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Forecasting civil conflict along the shared socioeconomic pathways

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Abstract

Climate change and armed civil conflict are both linked to socioeconomic development, although conditions that facilitate peace may not necessarily facilitate mitigation and adaptation to climate change. While economic growth lowers the risk of conflict, it is generally associated with increased greenhouse gas emissions and costs of climate mitigation policies. This study investigates the links between growth, climate change, and conflict by simulating future civil conflict using new scenario data for five alternative socioeconomic pathways with different mitigation and adaptation assumptions, known as the shared socioeconomic pathways (SSPs). We develop a statistical model of the historical effect of key socioeconomic variables on country-specific conflict incidence, 1960–2013. We then forecast the annual incidence of conflict, 2014–2100, along the five SSPs. We find that SSPs with high investments in broad societal development are associated with the largest reduction in conflict risk. This is most pronounced for the least developed countries—poverty alleviation and human capital investments in poor countries are much more effective instruments to attain global peace and stability than further improvements to wealthier economies. Moreover, the SSP that describes a sustainability pathway, which poses the lowest climate change challenges, is as conducive to global peace as the conventional development pathway.

1. Introduction

While the global incidence of armed conflict has declined markedly in recent decades [1], this trend may not continue. Poor economic performance [2] combined with sustained population growth [3], especially in developing countries, may lead to increased conflict in the future. The impacts of climate change may further hinder socioeconomic development [4, 5] and thus constitute a significant 'threat multiplier' to stability in vulnerable societies [6]. Assessing the impact of climate change on conflict, however, is complicated. Not only is the main impact likely to be indirect, but climate change itself depends on socioeconomic changes that also profoundly affect conflict propensities. Moreover, specific trajectories of socioeconomic development that facilitate peace may not necessarily facilitate mitigation and adaptation to climate change. For example, while economic growth lowers the risk of armed conflict, this growth is generally associated with increased greenhouse gas emissions and increased costs of mitigation policies. The newly developed societal scenarios [7, 8], known as the shared socioeconomic pathways (SSPs), for the first time permit a systematic investigation of how these links may play out in the future. This study represents the first attempt to simulate trajectories of future conflict along the five SSP scenarios, based on an estimation of the historical association between socioeconomic conditions and conflict involvement. We show that SSPs that imply high challenges to *adaptation* to climate change are associated with

Table 1. Global characteristics of the five shared socioeconomic pathways.

Pathway	Mitigation challenges	Adaptation challenges	Economic growth	Population growth	Education attainment
SSP1: Sustainability	Low	Low	High	Low	High
SSP2: Middle of the Road	Medium	Medium	Medium	Medium	Medium
SSP3: Fragmentation	High	High	Low	High	Low
SSP4: Inequality	Low	High	Medium	Medium	Low
SSP5: Conventional Development	High	Low	High	Low	High

Note: table adapted from Chateau, Dellink, Lanzi, and Magné [28].

increased levels of internal armed conflict in the future. Whether and in what way SSPs that imply high *mitigation* challenges will affect future conflict propensities is less clear.

The conflict research community has identified a handful of robust country-level correlates of civil conflict, the three most powerful of which are a history of prior conflicts, a large population, and a low level of socioeconomic development [9, 10]. Larger populations are associated with more conflict due to larger heterogeneity of identities and preferences, larger pools of potential rebels, and logistical challenges of controlling large territories [11]. Strong economic performance decreases conflict risk by strengthening networks of economic dependence among societal groups, reducing public grievances, increasing costs of rebel recruitment, and strengthening the state's counterinsurgency capability [12, 13]. Other aspects of socioeconomic development, including school enrollment levels, educational expenditures, and literacy rates, also have a pacifying effect [14, 15].

Previous attempts to evaluate the association between climatic conditions and conflict risk have largely focused on direct, short-term effects of variations in weather patterns, using proxies such as temperature, precipitation, and various drought indices. Taken together, this work reveals a weak and inconsistent climate effect, with some studies concluding in direct opposition to each other [16–21]. An indirect and conditional effect is more plausible, particularly because consequences of climatic shocks depend on the affected societies' resilience and adaptive capacity. Similarly, changing weather patterns and other physical processes associated with climate change can amplify common drivers of armed conflict, such as economic underperformance, food insecurity, and human displacement [22, 23], but these effects will vary with the affected societies' level of development. Current attempts to forecast future conflict trends [24–26] have not accounted for indirect effects of climate change.

