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Pathways of climate resilience over the 21st century

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Abstract

The impacts of climate change are affecting human societies today. In parallel, socio-economic development has increased the capacity of countries around the global to adapt to those impacts although substantial challenges remain. Ongoing climate change will continue to result in a pressure to adapt, while socio-economic development could make it easier to do so. Countries' effectiveness in fostering climate resilience will depend on the pace of both developments under different socio-economic and emission pathways. Here we assess trajectories of adaptation readiness in comparison with the continued emergence of hot days as a proxy for climate change hazards for different emission and socio-economic pathways over the 21st century. Putting the future evolution of both indices in relation to the observed dynamics over the recent past allows us to provide an assessment of the prospects of future climate resilience building beyond what has been experienced to date. We show that only an inclusive and sustainable stringent mitigation pathway allows for effective climate resilient development over the 21st century. Less inclusive or fossil-fuel driven development will not allow for improvements in resilience building beyond the recent past. Substantial differences emerge already in the 2020s. Our findings underscore the paramount importance of achieving the Paris Agreement goals to enable climate-resilient, sustainable development.

1. Introduction

Climate change hazards are emerging against a background of natural variability across the world (IPCC 2018). Substantial progress has been made in the detection and attribution of the human-induced climate change signal in a range of sectors and for individual extreme weather events (Stott *et al* 2016, Vogel *et al* 2019). Going forward, the detection challenge extends to the assessment of avoided climate impacts by mitigation action i.e. between a Paris Agreement compatible and a non-mitigation scenario. Regional and sector-specific differences in climate hazards are well established for warming increments of around 0.5 °C (Schleussner *et al* 2016b, 2017, Seneviratne *et al* 2018). Substantial regional benefits in avoided climate extremes may emerge within less than 20 years after the onset of mitigation action (Ciavarella *et al* 2017, Li *et al* 2019).

In the face of increasing climate hazards, fostering climate resilience is a central objective of climate policy established in Article 2.1b of the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC 2015).

The Special Report on Global Warming of 1.5 °C (SR1.5) of the Intergovernmental Panel on Climate Change (IPCC) defines climate resilience as 'the capacity of social, economic and environmental systems to cope with a hazardous event or trend, […] while also maintaining the capacity for adaptation, learning and transformation' (IPCC 2018). It goes further to introduce a temporal evolution in fostering climate resilience through the concept of

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'climate-resilient development pathways' as 'trajectories that strengthen sustainable development at multiple scales […] while reducing the threat of climate change through ambitious mitigation, adaptation and climate resilience'. Identifying characteristics of climate-resilient development pathways thus calls for an integrated assessment of the mitigation and adaptation dimension. The framework of coupling Representative Concentration Pathways (RCPs), which set mitigation targets, and Shared-Socioeconomic Pathways (SSPs) that provide the socio-economic development context for adaptation, can deliver such integration towards assessing climate-resilient development pathways.

Measuring progress under climate-resilient development pathways requires establishing a reference level. The highly context-specific and multi-dimensional nature of climate resilience (Tanner 2015), however, needs to be considered when trying to determine such benchmarks. Establishing globally applicable definitions of what constitutes 'high' climate resilience would thus certainly be challenging if not impossible. Here, we attempt to circumvent this issue by focusing on climate resilience building (De Souza *et al* 2015)—the temporal evolution of resilience-relevant mitigation and adaptation dimensions. We conceptualize the mitigation pathway dependent emergence of climate change related hazards as an 'adaption pressure' that needs to be counteracted by improved capacity in adaptation and socio-economic development in order to build climate resilience.

While the focus on the temporal evolution of climate resilience building rather than absolute levels helps to bypass some definitional and conceptual challenges, the question of benchmarking progress remains. We thus propose to assess the effectiveness of building climate resilience over the 21st century against the experience over the recent past. Without prejudging whether or not resilience building over the observational period has been efficient or successful, assessing the future evolution against experienced dynamics allows for a neutral benchmark.

