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Review of Solar Geoengineering for the Developing World: A Discourse on the State of Research and the Effects on Policy and Livelihoods for Africa

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Abstract

The world is experiencing a rapid increase in the global average temperatures at an unprecedented level, primarily due to human activities. Global actors' and policymakers' inability to find an agreed upon course of action to curtail the looming effects of these increased temperatures is an issue of global environmental and human security concern. Solar geoengineering, also solar radiation modification (SRM), has been proposed in many quarters as an option to reducing global warming while finding other alternatives to GHG emissions. This paper provides a summary introduction to climate science on solar engineering for the social scientists and policymakers from the global south. The paper assesses the status, effects, and preparedness of developing economies, especially Africa, in adopting SRM policies and practices. It observes that the effects of SRM for Africa have not been adequately researched due to the dearth of research and experts on SRM, specifically for Africa. It concludes that the reliance of a significant proportion of developing societies on climate-sensitive livelihood options makes the implication of SRM a worthy consideration for research and policymakers.

Keywords: *Geoengineering; solar radiation management; global warming; policy; Africa*

Introduction

The world is faced with multiple crises ranging from migration to global politics, human security, economics, and environmental security. Within the array of these challenges, climate change is seen as one of the greatest existential threats to humanity (Reynolds *et al.*, 2017:3). The global environment has experienced increasing extreme weather events in recent decades, ranging from rising sea levels, flooding, and drought in some quarters (Moore *et al.*, 2013:484) to cases of extreme heat, increased risk of hurricanes (Grinsted *et al.,* 2013:2667), and degradation of permafrost (Gao *et al.,* 2013:2). Studies and climate scenarios project more frequent and intensely extreme climate events for the future due to the changes in the mean, variance, and shape of the probability of distribution of weather and climate patterns due to climate change (IPCC, 2014:119; Ziervogel *et al.,* 2014:607). These changes can be exemplified from the occurrence of record-breaking heatwaves and temperature rises in Australia, the frequency of floods in Europe, parts of Africa, and Asia, to the drought in some parts of Africa, leading to the shrinking of lakes and often spelling doom for livelihood security (Ziervogel, 2014:605-608; Allen *et al*., 2018:1). Given these numerous challenges, it is pertinent to note that the vulnerability of the developing world, especially Africa, to these extreme weather events is enormous (Patrick, 2021). Given this, the need for mitigation and adaptation options in curbing the effects of these extreme events for Africa cannot be ignored.

Geoengineering has been cited in several quarters as a possible option for keeping the global temperature below the IPCC 1.5°C projection to avoid the impact of anthropogenic climate change (National Research Council, 2015). It is also seen as a possible alternative to emission reduction in the bid to counteract the effects of the increased concentration of anthropogenic greenhouse gases in the atmosphere while buying time in search of a workable solution to global warming (Jones *et al.,* 2011:176; Hamilton, 2014:439; Pinto *et al*., 2020:2). Studies on this methodology allude to the effects of the 1991 Mouth Pinatubo volcanic eruption, which led to a global cooling of approximately 0.5°C in the following year, as a viable demonstration of how climate geoengineering can serve as a technique for cooling the planet (Robock *et al.,* 2016:664).

The implications of this proposal on human and environmental security have generated a series of debates across various spaces and time. While seen as a viable option to curbing the adverse effects of global warming, its relative impacts and risks are still generally unclear, making it particularly controversial (Barrett, 2014:249; Reynolds *et al.,* 2017:10). A considerable number of studies have explored the potential of solar geoengineering in reducing temperature as well as keeping the global mean temperature below the IPCC 1.5°C projection (Irvine *et al.,* 2010; Kravitz *et al.,* 2011, 2013; Jones *et al.,* 2018; Moore *et al.*, 2019). Many others are sceptical about its practicability and application in terms of financial commitments, human and environmental security implications (Horton and Reynolds, 2016:440). This disagreement is primarily due to the magnitude of assumptions and the uncertainty regarding its effectiveness, costs, and impacts (Emmerling and Tavoni, 2018:395-398). Sceptics to geoengineering point to the inability to quantify in scale and magnitude the relative environmental, social, political, economic, legal, and moral impacts of such large-scale intervention in complex and dynamically interacting Earth systems.

