fund | CLIMADA model<br>+<br>exploratory data analysis |
| Tropical cyclone | Caribbean countries within the Caribbean Catastrophe Risk Insurance Facility | Is CCRIF effective? And what is its relationship with required foreign aid? | There are moral obligations for both recapitalizing CCRIF and providing financial aid for recovery | CLIMADA model<br>+<br>econometric analysis |
| Tropical cyclone | East Coast of the United States | What remote climate events will cause a “hard” insurance market in Europe? | A “hard” insurance market affects premiums levels, affordability and thus penetration rates. In addition, low penetration rates will demand the EU and member states to act as insurer of last resort. | CLIMADA model<br>+<br>data analysis/ stakeholder consultation<br>+<br>DIFI model |
| Tropical cyclone | East Coast of the United States | What is the impact of remote climatic events on foreign portfolio investments and on foreign direct investments of European private investors? | Impact on risk and returns of European private investors | CLIMADA model<br>+<br>Gdyn and FTAP models |





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## 2.1 The European Union Solidarity Fund under stress after pay-outs to the outermost regions

The European Union Solidarity Fund (EUSF) was established in 2002 and provides financial assistance to EU member states to cope with the economic losses caused by natural disasters. The amount of financial aid provided is based on the amount of direct economic losses and the country's or region's GDP.

As some EU member states have territories outside Europe, financial aid from the EUSF may be needed in response to remote climatic events. These territories form the so-called EU outermost regions and include French (Réunion, Mayotte, French Guiana, Saint Martin, Guadalupe, Martinique), Portuguese (Madeira, Azores) and Spanish (Canary Islands) islands. A thorough analysis of the impact on the EUSF capital availability due to pay-outs to the EU outermost regions is provided in Section 4 as an application of the method proposed in Section 3. Here, only the main objectives and findings are provided in this section.

The main objective is to assess whether, and to what extent, pay-outs to the outermost regions may plausibly compromise the stability of the EUSF, as historically these regions only had a marginal effect (see Fig. 2). Should this be the case, implications to EU public finance would be obvious as the fund would need to be recapitalized or even redesigned. To do so, we assume historic pay-outs for natural hazards in mainland Europe as fixed, and simulate what would have happened to the EUSF capital availability under counterfactual scenarios of the historic pay-outs to the outermost regions. Direct economic damages are estimated using the open-source and -access CLIMADA impact model (Aznar-Siguan and Bresch, 2019), and pay-outs and capital availability are estimated following the official pay-outs and capitalization rules of the EUSF. Results show that the contribution of the outermost regions cannot alone compromise the availability of capital of the EUSF. However, storylines can be identified such that, should a major event occur in mainland Europe and pay-outs to the outermost regions be required in the same period, the EUSF current capitalization rule would not allow to restore full capital availability. Moreover, under some future climatic and economic conditions this issue will be further exacerbated.



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## 2.2 Obligations of European countries towards the Caribbean Catastrophe Risk Insurance Facility

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) is an innovative policy intervention that seeks to address the economic consequences of extreme climate events for its member states. Currently, 19 Caribbean countries and three Central American countries are member of the facility. The CCRIF provides insurance against several natural hazards under its tropical cyclone, earthquake, and excess rainfall policies. A substantial fraction of the risk is passed on to private reinsurance corporations. A key objective of the CCRIF is the provision of liquidity quickly after the occurrence of the events (CCRIF SPC, 2016).

CCRIF was funded by a two Multi-Donor Trust Funds (MDTF) in 2007 and 2012 under the supervision of the World Bank. Both EU member states and the European Commission have participated in the MDTFs. Furthermore, both EU member states and the European Commission have moral obligations to provide financial aid should foreign countries with limited financial resources suffer severe economic damages (Brixi & Mody, 2002). Therefore, from a European perspective, the interest is twofold. First, it is relevant to assess whether the quasi-fiscal transfers to establish the CCRIF have resulted in an institution that is effective in mitigating adverse fiscal outcomes to member countries, namely in the CARICOM (c.f. https://caricom.org). Second, and related to the former, there is the need to understand whether and to what extent the CCRIF resulted into reduced reliance to foreign aid.

Understanding these relationships is a key first step in order to develop *storylines*. To do so, an econometric approach is adopted and a number of data about fiscal outcomes, hurricane damages, and CCRIF pay-outs are collected for the period 1990-2018. Data relative to the budgets of CCRIF countries were collected from the statistical authorities of the respective countries. Damages from hurricanes are estimated using the impact model CLIMADA (Aznar-Siguan and Bresch, 2019). Pay-outs of the CCRIF to its member countries are sourced from the CCRIF website.

The econometric analysis shows that hurricanes increase grants revenue by third parties in the quarter of the impact. This is presumably due to additional inflow of foreign aid, suggesting that the latter is needed for recovering from natural disasters. CCRIF pay-outs, however, negatively affect both grants revenue for several quarters after the event and public external



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debt in the financial quarter of the event. These results suggest that CCRIF could reduce member countries' reliance on external credit immediately after the disaster shock.

After having established, based on historic data, the relationship between reliance on foreign aid and the CCRIF, *climate and socio-economic storylines* can be developed. In particular, using the counterfactual approach described in Section 3, one can assess the extent of required foreign aid under alternative realizations of past tropical cyclones and various designs of the CCRIF, using e.g. higher or lower coverages, deductibles and capital availability.

## 2.3 A hard insurance market in Europe due to remote natural catastrophes

Large natural catastrophes may have economic impacts on the financial market. For example, the demand for capital that is needed to rebuild assets after a natural catastrophe can cause the price of capital to rise, which can increase the cost of insurance as insurers are trying to recapitalize after large amounts of claims are paid. After large natural- or man-made catastrophes, the high demand for capital can cause a "hard" supply-driven market[1], which, through the international reinsurance market, can cause rising insurance premiums in areas not directly affected by a regional catastrophe.

