in the political science literature that can be incorporated in future AC models. In particular, empirical studies of certain insurgencies shed light on the feedback effect between a regime's violence and the level of insurgency. For example, studies of the insurgency in Chechnya (*60*) and the Vietnam War (*61*) provide important insights for modeling the insurgency dynamics. In addition, data assembled in the Correlates of War project (*62*) can be used for validating future AC models, at least at the macroscopic level.

What will be needed in the future? Certainly advances in defense technology, which affect both regular and irregular warfare, will need models to assess their impact and optimize the employment of the resulting weapons and equipment. In particular, networks of sensors, which support the operation of unmanned systems, will require data fusion and machine-learning models that will facilitate an effective use of these two advanced technologies. Also, to better model and understand future armed conflicts, information technology should be implemented for systematically collecting data about the combat environment, actions, and outcomes during such events.

The emphasis in this article has been on quantitative models, but answering some broader questions may require more qualitative analysis of behavioral factors and social forces. Why does someone become a terrorist, and how can that process be stopped? How long does it take for a population to forget a multigenerational history of conflict, as in Northern Ireland or the Middle East? Insights from a range of fields, some described in this issue of *Science*, and further understanding of the complexity of human interactions during armed conflicts will need to be part of our arsenal in confronting these questions in the future.

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PERSPECTIVE

CLIMATE CHANGE AND VIOLENT CONFLICT

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Current debates over the relation between climate change and conflict originate in a lack of data, as well as the complexity of pathways connecting the two phenomena.

Since publication of the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), the debate on the security implications of climate change has intensified. Research in this area has made progress but remains controversial [for recent reviews, see (*1*–*4*)]. Although some quantitative empirical studies support a link between climate change and violent conflict, others find no connection or only weak evidence.

A major challenge for all studies is to find adequate data. Instead of using data on the long-term average and variability of temperature, precipitation, and other climatic variables that would clearly fall under the IPCC definition of climate change (*5*), many studies have used proxies, such as short-term data on weather and extreme weather events, or on natural phenomena of climate variability like the El Niño Southern Oscillation (*6*).

It is important to distinguish between the types of conflict used in various data sets. The widely used Armed Conflict Dataset of the Uppsala Conflict Data Program and the Peace Research Institute Oslo (UCDP-PRIO), for instance, sets a minimum of 25 battle-related deaths per year and involvement of at least one state government to be considered as armed conflict (*7*). This excludes other forms of violent or nonviolent behavior that may be affected by climate change such as protests, riots, or livestock theft, let alone conflict as a positional difference over interests, values, or goals. These distinctions are relevant as, in recent decades, climate variability may have been more associated with low-level violence and internal civil war—which fall below the UCDP-PRIO definition cutoff—than with armed conflict or war between countries.

Long-term historical studies tend to find a coincidence between climate variability and armed conflict, in line with some narratives about the evolution and collapse of civilizations [e.g., (*8*)]. For instance, Zhang and others (*9*) combine a set of variables for the time period 1500–1800 to identify climate change as a major driver of large-scale human crises in the Northern Hemisphere. Tol and Wagner (*10*) cautiously conclude that, in preindustrial Europe, cooler periods were more likely to be related to periods of violence than warmer phases. Similar findings have been presented for eastern China (*11*).

However, the results have been less conclusive for recent periods. For instance, in one study, a significant correlation between temperature and civil war in Africa between 1981 and 2002 is used to project a substantial climate-induced increase in the incidence of civil war in Africa until 2030 (*12*). Yet, this result is not robust for an extended time period and alternative definitions of violent conflict (*13*).

Food insecurity has been found to contribute to violence, as exemplified by recent "food riots" (*14*, *15*), but there is little empirical evidence that climate variability is an important driver of violent land-use conflicts—e.g., in the Sahel (*16*). In Kenya, changing rainfall patterns have the potential to increase resource scarcity as a driver of pastoral conflict (*17*). However, more conflict in the form of violent livestock theft is reported during the rainy season than during drought (*18*).

Similarly, conflicts over shared river systems have been associated with low-level violence, yet full-scale wars are unlikely [e.g., (*19*, *20*)]. Instead, an increase in international water agreements has been observed (*21*).

Finally, some studies suggest that natural disasters related to extreme weather conditions substantially increase the risk of intrastate conflict (*22*). In contrast, Bergholt and Lujala (*23*) find no increased likelihood of armed civil conflict due to weather-related disasters, and Slettebak (*24*) observes that, in crisis, cooperation frequently prevails.

New research is on the way as new databases on nonstate conflicts, low-level violence, social instability events, and geo-referenced spatio-temporal patterns become available (*25*–*27*) (table S1). In addition to data needs, it is important to account for complexities in the relation between climate change and conflict. There are multiple pathways and feedbacks between the climate system, natural resources, human security, and societal stability (Fig. 1).

Since the 1990s, there has been an extensive scientific debate on how the scarcity of natural resources affects violence and armed conflict (*29*, *30*). More recently, conflict studies pay attention to the vulnerability of natural and social systems to climate impacts (*31*). Vulnerability can be broken down into three factors: (i) exposure to climate change, (ii) sensitivity to climate change, and (iii) adaptive capacity (*32*). The last two can be affected by conflict. Many of the world's poorest people are exposed to various risks to life, health, and well-being. If climate change adds to these risks, it can increase humanitarian crises and aggravate existing conflicts without directly causing them.

The question is whether human development, resilience, and adaptive capacity can compensate for increasing exposure and sensitivity to climate change. In previous decades, humanitarian aid, development assistance, and wealth per capita have increased (*33*), which has contributed to a reduction of global poverty as a possible driver of conflict. International efforts to prevent and manage conflicts have also been strengthened, and the number of armed conflicts has declined since the end of the Cold War (*34*). In recent years, however, this trend slowed down or is being reversed. While the number of democratic states has grown over the past half-century, the number of fragile states with weak institutions has also increased (*35*).