Globally, substantial improvements in socio-economic development have been achieved over the recent decades (UNDP 2016). The development has been uneven, and many less developed countries are also being particularly exposed to climate change hazards (Byers *et al* 2018, Schleussner *et al* 2018). In countries characterized by low levels of development, substantial improvements in adaptive capacity will take decades (Andrijevic *et al* 2020b). At the same time, the impacts of climate change on economic performance are already apparent in many parts of the globe and contribute to widening inequality in wealth distribution between countries (Diffenbaugh and Burke 2019).

We assess climate resilience building by comparing the dynamics of a proxy for the adaptation dimension linked to the SSPs compared with the continuous emergence of extreme hot days under different RCPs.

2. Methods

2.1. Scenario-dependent adaptation readiness

Assessing future adaptation action requires the integration of different contextual information including social, political and sector specific considerations (Smit and Wandel 2006). Rather than focusing on adaptation action per se, we assess the extent to which a country is ready to implement adaptation actions, which is linked to the level of socio-economic development. The adaptation readiness index (RDY) is a component of the well-established Global Adaptation Index of the University of Notre Dame (Chen *et al* 2015). The RDY component tries to capture the ability of a country to leverage public and private sector investments and turn them into adaptation actions. Other approaches towards adaptation readiness seek to characterize whether human systems are prepared and ready to 'do adaptation' including on a local scale, but capture a similar idea of enabling conditions (Ford *et al* 2013, Ford and King 2013).

The RDY encompasses nine indicators in three dimensions: social readiness (social inequality, ICT infrastructure, education, innovation), economic readiness (World Bank doing business indicator) and governance readiness (political stability and non-violence, control of corruption, rule of law, regulatory quality) (Chen *et al* 2015). The RDY is calculated as the arithmetic mean of its nine constituent indicators, all scaled from their raw values to the range from 0 to 1 and weighted equally.

The RDY index was projected in line with the narrative of different SSPs have been provided in (Andrijevic *et al* 2020b), where past country-level trends in RDY were statistically explained by the dynamics of GDP per capita, population with post-secondary education and the gender gap in mean years of schooling after controlling for country-specific invariant characteristics and accounting for common shocks in the sample through year-fixed effects. RDY was projected forward to the year 2100 by imposing the coefficient estimates obtained from the regression analysis of the past trends on the internally consistent projections of GDP, education and gender gap in education, which are already provided in the quantified SSP framework. To illustrate changes depending on different initial states, countries are categorized according to their state of RDY in 1996–2015 (mean year 2005). The classification in 'low', 'medium', 'high', 'very high' follows quartiles of the mean 2005 distribution of countries. See figure 1(a) and table S2 (available online at stacks.iop.org/ERL/16/054058/mmedia) for an overview of the categorization.