Rising insurance premiums for natural hazards, such as flooding, increase the basic living expenses of households, which may reduce a certain standard of living after obtaining insurance coverage. As shown by Hudson et al. (2019), who project the impact of climate- and socio-economic change on flood insurance premiums in the EU, insurance can become unaffordable for lower income groups. Also, when natural hazard insurance is optional, rising premiums may discourage individuals from obtaining coverage, leaving them more financially vulnerable to the impact of natural disasters.

Tesselaar et al. (2020) estimated the effects of a hard insurance market caused by remote climatic events on the flood insurance premiums in Europe for different stylized flood insurance systems and under various scenarios of climate change. They found additional unaffordability of insurance, which causes households to stop insuring against flood risk when this is optional. The lower uptake of flood insurance may be an additional financial burden for

[1] In contrast to a «soft» demand-driven market, where (re-)insurance prices might not even fully cover costs (expected damage, capital costs and expenses).





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public budgets, as governments often provide ex post disaster aid to uninsured households affected by a natural disaster, thus acting as insurer of last resort.

Based on these findings, the goal is to study under what *climate and socio-economic storylines* a hard insurance market is triggered, and to then show which remote disasters will influence the EU flood insurance market, and thus establish possible premiums levels, degree of unaffordability and uptake of flood insurance for private European households. This is done by using the open-source and -access CLIMADA impact assessment model (Aznar-Siguan and Bresch, 2019) to estimate remote losses, complemented by comparison with historical data analysis and consultation of insurance stakeholders to assess the conditions under which global reinsurance prices can be affected by the estimated remote losses and, finally, the DIFI model (Hudson et al., 2019) to estimate the effects on flood insurance premiums in the EU.

## 2.4 The impact on European investors due to remote natural hazards

Many European private investors have assets in foreign countries. Thus, there is a potential impact of remote climatic disasters on the risks and returns of foreign portfolio investments and on foreign direct investments (FDI) by private EU investors. These will be assessed by first estimating direct losses with the CLIMADA impact assessment model (Aznar-Siguan and Bresch, 2019). Then, two Computable General Equilibrium (CGE) models, GDyn and FTAP, are used to assess the effects on foreign portfolio investments and foreign direct investments (FDI), respectively.





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# 3. Building climate risk storylines: a counterfactual approach

The definition of *storylines* adopted in WP4 follows Shepherd et al. (2018), who define *storylines* as *a physically self-consistent unfolding of past events, or of plausible future events or pathways.* The focus therefore lies on the identification of causal chains of events which are self-consistent and plausible. In other words, storylines must be rooted in a scientific understanding of the climatic and socio-economic systems and are not arbitrary narratives of alternative states of the world. Shepherd et al. (2018) mentions few advantages of taking a storyline approach:

- It increases risk awareness by framing risk in an *event-oriented* rather than a probabilistic manner.
- It strengthens decision-making by allowing one to *work backward* from a particular vulnerability or decision point.
- It allows exploring the *boundaries of plausibility*.

These three aspects are connected and relate to the very goal of a storyline approach: the understanding of causal links between climate forcing and impacts. To do so, storylines are framed in event-oriented manner exploring plausible "*what if"* scenarios. Thus, the development of storylines, at least in its initial stages, does not entail any consideration about the probability of the considered causal chain events. This leads to an increase in risk awareness, as people relate more easily to the description of actual (or fictitious yet plausible) events rather than probabilistic estimates. Furthermore, once *critical* storylines are developed, i.e., storylines that lead to high-impact events potentially requiring a redesign of policies and plans, one can then reason backward, identify the critical spots, and intervene accordingly. Finally, storylines allow exploring a wide range of impacts by analyzing, visualizing, and reasoning upon the consequences of all plausible events, even the very unlikely ones.

As storylines can be interpreted as a *physically self-consistent unfolding of past events,* they strongly relate to the concept of *counterfactuals*, by which one means events that *could have plausibly happened but did not* and specifically, to *downward counterfactuals*, which indicate *alternative past events where the outcome could have been worse than what actually happened* (Woo, 2019, Woo et al. (2017)). In this context, one single downward counterfactual refers to the alternative realization of a single climatic event, and climate risk storylines are built as a





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*combination* of several downward counterfactuals, in such a way to build alternative physically plausible *series* of events.

One obvious way to carry out a counterfactual analysis of climate events, e.g., tropical cyclones, is to use past forecast data. Although forecasts were made serving a different purpose, i.e. *predicting* the development of a climate event (e.g. the final path and intensity of a tropical cyclone), the ensemble of forecasts represents, when used retrospectively, physically plausible alternative realizations of what happened in the past. A description of how storylines are developed using forecasts as downward counterfactuals is illustrated in Fig. 1 and discussed below.

First, a set of counterfactual events is built based on past event forecasts for the area of interest. Then, the economic impact is estimated for each single forecasted track. In so doing, one can estimate a plausible range of impacts by simply looking at the lowest- and highest- impact forecasts. After that, an iterative procedure starts. This is the core of the whole analysis and it needs to be carried out following a participatory approach in consultation with stakeholders. Ideally, the analysts and stakeholders together agree upon on what (1) is a critical performance for the system under study (i.e. when the system does “break”) (2) storylines that do lead the system to these critical performances and, finally, (3) how these storylines can exacerbate under climatic and socio-economic changes in the future. The following section presents an application of the described approach to address the problem introduced in subsection 2.1.