To investigate security implications of alternative climate change-related scenarios, this study draws on the SSPs [8]. The SSPs were developed to evaluate the uncertainty in how impacts of climate change and the ability to mitigate adverse societal effects may evolve as a function of socioeconomic drivers. The scenarios are designed to span a range of alternative futures and are shaped by different assumptions about society, including economic development, education improvements, and population growth. Unlike earlier scenarios developed by the climate change research community—such as the Special Report on Emissions Scenarios—the SSPs are explicitly decoupled from the physical processes associated with climate change. Instead, each pathway is defined in terms of challenges to climate change mitigation and adaptation. High challenges to mitigation are here understood as involving high dependence on fossil fuel-based energy and low levels of international cooperation on global environmental issues. High adaptation challenges are characterized by low development growth rates, low investments in human capital, and increasing economic inequality [27]. Four of the scenarios (SSP1, SSP3, SSP4, SSP5) capture the four possible combinations of low and high barriers to adaptation and mitigation whereas the fifth (SSP2) represents a middle pathway. The key components of the SSPs are summarized in table 1.

Although the specified SSP scenarios comprise a variety of possible futures, one might imagine other constellations of economic and demographic development as well as greater spatiotemporal heterogeneity in growth rates that could be considered equally plausible pathways. For the sake of consistency and to provide an explicit evaluation of some implications of the modeling decisions underlying the original SSPs, we decided to remain true to these pathways. We reflect on some limitations imposed by the SSP framework in the concluding discussion.

The quantification of the five socioeconomic pathways are based on existing end-of-century projections of population, GDP per capita, and the proportion of young males with upper secondary schooling or higher. Figure 1 compares the projected trends in economic development and educational attainment across the scenarios. All SSPs display positive economic growth per capita, though aggregate and country-specific growth rates vary considerably between the scenarios. In fragmentation (SSP3) and inequality (SSP4), educational attainment rates remain very low, although they vary by socioeconomic level in SSP4. In