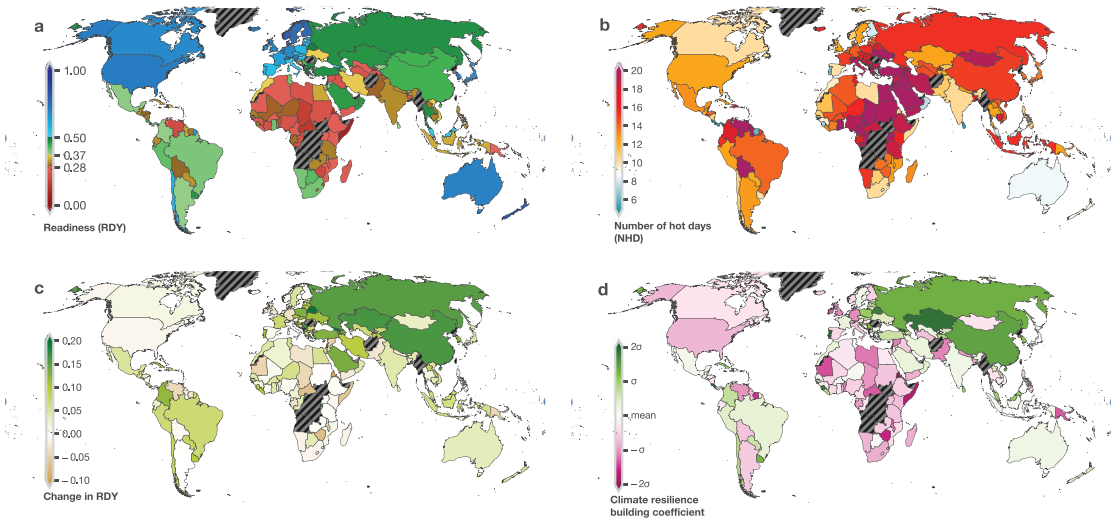


Figure 1. Developments of adaptation readiness and hot day emergence. (a) The adaptation readiness index (RDY) averaged over 1996–2015. Colors illustrate different country groupings (see section 2 and table S2). Red: low RDY, amber: medium RDY, green: good RDY, blue: very good RDY. (b) Emergence of the number of hot days (NHD) over the 1995–2015 period. (c) Absolute change in RDY over the 1996–2015 reference period. (d) The climate resilience building coefficient (CRBC) derived as the ratio of the pace of readiness improvements (change in RDY, panel (c)) versus NHD (panel (b)) over the reference period. Changes are scaled with respect to the underlying distribution across countries (compare figure 2(a)). Countries with missing data are hatched grey.

The rate of change of adaptation readiness RDY(yr, i) for a given year *yr* and country *i* is derived as the running mean of changes in adaptation readiness over a 21 year period centered on year yr.

Figure 1(a) depicts the RDY globally over the 1995–2015 period outlining substantial differences between countries. Over the last two decades, RDY has been improving for many countries, but not for all (compare figure 1(c)). Over the observational period, improvements in RDY have been generally higher for countries with higher RDY (figure 2(a), see section 2 for more information on the classification of countries). A notable exception are countries with very high RDY today, where comparably small improvements are observed. For countries in that category, however, the very high levels of RDY indicate limited need for improvements of adaptation readiness.

Countries with very low RDY to date are arguably those that would most urgently need to see improvements. However, at least over the observational period these countries exhibit the smallest median improvements with a significant number of countries also seeing decreasing adaptation readiness.

2.2. Emergence of extreme heat

Potential improvements in adaptation readiness will be met by an ongoing emergence of the climate change signal (Geiges *et al* 2020). To approximate this ongoing emergence, we focus on one specific heat-related indicator: the number of hot days (NHDs) (Vogel *et al* 2020). A multitude of climate hazards exist with strong regional differences and one heat-related index clearly does not provide for a comprehensive overview of all risks of climate change (Hoegh-Guldberg *et al* 2018). We however chose this index for two reasons specifically linked to the purpose of this study. Firstly, extreme heat is one of the most pertinent climate hazards (Coumou and Robinson 2013, Pfleiderer *et al* 2019) that is emerging globally, which makes it suitable for a cross-country comparison. Secondly, extreme heat indices have been shown to be highly sensitive to global warming, allowing for robust assessment of an emerging climate change footprint on decadal timescales (Pfleiderer *et al* 2018, Seneviratne *et al* 2018). While not being fully representative of the broad spectrum of climate impacts, heat extremes are driving a range of pertinent climate impacts including health risks (Saeed *et al* 2020) and labour productivity (Andrews *et al* 2018), crop failure (Schauberger *et al* 2017), and conflict risk and migration (Hoffmann *et al* 2020).

To derive the NHDs, we analyze the near-surface air temperature (tas) over land regions. We first compute the 90th percentile temperature distribution of each day based on the 31 neighboring days and 21 neighboring years. We then focus in the analysis on the 'warmest season' defined as having the three consecutive warmest months in the climatology (1970–2000). A hot day is then defined as a day that exceeds the 90th percentile temperature distribution within these warmest months of a 21 year moving reference period. The center year of the moving 21 year 90th percentile temperature distribution refers to the 20 years earlier than the year of interest, thus the 21 year baseline period is shifted to the respective 20 previous years. This shifting reference period serves as a proxy for continuous adaptation to the new climatic conditions.