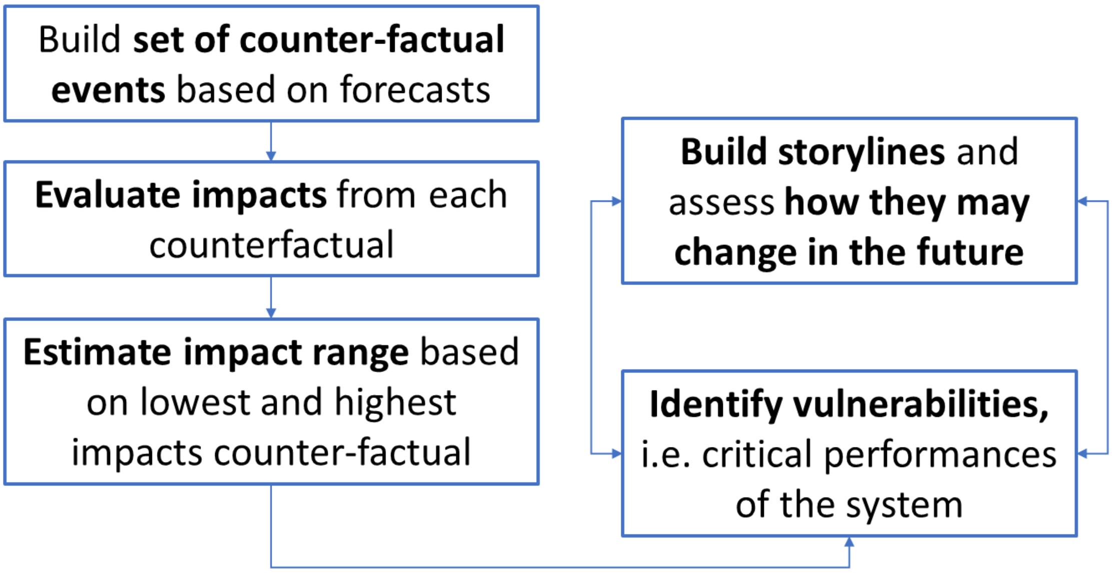


***Fig. 1*** *Schematic description of the approach used to build storylines.*





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# 4. Application to a case study: the European Union Solidarity Fund under stress after pay-outs to the outermost regions

As introduced in subsection 2.1, the European Union Solidarity Fund (EUSF) aims at providing financial aid to member states affected by natural hazards and suffering large economic losses. The EUSF follows clear pay-outs and capitalization rules. For the outermost regions, pay-outs correspond to 2.5 % of the direct damages and they are provided only if direct damages are above 1 % of the region's GDP. Thus, once direct economic damages are estimated and GDP data are available, it is straightforward to estimate pay-outs. Regarding capitalization rules, the fund annual capitalization amounted to 1000 M euros in fixed prices in the period 2002-2014 and to 500 M euros in 2011 prices with any unspent amount being carried forward for one year in the period 2015-2020.

Fig. 2 shows pay-out data and a simulation of capital availability given the pay-outs and the capitalization rules for the period 2002-2018. Bars indicate the total pay-outs, while the dotted black line shows the simulated capital. The blue and yellow bars indicate the share of pay-outs due to natural hazard events in mainland Europe and the outermost regions, respectively. Obviously, the former exceeds the latter in magnitude. Overall, no significant contribution from the outermost regions is registered, as only two pay-outs took place, in 2007 and 2017, and they are both very low compared to the overall magnitude of pay-outs. Interestingly, the capital level became critical (below zero) in 2016, after a large earthquake in Italy.

In order to build storylines, the approach illustrated in Fig. 1 is followed. The counterfactual events are simulated by using forecast data provided by the Observing System Research and Predictability Experiment (THORPEX), a big component of the World Weather Research Programme under the World Meteorological Organisation. In particular, the THORPEX initiated in 2005 the THORPEX Interactive Grand Global Ensemble (TIGGE) program which contains many forecasting data sets of tropical cyclone tracks from several international meteorological agencies (*THORPEX Interactive Grand Global Ensemble (TIGGE) Model Tropical Cyclone Track Data*, 2008, Park et al., 2008). The dataset contains historical tropical cyclone track data since 2008 and is updated constantly. Damages to the EU outermost regions are simulated through CLIMADA, an open-source and -access natural catastrophe modelling platform (Aznar-Siguan and Bresch, 2019).





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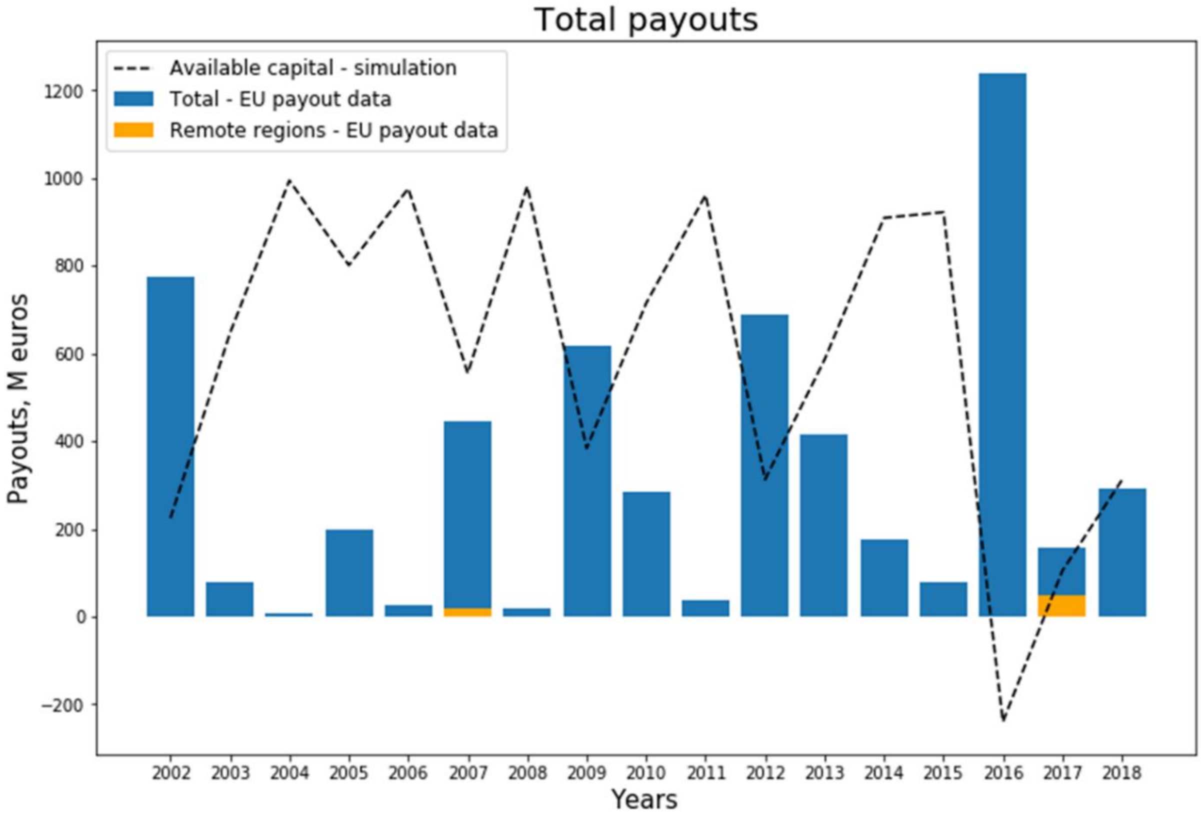


