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Review

Arctic Sea Ice Decline and Geoengineering Solutions: Cascading Security and Ethical Considerations

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Abstract: Climate change is generating sufficient risk for nation-states and citizens throughout the Arctic to warrant potentially radical geoengineering solutions. Currently, geoengineering solutions such as surface albedo modification or aerosol deployment are in the early stages of testing and development. Due to the scale of deployments necessary to enact change, and their preliminary nature, these methods are likely to result in unforeseen consequences. These consequences may range in severity from local ecosystem impacts to large scale changes in available solar energy. The Arctic is an area that is experiencing rapid change, increased development, and exploratory interest, and proposed solutions have the potential to produce new risks to both natural and human systems. This article examines potential security and ethical considerations of geoengineering solutions in the Arctic from the perspectives of securitization, consequentialism, and risk governance approaches, and argues that proactive and preemptive frameworks at the international level, and especially the application of risk governance approaches, will be needed to prevent or limit negative consequences resulting from geoengineering efforts. Utilizing the unique structures already present in Arctic governance provides novel options for addressing these concerns from both the perspective of inclusive governance and through advancing the understanding of uncertainty analysis and precautionary principles.

Keywords: geoengineering; securitization; ethics; climate change; arctic security; risk governance

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1. Introduction

Geoengineering solutions are receiving increased interest in the Arctic as potentially important components of climate change interventions [1]; however, few studies have explored the implications from geopolitical perspectives, or the risks for regional security implications within the Arctic. Through a critical examination of the literature and a survey of emerging technologies and security concerns, this article will help to identify some important aspects of national and international security and ethical concerns within the region. Although it is likely that an international agreement will provide the "what" and "how" toward an organized approach, some nations will be inclined to avoid signing and ratifying such conventions or protocols, or they may even withdraw later after ratifying such agreements [2]. In the Arctic, special difficulties can be expected concerning international efforts. Even the variety of established definitions of the Arctic, including ecological, political, and geographic, illustrate some of the preliminary challenges. Although international frameworks tend to provide definitions based on consensus, existing or emerging definitions of the Arctic may not always agree, and any overlapping aspects into sovereign boundaries would expectedly cause concern. In particular, the effects of Arctic geoengineering would clearly have impacts in other regions and latitudes [3], possibly pitting the national interests of the northern nations against those of mid-latitude and lower-latitude nations, especially as national interests often involve the concerns and priorities of numerous domestic key and primary stakeholders [4].

The scope and purpose of this article is to examine the common circumstances involving the pursuit of Arctic geoengineering solutions through internationally based management within the context of security and ethics, as well as to emphasize the importance of proactive and inclusive governance approaches toward the development of solutions. The international relations process known as securitization theory, also known as the Copenhagen School (a framework to understand how issues may transition from non-politicized, to politicized, to securitized [5]), provides a way to explore potential areas where geoengineering may be viewed as an existential threat in the future (whether actual or perceived), in order to assess ways that potential conflicts could be avoided proactively through governance mechanisms. The philosophical understanding of consequentialism (a perspective that outcomes determine ethical impacts) under the premise of inclusive governance helps to provide effective guidance from which to analyze possible trajectories and recommendations. The first section will act as the baseline of the current understanding of Arctic environmental targets, to include the hydrosphere, atmosphere, and cryosphere. The following section will detail relevant geoengineering scenarios and technologies. Next, a breadth and depth exploration of security-related concerns, ethical considerations, and challenges that have the potential to lead to conflict will be presented regarding international collaboration. Finally, the last section offers potential recommendations on how to navigate these combined challenges through proactive risk governance-based approaches.

2. Current Environment of the Arctic

Arctic sea ice is a bellwether indicator for high latitude climate change, and it plays an important role in regulating the climate by acting as a barrier between the cold polar atmosphere and the warm ocean. Sea ice in the Arctic has retreated from long-term median values (Figure 1) over the past several decades and it reached a record minimum area of 3.41 million km^2 on 16 September 2012 (Figure 1). This represents a 49% reduction, relative to the 1979–2000 climatology, and it caught the attention of scientists as well as the public. Sea ice decline has accelerated through polar amplification, as high albedo sea ice has been replaced by ocean, which absorbs sunlight and warms over the summer leading to further sea ice decline. Since 2012, each September, the minimum area continues to decline, as younger and thinner ice, which is easier to melt, has replaced older, thicker ice. Based on the latest projections of future sea ice from CMIP-6 simulations that were run with scenarios of expected anthropogenic forcing, summer sea ice is expected to disappear by 2050 [6]. The decline in sea ice has consequences for the Arctic as well as globally. Sea ice provides an important habitat for marine mammals, such as walruses and seals, as well as polar bears [7]. The disappearance of sea ice will change the way the ecosystem functions, and animals will either adapt or perish [8]. Indigenous peoples of the Arctic have strong cultural ties to the sea ice. They rely on sea ice for subsistence hunting and are impacted by the reduced safety from weaker sea ice, as more open water and thinner ice poses added risks [9]. The decline of sea ice is thought to increase the likelihood of a wavier jet-stream and severe cold weather events in the midlatitudes according to a growing body of scientists [10]. Sea ice is iconic, but the combined impacts of global warming are accumulating very quickly in many parts of the Arctic system. Studies show that as the permafrost thaws, it leads to increased greenhouse gases being released into the atmosphere [11]. The positive permafrost carbon feedback is of great concern for global climate stability. Some recent effects of warming are dramatic: methane blasts have been creating large craters in the Yamal Peninsula of Russia since 2014, and the most recent crater is 165 feet across [12]. Temperatures in the region continue to climb, and the Siberian town of Verkhoyansk hit a record high temperature of 100.4 °F in June 2020 [13]. The possible extinction of the iconic polar bear, and the potential of amplification of global warming from Arctic feedback to the climate system, is motivating diverse groups to find "expedient" geoengineering-based solutions (e.g., sea ice albedo control [14] and solar input management [15]) to the climate crisis.

