Our Two Climate Crises Challenge: Short-Run Emergency Direct Cooling and Long-Run GHG Removal and Ecological Regeneration

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Introduction

This paper is an effort to advance an urgent collective response to the ongoing two climate crises - shortrun global warming and long run GHG accumulation and ecological devastation, threatening the survival of global civilization. We begin in Section I by laying out some of the most critical *facts* driving this dual climate crises challenge - short-run emergency direct cooling and long-run GHG removal and ecological regeneration. Next, Section II outlines a general two climate crisis *framing*, particularly applicable to the US but relevant globally. and to many other countries. Section III analyzes some of the underlying economic, political, and scientific *obstacles* of the Section II framing. Section IV discusses public policy approaches to address both crises over time with reference to the recent Florin (2021) proposal to condition the deployment of SAI on credible global emissions reduction and removal. Section V concludes the paper by summarizing the policy perspective of the paper. Rather than conflating our two climate crises, or conditioning the solution of the first on a solution to the second, we need to address both crises on an emergency basis as called for in the Healthy Planet Action Coalition (HPAC). HPAC is calling for immediate development of an effective and responsible climate restoration plan to limit global warming to well below 1° C . Such a plan would include:[1]

1. Cooling the planet, particularly the polar regions and the Himalayas,
2. Reducing GHG emissions, including methane and other short-lived warming agents, and
3. Removing legacy CO_2, methane, and other GHGs from the atmosphere.

I. Critical Facts of Our Two Climate Emergencies

The current average global warming level of 1.2 degrees C above pre-industrial average temperatures is causing irreversible and catastrophic damage to humans and other species. If we fail to try immediately to cool our planet, and particularly the polar and Himalayan (the "third pole") regions , we will forego the possibility that at least some of this catastrophic devastation could be reduced or avoided.

At the current level of warming we may cross the first climate tipping point,the disappearance of summer Arctic sea ice, as early as this decade (see Figure 1 below). The reduced temperature difference between the poles and tropics created by polar temperatures rising three times faster than the global mean has already resulted in a deadly disruption of jet stream behavior.[2] This has slowed weather patterns and caused increasingly extreme weather events throughout the world. This continued disruption will amplify the risk of crossing other climate tipping points that will set off other irreversibly damaging climate feed-back loops.

[1] https://cf76f3c6-5f14-4369-a36c-52df89533a6f.filesusr.com/ugd/d0ff84_40cf2a9afb7140ad82aeaf0f11cea768.pdf
[2] https://www.amap.no/documents/download/6759/inline

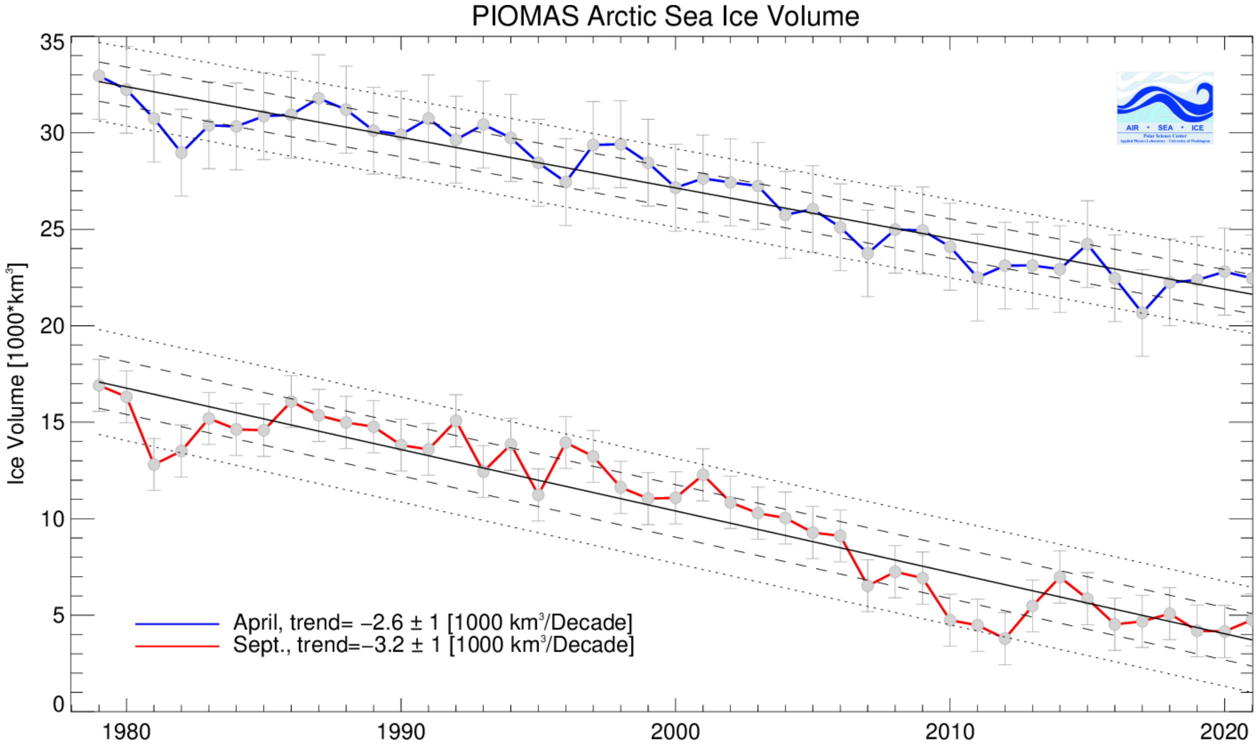

Figure 1: 1979-2021 Monthly Sea Ice Volume from PIOMAS for April and Sep.

Source: http://psc.apl.uw.edu/wordpress/wp-content/uploads/schweiger/ice_volume/BPIOMASIceVolumeAprSepCurrent.png

Downloaded 12/26/2021 from the Polar Science Center, Applied Physics Laboratory, University of Washington, USA.

Based on Figure 1 above, Sep. Arctic sea ice volume is declining at an average rate of 3.2 million cubic meters per decade. There were about 4.0 million cubic meters of ice left in September 2021. Based on this trend, *within 1.25 decades (by 2034), at the end of the summer peak melting season in September, there will be no measurable sea ice left in the Arctic.* Based on the current trend, from this point forward the Arctic will be increasingly ice free during the summer months until there is no measurable summer sea ice left (by 2106 based on the April trend in Figure 1).