In the same vein, Hamilton (2013:440) posits that it could be a slippery slope from the initial research to implementation once satisfactory resources have been invested. Others also look at the moral hazards and challenges of delaying the costly mitigation action in the hopes of a cheaper technological fix becoming available in the future, and the inability of the international community to come to a viable agreement on a low-cost emission cut trajectory. Barrett (2014:251-252), on the other hand, points to the issues of governance that geoengineering will evoke, as the decision of "who, when, and how" geoengineering will be deployed becomes a controversial geopolitical discourse. Again, while the impacts of geoengineering are saddled with many uncertainties, given the climatic emergency the world finds itself in, Keith *et al*. (2017:618), among others, opined that climate geoengineering is a backup measure that gives the world more time to transition to a low-carbon economy.

In view of the many unanswered questions which solar geoengineering poses, the need for more research in ascertaining its viability as a mechanism for curbing climate change and weather extremes is pertinent (Keith and Irvine, 2016:556). It is, therefore, no gain in saying that while the literature and research on the global impact of SRM are mostly uncertain, its implication for Africa is relatively silent. Studies on SRM options that focus specifically on Africa are limited in the literature. Given this, this paper seeks to assess the viability and consequences of geoengineering solar radiation management (SRM) in general as a mechanism for curbing climate extremes for Africa. The paper specifically aims to introduce social scientists and public policymakers/analysts to the discourse on solar engineering research in relation to climate change mitigation, emission reduction, and adaptation in the developing world. The rationale is premised on the need to contextualise the discourse outside the terminologies of core sciences to benefit policymakers and everyday practitioners in the global South.

The focus on Africa is motivated by the peculiarities of the region to climate change adaptation in view of her weak coping mechanisms, widespread poverty, and inadequate governance systems (Raleigh, 2011:82). This is also coupled with the significant dependence on climate-sensitive agriculture (Allen *et al.*, 2018:1). These factors combine to make Africa highly vulnerable to climate change (Pinto *et al*., 2020:1). Hence, the effects of any change or alteration to climate change have enormous effects on the overall wellbeing of a significant proportion of the population in Africa. Therefore, to set the stage for exploring SRM implications for policy and practice in Africa, it is pertinent to conceptualise the subject matter. While the paper is an exploration and call to action on SRM research in Africa. The main argument is that the applicability of SRM for Africa has not been fully explored. Hence, the ensuing sections give a review of SRM, its far-reaching effects, and the implications for Africa.

Global Earth Systems Reality: A Snapshot Review of the Problem

The Intergovernmental Panel on Climate Change's (IPCC) Representative Concentration Pathways (RCPs) models (emission scenario of 1950-2100) show a global mean temperature, which has continued to increase considerably since the 1850s, primarily due to the continuous emission of greenhouse gases (IPCC, 2014:177-130). The report pointed that CO_2 emission has maintained a steady increase since the industrial revolution at an average of 555+/- Pgc ($1Pgc=10^{15}gC$) of CO_2 being emitted from 1750-2011 mainly due to human activities, and leading to approximately a 40 per cent increase in atmospheric CO_2 since the pre-industrial period.

It also showed that except for RCP 2.5, other scenarios show an increase of over 2^oC by 2100 and beyond, with the risk of global warming reaching up to 7.8^oC by 2100 if no additional deliberate efforts to reduce Greenhouse gases emissions are taken (Millar *et al*., 2017:744). The report also affirmed that additional warming of $3\text{-}5^oC$ of the Earth's surface coupled with a further 0.5-1m sea-level rise is expected by the end of the century under the "business as usual" trajectory if no action is taken. However, it is worth noting that while this is the projection of a synthesis of models complied by the IPCC, critics argue that the authenticity and accuracy of these models are also subject to questioning as with other models (Knutti and Jan, 2013:370). In this sense, it is pertinent to note that no single model is conclusive in relation to projections on climate changes.