***Fig. 2*** *Pay-out data and simulated capital for the 2002-2018 period. Bars indicate the total pay-outs, while the dotted black line show the simulated capital. The blue and yellow bars indicate the share of pay-outs due to natural hazard events in mainland Europe and the outermost regions, respectively.*

## 4.1 Estimating the range of impacts from counterfactuals

Fig. 3 shows the obtained results in terms of pay-outs to the outermost regions (top figures) and capital (bottom figure) in the period 2008-2018. Total pay-outs to the outermost regions are shown both in terms of maximum annual pay-out (i.e. pay-outs from the highest-impact counterfactual each year) and cumulative annual pay-outs (i.e. cumulated pay-outs from the counterfactuals over a year) in the top-left and top-right panels, respectively. Capital is shown by accounting for total pay-outs, i.e. the sum of simulated pay-outs to the outermost regions (the cumulative case) and those relative to mainland Europe, accounted for by using the available data. Thus, the analysis assumes past payouts in mainland Europe as fixed.





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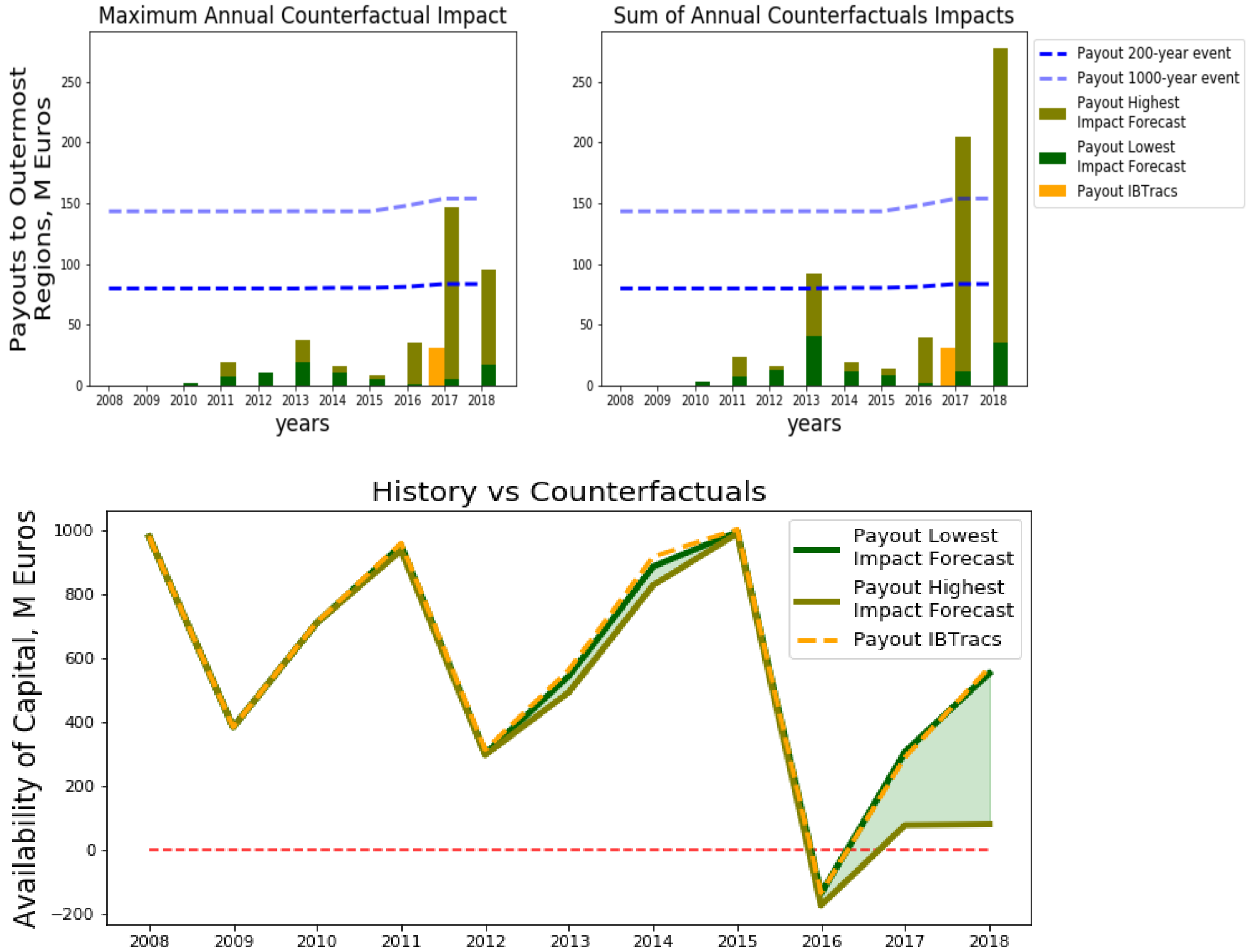