Estimates included in (Pistone et al 2019), and corroborated by multiple other studies using different data and methodologies cited in this paper, suggest that crossing this tipping point would have a radiative forcing impact equivalent to that of 25 years of GHG emissions at current rates. This would be in addition to projected increases in global warming based on current emission trends. Resetting this estimate to a 2016 baseline reduces this to 17.3 years of GHG emissions (Baiman 2020, p. 2 footnote 1, and acknowledged in communications with Kristina Pistone), and additional recalibration that assumes that the first "blue ocean" complete Arctic summer sea ice melt occurs in 2034 reduces this to about 13.2 years (Appendix A). These are GHG equivalent estimates of the (added) increase to global warming exclusively because of the loss of albedo (or ability to reflect sunlight) from complete summer sea ice melt (for a summary of possible other adverse effects see (Baiman, 2021 p. 5-6).

Though it is impossible to directly link any single catastrophe to climate change, there is little doubt that global warming has been a major contributor to the range of disasters plaguing the globe. A 2021 report by Christian Aid found that the six years with the costliest (over $ 100 billion) climate disasters have occurred since 2011. t A list of climate catastrophes in 2021 alone includes: 1. US: Texas: Winter Storm and Freeze, 2. Australia: Floods, 3. France: Cold wave, 4. Arabian Sea: Cyclone Tauktae, 5. India and Bangladesh: Cyclone Yaas, 6. Europe: Floods, 7. China: Henan floods and Typhoon In-fa, 9. US: Hurricane Ida, 10. Canada: British Columbia floods, 11. Brazil, Paraguay, and Argentina: Paraná River drought, 12. South Sudan: Floods, 13.Nigeria, Cameroon's Far North region, western Chad and southeastern Niger: Lake Chad Crisis, 14. US Pacific Northwest: Heatwave, 15. East Africa: Drought. The Report concludes that the combined cost of these catastrophes was nearly $200 billion with the most damaging (in financial cost terms) being Hurricane Ida, which killed 115 people and cost $65 billion in damages. Runner ups were the Texas winter storm and European summer floods.[3]

The climate crisis is not just increasing the incidence and severity of extreme weather events, but also is having a less immediately visible impact on commodity prices. A recent (12/29/2021) Wall Street Journal article notes that bad weather is a major factor in the 2021 run-up in commodity prices in the US and globally.. An extreme jump in natural gas prices has run up the cost of PVC pipe and paint resins. Drought in South America has wilted Brazil's corn intended for export and left the Parana River too shallow for efficient transport from Argentina's interior to Atlantic sea ports, leading to the highest corn and soybean prices in several years. The drought and heat waves in North America cut off hydro power generation serving California, and triple digit temperatures caused road buckling and death in Portland, Seattle and elsewhere. Increased demand on fossil fueled electricity generation to meet air conditioning demand drive up natural gas and coal prices. Raging wildfires in the Pacific Northwest forests in July caused increased lumber prices through the summer and early fall. Prices rose again in November due to floods in British Columbia. Drought induced grasshopper infestations of North Dakota spring wheat contributed to a USDA reported 44% decline in US wheat production in 2021. Similarly, weather across the Canadian prairie led to record oat prices. Flooding and extreme temperatures in China, the world's largest tin producer, led to record high tin prices. Flooding in Germany's industrial corridor closed metal production and recycling facilities. Freezing weather decimated Brazil's coffee crop leading to multiyear record high arabica bean prices. Hurricane Ida shut down Gulf of Mexico natural gas production that impacted not just heating and cooking costs,

[3] https://www.christianaid.org.uk/sites/default/files/2021-12/Counting%20the%20cost%202021%20-%20A%20year%20of%20climate%20breakdown.pdf

but also prices for fertilizer, cement, steel, and plastic, including resins, additives, and solvents. By October, natural gas futures were the highest since fracking began over a decade ago.[4]

In terms of aggregate data, a November report by Swiss Re, one of the world's largest reinsurance companies, estimates that at the current trajectory, global temperature is likely to rise to 2.6 degrees Celsius above pre-industrial levels and will reduce world GDP by $23 trillion by 2050. Poor countries will suffer the most. To put this in perspective, current (2020) world GDP is estimated at $84.54 trillion.[5] In the Swiss Re scenario, the potential GDP of the US, UK, Canada, and France would decline by 6-10 percent, while the GDP of Malaysia, the Philippines and Thailand would be reduced by one third.[6] But these are most likely an underestimates, as the Swiss Re report acknowledges that:

"Importantly, the framework does *not* consider tipping points, events such as the partial disintegration of ice sheets, biosphere collapses, or permafrost loss, that pose a threat of abrupt and irreversible climate change. This is because it is thought that tipping points will materialize well after the model horizon of mid-century only." (p. 30).

The assumption that tipping points will not materialize until after mid-century (2050) is almost certainly incorrect. Based on the trend shown in Figure 1, we are on track to begin crossing the first tipping point, the complete loss of summer Arctic sea ice, by 2034. By 2050, the Arctic will likely be ice free for extended periods of time during the summer. This will increase the risk of crossing other potentially more catastrophic tipping points, such as massive methane release from Siberian permafrost melting and a collapsed Atlantic Gulf stream – both related to Arctic amplification, that appear to also be starting far earlier than previously estimated (Lenton et al. 2019) (Velasquez-Manoff and White 2021).[7]

For all these reasons it is imperative that we implement emergency direct cooling measures, with a particular focus on restoring or slowing ice melt in the polar regions (including the Himalayan "third pole"), immediately. We cannot afford to wait for three decades and probably longer, to achieve zero emissions and remove sufficient GHGs from the atmosphere to prevent continued and accelerating climate deterioration.

Background Political Framing

The dominant discourse on climate change has for many years been framed as a Manichaean battle over the future of the world between the forces of good and evil.[8] The forces of good recognize that we are facing an existential threat of our own making; and the forces of evil deny

[4] https://www.wsj.com/articles/blame-bad-weather-for-your-bigger-bills-11640640525
[5] https://www.statista.com/statistics/268750/global-gross-domestic-product-gdp/
[6] https://www.nytimes.com/2021/04/22/climate/climate-change-economy.html
[7] https://www.smithsonianmag.com/smart-news/ticking-timebomb-siberia-thawing-permafrost-releases-more-methane-180978381/
[8] https://tif.ssrc.org/2020/11/16/social-climates-beyond-belief-and-doubt/ and https://mikehulme.org/the-manichean-mann-review-of-the-new-climate-war-the-fight-to-take-back-our-planet/

that climate change is real, don't believe it is caused by humans, , or are betting that capitalist entrepreneurship or some other *deus ex machina* will save the day.

