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The next climate war? Statecraft, security, and weaponization in the geopolitics of a low-carbon future

Benjamin K. Sovacool [a,b,c,*], Chad Baum [a], Sean Low [a]

[a] Aarhus University, Denmark
[b] University of Sussex Business School, United Kingdom
[c] Department of Earth and Environment, Boston University, USA

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ABSTRACT

The impacts of global climate change on international security and geopolitics could be of historic proportion, challenging those of previous global threats such as nuclear weapons proliferation, the Great Depression, and terrorism. But while the evidence surrounding the security impacts of climate change is fairly well-understood and improving, less is known about the security risks to climate-technology deployment. In this study, we focus on the geopolitical, security, and military risks facing negative emissions and solar geoengineering options. Although controversial, these options could become the future backbone of a low-carbon or net-zero society, given that they avoid the need for coordinated or global action (and can be deployed by a smaller group of actors, even non-state actors), and that they can "buy time" for mitigation and other options to be scaled up. We utilize a large and diverse expert-interview exercise (N = 125) to critically examine the security risks associated with ten negative emission options (or greenhouse gas removal technologies) and ten solar geoengineering options (or solar radiation management technologies). We ask: What geopolitical considerations does deployment give rise to? What particular military applications exist? What risks do these options entail in terms of weaponization, misuse, and miscalculation? We examine such existing and prospective security risks across a novel conceptual framework envisioning their use as (i) diplomatic or military *negotiating tools*, (ii) *objectives* for building capacity, control, or deterrence, (iii) *targets* in ongoing conflicts, and (iv) *causes* of new conflicts. This enables us to capture a far broader spectrum of security concerns than those which exist in the extant literature and to go well beyond insights derived from climate modelling or game theory by drawing on a novel, rich, and original dataset of expert perceptions.

1. Introduction

The impacts of global climate change on international security could be of historic proportion, challenging those of previous global threats such as nuclear weapons proliferation, the Great Depression, and terrorism [1]. For instance, global economic damages from natural catastrophes, many of them climate related, have doubled every ten years and reached trillions of dollars per year in total damages over the past two decades [2]. The climate-change risks faced by developing countries are even more staggering in magnitude, including vulnerability to extreme weather, deteriorating national security, and degraded public health, among others [3,4]. More explicitly, melting glaciers could flood river valleys in Kashmir and Nepal, and reduced rainfall could aggravate water and food security so that 182 million people could die of disease epidemics and starvation attributable to climate change [5]. Under the most severe of these projections, if the Greenland Ice Sheet would melt, sea levels could rise by 6 m – enough to inundate almost all low lying island states as well as coastal areas from San Francisco and New York to Amsterdam and Tokyo [6]. Military analysts have therefore suggested that climate change acts as a "threat multiplier" to national-security concerns, something that takes existing problems and makes them worse, impinging on global stability [7].

But while the evidence base surrounding the security impacts of climate change are fairly well-understood and with such understanding ever improving, less is known about the security risks around the deployment of emergent climate technologies. In this study, we focus on the geopolitical, security [8], and military risks facing negative emissions and solar geoengineering options. We term this the "next climate

* Corresponding author. Aarhus University, Denmark.
E-mail address: benjaminso@hih.au.dk (B.K. Sovacool).

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war" with inspiration from Mann [9], who argued that the first "climate war" was a soft war about ideas and knowledge. That political war was waged over ideas and knowledge about climate change itself, and fuelled by a "thirty-year campaign to deflect blame and responsibility and delay action on climate change." Our study, by contrast, points out how the next climate war, a second one, would not necessarily be a cold war, and could very well involve active military conflict or hybrid warfare, even a "hot war" or global nuclear conflaguration.

Although controversial, negative emissions and geoengineering options could become the future backbone of a low-carbon or net-zero society, given that they avoid the need for coordinated or global action (and can be deployed by a smaller group of actors, even non-state actors) [10]. Negative emissions technologies may already be necessary to account for committed emissions resulting from economic activity (and "locked in" global warming) and gaps in implementation facing the Paris Agreement [11]. For these reasons, some of the the climate-science literature suggests that negative emissions options "are essential" [12] for reaching climate targets, represent "an inevitable component" [13] of technology portfolios, and are "physically needed" to curtail global warming [14]. Solar geoengineering options are also being heralded as ways to "buy time" for mitigation and negative-emissions options to be scaled up [15], and to help address unknown and potentially dangerous tipping points in the climatic system [16]. Some suggest that solar geoengineering "must be considered" as a feasible option for supplementing carbon abatement [17].

In this study, we utilize a large and diverse expert interview exercise (N = 125) to critically examine the geopolitical, security, and military issues associated with ten negative emission options (or greenhouse gas removal technologies) and ten solar geoengineering options (or solar radiation management technologies). We ask: What geopolitical considerations does deployment give rise to? What particular military applications exist? What risks do these options entail in terms of weaponization, misuse, and miscalculation? We examine such existing and prospective security risks by means of a novel conceptual framework that captures a far broader spectrum of security concerns than those which exist in the extant literature (see Section 2) and which go well beyond insights derived from climate modelling and game theory by drawing on a novel, rich, and original dataset of expert perceptions.

In doing so, we aim to make four contributions. First, we expand the geopolitical discussion of climate protection beyond only references to the ability for deployment or research of geoengineering to cause conflict [18]. Geoengineering as an actual weapon in war is plausible but currently deemed to be unlikely, while conflict to stop the deployment of geoengineering, or as a spill-over from its consideration and research, is more plausible [19,20]. Our study thus expands the depth and scope of connections between conflict and climate technology.

Second, the risks posed by climate change are currently seen to be illustrative of indirect threat multiplication: states openly developing, initiating, reacting, or prohibiting the deployment of some climate technologies, makes the climate change's diffuse problem structure more direct, and introduces a widespread "security logic" into climate governance. A key aspect is elevation out of "normal politics," circumventing usual systems of deliberation or checks and balances, with potential for systemic brinksmanship [21]. These options need not be deployed in order to for this to occur – active research and political platforms might suffice [22].

Third, we reveal governance spillovers and linkages – our inquiry extends a lens to potential consequences of negative emissions and solar geoengineering beyond climate security and securitization. Considering or deploying would have complicating effects within climate governance (coordinated efforts to mitigate and adapt) as well as in adjacent global governance issues across economy and environment.

Fourth and lastly, we build on recent conceptual advances on the new "green" geopolitics of energy, e.g., how the relative power of countries like Russia, India, China and the Middle East oil producers might be affected by low-carbon transitions, and what energy geopolitics may look like by mid-century. This focus aligns with recent calls for more politically informed and refined discussions of the future geopolitics of energy [23].

2. Climate technology, energy resources, and conflict: towards a conceptual framework

To both ground and contextualize our study and justify our conceptual framework, this section reviews key themes within the global political economy of energy and with a specific focus on conflict and climate change, conflict and energy resources, conflict and negative emissions technologies, and conflict and solar geoengineering. Notably, this does include earlier work on conventional energy systems as well as fossil fuels and energy resources. We contend that this literature had broader relevance for negative emissions and solar geoengineering technologies as a useful analogue to better understand how security and military concerns are treated among energy and climate scholars. Our review includes both empirical studies as well as conceptual ones. The section concludes with a synthetic conceptual framework.

2.1. Conflict and climate change

The climate-security literature treats climate change as a "threat multiplier" for violent conflict and – more prominently – the varied socio-economic conditions of human welfare. Key elements include: systemic causality, situated (unique to actor) vulnerabilities and points of failure, and mismatches between academic assessment and security planning [24–27]. There is a hybrid understanding of state and human security in an environmental context [28,29]. Security rationales on climate are forward-looking but conservative: warning about, but ultimately coping with the implications of a warming climate for political, economic, and military activities [30,31], rather than advocating for a fundamental reformation of root economic causes [32].

2.2. Conflict and energy resources

The literature on conflict and energy resources is the most robust and established (compared to the more emergent literature on negative emissions or solar geoengineering). Here we summarize four distinct intellectual threads: oil embargoes and wars, manipulating cross-border energy flows, sanctions and the use of "energy weapons," and work on energy resources and military conflict [33].

We first note the work on historical *oil embargoes and wars*, one of the most famous examples being the nationalization of the Suez Canal. In 1956, Egyptian President Gamel Abdel Nasser nationalized the Suez Canal, seizing a British asset and particularly salient symbol of its imperial past. The crisis brought commercial oil flows through the canal to a halt, leading to severe oil shortages in Western Europe, a situation the press dubbed "Europe's oil famine." [34] It also triggered a military response from the UK, France, and Israel. US President Dwight Eisenhower, wary that the conflict would play into Soviet hands, declined to send additional oil shipments to needy European countries until the British and French had withdrawn their troops from the area. The oil-starved British and French quickly succumbed to American pressure and, a year later, the canal was reopened [35]. The Yom Kippur War and oil embargo of 1973 is another classic example.

In terms of *manipulations of energy flows*, another line of evidence suggests that decades of progressing globalization have brought us to an age of "connectivity" that creates opportunities for states to "weaponize interdependence" [36] and to pursue war by other, predominantly economic, means [37]. States have long used – or tried to use – energy resources and related technologies as instruments of foreign policy, a practice known as "energy statecraft." [38]. These different techniques of energy statecraft can serve goals that are benign – for example, to foster peace and interdependence between countries – or less benign – to exert geopolitical leverage over other countries. States can attempt to manipulate cross-border flows of energy directly. They can do so through sanctions or boycotts, as in the iconic case of the 1973 Arab oil embargo. In the case of natural gas, the much-publicized Russian–Ukrainian gas crises have often been interpreted as instances of the so-called Russian "gas weapon." [39,40] Another opportunity to disrupt physical flows of energy lies not at the upstream point of production, but at the midstream segment – that is, transportation. Grid-based energy flows like pipelines or electricity transmission lines offer opportunities for sabotage or attacks. Long-distance pipelines that cross multiple countries can be disrupted by the transit countries [41]. While most of the time, these pipelines operate without any notable problem, politically motivated disruptions have occurred [42].