Malm (2016:5-7), citing the IPCC AR5 WG1 report, argued that getting emissions to a relatively safe stabilisation scenario of 430-480ppm, which will prevent warming exceeding 2^oC, will require a radical decline in the discharge of over 600ppm under the business-as-usual emission trend. The safest route to avoiding this increase in the global mean temperature will be the decarbonisation of the Earth's systems. The viability of this route will require an urgent and ambitious mitigation strategy (including rapid change in global energy infrastructures) with immediate effect (IPCC, 2014:120). However, Ming *et al*. (2014:792) argued that the global economy's energy addiction to fossil fuel makes this strategy less viable, neither urgently nor in the short term. This is mainly because replacing the current protocol with renewable energies will be a herculean task.

In the same vein, it is important to note that while a radical reduction in anthropogenic CO_2 emission is the safest and surest route in mitigating global warming, the IPCC (2014:117) report also argued that warming caused as a result of already emitted CO_2 would continue for decades (or even centuries) to come even if a complete halt of greenhouse gases emission is achievable. The climate emergency this challenge emanates calls for urgent actions to rapidly cool the Earth's system as continuous heating of the thereof would only spell more doom for life on Earth as we know it. Given this, the need for a viable remedy in solving this global challenge becomes pertinent. The call for geoengineering the climate (in this case, SRM) as a possible option to ameliorating this challenge has been cited in many quarters. The following section will discuss geoengineering, focussing on solar radiation management and research as a growing approach to cooling the Earth systems.

Climate Geoengineering and the SRM Prospects

Geoengineering is generally the premeditated large-scale interference in the natural Earth systems using human-made strategies and scientific competencies, and technology to alter the climate either temporarily or permanently. It is seen as a 'quick fix' strategy while 'buying time' to lower global mean temperatures without altering the atmospheric concentration of greenhouse gases (Horton and Reynolds, 2016:438). In principle, geoengineering aims to manipulate the global temperature by changing the concentration of C_{02} in the atmosphere to counteract greenhouse-induced global warming (Kravitz *et al.*, 2013:8320; Cao *et al.*, 2015:188). It is seen as the measured manipulation and alteration of the climate system on a large scale aimed at reducing the quantity of solar radiation at the surface in the effort to offset the impact of anthropogenic climate change, while providing for additional time to find appropriate global mitigation strategies. To counter the effects of global warming, several geoengineering technologies have been proposed. These proposals are mainly Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) (Niemeier *et al.,* 2013:11,905). This paper focusses on SRM techniques and its impact in general, emphasising its prospects and impacts on Africa.

Solar Radiation Management (SRM) aims at counteracting global warming by reflecting solar radiation into space (Ming *et al.* 2014:792). It is popularly referred to as "sunshade geoengineering" (Kravitz *et al.,* 2011:162), and in some quarters as "parasol or umbrella effect" (Ming *et al.,* 2014:792). In principle, it implies the reduction in the amount of solar radiation into the Earth's system. In operability, it means a decrease of about 1.7 per cent of the approximately 240 Wm^{-2} incoming solar radiation at the top of the atmosphere [4Wm^{-2}/240Wm^{-2}] (Tilmes *et al.*, 2016:8222). This could be achieved in principle by using several techniques such as (i) The space-based method whereby reflectors are placed near the first lagrange point[1] of the Earth and solar system to reflect radiation to space (Cao *et al.,* 2015:188). (ii) The injection of sulfur dioxide (SO_2) into the stratosphere to oxidise and form aerosol sulfate particles, which then scatter incoming sunlight. The idea here is to mimic the effect of significant volcanic eruptions, as exemplified in the 1991 Pinatubo eruption, among others (Niemeier *et al.,* 2013:11,907; Robock *et al.*, 2016:664). (iii) Marine cloud brightening, which connotes the deliberate introduction of fine particles near the base of the low clouds to increase cloud droplets and reflect more sunlight (Jones *et al.,* 2011:176). (iv) The surface albedo-based method requires increased surface albedo to increase reflectivity (Vafakhah *et al.,* 2015:998). Figure 1 gives a pictorial overview of solar radiation management techniques, as discussed in this segment.