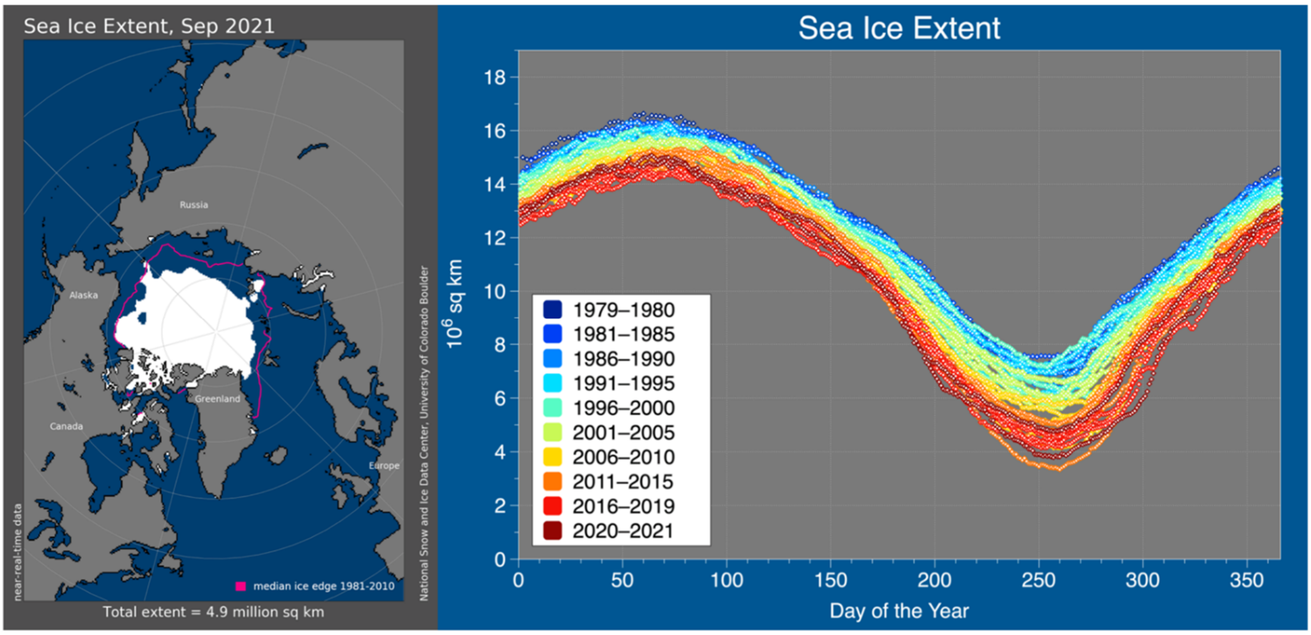

Figure 1. Left panel: sea ice extent (greater than 15% concentration) for the September mean compared with 2020 with record low 2012. Right: seasonal cycle of the daily Arctic sea ice extent in millions of square kilometers. Recent decades display sea ice decline in all months of the year. The left panel, and data for the right panel, is courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder. The right panel graphic is modified from a DataGraph template.

The decrease in sea ice is expected to lead to increased traffic from various activities [16]: resource exploration, new shipping routes, expanded scientific activities, tourism, geoengineering, and expanded fisheries. However, a lack of physical as well as policy infrastructure needs to be addressed in order to ensure environmental security in the Arctic. In this article, we focus on geoengineering activities as a potentially disruptive technology that could destabilize the polar north region [17]. Any proposed solutions should therefore include an understanding of climate change, geopolitics, and ethical considerations.

3. Arctic Geoengineering Solutions

Numerous options have been proposed for the deployment of geoengineering in and around the Arctic to protect existing sea ice or to promote further ice buildup. The majority of identified solutions are focused on reducing solar radiation from reaching the ice surface [18], delaying the melting of ice [19], increasing the production of winter ice [20], or a combination of these mechanisms. These efforts may be based locally in the Arctic, or remotely, and they vary substantially in cost and complexity. Some of the most involved methods require complex infrastructure systems and significant economic investments in order to achieve their results. Additionally, the degree to which these approaches are reversible or irreversible influences the potential risk associated with any proposed solution. This article is not focused on the validity of specific methods of sea ice-based geoengineering, but rather, on the increasing likelihood that in the near future, it is plausible that nation states, or powerful independent actors, may unilaterally deploy these efforts widely. Moreover, they may do so before other nation states or international actors can intervene or counter their methods. It is these factors that elevate the importance of this issue, and the need for preemptive and proactive measures and awareness surrounding geoengineering in the Arctic, to both prevent unnecessary escalation between Arctic powers and minimize the risks to Arctic residents. Although it is not the primary focus of this article, we will briefly explore a range of these options in order to contextualize calls for proactive solutions and agreements.

3.1. Solar Radiation Based Geoengineering

Reducing solar radiation from reaching the Arctic, and specifically sea ice, can be achieved through either blocking or reflecting sunlight and can theoretically be deployed anywhere between the surface of the ice, all the way to distant points between Earth and the Sun. Some of the more drastic proposed options in the past have included the deployment of a sunshade in space, located at the L1 Lagrange point, which would block a portion of solar radiation from reaching Earth [21]. This would be an incredibly costly option, with the potential to reduce solar radiation on a global scale, and it would require an estimated cost in the order of trillions of dollars to achieve; however, such an effort has the potential to generate a large scale international conflict over which nations, actors, or powers control that system, and to what extent it poses a greater net risk than it may help to offset. Closer to Earth, the injection of aerosols into the stratosphere to reflect or diffuse incoming solar radiation has been not only proposed, but there are groups actively working toward limited testing to better ascertain the benefits and risks [22]. Although these tests can be performed regionally, it may be more difficult to contain locally due to the atmospheric dispersion of those aerosols. Regionally, and closer to the surface of the ice, a number of projects have been proposed to limit surface albedo, ranging from tiny silica-glass beads [14] coating the surface of the ice, to the deployment of reflective sheets or blanket type materials to cover existing ice. The latter option has been explored in glacial regions to reduce melting with some success, although at substantial cost, and it is expected to have a limited broader application [23]. All of these efforts, although they vary in scale and proximity to the Arctic, offer ways to reduce the melting of Arctic sea ice through the reduction of incoming solar radiation.