If the debate on the securitization of climate change provokes military responses and other extraordinary measures, this could reinforce the likelihood of violent conflict. Main aspects of security concern include interventions in fragile

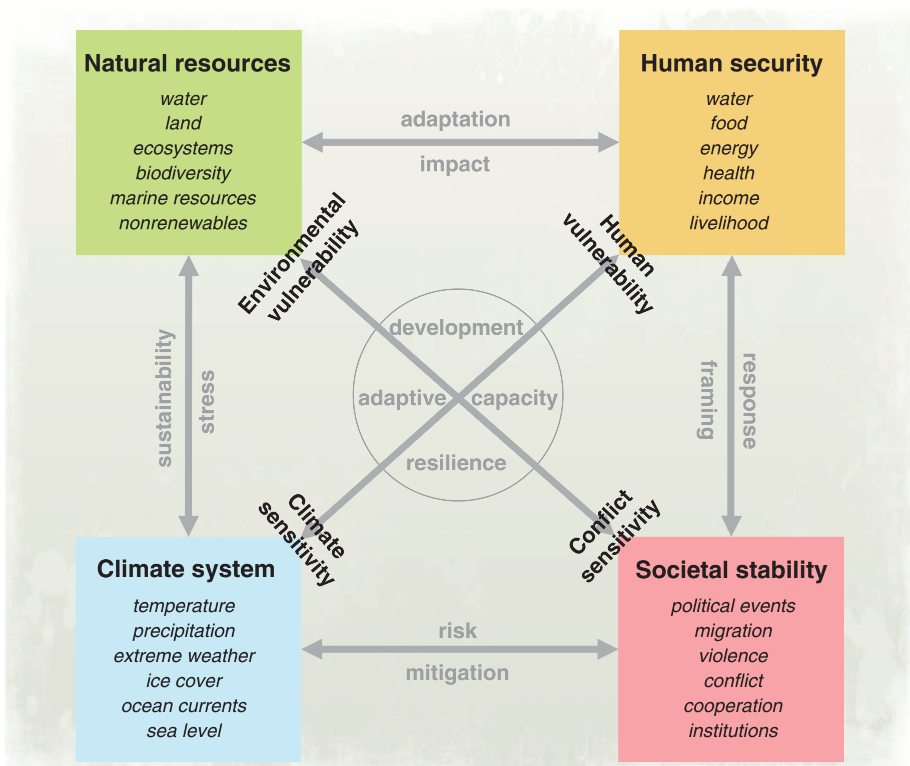

Fig. 1. Analytical framework of linkages between the climate system, natural resources, human security, and societal stability [based on (*28*)].

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Table 1. List of core research questions structured by the relations between causes and effects of the human-environment interaction.

	Effect			
Cause	**Climate change**	**Natural resources**	**Human security**	**Societal stability**
Climate change	Which climate feedbacks enhance or dampen the speed of climate change? Where are thresholds and tipping points?	How are water, land, and biodiversity affected by climate change, e.g., by drought, soil erosion, or flooding?	How do extreme weather and climate variability affect human livelihoods, health, income, and assets?	How does extreme weather affect social conflicts? How can research scenarios of impacts inform politics?
Natural resources	How do losses of natural resources affect climate change, e.g., through deforestation, ocean uptake, or desertification?	Are there relevant natural adaptation or substitution processes for the loss of natural resources?	How does resource availability affect human security? How to increase resilience and adaptive capacity?	Is conflict triggered by resource abundance or degradation? Does societal stability depend on natural resources?
Human security	Under which conditions do gains or losses of human security drive climate change and mitigation?	How does human (in-)security affect the use of natural resources? Does a decline in production reduce resource inputs?	Do elements of human (in-)security reinforce each other? Will security risks spread to neighbor regions?	Does human insecurity drive cooperation or conflict? Will human responses lead to social transformation?
Societal stability	How do social unrest and violent conflict affect carbon emissions? Will societal stability lead to climate mitigation?	How does societal stability affect resource exploitation? Can cooperation protect resource stocks?	How do conflict, societal instability, and cooperation affect human security and vulnerability?	Under which conditions do societies (de-)stabilize themselves or solve conflicts? What is the role of institutions?

states, the securing of borders (e.g., against disaster refugees), and access to resources (e.g., in the Mediterranean or Arctic region) [see (*36*)]. Other responses to climate change may also become causes of conflict, including bioenergy (as producers compete for land and food-related resources), nuclear power (which can lead to nuclear weapons proliferation), or geoengineering (through disagreements between states). Thus, there is a need for conflict-sensitive mitigation and adaptation strategies that contain conflict and contribute to cooperation via effective institutional frameworks, conflict management, and governance mechanisms.

Research Challenges

The balance between political and social factors and climate change could shift when the global temperature reaches levels that have been unprecedented in human history. There is reason to believe that such a change might overwhelm adaptive capacities and response mechanisms of both social and natural systems and thus lead to "tipping points" toward societal instability and an increased likelihood of violent conflict (*37*).

Although some fundamental issues have been raised in previous research, numerous interdisciplinary questions still need to be investigated to understand the feedback loops involved (Table 1). Models of the various linkages can build on a rich set of tools from complexity science, multi-agent systems, social-network analysis, and conflict assessment to extend previous data and experiences into future scenarios that cover different social, economic, and political contexts (*28*). Research across scientific disciplines will be needed to identify opportunities and coherent strategies to address societal challenges related to climate change.

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Supplementary Materials
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Table S1
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