Sanctions and *boycotts* are another prominent tool, often used by importers. In the mid-1980s, for example, Europe and the United States joined the efforts of a number of developing countries to place an oil embargo against Apartheid-era South Africa [43,44].Another high-profile case is the current oil sanctions against Iran, or the post-2014 energy sanctions against Russia over their annexation of Crimea [45]. Sometimes, countries can utilize their energy infrastructure to exert geopolitical pressure or seek to *stop* sanctions. In November 2021, for example, the leader of Belarus threatened to cut off gas supplies to Europe, restricting access to their pipelines, if the European Union imposed sanctions for how Belarus was treating migrants wishing to enter Poland [46]. This shows how energy resources can be used as a tool to gain concessions over completely unrelated issues such as immigration, human rights and refugees.

Finally, and most seriously, energy has been a key source of *armed conflict*, though probably in different ways than most people think. The dominant view is that oil and gas are scarce resources, which thereby provides direct fuel for most international conflicts and wars. The rapid depletion of conventional reserves coupled with the fast-growing energy hunger of countries like China and India is believed to trigger "resource wars" between major consumers. In reality, there have been few actual wars initiated primarily to territorially conquer oil and gas fields [47]. The first Gulf War may be an example, as well as Japan's invasion of Indonesia during World War II, but it is hard to find other examples. Oil may have been a factor in several other wars – the US invasion of Iraq in 2003, for instance, or the Iran–Iraq War – but even in those instances it never was the sole or even primary *casus belli*. Conquering oil fields or destroying enemy oil installations and supply lines might explain some of the military developments in major conflicts – like, for instance, the battle of Stalingrad in World War II – but that is fundamentally different from causing the conflict itself.

The logical consequence of the resource-war narrative, which guides how most people think about oil in international affairs, is that petrostates are likely to be the target of an attack rather than act as the aggressor. However, the evidence points in the opposite direction. Jeff Colgan's work has shown that "petrostates," where revenues from oil exports constitute at least 10% of GDP, have an "above average propensity to engage in militarized interstate disputes." [48] He found that "petrostates" engaged in military conflict at a rate about 80% higher than non-petrostates over the period 1965–2001 – a phenomenon which he called "petro-aggression." His explanation was that revolutionary leaders are able to rely on oil export revenues to consolidate power and provoke international conflict. Thus the international trade in oil as currently structured places large amounts of money into a political system ill-equipped to use it responsibly [49]. Examples of revolutionary petrostates are Iraq under Saddam Hussein (who invaded Iran in 1980 and Kuwait in 1990), Libya under Gaddafi (who engaged in four separate border wars with Chad, as well as a variety of militarized disputes with other countries such as Egypt, Tanzania, and the US), and Russia under Putin (who engaged militarily in Georgia, Ukraine, and Syria) [50].

Oil also impacts international security through its complicated links with terrorism. The world's most celebrated international renegade, Osama bin Laden, cast the West's consumption of Persian Gulf energy as a central part of a complicated narrative that features the plundering of the Middle East's riches. Islamist insurgents appear to have taken these calls at least somewhat to heart and have mounted episodic attacks against energy targets. In February 2006, for example, the Saudis thwarted an attack on the oil-processing facility at Abqaiq [51]. Overall, however, the material effects of these (attempted) attacks have been limited. Recent research has also dispelled the myth that ISIS has been able to generate a large income from exploiting oil fields and refineries in Syria and northern Iraq [52].

Colgan also developed a typology of "causal pathways" between oil and international conflict, depicted in Table 1 [53]. It lists no less than eight mechanisms linking oil to war, including classic resource wars, petro-aggression, and terrorism. Sovacool and Walter looked explicitly at hydropower and noted five ways the literature suggests it can contribute to conflict: dams can be a military tool, can be targeted during military campaigns, can be attacked by non-state actors to promote their agendas, can be used for political goals (jobs, poverty reduction), and can be a source of contention in political debates [54].

Other work has focused on typologizing or classifying forms of energy conflict. Månsson notes that sometimes the end goal of a conflict is

Table 1
Causal pathways between oil and international conflict.

Dimension	Pathway	Causal mechanism	Example(s)
External and international: geopolitics and resources	Resource wars	Oil reserves raising the payoff of territorial conquest	Iraq–Kuwait, 1990; Chaco War, Japan, 1941
	Risk of market domination	Threat of conquest to ally or key territory	US–Iraq, 1991
	Oil industry grievances	Presence of foreign workers creates grievances for state or non-state actors	Al-Qaida; Iran hostage crisis
Internal and domestic: politics in producing countries	Petro-aggression	Oil reduces the accountability of leaders, lowering the risk of instigating wars	Iraq–Iran; Libya–Chad; Egypt
	Petro-insurgency	Oil income provides finances for actors to wage war	Iran–Hezbollah; Saudi Arabia–Afghanistan
	Externalization of civil wars	Oil creates conditions for civil war that then lead to foreign intervention or spillover	Libya–NATO; Angola–Cuba; Sudan–Chad
Internal and domestic: Access concerns in consuming countries	Transit route	Efforts to secure transit routes create a security dilemma	Sudan; South China Sea; Strait of Hormuz
	Obstacle to multilateralism	Importers attempt to curry favor with petrostates to prevent multilateral cooperation	US–China friction over Iran; Sudan

Source: Modified from [55].

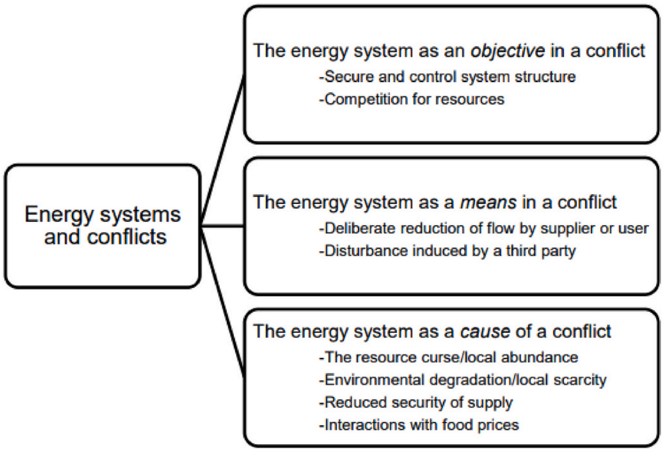

Fig. 1. A conceptual framework for energy resources and conflict.
Source [57]:

primarily for the participants to improve their own security by securing some part of the energy system, that is, energy is an objective in a conflict, such as the Iraqi invasion of Kuwait in the early 1990s (See Fig. 1) [56]. In a second category, an energy system is a means of initiating a conflict related to something else, such as Russia's use of its fossil-fuel exports to get concessions in other political areas from countries such as Belarus and Ukraine. In a third situation, an energy system is partly the root cause of a conflict, as it has destabilized a society and thereby contributed to, or exacerbated, a conflict, such as rapid environmental degradation causing refugees or creating social movements that try to topple governments, such as those ongoing with indigenous people in North America and Asia. Månsson then goes on to describe a fair number of actual conflicts that meet his typology, with dozens of examples including major wars but also border disputes, suppliers such as OPEC using their "oil weapon," and local attacks from terrorists and saboteurs in places such as Nigeria.

2.3. Conflict and negative emissions technologies

Only recently has a first framework been constructed to elucidate the potential geopolitical dimensions of negative emissions technologies as a broad suite of large-scale energy production, resource usage, carbon storage, and land-use systems [58]. Direct air capture approaches rely on massive energy costs which could be coupled with either existing fossil-fuel or novel renewable infrastructures - possessing the potential to entrench or reorient the global carbon economy and its geopolitics [59,60]. Meanwhile, land-use approaches (large-scale forestry or agricultural management) by necessity entail heavy spatial and resource usage as well as pose inequities and trade-offs for the populations currently resident on or adjacent to the land [61]. Ocean based and marine carbon removal, and even the protection of coral reefs for ecosystem restoration, could also intersect with fisheries conflicts around the world [62].

This deliberately geopolitical focus on various aspects of negative emissions and carbon removal is nascent, but raises issues highlighted by antecedent conflicts in global food systems. These studies cite land-grabs and ownership conflicts, the food versus ethanol dilemma (e.g. the 2005 global food crisis), "phantom commodities", the consequences of shifting prices in one-resource economies, and other issues and challenges confronting rural, smallholder communities – often accompanied by the particular pressures experienced by indigenous populations, or in the global South [63–65]. Others cite extractive industries in energy and other natural resources as relevant antecedents, raising questions of hazardous siting and carbon infrastructure lock-in [66]. As carbon removal technologies and their related approaches are looking beyond the terrestrial and into coastal and oceanic environments, some are increasingly concerned that the same logics of exploitation and conflict more familiar in the former could be repeated [67,68].

2.4. Conflict and solar geoengineering

The conflict literature is built mainly around stratospheric aerosol injection (SAI) – currently thought to be the only cost-effective, planetary-scale, and high-leverage form of solar geoengineering. Studies suggest that SAI could germinate contestation and conflict since its deployment would spread globally—aerosol injection would circulate similarly to the sulfur eruptions from volcanoes [69]. Moreover, extensive and recurrent global cooperation would be needed to sustain solar geoengineering for decades to centuries, and without interruption from wars and economic stresses, including unprecedented liability claims [70,71]. As such, geoengineering would pose long term maintenance and liability concerns for those countries that do deploy it. Others suggest that SAI's most resonant impacts may transpire ideologically, by fostering political brinksmanship [72] or by delaying decarbonization [73]. Dalby muses that security issues could make solar geoengineering the most important facet to "the new geopolitics of the Anthropocene." [74].