The difficulty or ease of deployment of geoengineering efforts also varies greatly, as does the reversibility of different methods. Although a sunshade may not be easily managed without significant investment and awareness, and would likely require substantial international collaboration and support to achieve, deploying large amounts of microbeads in the Arctic would be far more achievable in the near future, at a significantly reduced cost. Options which require little to no international collaboration, and can be rapidly deployed, become a feasible route for nation states or independent actors independently of the global consensus, and therefore, they are a larger point of concern regarding the unintended consequences of those actions and the repercussions for international relations.

3.2. Thermal Geoengineering for Ice Preservation or Production

Aside from reducing solar radiation, other solutions have been proposed to either reduce the ocean melt of sea ice or increase the production of winter sea ice. One of those proposed solutions depends on reducing the melt-off of existing near-ocean glacial ice by developing artificial sills to prop up and isolate the glaciers or ice sheets in areas such as Greenland, where seasonal waters may contribute to substantial warming and thawing events. The intention is that this separation would help to maintain these ice sheets in summer seasons and prevent catastrophic collapse [24]. Other solutions point to the deployment of large-scale wind-pump systems to help cool sea ice in summer and to bring water to the surface in winter to promote greater ice production during the cold season [25]. Both options are extremely costly and would require large investments both in economic and political terms, likely placing them in the realm of nation states. This is not to say lower cost solutions may not be developed for thermal geoengineering approaches, but few have been proposed at this time; however, solutions in this area may not be effective in the long-term in the face of continued warming, as warming at the global level is likely to outpace many of the reductions these solutions hope to address. Additionally, the unintended consequences of shifting Arctic currents and atmospheric conditions as a result of these methods are not yet well understood and could lead to potentially damaging results for the region, from fundamental changes in ocean dynamics to impacts on marine and Arctic species.

Both solar radiation management and thermal management technologies provide mechanisms for the preservation of existing ice, or the potential for the growth of new ice. In each category, options range in scale from extremely localized to global level mega infrastructure projects, with varying degrees of reversibility and cost to implement. These factors further strengthen a need for understanding these processes prior to implementation, to ensure that a holistic picture of any impact is well understood and is communicated as part of any deployment efforts.

4. Security-Related Challenges with International Collaboration

Additional concerns surrounding climate change geoengineering solutions involve security interests. Of the many frameworks from which to examine security issues, Buzan provides a fundamental international relations theory widely regarded as the "securitization" theory [26]. This architecture provides an effective framework to analyze security dynamics and security issues through a variety of actor levels (individual, sub-state, state, and international systems) and a wide range of sectors (political, economic, military, social, and environmental). Floyd extends this in her examination of environmental applications of the framework and asserts the need to consider consequentialism studies in order to properly evaluate the morality of (possible) (de)securitization outcomes [27]. The securitization theory bypasses the debate concerning the extent to which threats are either real or perceived. Instead, it offers a way to examine security in the ways that issues are socially constructed as a threat. The social construction of a threat is conducted in what is known as a speech act, where a high-level figure or collective articulates an issue in a way that is meant to elevate an issue that is managed in the political sphere to an escalated securitized level. This is an important component in the potential securitization of geoengineering efforts, as the threat need does not be objectively real in order to generate extreme measures in response.

However, the speech act alone is not enough. According to Van Munster, a securitizing speech act needs to follow a specific rhetorical structure, which is derived from war and its historical connotations to survival, urgency, threat, and defense [28]. This leads the Copenhagen School to define securitization as a speech act that must fulfill three rhetorical criteria. It is a discursive process by means of which an actor (1) claims that a referent object is existentially threatened, (2) demands the right to take extraordinary countermeasures to deal with that the threat, and (3) convinces an audience that rule-breaking behavior to counter the threat is justified; therefore, it is possible that even in the absence of environmental harm, geoengineering could be constructed as a threat in a variety of ways.

From a normative approach, consequentialism provides an effective means from which to examine issues involving the moral rightness of an act or something related to an act, including motives and policies. Classic consequentialism developed through a variety of claims, often involving prominent categories of theories, including (1) objective consequentialism, which involve theories that focus on actual or objectively probable consequences, and (2) subjective consequentialism, which involve theories that focus on intended or foreseen consequences, whereas non-traditional, proximate consequentialism, describes how the moral rightness of an act is determined only by proximate consequences [29]. Taken together, securitization and consequentialism provide powerful conceptual guides that are useful for examining Arctic geoengineering challenges toward collaborative agreements and efforts.

With little doubt, diplomacy and science will likely be charged to provide leadership in global geoengineering endeavors, including the Arctic region; however, to assume that an Arctic geoengineering solution will be developed and implemented through naturally peaceful and cooperative means might be a mistake. Additionally, domestic actors will likely pressure national authorities with concerns of local negative impacts. The securitization process helps to describe how such non-military concerns can result in issues of national security and interests, which could greatly affect the ability of an international coalition to adopt solutions; however, studying the securitization and consequentialism circumstances for the Arctic could help facilitate cooperative efforts toward resolving tensions in order to achieve desired regional objectives. At the very least, such considerations could help to manage overall expectations, as well as to acknowledge legitimate and competing perspectives.

Such challenges remain the purview of the diplomatic corps of the world who are well trained and experienced in dealing with multinational issues and tensions. For the circumpolar North, the Arctic Council represents the lead international institution with significant proficiency in overseeing efforts in support of environmental and Indigenous solutions. Although unlikely to directly oversee geoengineering efforts for the Arctic, the organization provides a highly relevant example of what coalition-led efforts offer in the realm of scientific uncertainty and understanding that is deeply connected to regional stakeholders. It is plausible that the Arctic Council could contribute to any number of components, whether through efforts to improve scientific understanding, through enhanced monitoring, or through the establishment of guidance based working groups, making the lessons learned there additionally valuable to any implementation strategies. Many Arctic Council projects and initiatives involve the study of processes that affect the entire region, not unlike geoengineering. The Arctic Council is by design a consensus-based organization, where the eight member nations retain decision-making authority, and six permanent participant groups representing Arctic Indigenous peoples have full consultation rights. Of note, the Arctic Council does not engage in issues of military security [30]. As a result, topics involving sensitive national security interests cannot get in on the agenda, or they are otherwise rejected if member nations are instructed or compelled to do so. The securitization process warns us that issues can go from acceptable dialogue and consideration to a diplomatically difficult situation—possibly even elevated to an emergency level in extreme scenarios. To maintain a geoengineering dialogue in a collaborative or consensus building environment such as the Arctic Council, it will require an understanding of potential conflict and competition points in advance to prevent or limit the securitization of these issues.