***Fig. 3*** *Results in terms of pay-outs to the outermost regions (top) and capital (bottom). Pay-outs are shown both in terms of maximum annual pay-out (top-left) and cumulative annual pay-outs (top-right). Results in yellow show simulations from historic tracks, while results in dark and light green show simulations from the lowest- and highest-impact forecasts, respectively. In the top panels, the dark and light blue dotted lines show the 200- and 1000- year pay-outs, respectively.*

Results in yellow show simulations from historic tracks provided by the IBTrACS database (Knapp et al., 2010), while results in dark and light green show simulations from the lowest- and highest-impact forecasts, respectively. For comparison, a probabilistic analysis is also carried out using an alternative repository of synthetic tracks provided by Bloemendaal et al. (2020). This allowed to estimate the 200- and 1000-year pay-outs, which are shown in the top panels as dark and light blue dotted lines, respectively. Looking at the results, two aspects are worth discussing further.

First, from the maximum annual pay-outs (top-left) one can see that some counterfactuals would have led to a pay-out higher than the 200-year level for two consecutive years, i.e. 2017 and 2018. On the same line and even more exacerbated, when looking at the cumulated annual



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pay-outs the counterfactuals analysis shows that the 200- and 1000-year pay-outs could have been exceeded three times (2013, 2017 and 2017) in six years and two times (2017 and 2018) in two years, respectively. Although this is, in principle, fully accounted for by the probabilistic approach – though deemed very unlikely – the advantage of the counterfactual, and the storyline, approach is that one can easily trace back *what* events would have led to such situations. This is discussed further below in more detail.

Second, when looking at capital (bottom panel), it is evident that, until year 2016, no counterfactual pay-out to the EU outermost regions would have led to a deviation from historical experience in any relevant way. After 2016, however, when major pay-outs to mainland Europe take place after the earthquake in Italy, some counterfactuals could have indeed prevented a full recovery of the fund in the subsequent years under the current capitalization rules. This indicates that, although pay-outs to the outermost regions are not substantial enough to compromise alone the availability of capital, they are important in recovering to acceptable capital levels should a major event hit mainland Europe in the same years.

As an example, Fig. 4 visualizes three selected downward counterfactuals compared with the actual tracks. Panel a), b) and c) show the tropical cyclones Leslie, Helene and Berguitta, respectively, which all took place in 2018. A downward counterfactual of Leslie (a) shows that this event could have been of a lower category but could have made landfall on the Canary Islands instead of moving north. Helene (b) could have hit the Azores and had a higher intensity. Berguitta (c) could have got closer to Réunion than the actual track and at a higher intensity, yet not making landfall.



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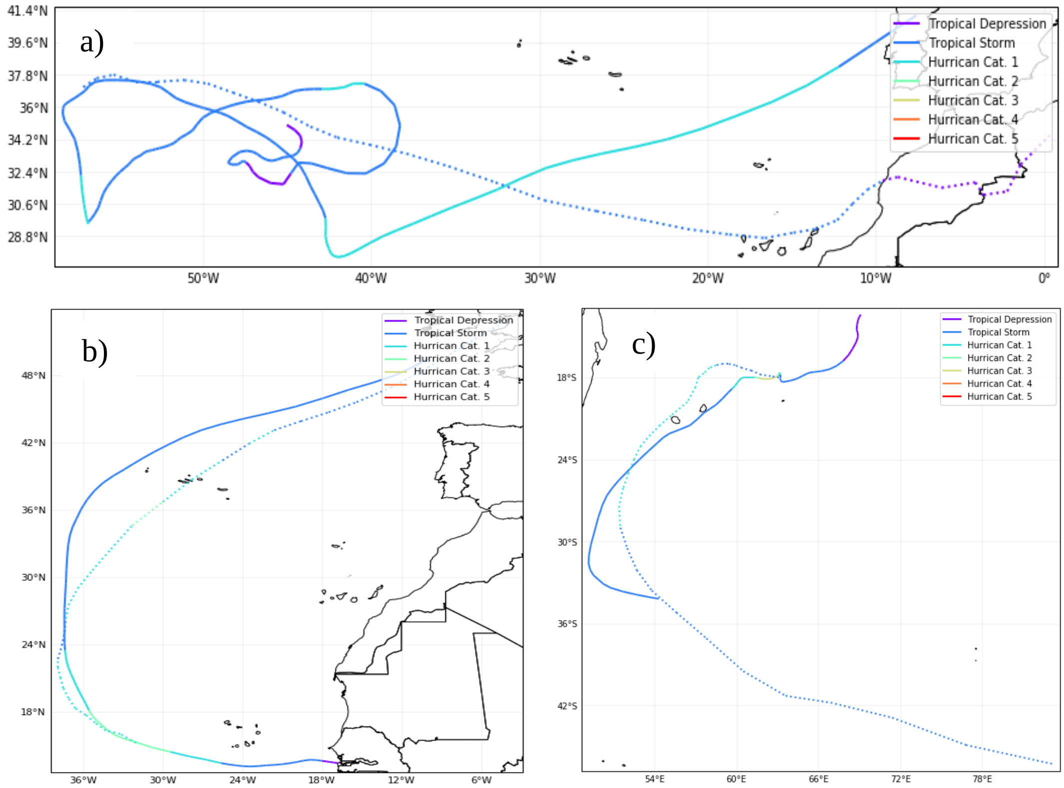