The benefits and risks of deploying solar geoengineering on a global scale are prominently projected by earth system models. But these are increasingly constructed as optimized, best-case scenarios that assume century-long technical controllability and global coordination [75,76] - and the value of these scenarios for geopolitical risk analysis and decision-making has been called into question for exactly this reason [77–79]. Key advocates also reduce security to "weaponization" - the direct use of SAI to impact an adversary's regional climate, weather patterns, and the systems they underpin. The implication is that SAI is too imprecise to directly weaponize, which may have merit – but a much more complex range of security issues is elided by this incorrect use of weaponization as a proxy [80].

SAI is less commonly imagined under non-ideal conditions, or as "unconventional" uses. These include deployments (or escalated research) conducted unilaterally, through proxy actors, via smaller coalitions, or in a decentralized set of deployments, or where multiple competing schemes attempt to offset each other [81–84].Some unconventional deployments have been assessed either as qualitative pieces of reasoning [85] or game-theoretic studies that calculate strategic state actions [86]. For some, unconventional scenarios are implausible and do not serve policy deliberation [87]. Others disagree - Corry argues that SAI research, or posturing – even without deployment – can serve as part of economic and diplomatic statecraft for achieving non-climate goals [88]. This is a valuable contribution; the goal of deploying SRM is usually assumed to be climate-related, rather than to (threaten to) affect climate as a proxy for other geopolitical aims. In this vein, Briggs and Matejova pose solar geoengineering as a potential kind of 'hybrid' conflict that combines eroding enemy infrastructure with technological, environmental, and economic dimensions [89].

2.5. Towards a synthetic conceptual framework

Drawing from these diverse strands of thought, we introduce a conceptual framework that captures a broader set of conditions and factors by which negative emissions and solar geoengineering options can shape geopolitics, statecraft, conflict, terrorism, and war (see Fig. 2). This framework explores four dimensions of how climate-technology deployment can interrelate with destabilizing politics, insecurity, and both internal and external conflict. The first is where climate technology can be utilized as a *negotiating* tool. In this category, climate geoengineering systems are used as a means by an actor to impair the security of other actors and achieve other, non-energy related, objectives. One example is geoengineering states deliberately using their power to get concessions on other things (trade, intellectual property). In the second dimension, climate technology is an *objective* for capacity,

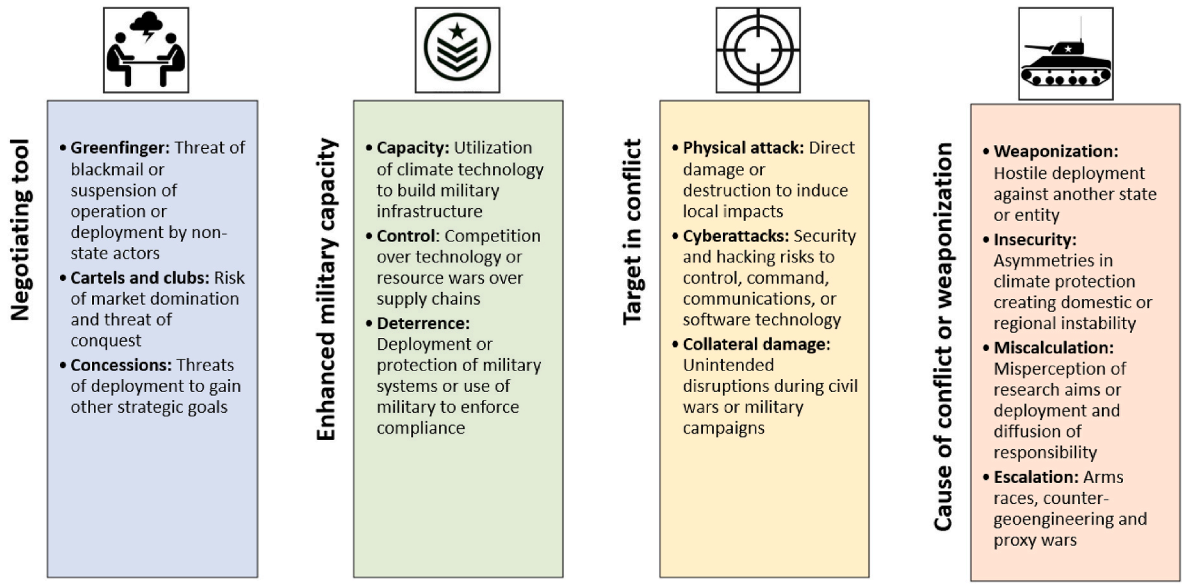

Figure 2. A conceptual framework for the geopolitics, securitization, and weaponization of negative emissions and solar geoengineering technologies.
Source: Authors. Although the qualitative analysis of our expert interview results (N = 125 participants) discusses numerous nuances and differences between the ability for various negative emissions and geoengineering technologies to create or contribute to conflict in the sections to come, we do approach them throughout the study from the same framework.

control, or deterrence. The end goal is for an actor or government to improve their own security by securing some part of the geoengineering system. Otherwise, deployment could be used to protect or enhance the security of existing military assets. In the third dimension, climate technology is a *target* in an ongoing conflict. This is where systems can be threatened or destroyed during existing disputes, civil wars, or regional conflicts. Such threats can be both intentional and accidental, as well as executed physically or through cyberattacks. In the final category, a climate technology or geoengineering system could even represent, solely or partly, the *cause of a new conflict*, as it has destabilized a society and thereby contributed to, or exacerbated, a conflict. For example, the exploration, production, or use of geoengineering resources can have side-effects that cause destabilizing environmental stress. In other cases, states may deploy weather modification or geoengineering as a hostile, intentional act.

We should note that these four broad dimensions operate at the level of ideal types. Some conflicts may be explained by several of the proposed categories or interactions between them. One example is a state that uses force to maintain control of a geoengineering system (first category), exploit such control to extort another state (second category), gain concessions during negotiation (third category) and reduce that state's environmental quality or weather, perhaps as a way to demonstrate its capacity to do so (fourth category). Most of the examples pointed to in our data fit cleanly within one dimension, but some cut across multiple dimensions. Furthermore, there are differences and varying degrees to which particular negative emissions or geoengineering technologies can engender conflict and instability. These include the much greater likelihood that a "switch on" or "switch off" of SRM would have a faster temperature response than carbon and greenhouse gas removal, the impact of the former on local weather patterns, the potential speed and ease of deployment of the former, and the relative lack of its buy-in in scientific and policy circles at this time. We will return to these themes in the Results and Conclusion.

3. Technology selection and research design

With our conceptual framework in place, this section briefly explains our selection of twenty different negative emissions and solar geoengineering options, elucidates our research design of original expert interviews, and discusses limitations with our approach.

3.1. Selecting a comprehensive portfolio of climate technologies

One novelty to our study is that it explores a broad diversity of negative emissions and solar geoengineering options and pathways. As Table 2 summarizes, this includes ten distinct options (drawn from the literature) including nature-based or terrestrial negative emissions technologies such as soil management, ecosystem restoration, and forestry as well as engineered solutions such as direct air capture and enhanced weathering. We also examine ten solar geoengineering options including various forms of albedo management, various ways of modifying clouds, the use of reflectors in space or the upper atmosphere, and stratospheric aerosol injection.

3.2. Research interviews

To determine the geopolitical and security risks that may arise with these 20 options, we relied on a large pool of semi-structured interviews, the asking of semi-structured questions in this instance to experts on the topic. We proceeded to interview prominent experts who had high levels of knowledge about our 20 options as evidenced by publishing high-quality peer-reviewed papers on the topic (from 2011 to 2020) or who possessed patents and intellectual property concerning the technologies. Moreover, our recruitment and sampling of experts focused on a mix of advocates and critics of both negative emissions technologies and solar geoengineering pathways.

We conducted 125 individual face-to-face interviews with experts closely associated with negative emissions and/or solar geoengineering research or commercialization over the course of May to August 2021. We explicitly asked, among other questions, "What are some of the governance or geopolitical risks with deployment?", "What particular military applications exist?", and "What risks do these options entail in terms of weaponization, misuse, and miscalculation?" Table 3 shows an overview of the demographics of our sample, and Annex I lists all 125 experts who participated (although it does not match them with their respondent numbers, to protect the anonymity of their statements). Although we did secure interviews with members of civil society and nongovernmental organizations as well those employed by governments

Table 2
Exploring a portfolio of negative emissions and solar geoengineering technologies.