Hence, for 2005 the reference 90th percentile temperature distribution refers to 1975–1995, for 2085 to the 2055–2075 reference period (see figure S1). NHD is computed as the sum of the

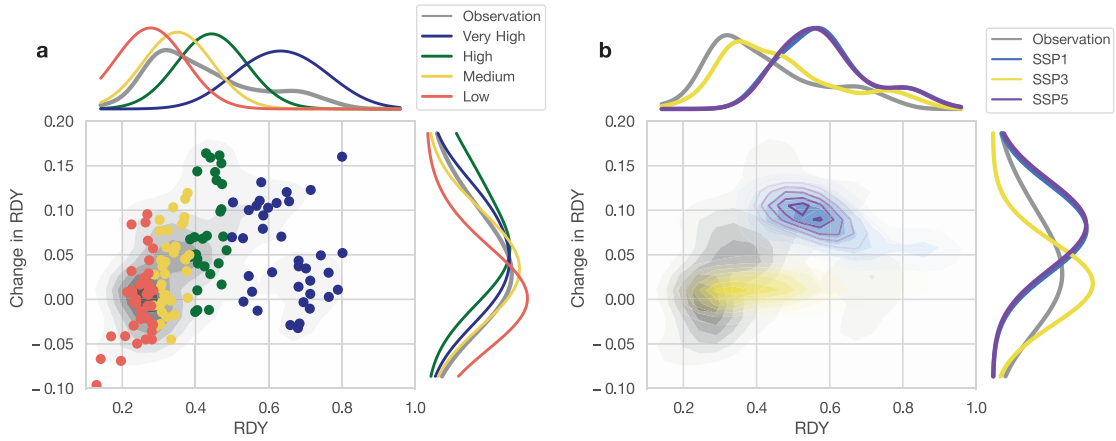


Figure 2. Evolution of adaptation readiness under different SSPs. (a) The change in RDY over the 1996–2015 period against the absolute values over the same period. Colors denote different country groupings classified by their 1996–2015 state of adaptation readiness (see section 2). Contours of the density functions are provided as well as probability density functions for the distribution of values for each country grouping. (b) Same as panel (a), but comparing the observed distribution with projections in 2050 under different SSP scenarios. Filled contours provide density maps of the distribution across countries.

hot days for each individual year for each model simulation on the grid cell level. We then aggregate to country level, derive the running mean with a 21 year window and derive median and ensemble spread over the model ensemble. We use simulations from the Coupled Model Intercomparison Project phase 5 (CMIP5) from historical (1995–2005) simulations and the emission scenarios RCP2.6, RCP4.5, and RCP8.5 (2006–2100) (Taylor *et al* 2012). One ensemble member is used per model, the available simulations depend on the emission scenario, where the complete list of models is provided in the supplementary information table S1.

For the recent reference period (1995–2015) we compare simulated NHD with observed NHD, i.e. NHD in a combination of the European Centre for Medium-Range Weather Forecasts ReAnalysis 5 (ERA5) and ERA40 (CDS 2019). We compute the mean difference of mean NHD from 1995 to 2015 for the multi-model median of the CMIP5 models for each country and the different emission scenarios RCP2.6, RCP4.5 and RCP8.5 (see figure S3). Overall, we find that CMIP5 models tend to show a slight negative bias, hence simulating too little hot days. When we average over the four country groups (low, middle, high, very high development) the mean biases vary between 0 and -3 d yr^{-1}. This can be partly related to strong heatwaves in our reference period such as the 2010 Russian heatwave or the 2018 Northern Hemisphere heatwaves, that are not captured in the climate model simulations in these respective years. We correct the CMIP5 projections for this bias by subtracting the simulated NHD in 2005 and adding the observed NHD in 2005 (averaged over 1995–2015) to all projections for each country and each model individually.

In a stable climate, the expected NHD emergence would be on average 9 NHD days per year such as in the reference period. As shown in figure 1(b), the emergence of NHD over the 1995–2015 period is not globally homogeneous and is subject to some natural variability. It is particularly pronounced over tropical regions. While this tropical signal is partly the result of the choice of the NHD metric that is assessed against natural variability which is comparably lower in tropical regions, it also is an illustration of the exposure of the most vulnerable regions to the early emergence of climate change impacts (Harrington *et al* 2016, Harrington and Otto 2018).