Within that context, it is not only possible but plausible that nations may not easily agree to geoengineering solutions as a result of conflicting national security interests. To disregard such opposition, even in an adversarial-based system (such as the United Nations), might lead to the development of dangerous consequences. Unlike the Arctic Council, it would be anticipated that the responsible body with regard to Arctic geoengineering would likely have two overarching organizational objectives: (1) identifying and defining the problem(s) to be resolved in a typical framework instrument (e.g., Vienna Convention), followed by (2) establishing the implementation, maintenance, and inspection/review requirements in a typical protocol instrument, such as the Montreal Protocol [31]. What determines the structure and authorities of any potential geoengineering-related organization is yet to be seen, although the history and process of similarly related endeavors are well-known and documented. Part of any international organization's efforts involving management of geoengineering will invariably include a significant amount of interdisciplinary literature reviews. For example, not only will the impact of global climate systems as a result of geoengineering need to be relatively well known, but a critical understanding of the processes and norms of securitization and consequentialism will also need to be a part of considerations where tensions over issues are concerned. It is of paramount importance that international organizations are set up for success from the start, because the alternatives are often exponentially counter-productive, and delays late in the process may lead to a failure to reach diplomatic solutions.

As with any international treaty/convention, the most commonly recognized types concern international law [32], but not all nations become full-party members, nor do all nations remain members. This would likely be the case with any framework convention and protocol involving Arctic geoengineering, especially because the vast majority of environmental agreements tend to function on the premise of reducing production, consumption, or processes, rather than the introduction of engineering-based solutions. For example, the international solution for dealing with the ozone problem as per the Montreal Protocol involved a significant reduction in use of the substances responsible for the problem. Other agreements have found solutions in reductions or a change in human behaviors, such as the precautionary moratorium on unregulated high-seas Arctic fishing activities, until a greater understanding of impacts could be achieved [3]; however, geoengineering solutions in the context of this article will likely involve adding something new to the environment, which, once released, might not be as easily controlled. This circumstance would be fairly novel and especially difficult as part of an agreement, based on ongoing monitoring and management requirements. Unlike other conventions where non-party member nations might not interfere with the agreement, geoengineering in the Arctic atmosphere would undoubtedly draw active opposition from non-party members. Whether in the Arctic, Northern Hemisphere, or anywhere else, affected nations could have a justification for withholding support, knowing full well that what happens in the Arctic does not stay in the Arctic.

This leads to the potential for a range of scenarios, where independent or unilateral attempts at geoengineering solutions may have consequences outside the intended area of impact, and may affect the food security, energy security, and other forms of security within other nation's political boundaries. Modeling efforts have already identified that asymmetrical approaches to geoengineering in the Arctic may lead to alterations in the Inter-tropical Convergence Zone (ITCZ), creating a reduction in local precipitation in portions of the Southern hemisphere [33]. Although the oceans and atmosphere form components of the global commons [34], alterations to those features have the potential to directly affect areas within terrestrial boundaries. Prior conflicts over fishing resources, including access and distribution, offer examples here as to the connections between shared resources and the potential for conflict. Previous efforts at geoengineering, such as iron fertilization, when connected with issues of fishery management, may provide insights as to the ability for such issues to become securitized [35]. Additionally, when framed as a disruptive technology, nation-states may be incentivized to develop cutting edge systems that produce improvements to regional outputs, whether from fisheries, agriculture, or other means, at the cost of neighboring or even distant regions, creating regional losses that may generate antagonistic perceptions.

5. Ethical Concerns with Broader Impacts

Although ethical considerations often depend on local or regional norms, the differences between these norms and how they are prioritized can lead to larger concerns or conflicts between regional actors or nation states, and domestic issues are not always limited by national boundaries in the Arctic. Although many attempts at geoengineering or climate engineering may originate outside of the Arctic, the impacts are likely to be observed earlier within the Arctic, where climate response is often amplified [36]. When it comes to geoengineering, the risks go beyond merely technical or security considerations, and may have far reaching ethical implications. Those ethical impacts have the potential to drive international conflict; therefore, it is important that ethical considerations play a role in the plans to enact geoengineering efforts. These considerations involve questions such as: What is the target climate, and who determines it? What is the likely distribution of impacts among Arctic nations? Who, or which groups, are responsible for the development and deployment of proposed solutions? To what extent can we seek to understand the unintended consequences? What is the potential for abuse of these systems? These questions primarily relate to two areas of ethical concern: (1) consequentialism, or the idea that end results determine whether or not the efforts undertaken were justified, and (2) inclusive governance, an approach examining the inclusion of those affected by decisions, in both processes in which efforts are undertaken and the distribution of outcomes [37].

5.1. Target Climate

One of the early issues with the implementation of geoengineering efforts is based on the question of target climate conditions within a region, and who determines which levels are acceptable. The now well-known recommendation to limit changes to 2 °C above pre-industrial temperatures was proposed as far back as 1990 through a report from the Stockholm Environment Institute [38]. At the time, this was initially seen as a less preferable option to a 1 °C target, but one that might be more achievable, along with efforts to limit decadal rises to no more than 0.1 °C in order to reduce negative impacts. The IPCC has since mirrored these assessments, but has provided analysis for risk levels in the 4 °C range as well, although this latter target is expected to have far more negative impacts globally [39]. More recently, concerns have mounted for the potential damage of a 1.5 °C level increase above pre-industrial conditions, as evidence of change has accelerated [40].