Type	Option	Description
Negative emissions	Carbon capture and utilization and storage	Employing technologies, processes or solvents that extract, capture, transport, utilize, and/or store carbon dioxide
Negative emissions	Afforestation and reforestation	Planting trees or vegetation to absorb carbon dioxide
Negative emissions	Bioenergy with carbon capture and storage	Harnessing specific energy crops (e.g., perennial grasses, or short-rotation coppicing) or increased forest biomass to replace fossil fuels, and capturing and storing consequent carbon dioxide
Negative emissions	Biochar	Managing the thermal degradation of organic material in the absence of oxygen to increase soil carbon stocks and improve soil fertility
Negative emissions	Soil carbon sequestration or enrichment	Growing cover crops, leaving crop residues to decay in the field, applying manure or compost, using low- or no-till systems, and employing other land management techniques to improve soil
Negative emissions	Ocean iron fertilization	Utilizing planktonic algae and other microscopic plants to take up CO2 and convert it to organic matter, some of which sinks and is sequestered in ocean
Negative emissions	Enhanced weathering and ocean liming or alkalization	Deploying physical or chemical mechanisms to accelerate the geochemical processes that naturally absorb CO2 at slow rates.
Negative emissions	Direct air capture	Capturing carbon dioxide from the air via engineering or mechanical systems, and then using solvents or other techniques to store it safely
Negative emissions	Blue carbon and seagrass	Harnessing the ability for coastal mangrove forests, tidal marshes, and seagrass meadows to accelerate their uptake of carbon dioxide
Negative emissions	Ecosystem restoration	Managing the restoration of ecosystems (including wetlands, peatlands, and grasslands) to reverse environmental damage and increase their ability to absorb greenhouse gases
Solar geoengineering	Space mirrors	Placing scatterers, reflectors, or spacecraft in outer space to reduce the amount of sunlight entering the Earth's atmosphere
Solar geoengineering	High altitude sunshades	Placing scatterers or reflectors in the upper atmosphere (e.g., stratosphere) to reduce the amount of sunlight entering the Earth
Solar geoengineering	Stratospheric aerosol injection	Dispersing aerosol particles through high-altitude jets (e.g., sulfur) into the lower stratosphere, where they would reflect a small portion of incoming sunlight back to space, cooling temperatures.
Solar geoengineering	Cirrus cloud thinning	Reducing cirrus cloud cover to facilitate the release of outgoing radiation and lower temperature
Solar geoengineering	Marine sky or cloud brightening	Coordinating fleets of ships to spray sea water into the air below marine clouds, thereby increasing their reflectivity and longevity
Solar geoengineering	Albedo modification via human settlements	Enhancing the reflectivity of buildings, roads, or other structures to cool the global temperature
Solar geoengineering	Albedo modification via grasslands and crops	Enhancing the reflectivity of grasslands, crops, and land to cool the global temperature
Solar geoengineering	Albedo modification via deserts	Enhancing the reflectivity of deserts to cool the global temperature
Solar geoengineering	Albedo modification via clouds	Creating new clouds or reflecting more sunlight from the surface to increase the heating of the lower atmosphere, improving cloudy-sky shortwave climate forcing
Solar geoengineering	Ice protection	Protecting glaciers and ice sheets by either slowing their melting or reflecting solar radiation via tarpaulins

Source: Authors

and commercial entities in the private sector, the sample is strongly concentrated towards experts at universities and research institutes (or who split their time between universities and one of these other sectors). That said, the sample does include scholars from more than 30 disciplines as well as a dozen participants from the Global South. Given that interviewees were speaking on their own behalf, and also given the sensitivity of the topic, the data from these interviews is presented here as anonymous with a generic respondent number (e.g., R10 for respondent 10, or R110 for respondent 110).

3.3. Limitations

Before outlining the results, and despite the many benefits of our large and diverse sample of expert interviews, e.g. by facilitating triangulation of different viewpoints and the range of perspectives engaged, we here highlight some shortcomings of our research design. One drawback to anonymity is that there is no guarantee this study can be replicated, because the authors cannot correlate the identity of respondents with interviewee statements. Another is that respondents tended to be more critical than positive; the results below, for example, are more serious and sober in their outlook. This is *not* because the authors were selective about comments, but perhaps because anonymity itself incentivizes people to be more forthcoming about problems and issues instead of strengths. Moreover, we took an ethnographic approach that did not correct or problematize responses, so we present the data unfiltered, even if our respondents may have had misperceptions.

Lastly, we note that our conceptual framework (Section 2.5) was developed from the emerging research on the geopolitics of energy and resources. While this ensures that our discussion is well-grounded in an established literature, we note that negative emissions and solar geoengineering options are not exact analogues. They do represent (i) ways to demonstrate one's level of national commitment to tackling impending problems related to climate change but also (ii) the kinds of risk-limiting investments that are increasingly demanded to reduce the incidence and impact of climate disasters. Nevertheless, the importance of oil and other energy resources to national security stems from the fact

Table 3
Summary of the demographics of experts who took part in our study.

Summary information	No.
No. of experts	125
No. of organizations represented	104
No. of countries represented	21
No. of academic disciplines represented	34
Cumulative years spent in industry or the research community	881
Average years spent in industry or the research community	7.8
No. of experts whose current position falls into the following areas:	
Civil society and nongovernmental organizations	12
Government and intergovernmental organizations	8
Private sector and industrial associations	11
Universities and research institutes	94
No. of experts from the Global South	12

Source: Authors.

that much of modern civilization has been established around and by means of them [90]. We do not claim that solar geoengineering or negative-emissions infrastructures are perfectly analogous to a new oil industry, nor that the next climate war will identically resemble wars of the recent past. Rather, the increasing reliance on these climate technologies to mitigate and forestall climate disasters could unintentionally provide the invitation for them to become higher-priority targets as indispensable parts of energy supplies, resource extraction, food or security systems, or as tools for negotiation and political leverage.

4. Results and discussion: insecurity and conflict in a carbon neutral and solar geoengineering world

Our results from the interviews provide strong support for our conceptual framework.

4.1. Climate technology as a negotiating tool

In this category, negative emissions technologies and geoengineering systems are used by an actor as a means to impair and draw attention to the security of other parties and thereby achieve other, non-energy related, objectives. Our data supports the existence of three distinct categories: Greenfinger, cartels and clubs, and concessions.

4.1.1. Greenfinger

The term "Greenfinger" is meant to evoke the James Bond villain Goldfinger, highlighting in particular the threat of global blackmail or suspension of operation of climate systems as a negotiating tool, especially if done by rogue states or terrorists, but also for more benign motivations such as a billionaire with a "green finger" deciding they want to save the world via pre-emptive deployment. R045 captured this latter scenario well when noting that:

> A billionaire megalomaniac like Richard Branson could deploy geoengineering quickly, some crazy man like Elon Musk, the kind of person that is more likely to have a kind of messiah complex these days. This could be a very dangerous thing.

R085 also spoke about how "powerful people" and "hidden actors" with "no patience" could become convinced to deploy:

> At the moment, the most powerful set of actors who don't get sufficient attention in terms of their potential to deploy geoengineering are the Silicon Valley finance folks. Venture-capital money. People who are impatient for climate action, who have resources to drive change, who bring a kind of libertarian worldview, and are comfortable bypassing political systems. They will do disruptive things, make it happen, bypass need for legitimacy or debate, or meaningful public input, transparency, all the things in principle government funding as opposed to private capital, unfettered and unhinged, could or should provide. "Private philanthropy" is a concern in this space at this moment, in this vacuum of clear governance and understanding of appropriate roles, which can lead to bad decisions, driven by powerful people with no patience for process.

R081 agreed and added that "a *capitalistic dictator* like Bill Gates or Elon Musk could decide to deploy at a moment's notice, dictating for all of humanity a pathway for climate protection" *(emphasis added)*. R040 also identified blackmail as a real possibility with negative emissions options, as malign actors could "threaten to release all of the carbon from their reservoirs" unless their "demands were met." R047 agreed and stated that: "It's a nightmare, and it's a totally understandable nightmare … where this kind of research leads you either to semi-rogue action from hostile states or private-sector rich dudes with money that launch a program from their couch in Vanuatu." R109 surmised that "the special sauce of private sector is to be ruthless and quick and that's not a good prescription for things that have, potentially, such large consequences."

R020 added that it could even be rogue nations or community groups, or even ordinary individuals, who act with green fingers:

> I really do envision a potential "greenfinger" scenario where a wealthy individual simply decides to do it [to deploy a massive climate geoengineering project]. It could also be a club of rogue nations or a group of countries in peril, think Small Island Developing States in the Pacific that band together with Jack Ma, Jeff Bezos, and Bill Gates, there are quite a few billionaires to choose from. But it could also be ordinary people and communities. In the realm of social media, nothing is stopping a number of individuals jointly funding or crowdsourcing geoengineering without any governance. Through Facebook, I could see thousands of people buying balloons, letting these carry sulfuric acid into the stratosphere, thousands and thousands of people doing this with the strength of social media, then you have deployment totally ungoverned.

This scenario diffuses the risk beyond a single individual to any group of committed individuals able to pool their financial resources, triggering visions of the potential for such efforts to even be crowdsourced. One study termed this "predatory geoengineering" to capture the potential for self-concerned, but ultimately reckless, actors to deploy their technology without concern for or full consideration of the consequences for others [91]. Wagner also identified the possibility for "greenfinger" action at the subnational level as well as other highly centralized forms of technology deployment for solar geoengineering (see Table 4) [92].

4.1.2. Cartels and clubs

Regional blocs of both negative-emissions and solar-geoengineering cartels could prospectively emerge, with the ability to control the pace of global climate change according to their own desires and geoclimatic situations as well as utilize that power to either dominate markets or create geopolitical obstacles to multilateralism, conflict resolution, and cooperation. R047 stated this explicitly:

> Solar geoengineering leads directly to cartels or clubs who can deploy the technology in question, moving from an experimental program to deployment. Geopolitical power relates here to those who can deploy, and deploy unilaterally, making them almost identical to strategic use of missile-based nuclear weapons … there are breakout risks and the tools that we use for studying strategic nuclear-weapons control between the United States and the Soviet Union could be applied to these [climate] technologies.

Table 4
Number of actors and deployment pathways for geoengineering including a Greenfinger scenario.

Number of actors or deployers	1	~10	~100	>~1000
Form of governance	Unilateral	Minilateral	Multilateral	Chaotic
Nonstate actors	"Greenfinger"	Moderately decentralized nonstate solar geoengineering	Decentralized nonstate solar geoengineering	Highly decentralized nonstate solar geoengineering
Delivery mechanisms	Newly designed aircraft	A fleet of aircraft	Multiple fleets of aircraft	Multiple fleets of aircraft or small balloons

Source: Modified from [93].

This comment recasts the strategic value of climate technologies as equivalent to nuclear-weapons stockpiles. R047 went on to articulate that negative-emissions options also enable cartel-like behaviour given there will be small clubs of early deployers:

> For carbon dioxide removal, you have similar club risks. You can assume people who have large assets of land will be disproportionately powerful. All of the major options are highly dispersed - forestry potentially has bad above-ground governance, soil carbon near agriculture bad agricultural governance, underground injection into deep saline aquifers bad water governance, lots of storage or support space bad geologic governance. These would likely create broad-based coalitions of actors that deploy together.