***Fig. 4*** *Example of downward counterfactuals (dotted lines) compared to the actual trajectories (solid lines). a) Leslie 2018, b) Helene 2018, c) Berguitta 2018.*

## 4.2 From counterfactuals to climate storylines

As stated above when introducing the approach in Fig. 1, the selection of the storylines, based on the analyzed counterfactuals, needs to be based on inputs from experts and practitioners. This entails iteratively visualizing the impact of combinations of counterfactuals and agreeing upon the ones deemed critical by the stakeholders involved. In the context of the current analysis, however, for the sake of time and resources, storylines were developed without recurring consultations with stakeholders. Instead, storylines are identified by referring to critical performances when compared to the 200- and 1000-year pay-outs estimated from the probabilistic analysis. It is worth stressing that the selection of storylines is somewhat subjective and, in principle, the number of all potential combinations of counterfactuals, and thus of storylines, is enormous. Three storylines are identified.

The first storyline (for short: *2 x Single*) reads as follows: *In 2017, a category 4 tropical cyclone makes landfall in Réunion (panel (a) in Fig. 5). The following year, an event following a similar*





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*path (panel (b) in Fig. 5 – which is the counterfactual of Berguitta in Fig. 4), yet of lower magnitude, impacts Réunion again.*

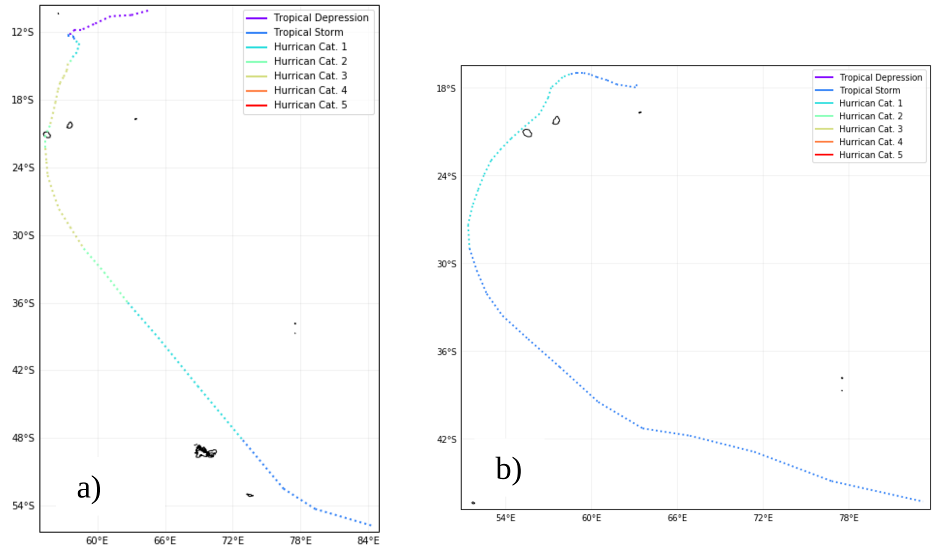


***Fig. 5** Events from the first storyline (2 x Single) in 2017 (a) and 2018 (b).*

This storyline leads to the exceedance of the 200-year pay-out two years in a row, a reference value when designing financial instruments. Thus, the storyline is considered critical.

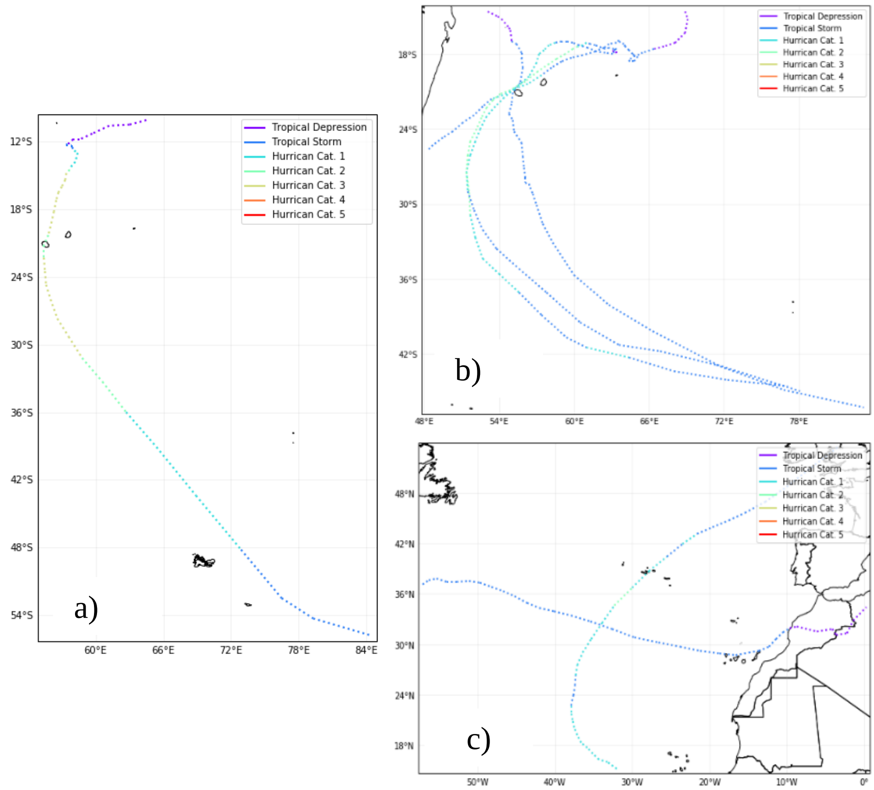


***Fig. 6** Events from the second storyline (Single + Series) in 2017 (a) and 2018 ((b) and (c)).*





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The second storyline (for short: *Single + Series*) reads as follows: *In 2017 a category 4 tropical cyclone makes landfall in Réunion (panel (a) in Fig. 6). The following year, a series of events strike both Réunion (panel (b) in Fig. 6), the Azores and the Canary Islands (panel (c) in Fig. 6)*. This chain of events leads to the exceedance of the 1000-year pay-out two years in a row. As the 1000-year pay-out is very unlikely to be exceeded in each single year, the fact that it was exceeded two years in a row is indeed critical.