Although a few areas are likely to aim for pre-industrial conditions, the target climate for geoengineering efforts is likely to vary for differently affected countries. Regions that have already made significant efforts to adapt to recent or current states of climate may even find a return to previous climates to be detrimental to their current practices, if not dangerous, leading to the potential for counter-engineering efforts by those negatively affected. Others still may aim for a target climate that has not yet been experienced, due to perceived benefits it may offer through increased natural resource access, economic growth, agricultural potential, strategic advantages, or to minimize the need to reduce emissions to previous levels [41]; however, any reductions from the current climate are likely to face substantial challenges and may take decades to fully achieve success [42]. The attempts to meet these goals are also likely to result in a range of experimentation efforts in the meantime, with short term and localized effects expected to contain significant uncertainty. Although international agreements may result in long term targets, such as aligning with the Paris Agreement, nation-states may find differences in what they consider optimal conditions [43]. The disconnect between these goals for nation states has the potential to lead to conflict, where a nation focused on reducing the rising sea levels to coastal communities impacted by the loss of protective landfast ice may contrast with the goals of a nation interested in increased Arctic natural resource development through improved access to offshore energy reserves made more accessible as a result of sea-ice decline. In the case of unilateral actors, the consequences of actions may be borne by different nations than those that initiate climate intervention efforts, especially if not addressed through inclusive forums that represent the range of concerns.

5.2. Distribution of Impacts

Results of geoengineering efforts pose additional challenges for Arctic residents, where impacts are unlikely to be evenly distributed, whether geographically, demographically, or socioeconomically [44]. Larger temperature swings due to global emissions are already being experienced in northern regions, as polar amplification has led to more significant shifts in temperature increases toward the poles [45]. With winter temperatures projected to increase by as much as 13 °C in the region under high emissions, as opposed to global averages in the 2–4 °C range, it is clear that the impacts of climate change will not be uniform, and that the Arctic is likely to see radical shifts in climate [46]. Similarly, geoengineering efforts have the potential to cause uneven changes when attempting to reduce warming, and may lead to larger swings in climate conditions, challenging localized adaptation efforts, and native plant and animal species already threatened under climate change [47,48]. Even the methods of implementation will likely alter the spatial distribution of climate adjustments, with aerosols having widespread effects, and local surface albedo related controls are more likely to be largely contained to regional changes, but may also have substantial effects. The extent of any geoengineering approaches in that case will depend on the range of communities and infrastructure within the area of impacts, and the ability of those groups to withstand those impacts.

As with the impacts of climate change itself, areas that are currently near change thresholds or tipping points are likely to be affected more rapidly, and more disproportionately through any geoengineering efforts. In the Arctic, this affects a wide range of communities, including but not limited to those in low lying coastal regions experiencing increased storm surges and erosion [49], those in areas where permafrost is reaching or surpassing thaw temperatures [50], and those in areas where shifts in the seasonality of the climate is undermining historical and traditional uses [51]. Additionally, many of those already impacted by climate change are facing resource constraints, making adaptation and mitigation efforts more challenging. As a result, having the ability to adjust to externally generated and potentially rapid shifts from geoengineering efforts poses additional challenges [52]. Efforts taken to adapt will proportionately be more costly, and the need to consider increasingly uncertain impacts from climate change becomes more difficult, including added risk assessment challenges [53]. This is not to say the existing challenges under climate change will not also pose many risks, but rather, that it needs to be considered as part of planning efforts that geoengineering may disproportionately and increasingly challenge vulnerable populations. Efforts undertaken without considering those factors may exacerbate them, especially for those communities lacking the resources for expensive mitigation efforts. Taken together, the disproportionate effects from geoengineering efforts in their distribution will require additional care to avoid the creation of unintended consequences. From a consequentialist perspective, the impacts to those at the local or regional level should not be overlooked in an effort to address challenges in other regions. Any nation or independent actor undertaking such intervention or geoengineering efforts must recognize that the possibility also exists to affect areas outside of their terrestrial boundaries, which may escalate cross-boundary tensions.

5.3. Unintended Consequences of Interventions

Although current efforts have primarily been focused on computer simulations, and in rare cases, small-scale experiments, once large-scale efforts are undertaken, there exists the potential for substantial unintended consequences, either due to unidentified interactions, potential miscalculations, or lagging responses. Although a sense of urgency exists among many with regard to the need for solutions to climate change, without proper due diligence, proposed solutions have the potential to exacerbate current challenges and add tension between nation states and their citizens, who bear the result of any experimentation. Under the concept of consequentialism, although the aim for expediency may be well intended, failing to understand the complex interactions leads to the concern that poorly understood outcomes may lead to a net negative outcome, worsening the situation for those affected. Although the available number of real-world experiments in geoengineering has been limited, the deployment of large renewable energy systems is more prevalent and can act as an example of positive intentions, resulting in potential net negative outcomes once studied. Solar and wind technologies, for example, are often recognized as a way to reduce carbon emissions and replace fossil fuel consumption through renewable pathways, and those technologies have received widespread support [54]; however, recent studies indicate that in large-scale deployments, depending on placement, the near surface changes to albedo and atmospheric conditions may produce net-warming [55], disruptions of local climate patterns [56], reduction of wind speeds [57], and a loss of precipitative transport inland [58]. By some indications, wind farms may "need to operate for more than a century before the warming effect over the Continental US caused by turbine-atmosphere interactions would be smaller than the reduced warming effect from lowering emissions" [56].

In addition to failing to mitigate carbon production, these studies highlight that mitigation efforts hold the potential to alter agriculture, water availability, the frequency, intensity, and duration of natural hazards, and a range of other issues that have the ability to amplify climate challenges and could increase the potential for conflict. Concerns over the understudied or poorly understood consequences of geoengineering have already led to push back from some Indigenous groups in the Arctic. In March of 2021, the Saami Council, representing the Saami (Sámi) people, wrote an open letter to the Stratospheric Controlled Perturbation Experiment (SCoPEx) Advisory Committee, which is part of a project by Harvard University attempting to test stratospheric aerosol injection technology in Sweden [59]. The letter voiced several issues, including the potential for termination shock, "irreversible sociopolitical effects", and concerns that the team did not "have any representation from the intended host country". Citing concerns from the Saami Council and environmental groups, Sweden's space agency cancelled the flights that would have been the first active test of aerosol injection technology [60]. These challenges further highlight the need for an inclusive risk governance approach, to ensure stakeholder concerns are a component in the design and deployment of eventual intervention methods. Additionally, such an approach would provide a mechanism to communicate risk more effectively between groups.