R040 even put this in terms of the emergence of a new "Green" Organization of Petroleum Exporting Countries (OPEC):

> Some negative-emissions options could give rise to an OPEC situation, or the natural gas situation in Europe with Russia. If bioenergy with carbon capture relies on bioenergy, to some degree you could think of a new 'Green OPEC' situation. If we're going to make a big energy system with bioenergy, there are clearly producers and consumers. Western Europe would not be able to produce the amount of bioenergy in the way that it's projected in the scenarios. And if it's consuming these amounts of energy that are mentioned in the scenarios, then it could not produce enough bioenergy itself. So, it would be importing bioenergy from Brazil. There are a few countries that will be exporters of biomass: Brazil, Russia, Canada potentially. And again, the same situation that we have for fossil fuels might emerge. Where a set of countries could, at some point, if there is such a reliance, come to dominate the markets.

Such a "Green OPEC" could conceivably operate similar to the existing OPEC in terms of its attempts and mechanisms to control prices and access to resources, or even orchestrate embargoes. It could also emerge organically, as funding and policy coordination create coalitions of countries with similar interests, which could lead to "Big Green Deals" around the world and new regimes of cooperation [94].

4.1.3. Concessions

A final negotiating dimension to climate technology could be threats of weather modification or deployment to gain other concessions (e.g., trade, energy prices, changes in national policy) and meet other national objectives—in line with the "energy weapon" discussion in Section 2. R087 identified how hostile, manipulative use of solar geoengineering as a threat was the *most likely* scenario, noting:

> I feel conflicted, one of the most likely ways solar geoengineering will get used in a political context is as a political threat: tropical countries are vocal about negatively being impacted. They will say if you don't offer us compensation, help us address the harm, give us aid or preferable trade deals, we will be forced to take matters in our own hands.

R102 also emphasized the very real "potential for things to go wrong" and that there could be "a lot of room for diplomatic conflict" over the deployment of negative emissions and solar geoengineering options, since they could empower actors to make demands for concessions if they were in control of technology vital to stabilize the climate. R028 talks about how such concessions could potentially emerge through international negotiations:

> There will be people who are unhappy with any decision. What do you do about that? Some of the ways that international negotiations handle that is, they say, "Oh, you're unhappy with that? F*** you, too bad." Sometimes some people will pay them money. Sometimes there will be changes in markets that are allowed, like after the Gulf War, for example, gas prices just kind of looped up. Why? Because they needed to pay for the Gulf War, and that was a way to do it economically, and we just sort of said, "Yes, you can have it; that's fine." So, this sort of stuff, this kind of horse trading, it's really interesting, and it doesn't always go well.

Adding more detail, R106 proposed that, given the difficulty and complexity of attribution, an "authoritarian leader who wants to show he is in control of things", both to the world and his own population, need not even have the capability to engage in geoengineering; but rather: "you pretend to control things, even of course if you don't control the secondary, tertiary effects. But at least you show you are moving the controls." In this regard, one could imagine someone like Kim Jong Un attempting to demonstrate their capability in this area, similar to what is currently done for nuclear weapons.

4.2. Climate technology as an objective for capacity, control, or deterrence

In this category, climate technology becomes an objective for an actor to enhance their own security by building their military capacity, securing or controlling some part of the geoengineering system, or deterring others from attacking it.

4.2.1. Building military capacity

States for example could utilize geoengineering technologies to build their military capacity, similar to the dual-use option of things like nuclear technology (to make nuclear weapons or generate nuclear energy) or chemical manufacturing (which can manufacture chemical weapons). R070 spoke about these risks with solar-geoengineering options related to aerosols, sunshades, and space shields:

> Options that depend upon the expansion of an aerospace or space industry are a security risk, as you are bringing high-tech space industries into countries that don't normally have them. Players gain new capabilities that they didn't have before, and these could spillover into an arms race or new technology in the hands of new actors could become military or hostile, that could be a possibility. If a rogue nation develops launch systems, that opens a door to their launching new satellites or defence systems or even missiles, creating tensions.

R010 also spoke about how, while solar geoengineering techniques might not be realistic weapons themselves, they could become "coupled to weapons, by enhancing military capability, especially how much it would improve high-technology skills, skills that would be very useful for crossover impacts on military design." R090 noted that the United States Air Force and Navy would likely benefit from having to design new planes for aerosol injection, or some aspects of cloud thinning, enabling them, and companies like "Boeing or Lockheed to take billions of dollars from taxpayers."

Some respondents also spoke about military capacity and negative-emissions technologies. R028 suggested that carbon dioxide removal could build military capability in research or engineering, noting that "any time you do anything this large-scale, the military industrial complex gets involved, it's just totally unavoidable that they will benefit."

4.2.2. Control

Actors could also compete militarily or otherwise for resources critical to geoengineering as well as engage in resource wars over minerals or supply chains needed to manufacture climate technologies. One such resource would be the ocean, a resource necessary for large-scale enhanced weathering (as a basin for run-off materials and storage) or ocean iron fertilization. As R025 explained:

> The risk of conflict can be severe, risks are transboundary in nature, risks also transcend military security, can facilitate international conflict: e.g. the South China Sea and options such as ocean protection there would be highly contested. What if the impacts are more negative in one country, more beneficial in another?

R081 mentioned the potential for these new systems to usher in an era of new resource wars (conflicts over control of resources, or to control their consequences), stating that "we don't want to have these new climate technologies because they're hyper-centralised, they have enormous geological risks. They can produce what sociologists refer to as the resource curse." R084 elaborated on this theme as well:

> That there is potential for some of these techniques – and I'm thinking particularly here of carbon dioxide-removal techniques – to operate in parts of the world which are generally less economically developed. So there is potential for use of large land areas, sparsely populated, which often correlates with a low development index. But there's also risk of the resource conflicts where money flows to the elites in those societies, or corruption where benefits aren't actually what they're thought to be, because of poor governance.

In addition to the potential for conflicts between nations or actors located in disputed territories, here the prospect is raised of provoking or heightening conflict between groups belonging to a particular society.

4.2.3. Deterrence

Climate technology could enhance the protection of military systems, augmenting potential deterrence—avoiding attacks because perpetrators believe they would not be successful, or would prompt strong retaliation. R103 commented that he believed early deployment would likely "involve the military" and could be used in military operations or extreme environments to protect installations—especially things like ice protection (for Arctic and Antarctic military bases) or ocean alkalinisation or fertilization (for coastal naval bases). R011 also suggested that "the military will likely be an adopter, to protect its installations. One of the great threats of global warming is sea-level rise, and every naval base is at sea level, I can see them using geoengineering to build resilience." R064 spoke about how there could also be direct military use for synfuels via direct air capture—meaning this could help various militaries reduce dependence on fossil fuels, especially oil, and provide an opportunity to enhance power projection in the Middle East. R107 stated that he believed navies would deploy marine cloud-brightening, shading, or fogging options or could be called on to build installations or conduct ocean-geological activities.

A corollary to this argument is that the military may be used for another form of deterrence, to deter noncompliance with meeting climate or negative-emissions targets. R064 spoke about how they believed "the military could be sent in to enforce compliance or ensure that afforestation or large-scale CDR projects are protected, the military could protect them to deter their destruction." R063 also picked up on this theme:

> I could envision an entire shift in how navies or militaries operate. They no longer depend on kinetic power, as sources of influence, or killing people, but pivot to protecting people rather than harming them. I can see armies and navies getting sent in to protect forests or oceans, global public goods, to prevent them from being cut down.

Stuart Candy has even envisioned—hypothetically, of course—how such military deployment could occur in the mid-2020s or 2030s with the creation of a U.S. Earth Force to serve alongside the Army, Navy, Air Force, Marines and Coast Guard, tasked with ensuring global climate security and enforcing compliance with international targets [95]. Fig. 3 shows what a futuristic advertising campaign might look like for such military deployment, in the name of deterrence of climate insecurity. Candy also asks one to imagine what could be accomplished if such military resources were repurposed towards climate-stability ends.

4.3. Climate technology as target in an ongoing conflict

This category encompasses when or where climate technologies or geoengineering systems could be threatened or destroyed during ongoing disputes, civil wars, or regional conflicts, notably via physical attack, cyberattack, or accidental collateral damage.

4.3.1. Intentional physical attack

The direct destruction of geoengineering systems could be of strategic value during ongoing military campaigns or conflicts as it would induce localized climate-change effects or decrease the morale of enemy populations. R002 said that:

> Stratospheric aerosol injection, cirrus cloud thinning, and cloud brightening could be all be military targets themselves. Countries could target them as key infrastructure during ongoing conflicts, just like militaries target power lines or GPS satellites and critical infrastructure now.

R064 added that "shooting down the planes doing aerosol injection, sinking the ships doing ocean protection, could be very plausible during conflicts." R056 noted as well that "high-altitude sunshades would be prone to regional targeting in a conflict," R099 mentioned the same vulnerability for "shooting down balloons" to stop aerosol injection.

Such attacks do not have to be direct. R002 expressed concern about the connections between cloud brightening or cloud thinning and military deployments, noting that they could be used for light versions of weather modification that could help enhance the potential for military success:

> You could potentially use it for weather modification because you can vary the perturbation on the timescale of days and at as fine a spatial scale as your intervention is done. So, if you've got, whatever it is, 500 ships that are doing this deployment, you could turn half on, half off. Eventually, what you would have is you could run your weather forecast with or without your marine cloud brightening on and then you could pick which weather forecast you like better, whichever one suits your military deployment or targeting.

R011 added that:

> I am not sure if it can be used as a weapon per se, but many of these technologies are linked with the longer history of climate and weather modification, where military uses of the technology are significant. The United States seeded clouds over Cuba to try to ruin the sugar harvest, and the government also did the same to try to make the Ho Chi Minh trail muddier in Vietnam … These technologies enhance the opportunity for the CIA to possibly control the weather of other states. I am sure the military is thinking about it.