The "deny or do nothing" position, most prevalent in the US and a handful of other countries, is hopefully weakening as calamitous climate change associated events like devastating floods, drought and wildfires, mammoth "derechos," and the 2021 "heat dome" in northwest United States , become more frequent and severe. But the dichotomous, moralistic (fossil fuel use is an "original sin"), political left/right, existential fight for survival, framing continues particularly in the US.

The good vs. evil frame has become dominant for good reason. It contains kernels of truth. Special interests including fossil fuel interests, right wing billionaires, media moguls, and oligarchic elites, have conspired to deny the truth and block GHG mitigation and adaptation efforts. [9]As a result the political response, particularly at the global level, is wholly inadequate and dispiriting. And, in an already unconscionably inequitable world, the poorest and most vulnerable countries and people will continue to suffer the most.

So, while the good vs. evil frame is understandable, has some basis in truth, and has served an important purpose, it has become an obstacle to practical progress. Among its defeating characteristics, the frame:

a) Does not offer hope, particularly in the face of repeatedly backsliding or inadequate political responses.

b) Presents climate change in purely moralistic or political terms and ignores objective embedded physical, social, and political system infrastructure that blocks or slows GHG mitigation and adaptation regardless of morality or politics.

c) Fails to fully promote the imperative to lift up standards of living for billions of people even as GHG emissions are reduced.

d) And most importantly, offers no immediate relief for climate change induced suffering due to already "baked in" effects that will be ongoing and worsening even if GHG emissions are reduced to zero now, and does not recognize that addressing the climate crisis in the short-term time period dictated by the climate is a practical problem of applying a *technological tourniquet to a critically bleeding planet*, and of CDR and CCSS as well as mitigation and adaptation, within *existing* social and economic systems that themselves will take much longer to evolve.

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[9] https://news.harvard.edu/gazette/story/2021/09/oil-companies-discourage-climate-action-study-says/
https://stopfundingheat.info/facebook-in-denial/ and
https://www.universityofcalifornia.edu/news/media-creates-false-balance-climate-science-study-shows

An alternative frame will recognize that:

a) Closing the carbon cycle is a long run *opportunity* for human civilization to evolve from "industrial hunter gatherer" to a more equitable and prosperous Renewable Energy and Materials Economy (REME) "industrial cultivator" state,

b) Fossil fuel use was not an original sin" but the basis for modern industrial civilization and addressing the climate crisis is, at least in the short term, not fundamentally a moral and political problem, but a practical and technological problem that must be addressed within existing social and economic systems,

c) We must address equity or our efforts will fail.

d) During the critically important short-term (at least several decades but possibly much longer) transition period we must keep the climate from spiraling out of control by trying to apply an emergency "tourniquet" to try to slow or reverse the worst climate impacts, and particularly the first imminent Arctic sea ice melting tipping point.

For more detailed analysis of this framing see Baiman (2021).

A more comprehensive version of this framing can also be found in a proposal put forth by the Envisination group (Pearce et al, 2021). This plan estimates that regenerating land and ocean fertilization to prior levels of life could potentially "sequester" in living organisms roughly 87% of the carbon necessary to get to achieve a sustainable global climate that is no warmer than 0.5 C above preindustrial by 2050. The rest of the sequestration would be roughly divided between natural geological methods such as rock weathering and biochar and basalt soil carbon enhancements, and mechanical methods performed by a REME economy with DAC and CCSU. This general approach (perhaps with more DAC and other engineered drawdown methods depending on speed and land use requirements) could, overtime, address the broadly natural ecological devastation on multiple fronts incurred by "hunter gatherer" industrial civilization that will be needed for long run sustainable human and other species survival on the planet (Pearce et al, 2021, p. 67, 77) (Baiman, 2020) (Seffen et al, 2015).[10]

II. The Limits of a Moral Suasion and Breakdown Strategy: Disciplinary Siloization and Real Political Economic Constraints to GHG Removal

The calculation that appears to have been made by a majority of climate activists, scientists, and political leaders, is that talk of a geoengineering tourniquet risks reducing the political pressure to eliminate fossil fuel use and implement a transition to a renewable and sustainable economy.

[10] Some DAC methods such as Lackner's "mechanical trees" are reportedly able to drawdown carbon 1,397 times faster than natural trees so that a "forest" of only 250 square miles of these trees (at 120,000 trees per square mile) could drawdown about one gigaton of CO2 a year (Baiman, 2021, p. 617).

This “moral hazard” argument, like the old breakdown and socialist revolution argument, appears to be based on the premise that moral suasion and increased climate catastrophe and suffering are worth bearing for the sake of a faster transition.

But a credible global GHG emissions reduction and drawdown plan has not been implemented (Baiman, 2021, Figure 1). And this is not just due to the general difficulty of arriving at a global political solution and the forces of corruption and vested interest, but is also: a) a reflection disciplinary siloization, and b) of real economic and political constraints to implementing a meaningful and rapid transition to a renewable and sustainable economy (Baiman, 2021).

Regarding a) or disciplinary siloization, climate scientists have been documenting this looming first climate tipping point and its abrupt and potentially catastrophic impact on the global climate for years but do not see themselves as responsible for proposing solutions. On the other hand, social scientists, who are focused on trying to develop plans and estimates for solutions, are focused on politics, economics, and technological change, that are rightly viewed as the fundamental locus and source of the problem and of potential remedies.

Arctic summer sea ice melt is a natural science phenomenon that is too far along at this point to be impacted by political, economic, or technological efforts to reduce near term GHG emissions reduction and removal. It therefore falls outside the traditional scopes of both climate scientists who are focused on documenting and understanding climate change, and social scientists and engineers focused on GHGs emissions. Thus, in spite of its well documented potentially abrupt calamitous impact on the global climate, that in the short term is likely to be more immediately harmful than increased GHG emissions, the possibility and urgency of trying to do something to slow or reverse this first climate tipping point is not being addressed by any government or international body. This lack of action persists, despite relatively modest cost estimates of $ 1-10 B for the various proposals (Baiman 2021, Table 1, p. 8).

Regarding b), or the real economic and political constraints to a transition to a sustainable economy. Fossil fuels account for 84 percent of the world’s energy and a large share of raw material inputs for much of modern industrial civilization (BP 2020: 4) (Baiman 2021). This is slowly changing. Solar is catching up and, in many cases, is less expensive than fossil fuel in terms of unit energy cost (even without accounting for the externality costs of carbon dumping that most fossil fuel producers do not currently bear), but not in terms of dispatchability and portability. Carbon-negative cement and concrete, and substitutes for steel, aluminum, fuel, fertilizer, and many other materials using carbon from the air, currently exist or are being developed. However, especially for developing countries, and particularly those who are dependent on fossil fuel or natural resource exports, often produced by public companies, there may be no other viable options.