5.4. Competition and Representative Decision-Making

In general, the government has a compulsory or requested role in managing negative externalities, often by a higher level of government or an adopted international body. Atmospheric geoengineering comes with many concerns involving negative externalities, in particular, environmental externalities. Traditionally, environmental externalities "arise when certain actions of producers or consumers have unintended effects on producers and/or consumers" and they become negative when an "action by an individual or group produces harmful effects on others"[61]. The OECD further defines environmental externalities "As a consequence of negative externalities, private costs of production tend to be lower than its "social" cost, where it is the aim of the 'polluter/user-pays' principle to prompt households and enterprises to internalize externalities in their plans and budgets [62]". Geoengineering does not fit these definitions very neatly, but the premise can be easily understood and adopted; however, whereas international agreements can help to manage expectations with externalities, the magnitude of uncertainty concerning geoengineering impacts would likely test the limits to which principles and norms could help resolve future issues.

Developing a multinational effort to confront issues often requires an effective understanding of how to manage domestic and foreign interests in order to achieve a "yes" regarding agreements or acceptability of proposals [63]. Proposing and committing to obligations and non-obligations as part of an agreement will quickly prove how difficult such endeavors are when trying to compromise within a spectrum of different interests. In addition to the theory involving 'securitization' discussed previously, Oran Young provides a useful macro-level approach when considering governance issues through three main fragmentations, including (1) jurisdictional, (2) sectoral, and (3) institutional [64]. Increased fragmentations expectedly create a parallel-like increase in the need for governance, not unlike the justifications for government intervention. Young explains that "jurisdictional fragmentation is a matter of the division of a region into a number of segments that are distinct with regard to their jurisdictional status while sectoral fragmentation, on the other hand, arises from the existence of distinct regimes dealing with specific activities, such as shipping, oil and gas development, fishing, and so forth". Institutional interplay and fragmentation occur when "responsibility for managing distinct human activities is distributed across a variety of public-sector agencies" [64]. Fragmentation as an example of structured organization in thinking not only helps to develop a meaningful understanding of competitive and/or conflicting issues, but also how interests can be understood and managed both internally and externally in a proactive manner.

As seen with issues relating to unintended consequences from geoengineering-based climate interventions, groups within the Arctic have already voiced concerns about the lack of representation regarding impactful decisions affecting the region. In the case of the Saami objections, the lack of inclusion in the decision-making process was an important concern, as those in the area of testing perceived that they were required to bear a disproportionate risk, without the ability to properly assess or contribute to the test design process. Similarly, in Alaska, concerns have been voiced regarding the Arctic Ice Project (formerly Ice-911), an effort to distribute silica-glass beads to improve ice albedo, and the inclusion of local perspectives on the assessment of risk [65]. Local critics of the effort have argued that the project may pose additional risks for residents and wildlife, and that a lack of community input may be adding another layer of complications for those already attempting to adapt and understand ecosystem changes, without the means to address those changes proactively [66]. It is particularly important to note that different communities and regional governance authorities are not homogenous and will have different perspectives as to the acceptable level of risk associated with any potential impacts. These mismatches have the potential for both domestic and international conflicts to arise. Understanding those perspectives will be an important concern when it comes to issues of self-governance and acceptance of technologies.

Which groups are responsible for deployment efforts plays an important role in understanding the level of support or opposition that geoengineering solutions are likely to receive. Inclusive governance is well suited to these challenges, because it has the potential to proactively identify conflict points, identify areas for strategic coalitions, and help balance concerns at domestic and international levels [67]. Through the use of inclusive governance approaches, the range of concerns can be better identified in advance, reducing the likelihood of the failure of proposed agreements once they reach the international level. As an example, longstanding concerns have existed in the Arctic regarding the causality of climate change and the disproportionate impacts of outcomes in a region that has been affected by outcomes not entirely within its control. In the past, this debate has centered around energy production and resource use concerns, where oil and natural resource extraction have been both an economic boon [68], but also a source for environmental damage and cultural upheaval through global consumption and local degradation [69]. The emergence of geoengineering may amplify this debate, where effects may be far removed from where experiments or full-scale deployments are conducted. Although groups impacted by geoengineering are likely to vary substantially, it is important to consider who or which groups will be responsible for the approval, development, and deployment of any geoengineering solutions. As negative impacts are unlikely to be equally distributed, it is imperative that those negative impacts are understood to the greatest extent possible prior to engaging in broader efforts, especially for non-reversible efforts. This approach toward inclusive governance has gained traction throughout the Arctic, as the Arctic Council has worked to balance the needs of nation-states with those of Indigenous permanent participants, and newer frameworks are emerging to support those efforts [70]. It has the advantage of assessing and responding to local needs early on, leading to greater support once initiatives move forward at the international level.

The concerns listed in this section are not exhaustive, but rather, they note areas that begin to highlight the uncertainties and challenges facing the development of solutions in the polar north that reduce the potential for escalation and the likelihood of consequences that could be perceived as antagonistic regionally. Any of the factors discussed previously have the potential to produce conflict, both within nation states and between them. They also have the potential to disproportionately affect those living in, and those who are connected to, the region in ways that may not always be clear initially. As geoengineering makes its way into wider adoption, and as nation states begin exploring it as a stopgap for current warming trends, it will be critical to consider these factors, and to include those affected by the decisions in the process, both to minimize negative outcomes for residents of the region, but also to avoid unnecessary escalation toward conflict.