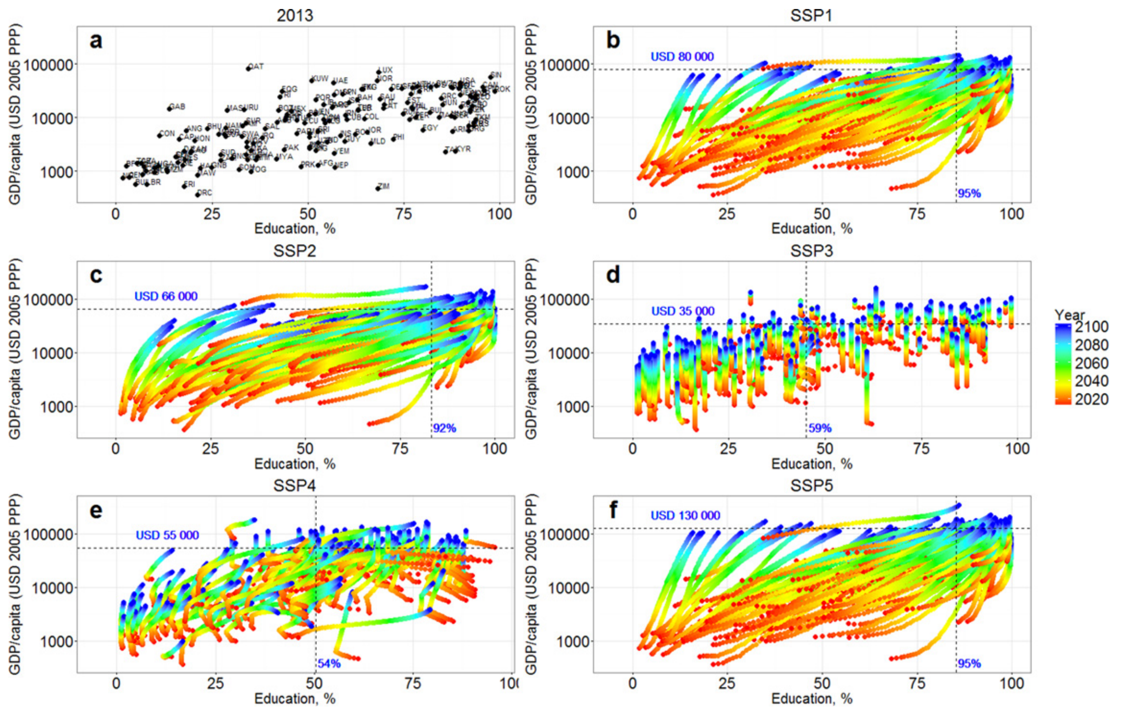

Figure 1. Projections of economic output and education levels along the shared socioeconomic pathways. Vertical axes represent $\log_{10}$ GDP per capita in constant 2005 US Dollars whereas horizontal axes represent secondary education attainment (%) among males, age 20–24. Panel (a) shows the situation in 2013 with three-letter country identifiers of individual countries (see table S12 in supplementary information for details); panels (b)–(f) visualize SSP1–SSP5 with colors denoting time scale from 2014 (red) to 2100 (blue). Dashed lines indicate projected end-of-century global means of GDP per capita and education level for each scenario.

both cases the countries' points of departure represent the situation several years prior to 2014, hence the downward adjustment in the initial years; see [29] for a complete description. The other scenarios assume continued progress in educational attainment throughout the century.

2. Methods and data

Our approach builds on the model presented by Hegre *et al* [25] and consists of three main steps. First, we assembled a joint dataset of historical and projected variables, covering all independent countries in the world for all years, 1960–2100 [30]. In addition to the socioeconomic indicators shown in figure 1, we include country-specific information on population size, conflict history, time since independence, and conflict involvement among neighboring countries, all of which have been shown to exert consistent influence on civil conflict risk [9, 10], and for which authoritative projections until 2100 are available. Historical conflict data are derived from the UCDP/PRIO Armed Conflict Dataset [1, 31]. A civil conflict is here understood as a military conflict between a state and one or more non-state actors over territorial or government control that results in at least 25 battle-related deaths in a calendar year. The analysis distinguishes between minor conflict (25–999 annual casualties) and major conflict ($\geqslant$1000 casualties). In line with the SSP framework, socioeconomic development is operationalized as GDP per capita and secondary educational attainment among men aged 20–24. The historical data as well as projections along the SSPs draw on two existing models. Population and education scenarios up to 2100 are based on the IIASA and Wittgenstein Centre for Demography and Global Human Capital model [32–34]. The original historical dataset spans 1970–2010. We extrapolate education rates back to 1960, assuming similar rates of change as for the 1970–2010 period. Historical GDP per capita statistics are derived primarily from the World Development Indicators [35]. Economic growth beyond 2013 is projected using an augmented Solow growth model with representations of human capital and fossil fuel usage, known as the OECD ENV-Growth model [28]. As the projected data come in five-year intervals, we linearly interpolate between the time steps. We also adjust the data to align the historical records with the starting point of the SSPs. Finally, a small number of countries for which we have historical data are not defined in the SSPs. To maximize the number of countries in our analysis we borrow adjusted projections from appropriate matching countries for these cases. See sections S3 and S8 in supplementary information for further details on the construction of the dataset.

Second, we developed a statistical model of civil conflict onset, duration, and termination. The unit of analysis is the country-year, 1960–2013. We use a