Efforts to transition to a REME economy with Envisionation-like carbon sequestration and ecological regeneration offer hope for a better political economic and natural future but this will take time, at a minimum several decades and possibly a century or more for planetary regeneration. The currently dominant approach of ignoring the distinction between these two crises has increased the risk of not directly addressing the first crisis of emergency cooling until it is too late, and has not, so far, been successful in generating a more rapid and effective response to the second and deeper long-run ecological regeneration crisis.

For example, the pervasive "carbon-free," as opposed to a "net carbon-free" or "carbon cycle closing," framing that erroneously paints the ecological of industrial civilization as a short-term "carbon pollution" issue has become an obstacle to practical progress in addressing climate change and making it an opportunity instead of a problem (Zachs 2019). The goal after all is not an economy free of carbon, or "carbon purity," but rather to reduce and drawdown "fugitive carbon" from the atmosphere and ocean, as carbon is not a pollutant but a primary molecule of life (McDonough 2016). There is no question that the world economy needs to achieve *net* "deep decarbonization" in the long run, but this cannot be done rapidly enough to solve the short-term cooling emergency, and rapidly (hopefully in a few decades) reducing atmospheric carbon *and* equitably raising global living standards will require continued innovative use of fossil fuels, for example adding negative emissions technology to existing natural gas fired electric power plants.[11]

The political and economic constraints to rapid GHG removal to resolve our second more fundamental crisis are evidenced in two recent incidents, and in the data shown in Figures 2) and 3) below.

The two incidents are: a) the President of Ecuador offering to not exploit newly discovered oil reserves in the Amazon rain forests if the international community would reimburse Ecuador for forgone oil earnings, and after getting no response, moving ahead with oil extraction (Goldman 2017), b) Norway (one of the most social democratic, environmentally responsible, and wealthiest (per capita) countries in the world) going ahead with exploitation of newly discovered

[11] Estimates suggest that atmospheric warming, from the elimination of fossil fuel SO2 aerosol cooling, could in the short term offset much of the initial cooling impact of net decarbonization (Samset et al 2018). If this is the case, though there is no question that a full transition to renewable energy is necessary in the long run, it may be wise to couple this with substitute tropospheric cooling aerosol methods such as marine cloud brightening and iron salt aerosol and continued *net* carbon-negative fossil fuel use (such as Global thermostat's (GT) Direct Air Capture (DAC) from natural gas power generation technology) in the transition period (sections III and IV).

north sea oil reserves using "green" technologies (Kottasovana 2020). If Norway cannot resist cannot fossil fuel exploitation, I doubt that any other major country in the world will be able to.

In support of this view, Figure 2 below shows that in 2019 over 1.5 billion people (20% of the global population) lived in low income, small, or western and central African countries, for which on average (weighted by population) 26% of total exports are fossil fuel exports that in 2019 generated approximately $ 149 billion of vital foreign exchange for these countries.

Fuel Exports as a Share of Total Exports and GDP (2019, 72 Low Income, Small, and Western and Central African, Countries)					
Country Name	Country Code	Pop 2019 (millions)	Fuel Exports % Total Exports	Fuel Exports % GDP	Fuel Exports $ (millions)
Europe & Central Asia (excluding high income)	ECA	418.8	27.3%	9.1%	$85,733.1
Other Small States	OSS	31.4	45.5%	26.3%	$43,037.8
Sub-Saharan Africa (excluding high income)	SSA	1106.9	25.7%	6.1%	$20,181.8
Weighted Avg by Pop			26.5%	8.2%	
Total		1557.1			$148,952.8
Share of Global Total		20.2%			

Figure 2: Liquid Fossil Fuel Export and GDP Share of Small States, and low income Sub-Saharan African and Europe and Central Asian, Countries Comprising 20% of the Global Population.

Source: Author's calculations from World Bank Indicators from www.worldbank.org/indicator/ downloaded 10/28/2021. Fuel Exports are SITC Revision 3, "3. Mineral Fuel, Lubricants, and Related Materials". ECA countries (20) are: Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Georgia, Kazakhstan, Kosovo, Kyrgyz Republic, Moldova, Montenegro, North Macedonia, Romania, Russian Federation, Serbia, Tajikistan, Turkey, Turkmenistan, Ukraine, Uzbekistan. OSS countries (33) are: The Bahamas, Barbados, Antigua and Barbuda, Bhutan, Guinea-Bissau, Guyana, Iceland, Jamaica, Kiribati, Lesotho, Maldives, Malta, Marshall Islands, Mauritius, Federated State of Micronesia, Montenegro, Namibia, Nauru, Palau, Qatar, Samoa, San Marino, Sao Tome and Principe, Seychelles, Solomon Islands, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Timor-Leste, Tonga, Trinidad and Tobago, Tuvalu, Vanuatu. SSA countries (19) are: Angola, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone , Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe. Note: Guinea-Bissau (2019 Pop. 1.9 million) is included in both the OSS and SSA countries.

A similar analysis by country shown in Figure 3 below indicates that in 2019 1.1 billion people (14.2% of the roughly 7.7 billion global population) lived in countries for which liquid fossil fuel exports constitute over 10% of total exports, and these generated over $ 4 trillion of foreign exchange for these countries.[2]

Note that this economic dependency on fossil fuels only accounts for liquid fossil fuel exports, and does not consider broader employment and income domestic economic fossil fuel dependence, or other forms of fossil fuel, or fossil-fuel based products, such as coal, natural gas, plastics, and fertilizer. These tables also do not consider the urgent need of low-income and developing countries for disproportionately faster growth of export earnings, energy use, and economic development in the coming decades.

Clearly, something more than moral suasion, and catastrophic but still (at least for now!) slow moving climate collapse, will be necessary to force global political leaders into action. Breaking down disciplinary siloization, as this paper attempts to do should help, but does not in itself offer a path forward.