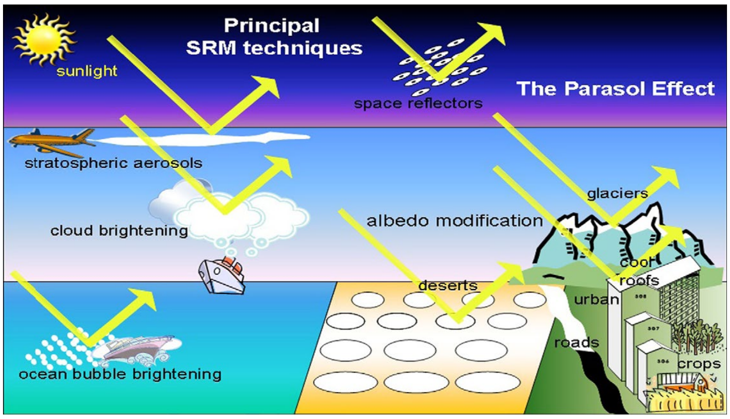

Figure 1: Overview of the principal SRM geoengineering techniques (Ming *et al.,* 2014:795)

It is no gainsaying that SRM is set up as a delay mechanism rather than a corrective measure in addressing the root cause of climate change in its practical sense. Critics argued that SRM allows for the continuation of $C0_2$ emissions, which means the indefinite maintenance of SRM to avoid sudden and unexpected global warming should the scheme be halted (Ming *et al.,* 2014:807; Saeed *et al.*, 2018:2). It also implies an excuse for global emission polluters to continue business as usual while shifting the consequences of their actions to future generations (Saeed *et al.*, 2018:2). The approach is also likened to 'fighting risk with risk' given the uncertainties of SRM's real-time application and the supposed endangerment it may lead to (Wolff, 2020:564).

Bearing in mind the uncertainties of solar geoengineering, the Geoengineering Monitoring Intercomparison Project (GeoMIP) was set up by a group of climate scientists from across the globe to understand the physical responses of the climate system to solar geoengineering (Kravitz *et al.,* 2011:162; Niemeier *et al.,* 2013:11,905). Using a similar simulation protocol conducted in

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[1] The Lagrange points are orbital points near two large co-orbiting bodies. They are positions in space where the gravitational forces of two large body systems (like the Sun and the Earth) produce enhanced regions of attraction and repulsion. Here, the combined gravitational forces of these two large bodies equals the centrifugal force felt by a much smaller third body.

four major experiments in terms of the CMIP6 tiers G1, G2, G3, and G4 experiments, earlier GeoMIP experiments explored the climate effects of reduced solar radiation as well as a stratospheric aerosol injection (Kravitz *et al.,* 2011:162,163; 2013:8320). The plan was to investigate the commonalities and variance among the numerous climate model responses to geoengineering schemes. Other schemes explored sea spray geoengineering and marine cloud brightening, solar dimming, stratospheric aerosols, and cirrus thinning (Kravitz *et al.,* 2013).

While G1, G2, and G3 were intended to produce an annual mean global radiative balance at the top of the atmosphere, G4 was designed to assess the uncertainties that could arise from estimating the impact of geoengineering when models are used to transform emission rates into concentrations. As depicted in figure 2, G1 involved the instantaneous quadrupling of CO_2 concentration from preindustrial levels while simultaneously reducing the solar constant to counteract this forcing. G2 experiment involved the positive radiative forcing of an increase in CO_2 concentration of one per cent per year, balanced by a decrease in the solar constant until year 50. The G3 experiment approximately adjusts the positive radiative forcing from the RCP4.5 scenario by injecting sulfate aerosols into the tropical lower stratosphere to keep global average temperatures nearly constant. The G4 experiment, like the G3, is based on the RCP4.5 scenario, where immediate negative radiative forcing is produced by an injection of SO_2 into the tropical lower stratosphere at a rate of 5 Tg per year (Kravitz *et al.,* 2011).