6. Navigating the Combined Challenges

The combination of declining sea ice and increased interest in the region, as well as the expansion of proposed solutions via geoengineering in the Arctic, makes the eventual deployment of those solutions much more likely. Without global agreements prohibiting the practice of geoengineering or providing regulatory oversight, nations will become increasingly motivated to take it upon themselves to protect their own interests to the greatest extent possible. This type of unilateral action not only poses problems from the perspective of international relations, but it also increases the chances of a lack of inclusive governance approaches leading to an increased risk of conflict at multiple scales of analysis. Although numerous approaches have been proposed for limiting the decline of Arctic sea ice, (e.g., solar blocking aerosols in the region, materials to reduce surface albedo on sea ice, or the use of complex thermal based systems to reduce losses or allow more ice to form), they vary substantially in cost, complexity, and reversibility [20]. Such solutions are continuing to push forward as a necessary means of preventing sea-ice collapse and further amplification of Arctic warming [14]. If the assumption is that geoengineering in the Arctic is not a matter of if, but when, then an important question becomes; to what extent will attempts to reduce sea ice loss through geoengineering by sovereign nations or independent actors result in an increase in geopolitical tensions? Secondarily, how can the international community identify and manage tensions generated by geoengineering approaches proactively [71]?

6.1. Additional Considerations

When it comes to the protection of Arctic sea ice, most of the affected domain currently resides in international waters. Any actions in those waters would be subject to a very limited range of international agreements, with minimal, and as of yet, untested enforcement capacity. Although the UN Convention for the Law of the Sea (UNCLOS) instituted agreements on ocean-based pollution, such actions taken in the attempt to preserve or protect environmental concerns could be seen as exclusionary to that purpose, and without the inclusion of the precautionary principle, they may be difficult to enforce [72]. Instead, vague applications may allow for sovereign nations or independent actors to carry out widespread geoengineering efforts in the Arctic with little recourse via current international law. As a result, the determination to engage in geoengineering in the Arctic has the potential to succumb to traditional power politics, as individual nations determine for themselves the best course of action for their own interests. Although this does not preclude the possibility of cooperative or collaborative efforts among nations, lacking an enforceable framework is also unlikely to prevent independent actions. The actions taken on individual or nation-state levels have the potential to produce negative consequences for other nations and groups when not enacted in a holistic and comprehensive manner. The scale of these consequences then acts as a point of division or securitization (such as the promotion of geoengineering as an existential threat requiring extreme response measures) for geopolitical actors, straining relations in an otherwise relatively stable political region of the world [26].

To minimize uncertainties and tensions involving collaborative processes regarding counter-warming issues, proactive agreements need to account for many factors, including geopolitical and national-interest concerns, especially as states begin to address the critical challenges of sea-ice loss and other climate related impacts. Although global geoengineering efforts may come to depend on large scale agreements under the United Nations, Arctic focused efforts may be achievable on shorter timeframes, with a specific focus on hemispheric changes, requiring Arctic leadership and oversight. Throughout the development of the agreement process, components of the final product can be streamlined by adopting and utilizing specified topical subcommittees including a subcommittee on the ethical deployment of geoengineering solutions in the Arctic (Figure 2). Even a non-binding forum would provide Arctic stakeholders with the opportunity to express concerns, highlight potential negative feedback from geoengineering solutions, and to facilitate studies of awareness and potential impacts of such approaches prior to their implementation. These subcommittees could help ensure due deliberation throughout the overall process as well as in the development of final product(s) and agreements. Such a subcommittee could potentially benefit from the work of the Arctic Council and their model of representation of affected groups. Additionally, the Arctic Council might be able to provide specific value-added aspects that could be used for regime updates and maintenance. As prior research efforts have indicated, many of the social consequences of these solutions are still not well understood, and will require greater efforts by technologists, social scientists, and policy makers to begin exploring the possible outcomes [73]. Although the Arctic is experiencing changes at a rate faster than most of the globe, this also provides an opportunity for the Arctic to take a leading role in developing responsible approaches to the implementation of radical solutions in the form of geoengineering. The development of international forums on the issue may help to guide these efforts toward maximum benefits while helping to reduce the potentially disastrous consequences for international relations and Arctic actors.