Fuel Exports Percent of Total Exports and Value (2019, Current $, By Country)						
Rank	Country Name	Fuel Exports % of Total Exports	Fuel Exports $ (millions)	Cumulative Fuel Exports $ (millions)	Pop (millions)	Cumulative Pop (millions)
1	Brunei Darussalam	82.2%	6,412.0	6,412	0.4	0.4
2	Kuwait	79.9%	898,052.9	904,465	4.2	4.6
3	Qatar	70.4%	64,774.0	969,239	2.8	7.5
4	Norway	54.3%	21,680.7	990,920	5.3	12.8
5	United Arab Emirates	50.8%	1,280,868.5	2,271,788	9.8	22.6
6	Russian Federation	45.3%	218,119.3	2,489,907	144.4	167.0
7	Kazakhstan	42.6%	1,332.1	2,491,239	18.5	185.5
8	Ecuador	35.1%	8,746.3	2,499,986	17.4	202.9
9	Mongolia	34.1%	2,135.5	2,502,121	3.2	206.1
10	Nigeria	31.7%	842.5	2,502,964	201.0	407.1
11	Malta	24.3%	349,875.3	2,852,839	0.5	407.6
12	Barbados	22.9%	929.6	2,853,769	0.3	407.9
13	Cyprus	20.7%	1,051.2	2,854,820	1.2	409.1
14	Indonesia	20.5%	13,365.7	2,868,186	270.6	679.7
15	Belarus	17.6%	8,142.2	2,876,328	9.4	689.1
16	Fiji	16.0%	1,367.7	2,877,695	0.9	690.0
17	Samoa	15.7%	99,321.6	2,977,017	0.2	690.2
18	Jamaica	15.3%	136,454.8	3,113,472	2.9	693.1
19	Australia	15.2%	51,294.1	3,164,766	25.4	718.5
20	Ghana	14.6%	12,017.4	3,176,783	30.4	748.9
21	Egypt, Arab Rep.	14.5%	7,680.4	3,184,464	100.4	849.3
22	Senegal	11.8%	77,796.1	3,262,260	16.3	865.6
23	Brazil	11.4%	30,313.6	3,292,573	211.0	1,076.7
24	Lithuania	11.2%	725,712.2	4,018,286	2.8	1,079.5
25	Malaysia	10.7%	402.2	4,018,688	31.9	1,111.4

Figure 3: Countries with Over 10% Liquid Fossil Fuel Export Shares (2019)

Source: Author's calculations from World Bank Indicators from www.worldbank.org/indicator/ downloaded 10/28/2021. Fuel Exports are SITC Revision 3, "3. Mineral Fuel, Lubricants, and Related Materials".[12]

[12] The Russian Federation, Nigeria, Malta, Barbados, Belarus, Ghana, and Senegal in Figure 3 are also included in one of the Figure 2 country groups.

II. How Can Short-Run Emergency Direct Cooling and Long-Run GHG Removal and Ecological Regeneration be Achieved?

> A recent broad international coalition of leading climate scientists, policy experts, and activists, that includes the author, has recently formed and proposed an "all options must be on the table" climate strategy.[13] These were formulated in two letters sent to G20 and COP26 delegates. The latter also became a petition that was signed in short order by over 500 people.[14]

In it we asked that:

"COP26 adopt a resolution committing to develop a climate restoration plan no later than 2023 to limit global warming to well below 1° C. An effective and responsible plan will need to integrate three approaches:

1. Cooling the planet, particularly the polar regions and the Himalayas,

2. Reducing GHG emissions, including methane and other short-lived warming agents

3. Removing legacy CO2, methane, and other GHGs from the atmosphere.

Needless to say, HPAC has received no serious commitment or response from COP26 or the G20 to this proposal. None the less, we firmly believe that there is no other reasonable path forward for addressing the climate crisis.

Point 2, and now increasingly 3, have broad theoretical support in the climate science and policy making community, though that theoretical support has not translated into a robust political reality. But, per the discussion above, point 1 has little support, and (with some notable and growing exceptions) is generally viewed as off the table for mainstream climate discussion.[15]

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[13] Full disclosure: the authors are founding members of HPAC and serve on the HPAC Steering Circle.

[14] See https://www.healthyplanetaction.org/ and https://www.change.org/p/john-kerry-tell-world-leaders-at-cop26-to-unite-now-on-a-climate-restoration-action-plan?utm_content=cl_sharecopy_31171781_en-US%3A7&recruiter=2690263&utm_source=share_petition&utm_medium=copylink&utm_campaign=share_petition

[15] See for example: National Academies of Science, Engineering,and Medicine. 2021. *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance.* Accessed at: https://www.nap.edu/catalog/25762/reflecting-sunlight-recommendations-for-solar-geoengineering-research-and-research-governance

As Section I documents, we are now in a climate crisis. As discussed in Section II, we need to immediately apply direct cooling or climate triage (point 1 above) to limit the harm and suffering to humans and other species as we try to reduce and remove GHGs as quickly as possible to stabilize the climate.

a) The Florin Stratospheric Aerosol Injection (SAI) Implementation Framework

We believe that a recent white paper by Marie-Valentine Florin (2021) expresses a policy view that has a near future chance of broad acceptance. Florin addresses her remarks exclusively to SAI (Stratospheric Aerosol Injection – see below and Baiman (2021)) and points out that long term and extensive deployment of SAI carries with it physical risks: "… such as long term potential changes to precipitation and evaporation patterns, stratospheric ozone depletion, and adverse consequences on biodiversity and ecosystem services." As well as: "… geopolitical, security, socio-economic, and ethical risks, such as the possibility of unilateral deployment by a rogue actor." In addition to the "moral hazard" concern that geoengineering may be so effective and inexpensive, as to remove the political impetus for necessary long-term GHG reduction and removal.

For the purposes of this paper we will not take issue with the widely held views of the potential physical risks of long-term SAI enumerated by Florin, though we believe that all are debatable and require further study, unlike the known and already present calamitous risks of continued warming discussed in Section I.[16] We also will not address the potential "rogue actor" security risks, though as aerosols rapidly disperse in the stratosphere, it is not clear how a rogue actor would benefit or not be quickly shut down by international authorities backed by global powers.

Furthermore, as Florin implicitly acknowledges by emphasizing that her plan is a "risk management" not a "crisis management" plan, if warming becomes a civilization extinction emergency, a "rogue action", like for example, unilateral US SAI deployment (which if not already researched and piloted and agreed to by the international community would be the worst way to do this!) could be viewed as a last resort global insurance, rather than a reason for blocking research and piloting of SAI.