2.3. The climate resilience building coefficient

The relative pace of hot day emergence relative to a moving reference period can be interpreted as a resemblance of adaptation pressure. Comparing changes in adaptation readiness with such a proxy for adaptation pressure can inform how climate resilience is being built over time. Increasing adaptation readiness will increase countries resilience, but the effectiveness of doing so will clearly depend on the temporal evolution of the adaptation pressure.

The climate resilience building coefficient (CRBC) allows to capture this interdependency as:

$$\mathrm{CRBC}\,(\mathrm{yr}, i) = \frac{\mathrm{RDY}\,(\mathrm{yr}, i)}{\mathrm{NHD}\,(\mathrm{yr}, i)}.$$

Note that while the CRBC can be negative (mainly over the observational record), only the interpretation of positive values is meaningful in terms of a country intercomparison.

3. Results

3.1. Scenario dependent evolution of adaptive capacity and heat emergence

In order to assess the future evolution of the RDY, it needs to be related to narratives of future

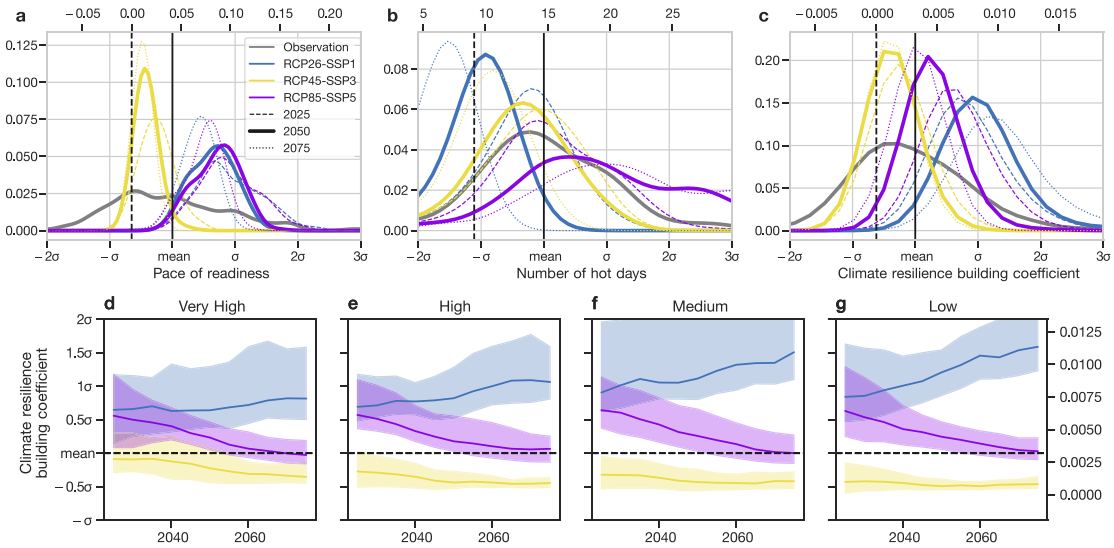


Figure 3. Climate resilience building under different SSP-RCP scenarios. (a) Probability density functions of the pace of readiness changes under different SSP scenarios for 2025 (light dashed), 2050 (full) and 2075 (dotted). The lower *x*-axis provides the scaling relative to the observed distribution denoting the mean and the values in terms of standard deviations, whereas the upper *x*-axis gives absolute values. The mean value of the observed distribution (black line) as well as the zero line are highlighted (dashed line). (b), (c) Like panel (a) but for the number of hot days (b) and the climate resilience building coefficient (c). In (b), vertical lines denote the mean of the observed distribution (black line) and the no climate change expectation value of 9 d (dashed line). Vertical lines in c denote the mean (black line) as well as the zero line (dashed line). (d)–(g) Temporal evolution of the climate resilience building coefficient under different scenarios for the four different country groupings (compare figure 1(a)). Changes are provided in terms of standard deviations of the observed distribution.