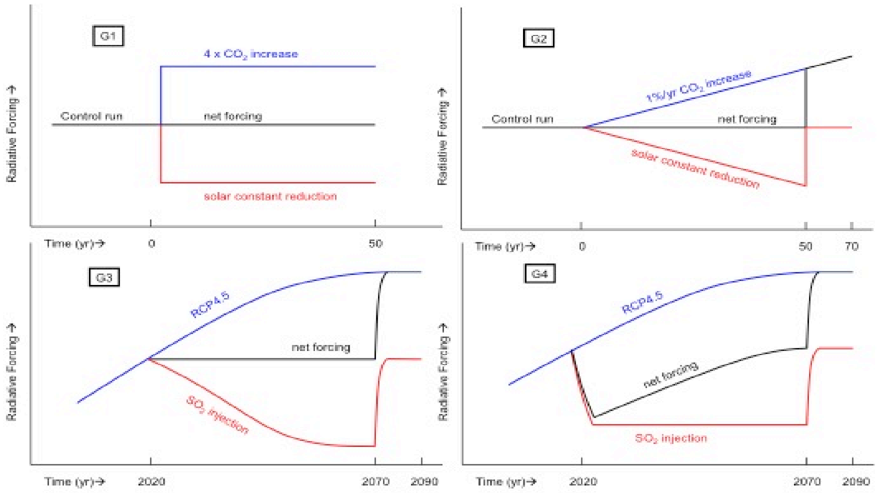

Figure 2: Solar Geoengineering Models in terms of the CMOP6 tires G1, G2, G3 and G4 (Kravitz *et al.,* 2011:164)

It is important to state that there has been a growing body of literature based on GeoMIP simulations and other geoengineering data on the short-term and long-term intervention strategies for geoengineering. These include forcing and feedbacks in response to SRM (Kashimura *et al.,* 2017); SRM and CDR (Tilmes *et al*., 2016); Stratospheric ozone response to sulfate geoengineering (Pitari *et al*., 2014); Artic cryosphere response to sulfate geoengineering (Pitari *et al.,* 2014); critical uncertainties for space-based solar geoengineering (Irvine *et al.* 2010:1-6); albedo enhancement (Robock *et al.,* 2016); precipitation seasonality (Bal *et al.,* 2019); Greenland ice sheet (Moore *et al.,* 2019); and Regional climate impacts (Jones *et al.,* 2018) among others. Other designed GeoMIP experiments explored marine cloud whitening (Kravitz *et al.* 2013), land and ocean albedo enhancement (Visioni *et al.,* 2017); counter geoengineering (Heyen *et al*., 2015; 2019); Precipitation response (Laakso *et al*., 2020); Weakening of the extratropical storm tracks (Gertler *et al*., 2020); mitigation of Arctic permafrost carbon loss (Chen *et al*., 2020) among others.

It generally remains unclear whether decreasing the global mean temperature by SRM can reduce the number and intensity of extreme events due to the associated distinct regional patterns in temperature and precipitation changes. While some regions may benefit considerably from the exercise, others may face worse circumstances that would otherwise be non-existent without geoengineering (Irvine *et al.,* 2010:3; Kravitz *et al.*, 2013:8328). Tilmes *et al*., (2016:8228) and Niemeier *et al.* 2013:11,913) also argue that the overall impact of SRM as a mechanism for offsetting the global climate could affect the hydrological cycle as the amount of precipitation, particularly for the tropical regions, would be considerably reduced. Other scholars concluded that SRM would generally lead to the significant cooling of the tropics with relatively less cooling of the higher latitudes, related sea-level reduction, reduced ENSO variability, increased Atlantic overturning, and a reduction in the intensity of the hydrological cycle (Kravitz *et al.,* 2013:8322-32). SRM techniques could also significantly impact regional temperature and precipitation patterns, thereby reducing several physical risks of climate change identified by the IPCC (Reynolds, 2017:12). It could also lead to changes in the occurrence of extreme events (Curry *et al*., 2014:3901) and increased productivity due to a reduction in heat stress and fertilisation effects of increased atmospheric $C0_2$ despite decreased precipitation (Jones *et al.,* 2011:180; Kravitz *et al.,* 2013: 8320).