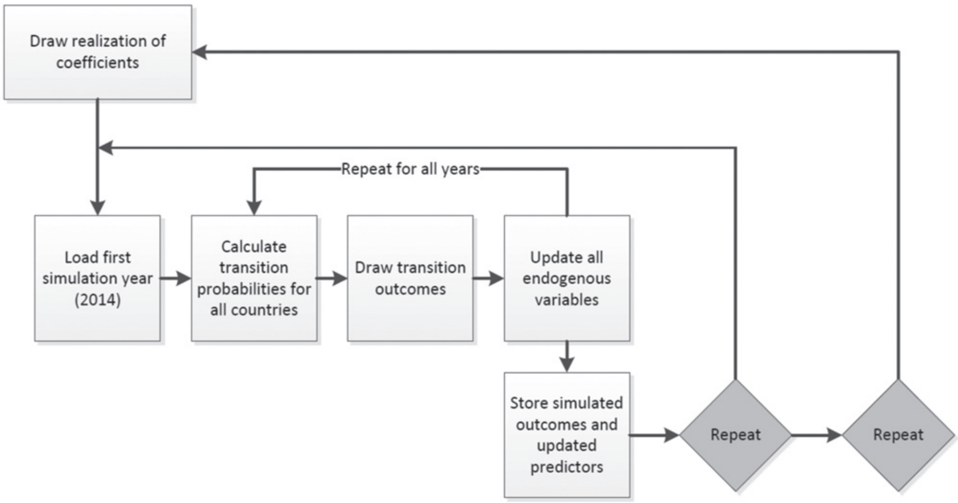

Figure 2. Flow chart of the simulation process.

random-effects multinomial logit model to estimate the transition probabilities between peace, minor conflict, and major conflict as a function of temporally and spatially lagged conflict indicators, population, GDP per capita, and educational attainment, as well as interaction terms for these socioeconomic factors, decade constants, and country-specific intercepts. The results from this model, which are used to inform the forecasting simulation, are reported in section S3.3 in the supplementary information. The preferred statistical model and inclusion of terms were determined based on an out-of-sample evaluation of model performance across various specifications; see section S5 for details.

Third, we used the statistical model and a simulation procedure to generate annual projections of armed conflict for each country over the SSPs, 2014–2100. Specifically, the procedure (i) calculates the transition probabilities for a given year for all countries based on a realization of the statistical coefficients, (ii) draws a conflict outcome based on these probabilities, (iii) updates all conflict variables, and (iv) moves on to the next year using the updated conflict history data. This is repeated for all years and for a large number of realizations of the estimated probability distributions of coefficients. In total, we run 9000 simulations for each scenario to account for the uncertainty in the parameters (40 simulations for each of 15 realizations of the country intercepts for each of 15 realizations of parameter estimates). The general setup of the simulation procedure is shown in figure 2.

3. Results

We began the simulation analysis by estimating the historical effect of socioeconomic development on civil conflict occurrence, 1960–2013. The results from this empirical analysis, documented in table S3 in supplementary information, are consistent with those reported in earlier research [10, 12, 13]. Based on the observed situation at the end of 2013 and the estimated probabilities of transition between different levels of conflict implied by our empirical model, we then simulated the annual incidence of civil conflict onset, duration, and termination for all countries across the globe along the five SSPs, 2014–2100.

Figure 3 shows the aggregate results from these projections, expressed as the annual proportion of countries in armed civil conflict by scenario and region. Because the conflict forecasting procedure is probabilistic in its approach, it generates prediction intervals around the mean projections. Each projection is shown with a one-standard deviation prediction interval—i.e. the band within which 68% of the simulated proportions lie, assuming logistic-normal distribution [36].

In line with earlier forecasting efforts [24], we find that global conflict incidence declines as socioeconomic development (GDP per capita and education) increases, while larger populations generally are associated with higher rates of conflict. In sustainability (SSP1), middle-of-the-road (SSP2), and conventional development (SSP5), the positive socioeconomic projections outweigh the impact of expected population growth and result in declining conflict rates over time. In the fragmentation (SSP3) and inequality (SSP4) pathways, however, low investments in education and technological innovation and medium to high population growth imply upward conflict trends. Overall, the most dramatic reduction in global conflict is observed in conventional development, where the mean estimate of projected end-of-century incidence is only a quarter of that of fragmentation. Although conventional development has the highest rate of economic growth and the lowest overall global conflict burden, this result is not statistically different from the sustainability scenario (SSP1), in