Although seemingly innocuous, these sorts of changes could tip the

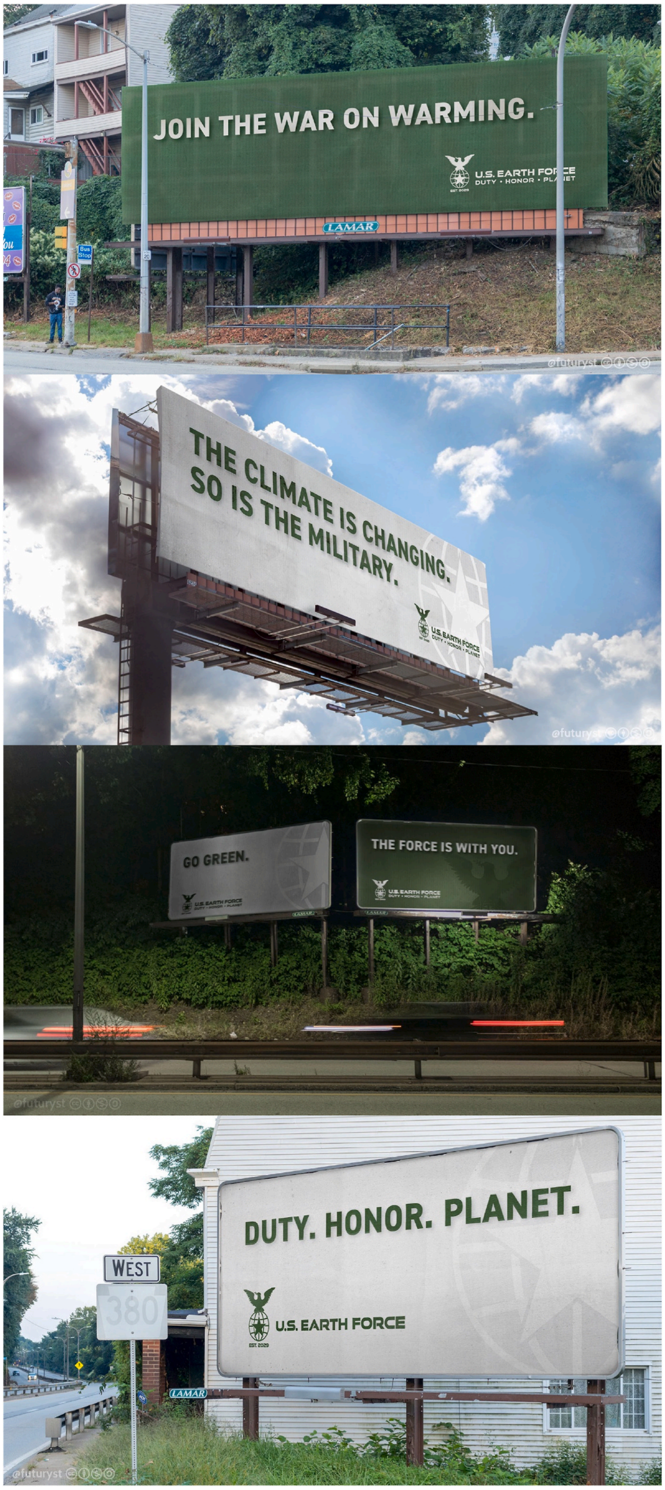

Fig. 3. A hypothetical deployment of a militarized U.S. "Earth Force" to enforce climate targets and deter carbon emissions.
Source: Stuart Candy (used with permission).

scales of future battlefields marginally towards victory.

4.3.2. Cyberattacks and information warfare

Our participants mentioned various risks related to security and hacking for control, command, communications, and software, including ransomware. R034 put it this way:

> We've weaponized the internet and software, so certainly something as physical as carbon dioxide removal or solar geoengineering has a very real security vulnerability. The control systems, the software systems would all be prone to cyberattack.

R070 also discussed the risk of "terrorism" and "cyberterrorism" against the "control centers" for solar geoengineering, adding that "due to hacking, one could lose the system partially or completely." R081 even spoke about how carbon dioxide-storage facilities could be prone to "hacking, the systems controlling them could be hacked." As they went on to explain:

> Some inventive people might intentionally attack a system, there are some people who can turn everything into a weapon. I mean, reservoirs might be interesting for pirates and blackmailing, but I think the attack will not be physical. I think the attack will be mostly on software so the systems might be hacked, and you might blackmail whatever, a company or government who will say "if you are not paying me, whatever, ten billion Bitcoins, I'm going to release ten gigatons of carbon in an instantaneous impulse from your reservoir" … terroristic attacks or some kind of hacker attacks on the reservoirs are a risk.

4.3.3. Accidental collateral damage

Unintended disruptions during other conflicts (e.g., civil wars, military campaigns) came up as a final concern. R055 said that "there is enough collateral damage already during conflicts, power plants and pipelines get attacked or destroyed all the time, I don't see why geoengineering infrastructure would be any different." R100 added that "negative emissions technologies would need to be ubiquitous by 2050 or 2070 to the point where they would certainly be deployed among fragile states or within war zones, carbon-storage reservoirs would also invariably exist in some conflict zones, all of this would create a security risk."

4.4. Climate technology as a cause of new conflict

In this final category, climate technologies are solely or partly the cause of conflict, notably, by destabilizing a society and thereby contributing to a new conflict. Our evidence supports four different aspects to this dimension: weaponization and hostile deployment, insecurity and asymmetrical protection, miscalculation, and arms races along with counter-geoengineering.

4.4.1. Weaponization and hostile deployment

Weaponization would be the most direct route to conflict, as it involves the hostile deployment of climate technology (most likely, though not limited to, weather modification) against another state or entity leading to a great power war. Some of these weapons could be quite powerful. R096 argued that deployment of some ocean technologies could even be engineered to cause mass dead zones (affecting fishing and food supply):

> If governments cannot be trusted with human rights or fairly benign technologies, then they cannot be trusted with these technologies, the risks of them being used as weapons is too large. Ocean-based carbon dioxide removal or fertilization could be weaponized, with enormous consequences for fisheries. One could even devastate fishing areas by creating dead zones.

R063 agreed and also noted that "ocean fertilization can create dead zones, so economic disruption to fishing stocks and the protein source for many coastal countries could be jeopardized."

Others spoke about the conversion of climate technologies into weapons that could affect rainfall, kill off agriculture of affect crops, degrade forests, or interfere with water security. R034 stated that:

> Many of the solar geoengineering options raise the same concerns about weather modification or rainfall modification. There is a strong risk of effects to crops and food security, because of changes in solar radiation.

R047 even spoke about fears that "Chinese actors will use solar geoengineering to intentionally disrupt the monsoon to harm India." R104 also noted that many negative-emissions and solar geoengineering options could give states "the ability to specifically target and disrupt other ecosystems, including forests." As R104 went on to explain, centralized systems and large-scale systems would aggravate this particular security risk:

> Yes, so the ability to impact other people's ecosystems in targeted or general ways goes up the more you do atmospheric management systems, whether it's because you're going to see things or you're going to unsee things, so risks of conflict over rainfall, as terrestrial water systems get overbuilt, go up. So, there are a lot of built-in risks to the more centralised system, whether it is a source of disruption or a target.

This statement also confirms that deployment could threaten corollary systems related to things like water supply. R007 added that "if stratospheric nanoparticles can direct sunlight into particular areas, this can become a very serious security issue or weapon." R035 spoke about how recent research advances in "stratosphere-troposphere coupling" could enable a military to "change the positions of the weather patterns and the jet streams and the rest of it, by affecting the circulations of radiation or ozone in the stratosphere."

Other respondents spoke about why climate technologies would make optimal weapons, with arguments grounded in their ability to be rapidly deployed and cheaply produced. R002 suggested that some options could be deployed in *days* rather than months: "cirrus cloud thinning and cloud brightening can change weather in a matter of days, you could equip 500 ships to do it very quickly." R047 argued weaponization could be done cheaply as well, with a crude military program costing only $10 billion a year, so cheap "even Bangladesh or a Belarus can afford it." R024 also expressed concern these options would make "fast, dirty, and cheap" weapons.

In terms of governance and the likely repercussions of hostile use, R099 added that should such deployment occur, there is little in terms of governance or international control to stop it:

> In terms of weaponization, there is no mechanism to deal with such conflicts, should they arise. The United Nations General Assembly and climate convention are all very weak, majority-based, consensus-based approaches with no binding power. The Security Council is incompetent and has zero legitimacy where it matters. The international community is absolutely unfit to deal with these sorts of security challenges.

The 1976 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) expressly forbids weather modification as a weapon, but Horton and Reynolds write that it is unlikely to stop or prohibit hostile states from using it if they wanted to [96]. R106 expressed concern that "if you are going to suffer from climate change, and you have only one chance to improve your situation by weaponizing the technology, you won't care if the international community accepts it."

Deployment among populist or authoritarian states is an added driver to this concern, as such regimes are unlikely to worry about international-relations repercussions and they would not be "contained" in the way many democratic states would be [97]. R106 expanded on this theme, and stated that:

> The Chinese regime could readily resort to solar geoengineering technologies, given their longstanding experience now with weather modification on smaller scales. They think that the Olympics in 2008 were a success, in terms of weather modification. It eventually boils down to the calculation of the leader, whether the direct risk of a climate change impact to himself or herself is higher than the uncertain risk that eventually will come. And of course, again, the question is, how ruthless is the leader? I am now getting into really historical [comparisons] that may be disturbing, but Hitler said, when the war was clearly lost, "Now I am willing to go down and also destroy the whole country." Well, we have seen authoritarian leaders who are willing to tolerate a lot of collateral damage. And they may be willing to deploy solar geoengineering to do the same.

R007 iterated how they believed "the Indians, Russians, and Chinese are thinking about weaponization of these options, and they are not covered by the same legal constraints as the United States or the ENMOD treaty … I am also sure a regime like North Korea would love it."