It becomes interesting to observe that while SRM and geoengineering, in general, could re-establish the earth's system in terms of reducing the pace of the global warming trajectory, the scheme will lead to a different and largely uncertain form of climate change. This is due to different spatial and temporal forcing of increased $C0_2$ compared to reduced solar radiation. It therefore implies that the avoidance of one danger stands the risk of exposing one to another threat, which may be worse than the former. Irvine (2010), Niemeier *et al*. (2013), and Ming *et al*.'s (2014) studies concluded that while SRM as an emergency mitigation option could ameliorate global warming, it can also drive global and regional climate change outside the extent of greenhouse gases-induced warming, creating novel conditions that may be regionally disproportionate.

The findings from these studies summarily argued that while there could be enormous benefits to geoengineering, its consequences could be potentially severe due to its many unknown factors. Hence, further studies are needed to ensure a holistic understanding of its application and widespread impacts. The immediate and obvious deficit of these bodies of work is the dearth of scientists and social scientists from Africa. There is also little or no real focus on Africa and the developing world. The need for a robust focus on the developing world considering the effects of climate change and solar geoengineering for these regions of the world presents an opportunity for future research.

SRM Specification for Africa: Policy, Practice and Livelihood Options

The need for a quick solution in ameliorating the enormous impact of climate change in the developing world, especially for Africa, is of immediate necessity. This is largely due to Africa's vulnerability to climate change. The continent is already experiencing warming higher than the global average coupled with the projected changes in temperature, which indicates the possibility of increased temperatures across the continent (IPCC, 2014:122). The frequencies of extreme events such as droughts, floods, and heat stress are becoming an everyday reality due to the changes in the mean, viability, and extremes of precipitation and temperature (Ziervogel *et al.,* 2014; Pinto *et al*., 2020). This is further complicated by weak coping strategies conditioned by poverty, ineffective and weak government institutions, damaged and neglected public infrastructure, among others (Hosea and Khalema, 2020:26; Patrick, 2020:2-3; Ziervogel *et al.,* 2014:606).

The implication of climate change, especially temperature and precipitation changes for the livelihood of most of the population in Africa, is therefore, a crucial issue in policy and research discourse. Studies show that agriculture accounts for over 70 per cent of employment in Africa and about 30 per cent of her GDP (Allen *et al*., 2018:1). This, by implication, connotes that most of Africa's population are dependent on climate-sensitive livelihood options hereby, making them more vulnerable to frequent and abrupt climatic alterations. Given this, the introduction of the SRM option as a mechanism in controlling sharp climatic changes by ensuring temperature stabilisation becomes a substantial policy option for livelihood security (Pinto *et al*., 2020:1-2). However, the financial capacity for implementing these SRM alternatives for developing economies, especially Africa, is considerably lacking.

Factoring in the generally weak coping strategies of both the government and the people of Africa in the face of climate change, a negative impact of SRM for this region would be catastrophic. As Robock *et al*.'s (2008) study opined, the application of SRM poses a negative effect. It reduces summer monsoon rainfall in Asia and Africa, potentially threatening the food supply for billions of people. Owing to the number of food-poor households in Africa, the propensity of policy action (in this case, SRM application) posing a threat to food security becomes a crucial policy concern on many fronts. Irvine (2010), Niemeier *et al*. (2013), and Ming *et al*. (2014), also argued on the unintended 'out of the box' challenges SRM might pose. For Africa, the incapacity of governments will most probably worsen the situation of proffering adaptive measures in ameliorating these vulnerabilities. This incapability will be evident in institutions' inability to provide appropriate governmental capacity to prevent, monitor, mitigate and/or manage hazards and disasters, both frequent and intense, due to climate change (Willemien *et al.,* 2012). Politically, most governments in Africa are more reactionary than proactive in climate change adaptation and policy formulation is due mainly to their incapacity to forge a proactive course of action in the nation's community. This may explain the relatively minimal consideration of SRM application and research within the sphere of policymakers, especially in Africa.