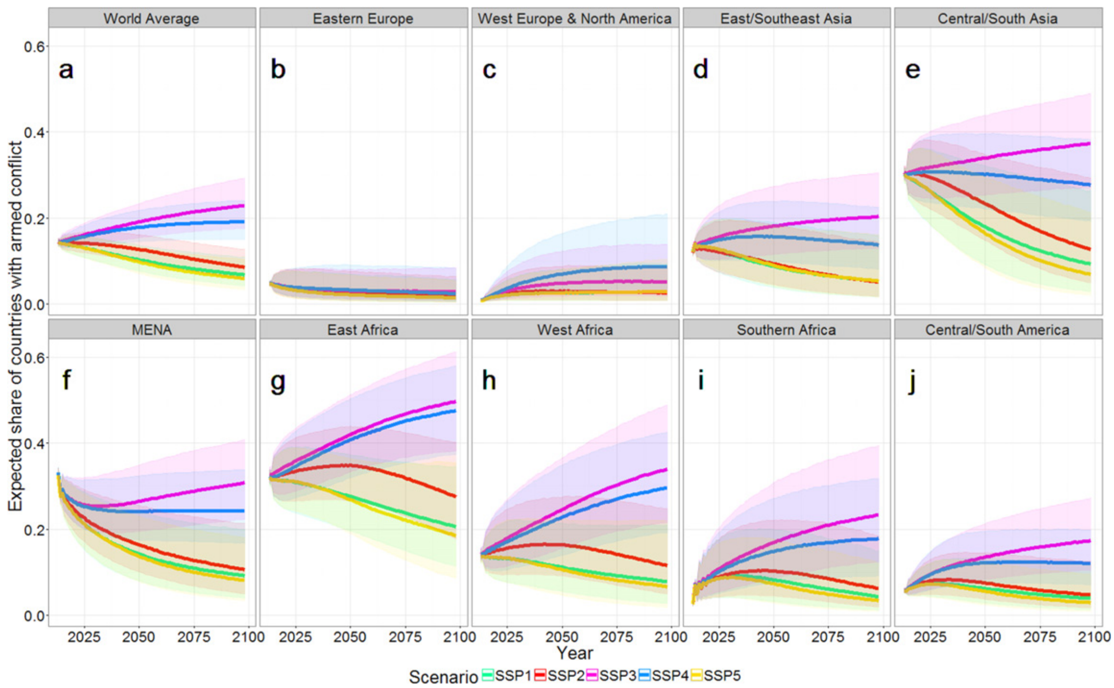

Figure 3. Projected proportion of countries in armed conflict by scenario and year, 2014–2100. Panel (a) shows the world average results; panels (b)–(j) show regionally disaggregated estimates ('MENA' refers to the Middle East and North Africa). Shaded areas represent one SD (68%) prediction intervals. Table S12 (supplementary information) provides details on the region classification.

which the world has a far better capacity to adapt to and mitigate climate change.

GDP per capita is essential to conflict reduction primarily to the extent that it is translated into broader social welfare improvements. High educational attainment rates may better proxy this type of development, and projections for education are the same in sustainability and conventional development. By contrast, fragmentation implies a marked increase in global conflict over time for most regions. For inequality, the richer developed countries do equally well as in conventional development. The poorer countries, however, have conflict risks that are more akin to fragmentation since the global average improvements in socioeconomic development are driven largely by the wealthiest countries that already enjoy very low conflict risks. Expectations of sustained population growth in Africa also increase the conflict rate, especially in the high population growth pathway of fragmentation. There is modest spatial variation across scenarios in the sense that existing conflict clusters (Central Africa, the Middle East, and South Asia) remain centers of instability throughout the century in all pathways, but the magnitude of conflict varies considerably. Overall, the lowest estimated rates of conflict are found in Eastern Europe, owing to the region's low and declining population and sustained economic growth.

To demonstrate the positive security impact of improvements in socioeconomic conditions and restrained population growth—which by design are associated with lower barriers to climate change mitigation—figure 4 visualizes the difference in estimated end-of-century conflict risk between fragmentation (SSP3) and sustainability (SSP1). In this setting, wealthier countries are minimally affected by the choice of scenario; their conflict propensities are small across all SSPs. In contrast, most countries in the developing world show dramatic reductions in conflict incidence with sustainability relative to the fragmentation pathway. More generally, the improvements in socioeconomic conditions in Africa —a present hotspot of armed conflicts—play an important role in reducing future global conflict burdens. This is highlighted by inequality (SSP4), where Africa continues to observe increasing conflict rates due to low socioeconomic development and high population growth. Additionally, the marginal impact of more modest economic growth in sustainability compared to the fossil fuel-dependent conventional development (SSP5) does not imply a significant increase in conflict risk because the burden of lower rates of economic growth are absorbed by wealthy, robust countries. Section S7.1 in the supplementary information provides further details on regional and country-specific results from these simulations.