socio-economic development. Here we make use of recently provided RDY projections linked to the SSPs (Andrijevic *et al* 2020b). The SSPs present a set of quantified scenario narratives of the evolution of societies globally in the 21st century (O'Neill *et al* 2017). Figure 2(b) shows the RDY evolution over three distinct SSP scenarios: SSP1, SSP3 and SSP5. SSP1, the 'sustainability' scenario, is characterized by fast socio-economic development as a result of investments in education, health, renewable energy sources, and of declining inequalities between and within countries, strong international cooperation, thus limiting impacts and increasing capacity to cope with climate change. SSP3, also termed 'regional rivalry', is much the opposite: it is a scenario of stalled socio-economic progress and a growing divergence between economies, weak international cooperation and increase in internal and international conflicts, resulting in low capacity to cope with impacts of climate change. SSP5 is similar to SSP1 in terms of socio-economic development, but assumes it to be largely fossil-fueled, thereby resulting in much larger emissions' footprint than the SSP1 scenario.

Under the SSP3 scenario, little deviation of RDY from today is projected over the 21st century with limited improvements in RDY in particular for the most vulnerable today (figure 2(b), amber). In contrast, the high development assumptions in SSP1 and SSP5 would lead to rapid improvements in adaptation readiness achieved only by a small number of countries over the observational period resulting in similar probability density functions (figure 2(b), blue, purple). The 21 year rate of improvements is highest in the near-term (2025, dashed lines in figure 3(a)) and for the countries with the lowest adaptation readiness to date. Improvements in RDY slow down over the 21st century as developing countries are catching up and global inequalities are reduced (Rao *et al* 2019).

These trends in RDY can now be compared with the temporal evolution of climate emergence. By design, our NHD index is sensitive to the emergence of ongoing climate change and can be interpreted as an 'adaptation pressure' that requires ongoing adaptation efforts to counterbalance. A significant adaptation potential exists with regard to heat extremes (Klein *et al* 2014) and countries at a certain level of development may be very well adapted to its impacts (Carleton *et al* 2018). However, rather than assessing the NHD index solely in terms of its implications on extreme heat alone, we here interpret it as a proxy for ongoing emerging climate change and resulting adaptation needs or pressure faced by societies (De Coninck *et al* 2018). As shown in figure 3(b) for different RCPs, future evolution of NHD exhibits a clear scenario dependency over the 21st century. Under the very high concentration scenario RCP8.5, NHD emergence will continue to increase with half of the world's countries experiencing the emergence of about 20 NHDs by mid-century (about twice what would be expected by natural variability alone). A significant number of countries would experience an emergence of more than a month (30 d) of hot days within two decades, well above twice the current rate and outside the observed range. This represents a substantial acceleration from observed trends.

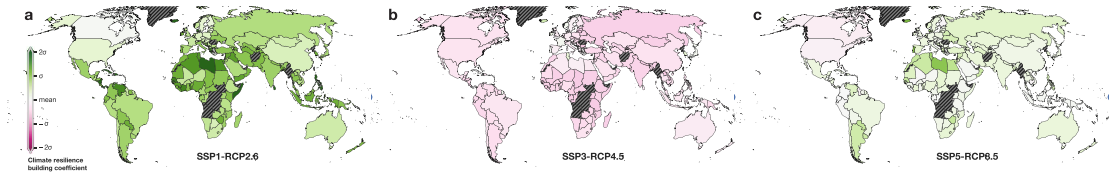


Figure 4. The climate resilience building coefficient in 2050 under different SSP-RCP scenarios. (a) SSP1-2.6, (b) SSP3-4.5, (c) SSP5-8.5 scenario. Values are shown relative to standard deviations of the observed distribution (compare figure 1(d)). Countries with missing data are hatched grey.

NHD emergence under the RCP4.5 scenario resembles observed trends (yellow lines in figure 3(b)). Under the RCP2.6 scenario that holds the global mean temperature increase to below 2 °C above pre-industrial levels with a 66% probability, a slow-down in NHD is apparent. By mid-century, NHD emergence is robustly below the observed distribution and towards the end of the century, the median experienced NHD falls below 9 d in conjunction with slowly declining temperatures under this scenario (IPCC 2013).