Some respondents spoke not about specific applications as weapons, but grander, larger security concerns such as shifting geopolitical trends and even the risk of great power wars. R045 said that:

> Deployment could lead to real conflict between nations. There are inherent political and strategic risks from deployment. There is the very profound risk of geopolitical conflict arising from any nation or group of nations being able to control the global thermostat or the climate system and placing control in their own hands and no one else. This is an enormous danger to the international world order. All sorts of conflicts could emerge between major powers, e.g. Russia spraying sulphate aerosols in the Arctic, the USA responds dangerously. Or unexpected environmental impacts, like the shift of the Indian monsoon, another Cuban Missile crisis could emerge over sulphate aerosols around the world. That is a most profound risk.

R071 even argued that these climate technologies are as dangerous as nuclear weapons and could even result in nuclear war, noting: "once you put your hand on the thermostat and can control the global thermostat, this can lead to the real risk of military conflict. It could lead to people fighting with nuclear weapons over who does it."

4.4.2. Insecurity and asymmetrical protection

This aspect captures insecurity via asymmetries in the levels of climate protection that are feasible or affordable across countries and which could thus propagate in internal or regional political instability. R113 spoke about how negative-emissions development would likely strain existing land-based systems for food, forests, and water, generating internal insecurity:

> Yes, absolutely, there are negative impacts domestically. So for bioenergy with carbon capture and storage, you grow crops, you don't have access to land for other purposes, you lose capacity for development, whatever it may be, as well as food, you affect water supplies, you have trade-offs with crop growth. Afforestation can lead to changes in precipitation patterns, and you have trade-offs then with decisions about location of carbon dioxide removal investment infrastructure against changes in weather patterns locally, which is a really big problem.

R111 also spoke about the risk of deployment causing "cascading impacts" to local ecosystems wherever options are deployed:

> If a country will hypothetically reduce temperature and deploy options at large-scale, we don't know what is going to be the impact on humans or ecosystem or animals or plants. If we are going to change rainfall patterns, we don't know how it will impact agriculture. There might be a region where there is normal rainfall and we do sun shields or aerosol injection, and then it is going to change rainfall patterns … There are so many known unknowns.

R112 agreed and also noted multiple ways that climate technologies could aggravate stress to land and water resources, with spill over impacts that are "huge:"

> The negative effects on food and food security, on acidification of water, on ecosystems, particularly rivers, on food supply, on freshwater fish, could be serious … And if you imagine that something like that occurring in a geopolitical hotspot like the River Jordan, if the River Jordan is affected upstream, the implications politically in terms of security downstream are huge, absolutely huge.

R028 noted how some governments are already deploying pilot projects to enhance the weather, pointing to “Sky River”:

> That’s China’s program to do weather modification to create rain over inland China. It has massive transboundary issues. When anyone builds a dam upstream, people downstream care about it, so you can imagine how much insecurity this program can create.

R076 added that even nature-based efforts like afforestation programs could present security risks when done at scale; they suggested that “things like the Trillion Trees initiative have a serious risk of ignoring the complexity of ecosystems and disrupting a host of natural systems all for the purpose of sinking carbon … it could be destabilizing to many communities.” Indeed, in their own assessment Horton and Reynolds concluded that “even if militarization and direct conflict are unlikely, the indirect effects of climate engineering could operate as drivers of existing conflicts.” [98].

4.4.3. Miscalculation

Hostile deployment may not need to be “real” in order for it to spawn conflict; it could instead result due to misperceptions of what has occurred or be prone to miscalculation. R001 articulated this extremely well under the term of “indirect weaponization” or “political weaponization:”

> The political risks of deployment are very hard to predict, it depends on who is doing it, how it is being done, and who is deciding. It might not even need to be done to be a risk, to procreate a geopolitical conflict. A country could accuse their neighbour of doing strategic aerosol injection if their rainfall patterns have changed, or they saw some suspicious aircraft activity, or the signal-to-noise ratio for understanding atmospheric dynamics seemed different. It is hard to say with certainty and a short period of time whether one has done it, which means it could be used politically even without actually being used; a ploy, or an indirect or political weapon in that sense. It doesn’t have to be technically feasible to have a political effect as a signalling effect, to feed into a process of political weaponization. The fact that many options are believed to be cheap, fast, and easy only makes this political threat more credible.

R047 framed the risk in terms of “inadvertent weaponization” or “psychological weaponization:”

> It’s possible that you could inadvertently weaponize these options. So you start a programme, and then there’s a rapid warming that happens when you stop doing that stuff. In the termination-risk world, you could accidentally weaponize something, because you stopped paying attention to it. You could accidentally allow your virus to sneak out of your lab, because you weren’t paying attention to that problem. So in that sense, it’s not so much weaponization as just being an idiot, and then accidentally causing massive harm to the world. The perception of weaponization, though, is more interesting. If we knew there was a fleet of Chinese or Russian aircraft flying around, modifying the climate, that’s psychological weaponization. It could make everyone feel vulnerable.

These issues of weaponization or a termination shock have even permeated recent popular literature, with Neal Stephenson’s *Termination Shock* and Gwynne Dwyer’s *Climate Wars* coming to mind.

R007 added that misperception could involve not only deployment, but intent to deploy, or concentrated research in an area, all which could feed “conspiracy theories” that lead to uncertainty:

> What I tend to write about are the security risks, and I don’t mean security risks in terms of militaries necessarily going to war with one another over these technologies, but more in terms of the unpredictability of impacts, the difficulty in attributing changes in environmental systems to particular actions, and then the whole background of misinformation, conspiracies, and what not. Which means that any country that tries to deploy these technologies, and especially the more space-age technology it is, the more uncertainty there is going to be, at least in terms of social acceptability and conspiracies. Say you put up a sunshade or some sort of mirror, and then something else happens, somewhere in the world, and then people are going to attribute it to that; they’re going to draw a direct line between A and W, regardless of how many points are in between.

R020 spoke about how such miscalculation could even lead to great power wars (having the same effect as weaponized deployment in 4.4.1, but without the intent):

> Imagine that stratospheric aerosol injection takes place, especially if it’s a unilateral kind and then the monsoons in India are failing, even if you can’t actually prove that is because of geoengineering, the perception is enough to create the Third World War, especially if it’s China doing the geoengineering and India is suffering.

R064 similarly envisioned a scenario where:

> India decides to start solar geoengineering, a few years later major floods occur in Pakistan. Pakistani politicians blame these on India. Whether physically plausible or attributable doesn’t matter, geopolitical rivals can use it in a way that sparks or intensifies conflict.

In such situations, determining causation or responsibility wouldn’t matter, as “victimized states” could cast blame regardless of whether they actually believed someone was at fault, even if just as a means to distract the public and promote a “rally round the flag” response. And in response, they could still posture and demand compensation, retaliate with sanctions, or even attack soft targets [99].

4.4.4. Escalation

Our last mechanism for potential conflict via climate technology concerns the risk of escalation via arms races, counter-geoengineering, and proxy wars. R064 identified this risk as weaponization via “arms races” or “technology races," noting that “types of adversarial conflict could also emerge like an arms race of accelerated deployment.” R098 captured this risk eloquently:

> With geoengineering, countries could say “Others are creating a risky political climate, and then we have to respond that.” That’s the way we justified our massive infrastructure on biological and chemical weapons. We just said, “Oh, the Soviets are doing it. We have to prepare for that.” That’s why we responded with this kind of research … and a "let’s see what happens" attitude.

Development or deployment could generate a competitive political dynamic that incentivizes countries to all match or even exceed rivals’ funding efforts for negative emissions or solar geoengineering, resulting in a “capacity race” [100].

An additional dynamic within this risk has been termed “counter-geoengineering,” whereby countries start to develop technical capabilities to modify the climate or deploy their own geoengineering, in order to counteract the unwanted activities of others and with the core strategic intent of stopping it. R022 explained this logic as follows:

> The idea of counter-geoengineering is that even if you didn’t want a neighbour to do it, you develop the capabilities to do it. You might tell me: “Look, you start putting up sulphates and I’m going to release loads of difluoromethane." If you’re able to credibly threaten to counter-geoengineer, that gives you a veto over my deployment. Therefore, no-one can unilaterally do solar geoengineering until there’s an agreement amongst everyone who has the power to

counter-geoengineer…. from a game-theoretic perspective it is plausible that, if you could create counter-geoengineering, then it would mean no unilateralism and enforced negotiation over its use.

R071 similarly hypothesized how a country could threaten to release ozone-depleting substances to stop another state from deploying aerosols:

Well, a state could counter aerosol deployment by responding with chlorofluorocarbons. Chlorofluorocarbons are cheap to produce and they're really efficient in heating the system, but of course now you're really setting up your own control on the climate system. Their intervention could be focused on climate forcing, a state could respond with counter-forcing: a logical response in my view.

R074 spoke about how such actions will likely lead to multiple non-cooperative and detrimental games (in the game-theoretic sense) among state actors:

The non-cooperative game potential is terrible, because you're just deploying in two different directions and all the different side effects, they will just accumulate. And in the end, we will not see a lot of cooling or changes to the climate, but we will see a lot of military conflict, a lot of, maybe, environmental side effects, and so on, and so on. If it becomes a game purely of countries not talking to each other and being just adversaries, then counter-engineering would be pretty bad … It's definitely the case that counter-engineering would increase the fragility of the whole system, because if cooperation then breaks down at some point in time, well, we don't want to see that world happening.

R091 also spoke about how counter-geoengineering not only creates destabilizing political effects but wastes resources and leads to sub-optimal outcomes as well, as "counter geoengineering sees a lot of money being spent with very limited effects on the temperature and a lot of other negative physical effects of these technologies being deployed and nothing happening." They also noted that such counter-engineering could occur the moment any country initiates large-scale deployment: "the moment that you have deployment, especially without global agreement, all of a sudden counter-geoengineering becomes very relevant and very important."