4. Discussion

Our projections of armed conflict are a function of the quantified variables defined exogenously in the SSPs. The projections for armed conflict also have implications for these variables, notably GDP. The SSPs are

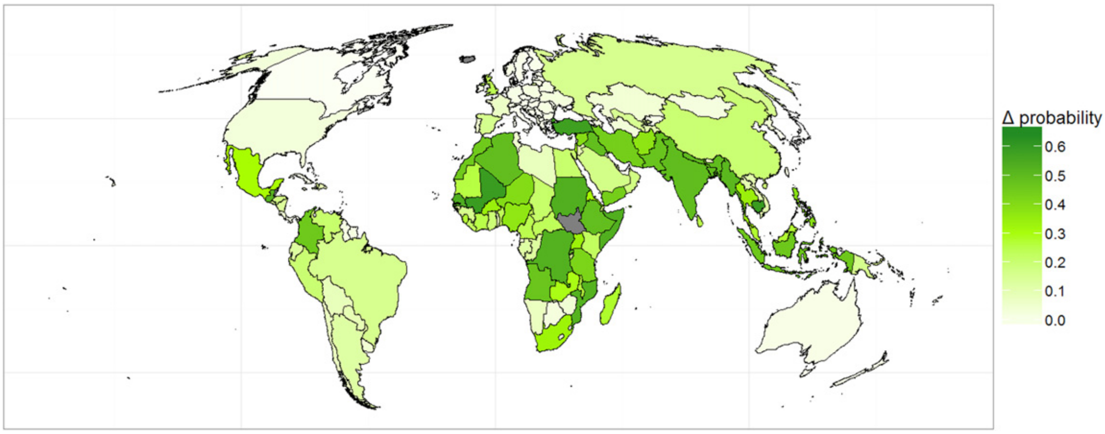

Figure 4. End-of-century differences in estimated conflict risk between SSP1 and SSP3. Darker shades indicate larger benefits in terms of reduced absolute conflict risk by shifting from the adverse regional fragmentation scenario (SSP3) to a sustainable growth scenario (SSP1). Countries in gray have insufficient historical data to be included in the forecasting model.

designed to span a range of expectations for future development trajectories, but the limited set of alternative scenarios and modeling assumptions necessarily imply that other, perhaps equally plausible, futures are not captured. For educational attainment, the more optimistic SSPs project near universal secondary education rates by the end of the century, while fragmentation (SSP3) and inequality (SSP4) assume virtually no progress at all for most countries. These bounding assumptions are reflected in the two distinct sets of projections of conflict incidence (figure 2). By contrast, GDP growth rates over the century differ in magnitude across SSPs, but all are positive. Thus, if we construct our model using GDP per capita only, the five SSPs have more similar conflict incidence forecasts (section S7.2 in supplementary information). Due to the assumptions of convergence in the OECD ENV-Growth model [28], even the most pessimistic scenario—SSP3—projects positive growth in GDP per capita for all countries. Historically, however, growth has been much more uneven across countries over the last four decades [37]. A partial reason is armed conflict, which often critically stunts GDP growth and other welfare developments [38, 39]. These types of political obstacles to growth are not included in the OECD ENV-Growth model and thus are not reflected in the SSPs. Lower economic growth in the SSPs that do not have broad societal development, such as SSP3 and SSP4, could generate further armed conflict which in turn may cause additional hindrances to mitigation and adaptation. For this reason, the end-of-century conflict rates for the worst-case scenarios should be considered conservative estimates, and the value-added of following a sustainable growth pathway may be larger than suggested by the simulation model[7].

[7] In the supplementary information (figure S17), we show results from an additional simulation, based on SSP3 but with no improvement in GDP per capita or education. This model yielded incidence rates slightly higher than those of the original SSP3.