While SRM is also likely to redress regional temperatures and precipitation trends (Curry *et al.,* 2014), lower temperatures and sea-level rise (Moore *et al.,* 2010), curb the frequency as well as the magnitude of tropical cyclones (Moore *et al.,* 2015), and lead to increased plant productivity (Herzog and Parson, 2016) among others. Hypothetically speaking, the reduction and general alteration in the global hydrological cycle as a result of SRM application will have an enormous impact (positive or negative) on livelihood options. The favourable implication of these trends for the developing economies' livelihood support is enormous. However, it is pertinent to note that while there are numerous positive gains in implementing SRM, studies show that the negative implications of these mechanisms cannot be swept off the radar (Bala and Gupta, 2019:24). The uncertainty of the magnitude or direction of these negativities for Africa calls for further research on the subject matter. In supporting this assertion, Pinto *et al*.'s (2020) study opined that the impact of SRM on Africa is largely unclear. Hence, the results from general globalised experiments must be interpreted with caution.

Using simulations from the Geoengineering Large Ensemble, the study concludes that SRM reduces temperature means and extremes while its effects on precipitation for Africa are not linear. In the same vein, Da-Allada *et al*.'s (2020:3) study on SRM application in the West African summer monsoon indicated that while there has been a precipitation increase in West Africa, Northern Sahel, and Southern Sahel compared to present-day of under RCP 8.5, under SRM application of stratospheric aerosol geoengineering (SAG), the West Africa summer monsoon remains unchanged relative to the present-day climate in the Northern Sahel. At the same time, West Africa, and Southern Sahel have experienced reduced rainfall. The study shows that the deployment of SAG to limit warming could offset climate change on the precipitation in the Sahel region while leading to an over-effectiveness in Western Africa. This, therefore, suggests that the application of SRM in this light could turn a modestly positive trend into a negative trend, which is a risk that is twice as large.

In this sense, the application of SRM options places most of the population in Africa at risk should SRM application negatively affect the climate for the region. In view of this, the need to holistically assess the implication of SRMs for the developing world cannot be overemphasised. This is even truer for Africa as there is very little (if any) policy response to SRM application, nor its impact assessment. For instance, while SRM might pose an immediate policy solution to the impact of climate change for Africa, the viability of this mechanism or strategy specifically and holistically for the continent in terms of socio-economic and political impact assessments is yet to be fully explored. This may be largely due to the novelty of such engagement in Africa. There is, therefore, a need to fully understand the potential implications of SRM options for individuals, nations, sub-regional configurations, and the continent at large as the results of SRM research needs to be interpreted with precaution. In line with this assertion, one can categorically say that policy considerations for SRM application in Africa are largely lacking as policymakers and practitioners are, to a more significant extent, unaware of SRM and its applications and impacts for Africa in general.

There are also relatively few studies that specifically look at the impact of SRM on Africa as a whole. Pockets of reviews available which focus on Africa look at SRM impacts from a regional perspective of one or more regions in Africa and not holistically (Da-Allada *et al*., 2020; Pinto *et al.*, 2020). Other reports on SMR impacts with a supposed discussion on Africa are in most instances unbalanced reports which tended to emphasise the risks of SRM while glossing over its potential benefits (Darius *et al*., 2017; Straffon and Burley, 2018; Saeed *et al.,* 2018). The only available project on SRM related impacts focussing on Africa is the Developing Country Impacts Modelling Analysis for SRM (DECIMAL) project organised by the SRM Governance Initiative (SRMGI). However, this project hinges on some countries in the Western and Southern African regions (precisely three countries out of 54 in Africa; Benin, Ivory Coast, and South Africa) (Rahman *et al.,* 2018:22; Bala and Gupta 2019:23). There is little or no behavioural or human impact assessment of SRM pros or cons specifically for Africa in the same vein. Most studies that discuss Africa do so as a 'passing reference' in the discussion of a globalised context of the SRM impacts. This may primarily be a result of few researchers (science and social sciences alike) within and outside the continent with a focus on SRM impacts for the developing world.