Florin cites a number of possible SAI risks but her primary concern (and that of climate scientists and policy makers) about SAI is that it:

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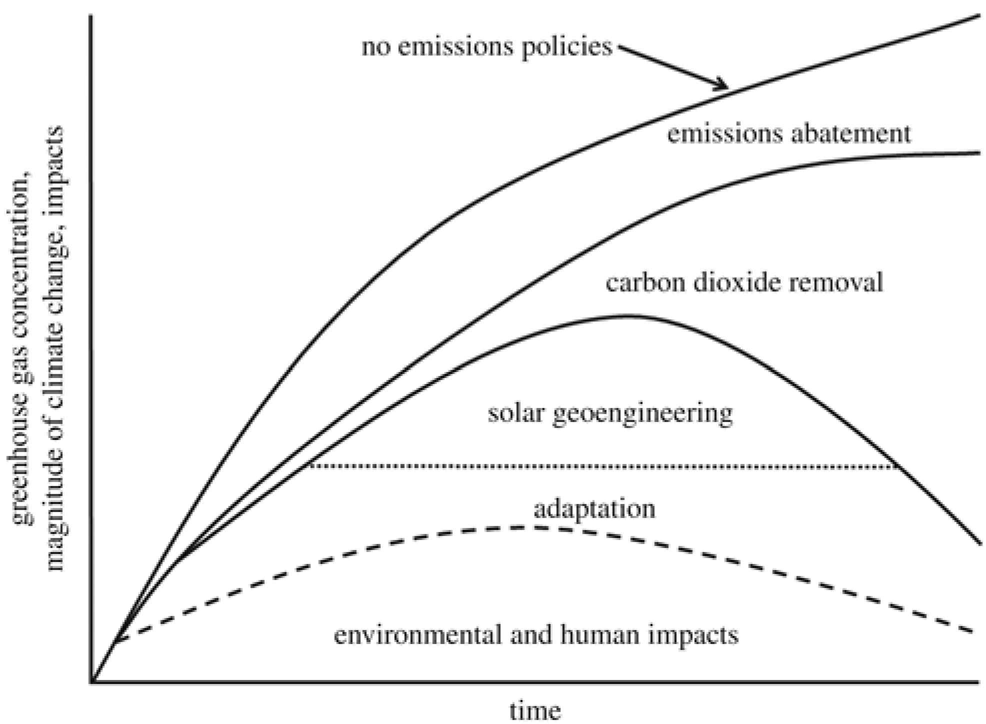
[16] For example, there is now an extensive literature studying the possibility of carefully targeted SAI to achieve specific (beneficial) broad special and temporal levels of warming and precipitation. See: "Expanding the design space of stratospheric aerosol geoengineering to include precipitation-based objectives and explore trade-offs", Lee et al, Earth Syst. Dynam., 11, 1051–1072, 2020, https://doi.org/10.5194/esd-11-1051-2020

- potentially be *too inexpensive,* as it is estimated at $3.6 billion for startup and $2.25 per year operational costs, or less by mimicking forest fire lofting
- And so *effective* at cooling the planet, as the 1991 Mount Pinatubo volcano is estimated to have lifted about 15 million tons of sulfur (as opposed to 3.3 million tons per year in the SAI estimate above) into the stratosphere and cooled the planet by 0.6 degrees Celsius for 15 months

that it would substantially reduce political pressure for long-run necessary global GHG mitigation and adaptation.

Given the enormous inertia in the way that current global governance is organized and operates, it is possible that successful SAI could make global political paralysis on GHG emissions and drawdown worse. But it is also possible that a successful global direct cooling effort would provide the motivation and hope for the implementation of a serious mandatory global emissions reduction and drawdown regime that, as argued below, is necessary for credible GHG drawdown.

Florin proposes a "shaving the peak" or "buying time" temporary role for SAI per Figure 4 below, that is based on an adaptation of the widely publicized plot by Long and Shepard (2014).[17]



[17] https://link.springer.com/referenceworkentry/10.1007%2F978-94-007-5784-4_24

Figure 4: "Shaving the Peak" Implementation of Stratospheric Aerosol Injection Solar Geoengineering

Source: https://royalsocietypublishing.org/doi/10.1098/rspa.2019.0255 **(**Reynolds, 2019, Figure 3). Original by Jane Long and John Shepherd: The strategic value of geoengineering research**.**

She proposes a non-emergency risk management decision framework for temporary deployment of SAI that specifies the following conditions to "when to start" (t1) and "when to stop" (t2):

"**When to start (t_1)**

This proposed framework suggests three conditions for policymakers to decide when it is time to begin SAI *(t_1)*. t_1 can only exist when all three of the following conditions are met:

1. We are close to crossing one or more dangerous ecological thresholds ('overshoot'), beyond which irreversible shifts and damage would occur in the ecosystems. Such thresholds would need to be specified in advance (but might evolve with new science). Deployment would not wait until the tipping points have occurred, which would be too late, but start when early warnings are detected that important socio-ecological systems are coming close to a regime shift.

2. We are quite sure that we are on the path to sufficient CO_2 emissions reduction globally.

3. There is clarity as to when SAI can be stopped (t_2).

t_1 only exists if all three conditions above are met (including that t_2 can be identified).

When to stop (t_2)

t_2 is the time when the danger of irreversible damage has been avoided, and CO_2 concentration has started to decline. t_2 can only exist when the following conditions have been met:

4. It can be identified before t_1, i.e., before SAI is started.

5. Emissions will continue to be reduced during SAI deployment (should not go up again).

6. Sustainable large-scale CDR has been implemented effectively (CO_2 atmospheric concentration continues to decline)."

We understand the thinking behind the Florin proposal and applaud the effort to devise a workable strategy that I think may allow SAI to be finally be seriously considered in dominant climate policy circles. By sequencing the start of SAI direct cooling after a credible GHG emissions reduction plan, and SAI cessation after a credible GHG drawdown plan, Florin's proposal goes some way toward acknowledging and responding to the two climate crises that we are facing.

Unfortunately, however, we believe that even the Florin plan may not be adequate as we need emergency cooling now, and we may need SAI before a credible global GHG emissions reduction and removal plan, that will require a binding international cap and trade agreement, can be implemented.

b) SAI is not the only form of climate triage or direct cooling, and local direct cooling methods are urgently needed now

Many different cooling methods have been proposed with very different local, regional, and global, ranges of potential impacts, and we are proposing that all be carefully studied, piloted, and, if believed to be successful and safe, very gradually implemented pending the outcomes of continuous assessment.

Second, it must also be kept in mind that the evaluation of risks of these methods should always be in the context of the certainty of increasing climate catastrophe if we are unable to cool the planet, and particularly the poles.

Third, we believe that trying, hopefully successfully, to reduce or eliminate short-term catastrophic climate change is one of the most important immediate things that we can do for global climate equity, as there is little doubt that a disproportionate share of near term (hopefully not longer than thirty years) harm from climate catastrophe will be born by the most disadvantaged among us, including both countries, and individuals within countries. The growing numbers of desperate climate refugees searching for a location in the world where they and their families can survive with dignity is evidence of this.