The simulation draws on the three quantified indicators of socioeconomic development, but the SSPs also have qualitative narratives, or storylines, that describe five societal dimensions, including institutional quality and political stability [27]. Other non-quantified variables, such as oil revenues and inequality, may also affect future conflict risk. The higher reliance on fossil fuels in SSP5 would likely increase the estimated conflict propensity in countries that are highly dependent on such revenues [12, 13] or vulnerable to commodity price fluctuations [40]. Similarly, SSP4 entails high intra-country inequality that also could exacerbate conflict [41]. Importantly, the ability to manage grievances that can produce conflict depends on the legitimacy of political institutions [42]. In our model, institutional effects are captured partly by the socioeconomic variables from the SSPs and partly by country-specific intercepts that reflect unobserved differences between countries in the underlying conflict risk. Obviously, the country-specific intercepts approach implies a strong assumption about time-invariance. Although it is important to account for static risk factors (e.g., landlockedness, terrain, and historical legacy), political institutions and other malleable societal and contextual features are likely to change over the course of the century. Indeed, the evolution of national and intergovernmental institutions in the storylines for the SSPs is central to defining the challenges to mitigation and adaptation, where capable and responsible institutions are more likely to facilitate these actions. Absent quantification of these storylines, they are best accounted for by making qualified judgments about the simulated conflict trajectories.

An attractive feature of the SSPs is the opportunity to consider various combinations of societal and climate change scenarios in an integrated framework. At the same time, the explicit disconnect between the SSPs and climate change (beyond the different mitigation and adaptation challenges they impose) means that the conflict projections presented here do not directly capture effects of climate change. We show, however, that SSPs 3 and 4 that imply high challenges to adaptation to climate change are uniformly associated with increased levels of internal armed conflict in the future because societies that lack the capacity to adapt to climate change are the same as those that struggle with armed conflict. Whether and in what way SSPs that imply high mitigation challenges will affect future conflict propensities is less clear, however. If, as in SSP5, high mitigation challenges due to fossil fuel-driven economic growth are associated with low adaptive challenges across all countries in the world, we do not predict more conflict than SSP1, which implies small mitigation challenges. If the high mitigation challenges, on the other hand, unfold together with high adaptation challenges in large parts of the world (as in SSP3), armed conflicts will continue to be a serious global problem in the future. This assumes that there is no direct or indirect impact of climate change on conflict. In a final test, we investigated a possible separate effect of temperature anomalies on conflict risk. This test revealed a weak and insignificant effect in the historical sample, and accounting for temperature anomalies did not improve the predictive performance of the model (section S5 in supplementary information). We did not consider a direct effect of precipitation on civil conflict as the association between rainfall patterns and climate change is less well understood, especially at finer levels of spatial resolution [43].

Climate change, however, may indirectly affect core drivers of armed conflict. Radical mitigation policies or adaptation challenges may halt improvements to living conditions that are important to restrain conflict. Recent research provides little support for an indirect association between drought and conflict via poor agro-economic performance [44, 45], but this is an area that requires more research. This research, however, should not ignore the powerful impact on conflict propensity implied by socioeconomic development in itself.

Three other patterns in our simulations have particular policy relevance. First, the trajectory of future socioeconomic development will have a substantial impact on both the incidence of global conflict and the capacity to mitigate and adapt to climate change. Two of the five SSPs imply a reversal of the recent decline in armed conflict, with end-of-century global conflict rate for SSP3 being twice as high as today's and four times higher than that projected for the optimistic SSP5. Regional and between-country differences in estimated conflict risk across the pathways are more dramatic still (supplementary information, table S8). Second, while rapid, universal growth in GDP per capita is associated with substantial decline in the long-term risk of civil conflict, our model also shows that achieving broader socioeconomic development, as expressed by higher educational attainment rates, offsets most of the additional risk from reducing economic growth. The risk-reducing effect of education is especially pronounced among countries in the developing world. Third, our simulations reveal that investing in a sustainable future is fully consistent with an ambition of global stability and peace while simultaneously having comparatively low barriers to climate change mitigation and adaptation. Poverty alleviation and educational improvements in the global south thus stand out as key policies in achieving both objectives.

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