It is interesting to note that Da-Allada *et al*. (2020) and Pinto *et al*.'s (2020) studies are not only the few studies available with a specific focus on Africa, but also two of the very limited studies (if any) dominated by African researchers focussing on an African-centred SRM research. While this is not the focus of this paper, external players (especially from the Global North), discussing and proffering policy recommendations (and research) to the problem in the Global South, need to be re-addressed. There is, therefore, the need for a conscious effort by African stakeholders and the research community to spearhead the narrative in the discussion of and solution to African problems. This is crucial as African researchers will better understand their own challenges in contextual terms compared to an ‘outside’ scholar’s view. Given this, African researchers' need for more engagement (social and core sciences) in finding collaborative spaces in the research on SRM impacts for Africa is crucial both for policy and research engagement.

This paper contends that climate change is a problem created mainly by humans, and therefore only humans can solve it. The solution is achievable if we make concerted efforts to do so. The tipping point for action in the face of these global climate changes is relative to one's environment, community, occupation and professional concerns, and the degree of vulnerability. Like many others worldwide, the impact of global climate changes signifies extinction for many species and loss of livelihoods and adaptation challenges for humans. The reality of these impacts is more evident in Africa due to its weak coping strategies, low infrastructural capacities, poor governance systems, general widespread poverty, and over-reliance on climate-sensitive livelihood options.

This paper has observed that geoengineering has been suggested to be a viable option to curb the immediate adverse effects of climate change given the climatic emergency the world finds itself. However, there is a need for further research in ascertaining its viability in view of the many unanswered questions which solar geoengineering poses. The paper also observed that while SRM and geoengineering, in general, could reduce the changes to the climate from global warming, it is likely to bring about a different and largely uncertain form of climate change. This, therefore, may imply the avoidance of a danger which may lead to a more significant threat than the former. Thus, the paper argued that the reduction and general alteration in the global hydrological cycle courtesy of solar engineering would have a high impact on livelihood options which are heavily reliant on climate-sensitive resources. The favourable implication of these trends for the developing economy livelihood support is enormous. However, it is pertinent to note that while there could be numerous positive gains in implementing SRM, the negative implications of these mechanisms cannot be swept off the radar. The implication for Africa if SRM application produces a negative consequence becomes worrisome.

Conclusion and Recommendation

While the SRM route is a viable option for reducing the risk of global warming, it will not reverse the climatic consequences evenly in all regions. The necessity for a holistic investigation of SRM options for African societies which have significant population reliant on climate-sensitive livelihood options cannot be ignored. Therefore, there is a need for engagement in relation to SRM research in a bid to fulfil not only ethical requirements for research but also to improve trust and ensure that SRM research and deployment are informed by societal values and needs. In this sense, vertical and horizontal stakeholders' engagement should be encouraged in terms of government, public, and private partnerships to explore SRM for Africa, given her developmental peculiarities. The involvement of organisations such as the Africa Union (AU), sub-regional organisations like the Economic Community of West African States (ECOWAS) and Southern African Development Community (SADC), national governments, and research agencies in Africa will be crucial for policy formation and SRM needs for Africa.

There is also the need to establish multidisciplinary and transdisciplinary synergy by African scholars in the core sciences and social sciences disciplines to understand the peculiarity of Africa in terms of SRM research. The regional disparity envisioned in SRM's impact on the climate may explain the scepticism in some quarters, which sees SRM as a conspiracy to justify business as usual and avoid the responsibility of emission cuts. It is also viewed as another mechanism to perpetuate western dominance in research and policy formulation to the detriment of the global South. Whatever the case may be, studies on geoengineering advocate that the impacts of geoengineering would generally reduce climate impacts. Given this, it becomes pertinent to agree that one way or another, the Earth system is heating up at an unprecedented rate, which demands urgent and immediate action. However, geoengineering as a policy option is intertwined in a complex web of ethical, moral, societal, legal, political, and governance quagmire that makes its implementation a mirage. Despite this reality, the pathway to which researchers and policymakers would take may imply that one rather embraces SRM as the lesser evil than to wait, continue with ‘normalcy,' and expect a miracle in the solar system.

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