We therefore believe that the claim, without evidence or study, that the risks of attempting to cool, regardless of method attempted, will always be greater that the risk of doing nothing to save the Arctic sea ice, and reduce or reverse the certainty of increasing climate catastrophe (that will occur as long as the stock of GHGs in the atmosphere is increasing) cannot be justified as such inaction could cause immeasurable and potentially avoidable, increased human and species suffering.

To the contrary, just listing some of the cooling methods that have been proposed, shows that the range of possible impacts, with some relatively confined, to others with greater scope for unanticipated adverse impacts, is very large, so that these impacts cannot be peremptorily dismissed as unacceptable, particularly when compared with the risks of not doing anything.

Some of the proposed methods are:

· Marine Cloud Brightening (MCB) can mitigate extreme weather by adding salt to the air. Brighter clouds cool the ocean surface, cutting the intensity of storms and helping manage local impacts of ocean heat on drought and flood and ecosystems. MCB trials are currently funded by the Australian Government to cool the Great Barrier Reef to stop coral bleaching.

· Mirrors for Earth's Energy Rebalancing (MEER Reflection) offer local and regional cooling solutions based on deployment of arrays of mirrors on the earth's surface.

· Wind driven sea water pumps could increase Arctic winter ice formation, slowing summer ice melt and methane release.

· Surface Albedo Modification is a localized technique to spread hallow glass microspheres on ice surfaces to improve reflectivity.

· Iron Salt Aerosol can extend the numerous natural cooling effects of iron-rich dust, cutting methane, brightening clouds and increasing ocean biomass productivity.

· Stratospheric Aerosol Injection, mimics the major natural cooling effect of volcanic eruptions involves the injection of aerosols into the stratosphere for global cooling.

· Cirrus Cloud Thinning could reduce cirrus cloud heat trapping in the upper atmosphere.

We urgently need direct cooling. We are beyond the point of deliberately not taking measures to reduce or eliminate immediate climate catastrophe, in order to increase pressure for long term GHG reduction and removal. We are already in a "climate emergency" that requires deployment of direct cooling methods. Furthermore, as I believe that Florin's conditions 2) and 6) will not be credible without implementation of b) below, it may well be necessary to deploy emergency SAI, as GHG reduction sufficient to stabilize the climate may take a century or more if b) below is not put in place.

c) Mandatory global cap and trade regimes are necessary to achieve credible GHG drawdown

It is widely recognized that the politics of climate change are currently paralyzed. We can't have credible GHG reduction and removal without a sustainable (REME) economic transition in developing countries. But developing countries cannot afford to do this without massive financial and technological help that equalizes life opportunities across the globe going forward. The only way to achieve this is through a binding global cap and trade system for both emissions and withdrawal (Chichilnisky and Bal, 2019).

For all of these reasons, moral suasion and Paris Accord voluntary "Nationally Determined Commitments" (NDCs) are unrealistic and unworkable paths for rapid global GHG emissions reduction and drawdown in the next few decades. The only way to realistically and efficiently achieve this is through binding global cap and trade regimes that explicitly include mechanisms like the Kyoto "Clean Development Mechanism" (CDM) that transferred $ 303.8 billion from rich countries to poor countries for mitigation and adaptation.[18] In contrast the Paris Accord voluntary Green Climate Fund (GCF) had over the period 2014-2021 (as of 9/2021) raised only $16.8 billion.[19] An alternative would be for the US to simply create the global currency (US dollars) necessary to fund a climate transition, but this appears less politically feasible than an enhanced Kyoto-like global cap and trade regime, a version of which has been implemented but then (very unfortunately!) allowed to lapse in 2015 (Baiman, 2020).

Interestingly, the EU was the only major region of the world that continued to internally enforce a Kyoto-like cap and trade internal Emissions Trading System (ETS) after the global mandatory Kyoto accord was replaced in 2015 by the voluntary Paris Climate Agreement. The EU ETS, along with individual country carbon taxes on sectors not yet covered by it, has been the only major region of the world to significantly cut, by 24% from 1990 to 2019, its GHG emissions since 1990.[20] In contrast, US GHG emissions increased by 2% over this period.[21] Though the EU may impose a "Carbon Border Adjustment Mechanism" that hopefully will induce some of its trading partners to implement similar ETS or carbon tax systems. These now reportedly apply to about a fifth of global GHG emissions.[22] However, per Figures 2-3, a *global ETS* like that generates enforceable *transfers of investment from rich to poor countries* is the only realistic and equitable way to a achieve global GHG reduction and removal.[23] [24]

But the proposed EU Carbon Border Adjustment Mechanism is a reminder that serious efforts to transform the global economy require mandatory and enforceable rules like that of the WTO. In my view the free trade doctrine is fundamentally erroneous and economically harmful, but regardless of its merits, but I don't think any serious proponent would suggest that it could be

[18] https://unfccc.int/sites/default/files/resource/UNFCCC_CDM_report_2018.pdf According to this 2001-2018 UNFCCC report, the CDM led to the investment of $ 303.8 billion in climate and sustainable development projects that resulted in an almost 2 GT CO2eq emissions reduction in the developing world.

[19] https://www.greenclimate.fund/about/resource-mobilisation/irm $ 7.2 billion during the 2014 Initial Resource Mobilization (IRM) and as of Sep. 2021 another $ 9.6 billion during the first replenishment (GCF-1) 2020-2023 period.

[20] https://ec.europa.eu/clima/eu-action/climate-strategies-targets/progress-made-cutting-emissions/kyoto-2nd-commitment-period-2013-20_en

[21] https://www.epa.gov/climate-indicators/climate-change-indicators-us-greenhouse-gas-emissions

[22] https://www.worldbank.org/en/news/press-release/2021/05/25/carbon-prices-now-apply-to-over-a-fifth-of-global-greenhouse-gases

[23] https://ec.europa.eu/taxation_customs/green-taxation-0/carbon-border-adjustment-mechanism_en

[24] https://www.worldbank.org/en/news/press-release/2021/05/25/carbon-prices-now-apply-to-over-a-fifth-of-global-greenhouse-gases

voluntarily implemented (Baiman, 2017). How can we expect a more radical and fundamental transformation of the global economy to a REME to be achieved through voluntary Paris Accord NDCs and GCF philanthropy?