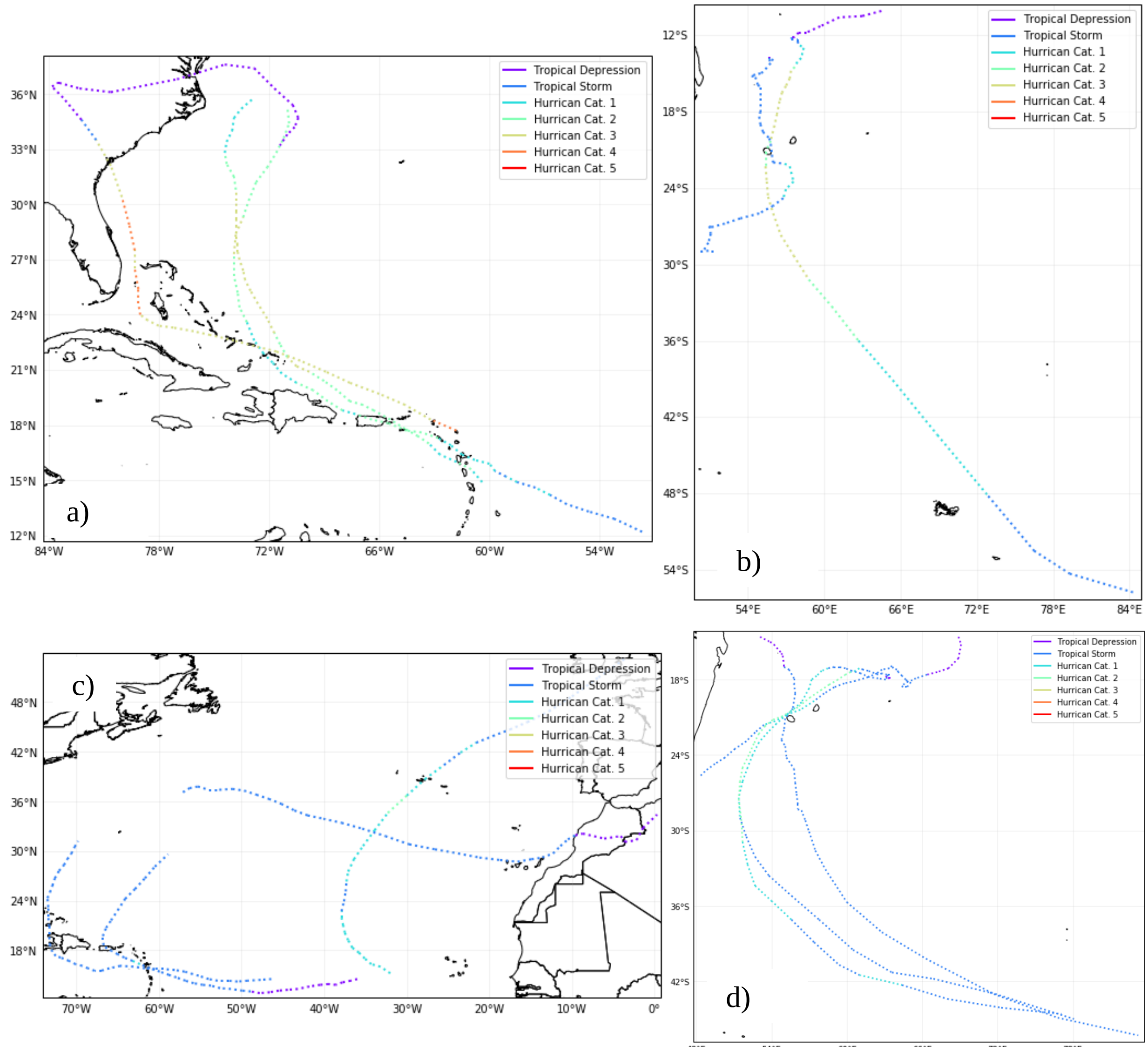


***Fig. 7*** *Events from the third storyline (2 x Series) in 2017 ((a) and (b)) and 2018 ((c) and (d))*

The third storyline (for short: *2 x Series*) reads as follows: *In 2017 a series of events strike both the Caribbean (panel (a) in Fig. 7) and Réunion (panel (b) in Fig. 7). The following year, another series of events hit Caribbean countries, the Azores, the Canary Islands (panel (c) in*





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*Fig. 7) and Réunion (panel (d) in Fig. 7).* This chain of events leads to a worst-case scenario corresponding the lower bound of the range shown in Fig. 3.

## 4.3 Projecting the climate risk storylines into the future

The three identified climatic storylines are evaluated under various degrees of future climatic and socio-economic change. Results are reported in Fig. 8 as heatmaps. Each row indicates a storyline, while columns indicate results for two consecutive years in the future – originally 2017 and 2018. In each panel, the x-axis indicates increase in tropical intensity, the y-axis indicates increase in GDP in the outermost regions and the z-axis (i.e. coloured cells) indicates capital levels. Capital below and above zero is reported in shades of red and blue, respectively. Thus, red areas are the critical ones. The heatmap illustrates what would happen to capital in a potential future should GDP and tropical cyclone intensity increase with respect to todays values. It is worth stressing that it is assumed that capitalization rules are fixed. This is indeed a simplification as one would expect the capitalization rules to change as GDP also changes.