3.2. Building climate resilience

Comparing the temporal evolution of the increases in adaptive capacity, proxied by RDY (figure 3(a)), and hazard pressure, proxied by NHD (figure 3(b)), allows for an assessment of how effective countries may be in building climate resilience under different socio-economic and warming trajectories. We propose a CRBC as the ratio of RDY improvements vs. NHD emergence that allows to capture this interdependency (figure 3(c); see section 2). The CRBC exhibits several characteristics that we consider meaningful when assessing progress made towards climate-resilient development pathways. Firstly, it is sensitive to the ongoing emergence of new climate hazards. Achieving net-zero emissions and thereby a peak in global mean temperature leads to a constant climate hazard component, meaning that every improvement in the adaptation dimension contributes to resilience building. On the other hand, an accelerated emergence in the climate hazard requires bigger improvements in adaptation-enabling conditions to continue to build climate resilience at the same pace.

Comparison with the observed CRBC allows to assess the evolution of this index under different socio-economic and climate futures illustrated by different SSP-RCP combinations (compare figure 3(c)). Firstly, the distributions of different SSP-RCP combinations are narrower than the observed distribution, illustrating the observation of a diverse pace of socio-economic progress across countries, while the SSPs provide for a global narrative leading to a more uniform evolution (compare figure 3(a)). At the same time, the different SSPs taken together resemble well the observed distribution which supports the meaningful comparison. A notable exception is the presence of declining readiness for a significant number of countries over the observational period. Such declines are almost absent from the SSP-based projections (negative values are only projected under SSP3 and only for a few countries). The lack of declining socio-economic trends in the SSP framework has been criticized as inherent scenario optimism (Andrijevic *et al* 2020b).

Compared to the observed trends, resilience building under the SSP3-RCP4.5 is slowed down, yet well within the observed cross-country variability (yellow lines figure 3(c)). In particular, improvements in countries with lowest adaptation readiness today will almost come to a halt (compare figure 3(g)). In comparison with such a 'rocky road', a high fossil fuel development driven narrative exemplified by the SSP5-RCP8.5 would represent some improvements in building climate resilience in the near-term, but with declining efficiency over the 21st century as ongoing emergence of climate change hazards continue to increase adaptation needs. After 2050, resilience building under such a scenario would slow down to present-day levels despite the very optimistic assumptions of rapid socio-economic development. This finding questions the narrative of 'low adaptation challenges' assumed under a SSP5 scenario, even without considering limits and barriers to adaptation being transgressed due to ongoing warming (IPCC 2018).

In contrast, under the SSP1-RCP2.6 scenario, resilience building will improve substantially already in the near-term and even accelerate over the 21st century (compare figures 3(d)–(g)). By 2050, almost all countries will build resilience faster than the mean pace over the observational period and about half of the countries will improve at rates above one standard deviation of the observed distribution (compare figure 3(c)). Improvements in resilience building are highest for countries with currently medium or low adaptation readiness (figures 3(f) and (g)), some of which have experienced a deterioration in adaptation readiness over the recent past (compare figure 1(d)).

Figure 4 allows for a direct comparison of the regional resilience building under the different scenarios. Despite development improvements being comparable in the SSP1-RCP2.6 and the SSP5-RCP8.5 scenario, and most pronounced in countries with lower development often located in low latitudes, it is also those countries for which

the differences in climate resilience building between both scenarios are most pronounced. This indicates that building climate resilience, in particular for countries that most urgently need to see improvements, critically depends on stringent climate mitigation. Under a 1.5 °C compatible scenario RCP1.9 characterized by the most stringent near-term emission reductions, development benefits would be even higher including in the near term (Nauels *et al* 2019, McKenna *et al* 2020).

4. Discussion and conclusions

When interpreting our findings, it is important to be mindful that the analysis presented here does not attempt to provide indications whether countries are climate resilient or not, but rather provides an assessment of potential temporal and scenario-dependent evolution of resilience building.

This forward-looking approach aims to inform assessments of progress towards the goals set out in the Paris Agreement Article 2.1b to 'foster climate resilience' and 'low greenhouse gas emissions development' (UNFCCC 2015). Our analysis shows that the achievement of both goals is intertwined, as stringent climate mitigation is key for effective resilience building.