A global mandatory net carbon “dumping fee” or “cap and trade” market for GHGs with a cap that very rapidly goes to zero, based on responsibility and capacity, and enforced by national governments should be established.[25] A revived global Emissions Trading System would increase the efficiency and scope of drawing down GHGs and lead to a large transfer of funding and investment to developing countries, as occurred under the Clean Development Mechanism (CDM) of the Kyoto Protocol, and would address the regulation and governance issues raised by critics (Chichilnisky and Bal 2019; Hahnel 2012). Hahnel points out that as national GHG emissions can be more accurately estimated than those of many specific transactions, individual countries can be held responsible for their emissions regardless of whether traded GHG offsets are real or not – an issue that is less likely to be a problem for carbon capture than for, especially natural, GHG mitigation.[26] An additional, or alternative, global cap and trade market for produced CO2 extracted from the atmosphere or ocean, and a “Clean Investment Mechanism” to support investment in this “Negative Emissions Technology” in developing countries, analogous to the Kyoto CDM, has recently been suggested.[27] A Clean Investment Mechanism would foster profitable investment in Negative Emissions Technology in developing and developed countries to achieve carbon capture goals and comply with the1997 Byrd Hagel law stipulating that any US climate response grow the economy. If the Clean Investment Mechanism included social floor regulations, such as wages, working conditions, and corporate income taxes, it could serve to leverage capitalist incentives to rapidly scale up production of CDR, a public good, and raise living standards in developing countries (Baiman 2017: 135–63).

IV. Conclusion

We are facing both a short-term emergency cooling crisis and a long-term GHG drawdown planetary ecological crisis. We must address both. The first requires emergency direct cooling, or temporary “triage” or a “tourniquet, for our bleeding planet”. The second requires rapid GHG emissions reductions and drawdown and natural planetary regeneration that realistically will take at least a few decades and may take a century or more. Conflating the challenge and opportunity of the second crisis with a response to the first crisis will not produce a rapid and credible global

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[25] As proposed for example by the Greenhouse Development Rights Framework (Greenhouse Development Rights 2021).

[26] For example, California’s cap and trade law carbon dioxide compliance offset protocols (Urban forest, and US forest) apply exclusively to natural mitigation (California Air Resources Board 2021).

[27] As suggested by Graciela Chichilnisky in a working document of the Elk Coast Institute DAC Climate Mobilization Summit in 2021.

response to the second crisis because of structural economic inequity and fossil fuel dependency that is deeply embedded in the current global economy. Realistically, we need emergency direct cooling to address the first crisis and a long-term binding global cap and trade “emissions trading system” (ETS) to address the second. The Florin proposal that conditions SAI direct cooling on credible GHG emissions and drawdown is a step in the right direction, but omits other direct cooling methods and effectively makes the deployment of SAI contingent on a global ETS that may not be possible before the deployment of SAI becomes necessary. Rather than conflating our two climate crises, or conditioning the solution of the first on a solution to the second, we need to address both on an emergency basis by putting all options on the table as called for in the HPAC proposal.

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Appendix A

Pistone et al (2019) use the approximate formula f = (5.35 W/m^2) ln(x/R) where f is radiative forcing relative to R, and x atmospheric concentration (Pistone et al 2019: 7479). For a given R and f this implies that: . The authors used f=0.71 $W/m^{2,}$ which they estimate is increased radiative forcing from 1979 to an ice-free Arctic, but used 2016 400 CO2 ppm for R, to get 456.8 CO2 ppm, or an increase of 56.8 CO2 ppm, from Arctic sea ice melting. They then multiply this by 7.77 and divide by 0.44 to get 1002.5 GT increased CO2 in the atmosphere. By dividing this by average 2019 emissions of 40 GT CO2 they derive an estimate of 25 years of CO2 emissions at current levels.

However, they estimate 0.5 W/m^2 not 0.71 W/m^2 as radiative forcing from 2016 (Pistone et al 2019: 7476). Correctly starting with f = 0.5 W/m^2 and using the same procedure as above produces an estimate of 17.3 years of 40 GT CO2 emissions from 2016 as shown in (Baiman, 2021) and column F below.

Finally, doing a similar calculation in column I, assuming 2034 estimated CO2 ppm of 460 and 2034 to ice free summer Arctic radiative forcing of 0.3 as in cell I6 results in increased warming equivalent to 529.5 CO2eq GT or 13.2 years at 40 CO2eq GT GHG emissions per year. Eyeballing from Figure 1 an estimate that by 2050 the Arctic will be ice free for about three months (Jul, Aug, and Sep) suggests that loss of reflectivity from 2034 to 2050 will increase warming by 264.7 CO2eq GT or 6.6 years of 40 CO2eq GHG emissions per year per calculations in the lines at the bottom of the spreadsheet.

Columns:	B	C	D	E	F	G	H	I	J	K			
Rows													
		Paper											
		Pistone et al, 2019			Baiman, 2021		Baiman, 2022						
6	Pistone et al estimate of 1979 to ice-free Radiative Forcing	0.71		Pistone et al estimate of 2016 to ice-free Radiative Forcing	0.5		Estimated 2034 to ice-free Radiative Forcing	0.3	=F6-K14	Estimated 2016 to 2034 Radiative Forcing			
7	Parameter	5.35			5.35			5.35					
8	=B6/B7	0.13271			0.093457944			0.063147			Forcing from 1979 to 2016		
9	=Exp(B8)	1.141919			1.097964426			1.065184	C6-F6=	0.2			
10	2016 CO2 ppm	400		2016 CO2 ppm	400		2034 CO2 ppm Estimate	460		37	Years		
11	=B10*B9	456.7676			439.1857705			489.9845	K9/K10=	0.005405	Forcing per year		
12									K11*2=	0.010811	Double this for 2016 to 2034		
13	=B11-B10	56.76765			39.18577052			29.9845		15	Years		
14	Paremter	7.77			7.77			7.77	K13*K12=	0.162162	Forcing		
15	B13*B14	441.0846			304.4734369			232.9795					
16	Parameter	0.44			0.44			0.44					
17	B15/B16	1002.465			691.9850839			529.4989					
18	=B17/40	25.06163			17.2996271			13.23747					
	By 2050 based on current trends 3 months (out of 6 month summer from Apr to Sep) of ice free Arctic (July, August and Sept.)												
	Assuming ice free Arctic from 2034 to 2059 adds ice free Aug and Jul or 1/2 of 13.2 and of 529.5 or:										6.618737	years and	264.7495
	additional CO2 carbon in the atmosphere, or conservatively at least six years of equivalent 40 CO2eq GT GHG warming.												
	Ice free Jul, Aug and Sep estimated by eyeballing parallel trend line from 2050 to vertical axis in Figure 1.												