Looking at Fig. 8, it is clear how the first storyline is never critical under the assumed future conditions. Furthermore, none of the storylines is critical in the first year, highlighting the fact that the contribution of pay-outs to the EU outermost regions can become relevant only when effects cumulate over time. Both the second and third storylines become critical during the second year for certain combinations of increase in tropical cyclone intensity and GDP.

In the spirit of the storylines approach, by looking at the heatmap one can start reasoning backward and understanding what can happen under various future conditions and chain of events. For instance, the second storyline set in a future setting can now read as follows:

> *In a future world where the intensity of tropical cyclones increases by 5 % and GDP grows by about 10 % with respect to today's values, an earthquake occurs in mainland Europe and - at the same time - a major tropical cyclone makes landfall in Réunion. In the following year, a series of tropical cyclones hit Réunion, the Azores and the Canary Islands. The capital of the EUSF, under today's capitalization rules, is completely depleted.*

With the proposed approach, the number of such *stories* one can build in a participatory fashion is endless. Yet, they would not be arbitrary as they would all be based on simulations from state-of-the-art methods and models and they would be subject to the critical judgment of scientists and practitioners involved in their selection.


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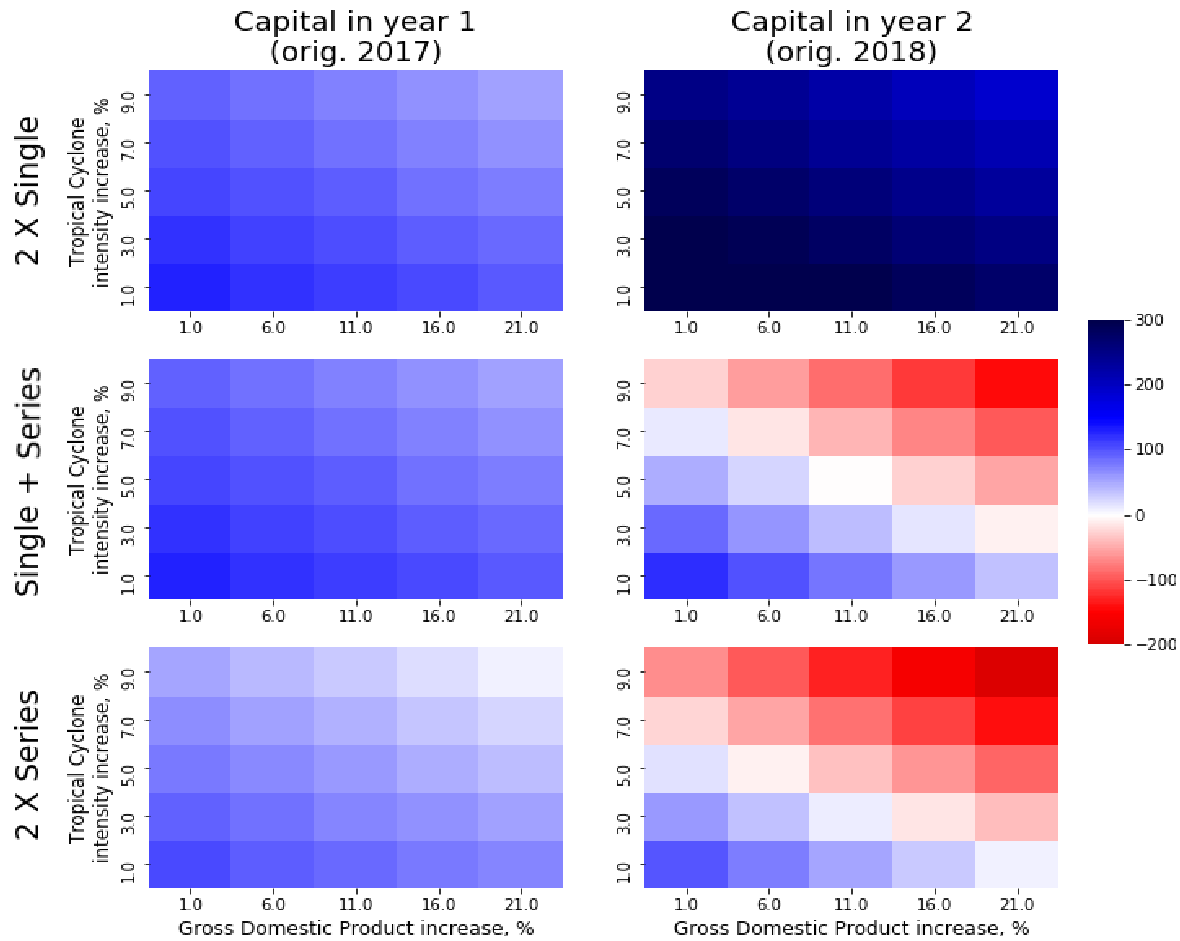


*Fig. 8 Assessment of capital availability for the three selected storylines under various degrees of future climatic and socio-economic changes.*

# 5. Future steps

This report summarized the status of storyline development within WP4. The report (1) discusses the four identified problems of public and private finance, which will be addressed in more detail in future work, (2) introduces a general framework for developing storylines and (3) describes a preliminary application to one of the identified research problems. Future work will develop along two lines:

- Continue the work on the four research problems currently identified. This entails to (1) finalize the analysis of the research problem in subsection 2.1, (2) keep working on the one in subsection 2.2 and (3) start to analyze the two research problems introduced at sections 2.3 and 2.4.





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- Formulating and addressing other relevant research problems. Previous interactions with the stakeholders highlighted how issues related to public and private finance are highly interdisciplinary and seldom confined to the financial world. Cooperation and coordination with other WPs are therefore crucial.

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