We find that even under scenarios of unprecedented global socio-economic development (SSP5), the impacts of unmitigated climate change cannot be 'outgrown'. Furthermore, our results highlight the potential for very-near term benefits of inclusive climate resilient development pathways (RCP2.6-SSP1) as soon as 2025 (compare figure 3(c), dashed blue line). While initially strongly driven by socio-economic change, our findings equally illustrate the very near-term benefits of mitigation slowing down near-term warming (McKenna *et al* 2020).

In order to provide this integrated assessment of climate resilience building, a range of strong assumptions and heuristic choices had to be made. First and foremost, our assessment of climate resilience building is based on the linear comparison between adaptation readiness and a hazard pressure proxied by the continuous emergence of NHDs. For both the climate and the adaptation readiness dimension, however, non-linearities may be present. The adaptation readiness score applied here has been developed to assess the enabling conditions for adaptation that might not directly translate into countries abilities to deal with the impacts of climate change in a linear fashion. An improvement of 0.1 points in RDY might have very different real-world consequences depending on the state of development. On the other hand, a single heat-related index is of course not able to cover the full range of climate impacts. However, systematic assessments of future climate risks indicate rapidly escalating risks at 1.5 °C of temperature increase above pre-industrial levels and beyond (Hoegh-Guldberg *et al* 2018, Lange *et al* 2020). The emerging NHD does not account for non-linearly increasing risks of climate change (IPCC 2018) with increasing warming, or the crossing of absolute thresholds for ecosystems, agricultural productivity or even human inhabitability (Im *et al* 2017, Schauberger *et al* 2017). With ongoing warming, also adaptation limits may increasingly be reached or exceeded (Thomas *et al* 2020). An emerging heat-related index therefore appears to be a rather conservative choice for a proxy for climate impacts.

Furthermore, under the SSP framework there is no feedback of climate impacts on the development trajectory. Accounting for climate impacts the development trajectories may give rise to increasing inequalities between countries with increasing warming (Taconet *et al* 2020). Similarly, adaptation readiness is projected to marginally improve (or at least not deteriorate) for the vast majority of countries even under an SSP3 scenario largely linked to improvements in future governance under the SSPs (Andrijevic *et al* 2020b). The same holds for other adaptation relevant indicators such as (gender) inequality (Rao *et al* 2019, Andrijevic *et al* 2020a)

Over the observed record, however, several countries have experienced a decline in adaptation readiness, many of which have been affected by outbreaks of armed conflicts or civil unrest (compare figure 1(c)). Unfortunately, it seems plausible that conflict outbreaks will continue to occur in the future and that outbreak risks may even increase depending on the climate and socio-economic scenario (Hegre *et al* 2016, Schleussner *et al* 2016a, Ide *et al* 2020).

These considerations need to be kept in mind when interpreting our results. However, they rather render our assessment conservative and thus support our key finding that stringent climate mitigation is key for efficient climate resilience building. As illustrated in figure 4, our approach allows to provide guidance on the determinants of efficient climate resilience building down to the level of country groups or even individual countries compared to what they have experienced already. Without prejudging whether or not recent progress can be deemed 'good' or 'sufficient', it can be assessed if the challenge of building climate resilience is increasing or decreasing depending on the socio-economic and climate pathway. While socio-economic development is, at least partly, also linked to decision making and progress on the national level, the emergence of a climate hazard is the result of global emissions, largely driven by a small number of big emitters (Geiges *et al* 2020). Whether or not the world's most vulnerable nations will succeed in building climate resilience is thus partly out of their own hands and becomes a global responsibility. This is now even more the case with countries are dealing with the social and economic consequences of the COVID-19 pandemic, while national stimulus packages of

developed countries exceed the required investments into a green transition by an order of magnitude or more (Andrijevic *et al* 2020c). While the COVID-19 related economic downturn has neither helped the climate nor climate resilience, a strong green stimulus could set the world on track for limiting warming to 1.5 °C (Forster *et al* 2020). Climate resilient development pathways need to be aligned with achieving the temperature goal of the Paris Agreement.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Author contributions

CFS, MA, PP, FELO and SIS designed the research; PP, MA, MMV and CFS performed the analysis; CFS wrote the paper with contributions by all co-authors.

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