As a final aspect of this risk, two respondents (R044, R081) mentioned how the revenues from geoengineering could enable actors to be aggressive, to instigate wars or finance the waging of war, with the proceeds or financial gains made from investing in climate technology.

5. Counterpoints: de-securitization, threat deflation, and permissive tolerance

Much of the perspectives above discuss the threat of climate technologies and reveal how climate action can be securitized or contribute to arms races and militarization. But there are also strong undercurrents throughout our interview data downplaying the threats posed by these technologies, seeking to de-securitize the discussion. Some data also elaborates on the likelihood that states will simultaneously support and oppose deployment in different constituencies and to different ends, depending on how such actions fit within their agendas.

5.1. De-securitization and threat deflation

Some of our experts, rather than constructing climate technologies as a security threat or potential weapon, argued the opposite, believing that such technologies would make poor weapons and would contribute little to militarization. R001 spoke about how direct weaponization of solar geoengineering would depend on predictability, provability, precision and control, while emphasizing how these would not be likely with negative emissions technologies:

Direct weaponization is unlikely in my view, given the unpredictability of these options, and also provability, lack of precision, to show that it's been done is difficult. In short: these technologies are not good enough to be used as reliable weapons. Which leads me to then ask: If the military cannot depend on them for a climate weapon, can we depend on them for climate protection?

R023 added that: "I realize some people are concerned about militarization, but I believe there are much easier ways of conducting war." R042 also stated that:

If I am a rogue state, and I want to do something bad to another one, I would use digital technologies, why would you even need negative emissions or solar geoengineering? There are so many available cheaper, more proven, cost-effective conventional weapons. I am not so worried about the geopolitical risks to these nascent and unproven climate technologies.

R071 stated that: "I don't want to think as a terrorist, but there are other ways to mess up society much faster than trying to geoengineer the climate; terrorists have much nastier things at their disposal." R085 agreed and noted that "strategic aerosol injection makes for a lousy weapon." R097 added that:

I'm pretty firmly on the side of the fact that it's very, very hard to weaponize. It's not targetable, it's not discriminative, you can't aim it, as far as I understand. Now, that's not to say that there wouldn't be harms from one country to another. If India did it, it could have harms on China or vice versa, certainly. But as a weapon, it's extremely crude. There are much better weapons to use, much more targeted weapons, if you wanted to harm somebody. Certainly, you can use the environment as a weapon. The US did it in Vietnam, and Saddam Hussein did it in the first Gulf War. You could break a dam. These would all make more effective weapons than climate technologies.

One theme in our data was the difficulty of using negative emissions technologies as weapons. R047 noted that negative emissions technologies "do not seem weaponizable; nobody is trembling in their boots." R064 concurred when they noted that "carbon dioxide removal doesn't have any weaponization issues, partially because it's so slow, even if they were used in an India-China war, freezing CO2 out of the atmosphere: this would be a decade-long project, making it implausible as a weapon."

One of the key challenges to using solar geoengineering specifically as a weapon was lack of precision in its targeting and accuracy in use. R047 explained it this way:

One has to distinguish between perception and reality. Reality is, it would be very hard to weaponize the technology, because solar geoengineering as we understand it is essentially a zonal play. So you're putting particles into the stratosphere. Then, in the stratosphere, they're mixed zonally, so within a 5 or 10-degree latitude band, roughly at altitude. Then they slowly diffuse out of the zone, such that they cover an entire hemisphere in a year or so. Then they do inter-hemisphere transfer within 2 or 3 years. The problem is, by the time you're getting to inter-hemisphere transfer, your particles are already raining out, so you need to continually refresh. What happens when you do this is, you overweight the injection of particles into your zone. Wherever your aircraft have access, you have this 5 or 10-degree range of where they cause damage. This is a very imprecise weapon … So you could deploy these things, and then they would zonally mix. But that means that weaponizing the system is pretty hard, because the effects are zonally distributed, and you're going to get hurt, or plausibly, as hurt.

The last part of this statement is telling because it also indicates that weaponization of solar geoengineering could cause as much harm to the country initiating the attack as to the one receiving it. R064 also spoke about difficulty in targeting for such systems. In their view:

> Weaponization not plausible, they are too poorly targeted. The basic problem for stratospheric aerosol injection is that it is close to impossible to perfect the targeting, hemispheric or even global deployment. If you are a Great Power X, and you want to use it to harm geopolitical rival or enemy Y, maybe you get some sort of serious effect for them, but you will have all sorts of other effects on other countries, including allies, and even yourself. Militaries are moving to precision weapons: this isn't that; this is a blunt weapon that would just widen any conflict.

It may very well be less likely that negative emissions and solar geoengineering technologies will be used in warfare, but more likely that these technologies will be used to restrict the development of related industries in other countries. For example, in the future, after solar photovoltaic systems could come to occupy a large proportion of the power generation structure, the power system can be destroyed by destroying the photovoltaic system, and thus provide an advantage in warfare. Therefore, the role of these new climate technologies in warfare is perceived by some experts as more indirect than as a direct weapon.

5.2. Permissive tolerance, strategic ambiguity and brinksmanship

A second complicating factor emerging from our data was that states would be more strategic about simultaneously supporting and restricting the military applications of climate-engineering technologies, a sort of "permissive tolerance" where actors would complain if something went wrong but would openly support options that went right. R098 articulated that:

> The most realistic political response that I see involves a lot of permissive tolerance. This refers to an attitude of "Let others do stuff, and then just wait and see." Officially, you can always complain but you're kind of happy that somebody else is taking the blame. And let's see what happens.

The potential for permissive tolerance and brinkmanship complicates the security risks posed in Section 4, as it implies states could pursue a more complex pathway of strategic ambiguity. They could discretely pursue contradictory aims and ends with their technologies, or publicly assume different stances when it comes to the use and deployment of said technologies.

6. Conclusion

Although the future impacts of climate change on global security remain uncertain, one certainty is that the deployment of climate-engineering options could have profound security implications for states, regions, and even the global political system. As summarized in Table 5, low-carbon technologies could be used as military negotiating tools, as mechanisms to build military capacity or secure resources and supply chains, as physical or cyber targets in ongoing conflicts, or as major causes of new conflicts arising from direct weaponization, direct and adverse impacts on insecurity, or even the risks of miscalculation or escalation via counter-geoengineering.

Our expert-interview exercise with leading thinkers on the topic revealed how climate technologies can potentially propagate very different types of conflict at different scales and among diverse political actors. Conflict and war could be pursued intentionally (direct targeted deployment, especially weather-modification efforts targeting key resources such as fishing, agriculture, or forests) or result accidently (unintended collateral damage during existing conflicts or even owing to miscalculation). Conflict could be over material resources (mines or technology supply chains) or even immaterial resources (patents, software, control systems prone to hacking). The protagonists of conflict could be unilateral (a state, a populist leader, a billionaire) or multilateral in nature (via cartels and clubs, a new "Green OPEC"). Research and deployment could exacerbate ongoing instability and conflict, or cause and contribute to entirely new conflicts. Militarization could be over perceptions of unauthorized or destabilizing deployment (India worrying that China has utilized it to affect the monsoon cycle), or to enforce deployment or deter noncompliance (militaries sent in to protect carbon reservoirs or large-scale afforestation or ecosystem projects). Conflict potential could involve a catastrophic, one-off event such as a great power war or nuclear war, or instead a more chronic and recurring series of events, such as heightening tensions in the global political system to the point of miscalculation, counter-geoengineering, permissive tolerance and brinksmanship.

Moreover, our findings point the way towards fruitful research directions. In this study, we interviewed a broad sample of experts about the military and security issues arising with negative emissions and geoengineering. But future work could more directly engage with military and security practitioners themselves. Many of the 20 technologies we examine within the GENIE project are still immature, and as a result the scale of their application will change greatly in the future, along with their potential impact on warfare. Future analysis should explore varying pathways through which the different technologies could impact warfare, at different time stages, and refine those scenarios as more knowledge is accumulated and uncertainty diminishes.

Nevertheless, the varied and compelling ways in which climate-technology deployment links to multiple dimensions of security and conflict strongly suggest that the topic deserves far greater attention within the political science, geopolitics, and international relations literatures. Particularly, there is a strong need for research on the prospective geopolitics of solar geoengineering and negative emissions. But it also unveils the myriad ways in which a net-zero, carbon-neutral world could be more politically destabilized and geopolitically insecure than our current (already unstable) world order. States and actors will need to proceed even more cautiously in the future if they are to avoid making these predictions into reality, and more effective governance

Table 5
Summary of the geopolitical and international security dimensions of negative emissions and solar geoengineering technologies.

	Negotiating tools	Enhanced military capacity	Targets in ongoing conflict	Cause of conflict or weaponization
Negative emissions technologies	Formation of carbon dioxide removal clubs, risk of a "Green OPEC", heightened diplomatic conflict	Coupling with military industrial complex, resource curse over forestry or oceans, military enforcement of climate targets	Risk of carbon reservoirs being targeted by terrorists or geopolitical blackmail by countries storing carbon	Use of ocean techniques to devastate fisheries, or land-based techniques to devastate forests or agriculture, ability to control global thermostat, strengthening of authoritarian or populist regimes, internal insecurity due to cascading impacts
Solar geoengineering techniques	Pre-emptive deployment by a Greenfinger, formation of geoengineering clubs, use of "energy weapon" or "weather modification" to get concessions	Augmenting aerospace or space capacity, crossover high-technology skills, protection of military bases	Technology (aircraft, ships, balloons) and programs could be targeted as critical infrastructure, cyberattacks on control systems	Interference with rainfall, monsoons, sunlight, and ecosystems, risk of miscalculation over deployment aims, cycles of counter-geoengineering

Source: Authors

architectures may be warranted to constrain rather than enable deployment, particularly in cases that might lead to spiralling, retaliatory developments toward greater conflict. After all, to address the wicked problem of climate change while creating more pernicious political problems that damage our collective security is a future we must avoid.

Credit author statement

All authors contributed equally to: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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