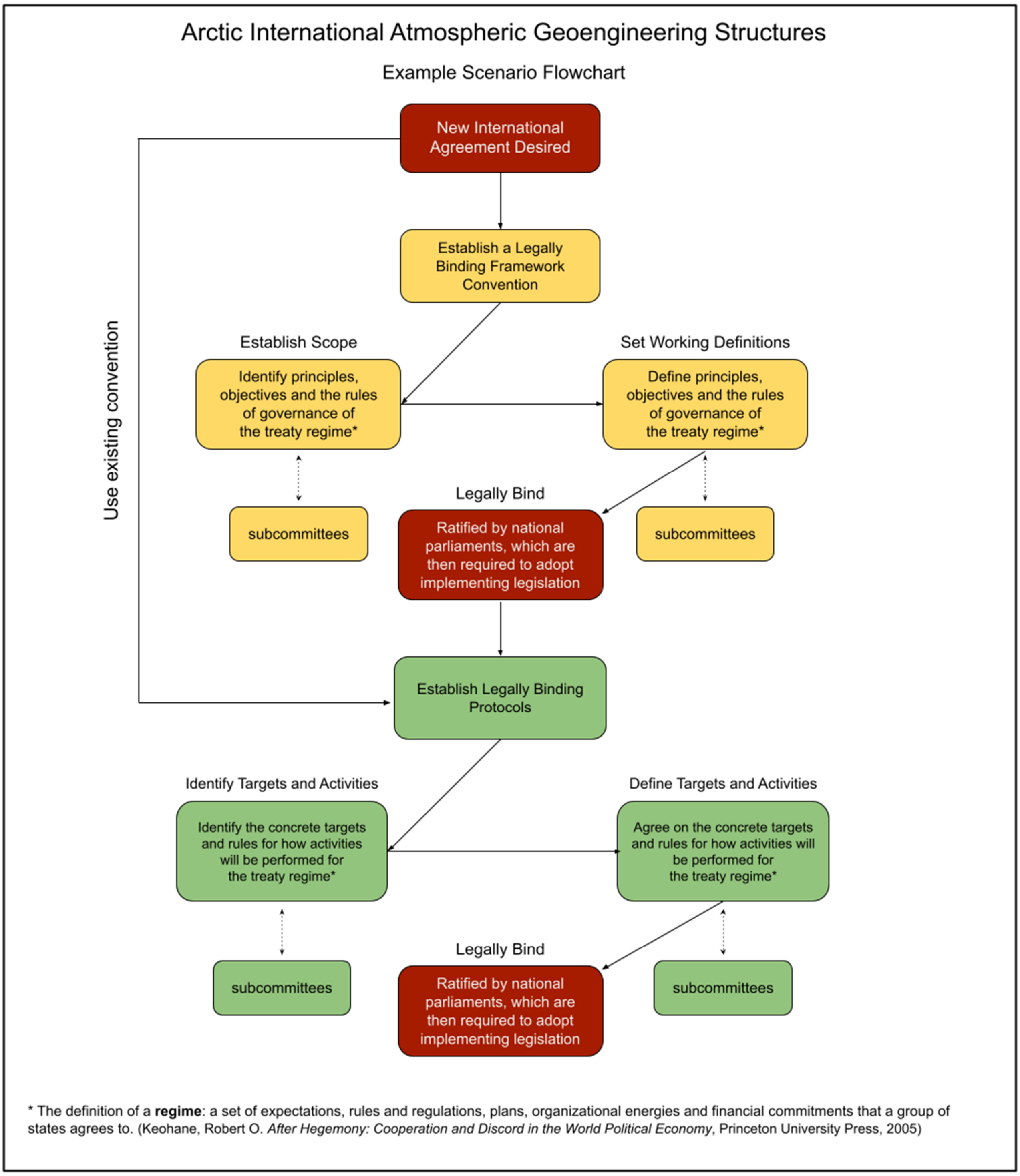

Figure 2. Sample possible flowchart for international agreements.

6.2. Risk Governance

To explore the prior questions, it is important to look at the problems from an approach that considers not only risk, but the perception of potential risk, as both play an important role in international relations and the likelihood of conflict. The Risk Governance framework, originally outlined by the International Risk Governance Council in a 2005 white paper, which has since expanded, proposes a multi-phase process toward governance, to include (1) pre-assessment, (2) risk appraisal, (3) risk characterization and acceptability judgements, and (4) risk management [74]. A key difference from other governance frameworks is a focus not only on assessed risk but also on perceived risk, as decision-makers often rely on perceived risk when making decisions under uncertainty. This focus on perceived risk allows for potentially affected stakeholder or rightsholder concerns to be integrated into the planning process proactively, and it also identifies a range of areas that may lead to internal or external conflict through their consequences. An earlier focus on cultural concerns during the pre-assessment phase, as recommended, could help identify the types of issues that led to the conflict over proposed aerosol delivery feasibility testing in the Saami lands in Sweden. Additionally, added emphasis on stakeholder and researcher collaboration could help to better identify the unintended consequences at a regional level, based on local stakeholder concerns and priorities. This approach has the potential to not only better align stakeholder and decision makers on risk tolerance, but newer approaches also consider the substantial uncertainty associated with emerging technologies.

In 2015, guidelines were released for emerging risk governance, which provided additional recommendations for risks that hold high uncertainty, such as geoengineering, and they specifically include an increased emphasis on complex scenario development to better understand potential outcomes from poorly understood risk environments [75]. The benefits of added scenario planning allow for the exploration of "what if" events, in order to better understand the trajectories of catastrophic risk pathways well in advance. Based on the outcomes of these scenario planning exercises, governance strategies can be developed that better address these risks appropriately and proactively, whether it is to increase research on the emerging risk, to focus on precautionary measures to avoid worst case scenarios, to modify the risk appetite, or other options. So far, this extended framework has seen some exploration for solar radiation management approaches toward geoengineering, but further application within the Arctic, and the area of sea-ice based geoengineering efforts, could help to inform the specific planning needs of Arctic nations and stakeholders when addressing geoengineering-based risks [76]. In the case of regional opposition, as mentioned earlier regarding tests on current technologies, the risk governance approach encourages early inclusion and understanding of stakeholder concerns to better develop approaches that may reduce conflict or identify areas needing greater cooperative engagement early on in the pre-analysis phases, by considering value perspectives that may lead to disagreements later. Additionally, the merging of risk governance with approaches outlined in securitization theory may offer a greater and more comprehensive look at the potential for both domestic and international risk that is presented through this emerging set of technologies, as they pose potential challenges at all levels of analysis [77].

7. Conclusions

The rapid decline of sea ice, combined with increased interest in the Arctic, is pushing nation states and independent actors in the direction of action to protect and preserve Arctic ecosystems. With advances in technology and proposed solutions, it is increasingly likely that these actors will make use of geoengineering solutions to help curb the losses of sea ice and protect national interests. This is not to say that the efforts themselves should be avoided, but that they must be done with a level of care and precaution, in order to avoid or minimize the negative consequences. The current lack of global action to curb emissions may spur these groups to act independently when combined with an increasing number of extreme events due to climate change. Without robust frameworks and agreements in place to promote careful action, or to consider unintended consequences toward other stakeholders in the region, these geoengineering efforts have the potential to trigger geopolitical disagreements or conflicts, as disagreements arise about best practices or which area receives disproportionate impacts from these efforts. The Arctic is uniquely positioned to develop and implement many of these agreements prior to the impacts of geoengineering efforts being felt. As a result, it is imperative that nation states and international bodies across the Arctic begin work toward a unified approach to these solutions, in order to help protect individual interests, but also to promote a safe and responsible path towards addressing this challenging problem. Recently evolving frameworks in risk governance are well suited to guide the kinds of challenges geoengineering presents, but they may do so more effectively if adopted earlier on in the process. By working to advance international frameworks focused on identifying the consequences of potential decision pathways sooner, and by focusing on the inclusion of those groups affected by the consequences of proposed measures, it will allow for the safer exploration of proposed interventions through collaborative mechanisms.

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