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Author for correspondence:
H. Lawford-Smith
e-mail: holly.lawford-smith@unimelb.edu.au

†Present address: SHAPS, University of Melbourne, Melbourne, Australia.

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Global change biology

Accelerating the carbon cycle: the ethics of enhanced weathering

H. Lawford-Smith[1,†] and A. Currie[2]

[1]Department of Philosophy, University of Sheffield, Sheffield S3 7QB, UK
[2]CRASSH, University of Cambridge, Cambridge, Cambridgeshire CB2 3QY, UK

HL-S, 0000-0001-6352-7377

Enhanced weathering, in comparison to other geoengineering measures, creates the possibility of a reduced cost, reduced impact way of decreasing atmospheric carbon, with positive knock-on effects such as decreased oceanic acidity. We argue that ethical concerns have a place alongside empirical, political and social factors as we consider how to best respond to the critical challenge that anthropogenic climate change poses. We review these concerns, considering the ethical issues that arise (or would arise) in the large-scale deployment of enhanced weathering. We discuss post-implementation scenarios, failures of collective action, the distribution of risk and externalities and redress for damage. We also discuss issues surrounding 'dirty hands' (taking conventionally immoral action to avoid having to take action that is even worse), whether enhanced weathering research might present a moral hazard, the importance of international governance and the notion that the implementation of large-scale enhanced weathering would reveal problematic hubris. Ethics and scientific research interrelate in complex ways: some ethical considerations caution against research and implementation, while others encourage them. Indeed, the ethical perspective encourages us to think more carefully about how, and what types of, geoengineering should be researched and implemented.

1. Introduction

National and global regulatory measures are required to control the effects of anthropogenic climate change. In contrast to measures that incentivize lower emissions, as well as substitute fossil fuels for alternative energy sources, geoengineering involves interventions downstream from business-as-usual greenhouse gas (GHG) emissions. One set of strategies—solar radiation management (SRM)—manipulate other factors determining the Earth's temperature. Another set—carbon dioxide removal (CDR), or more recently negative emissions technologies (NETs)—extract carbon from the atmosphere itself. This can be achieved by using synthetic mechanisms to capture and store carbon, or by enhancing or accelerating natural mechanisms that already do this. The latter of these includes enhanced weathering—our focus—as well as afforestation and other techniques.

In deciding which options to encourage and enact, policy-makers face not only questions about efficiency and engineering, but also ethics. We provide an overview of the ethical issues arising from NETs, particularly enhanced weathering, aiming to focus on issues not already covered in detail elsewhere [1,2]. Although the ethical considerations are quite general, they interact with different techniques and strategies in different ways. Furthermore, different ethical considerations are potentially in tension. Some ethical issues turn in part on uncertainty about the effectiveness and consequences of enhanced weathering, and so motivate further research; while others offer the opposite council, as the development of enhanced weathering techniques might itself come at an ethical cost.

Silicate weathering—the process whereby silicate transforms into carbonate—affects the global carbon cycle; as does the breakdown of carbon by aquatic biological agents, and the transferal of terrestrial CO_2 into the oceans. Thus, the global carbon cycle's efficiency depends in part on terrestrial and aquatic biochemical composition. Although on short time scales natural weathering processes are comparatively weak [3], such processes could be radically amplified, turning the Earth into a more efficient carbon processor [4]. The basic biochemical processes involved are well understood [5] and can be studied at a local level [6]. Indeed, the basic notions are quite simple: given that global carbon processing is in part driven by how much silicate is exposed to weathering, increasing its exposure by dusting large amounts of the Earth's surface with finely ground, highly reactive, silicates would increase that processing, particularly if coupled with biotic aids (such as certain plant varieties). The specifics are varied, from large-scale terrestrial dusting [7,8], to incorporating industrial by-products [9], to increasing oceanic olivine [10]. Enhanced weathering techniques are sometimes considered to be a less extreme option than SRM, and perhaps implementable at a relatively local level (we shall emphasize this point below). Furthermore, given that agricultural practices already alter large sections of the Earth's surface in analogous ways (mineral fertilization to increase soil alkalinity, soil tilling and liming, etc.), there is potential for enhanced weathering to piggyback on existing practices. Finally, increases in oceanic alkalinity would potentially come with the co-benefit of alleviating acidification and increasing biomass.

However, uncertainty about the global-scale efficiency and effects of enhanced weathering is high. The reasons should be familiar: global systems are complex, interconnected and thus difficult to model. Even in comparison with SRMs, enhanced weathering is understudied at global scales, and models are not well resolved [10]. Some mineral outputs of enhanced weathering are potentially toxic at high concentrations. Organic and inorganic CO_2 dynamics are coupled in complex ways [11], and it is unclear how manipulating mineralogical composition will affect biological CO_2 absorption, and *vice-versa*. The practical costs of locating (or generating), processing and transporting the large volumes of minerals required for large-scale enhanced weathering (to say nothing of the production costs of biotic materials) are likely to be immense. The possible side effects, both apparently beneficial and problematic, are voluminous [10]. For more on the specifics of enhanced weathering, see the other papers in this collection.

In addition to these practical, theoretical and empirical challenges, weighing the advisability of enhanced weathering against other candidate strategies has ethical dimensions. We highlight these, with a specific focus on the role of states, both because this simplifies an already complex discussion and because states are plausibly in a position to both regulate and initiate strategies for mitigating and reducing climate change, as well as entering into the kinds of international agreements required. Where other reviews of the ethics have been general across geoengineering [1,2], we will focus on the relationship between relatively general ethical considerations and the specific case of enhanced weathering.

2. Post-implementation scenarios

Pak-Hang Wong [12] argues that the ethical debate over geoengineering misses important ethical issues arising *post*-implementation. These include the responsibility for continuation and monitoring, which he refers to together as 'the requirement of maintenance' [12]. Indeed, some enhanced weathering techniques require significant infrastructure. And the best locations for implementation in terms of climate and mineralogy lack existing agricultural systems to co-opt [10]. Further, ongoing monitoring of the effects would be costly.

Who is responsible for maintenance? How should the burden of maintenance be shared? There is no easy answer to such questions: we might think that the party who implements the geoengineering technology is responsible for maintenance into the indefinite future; but equally we might think that they have done more than their fair share by absorbing the costs of implementation, and thus maintenance should fall to others.

Many authors note the risks of any abrupt halt to certain geoengineering interventions (although they usually have SRM rather than CDR in mind [12–15]), a risk that becomes more likely to materialize if responsibility for maintenance, once geoengineering techniques have been implemented, is spread between groups. Wong argues that any ethics of geoengineering must take a long-term perspective [12]. Given that, generally speaking, geoengineering measures are often presented as impermanent, stopgap measures, maintenance and removal costs must be considered alongside implementation. It is not obvious, for instance, how long the effects of enhanced weathering might last. If a decade has been spent adding vast quantities of silicate rock to previously mineral-poor areas, what downstream effects would occur were we to turn off the tap? In this regard, SRM is likely more problematic than CDR, but the more dramatic *vis-à-vis* scale and impact CDR interventions are, the less likely we are to be able to predict and understand the implications of cessation. Post-implementation scenarios, then, raise both ethical and empirical puzzles that remain unresolved.

3. Failures of collective action

It is often thought that a tragedy of the commons (TOC) between states is a major block to national and global action on GHGs. That is, the interests of each state (business-as-usual or increasing emissions) come apart from what is in the interest of states taken together (mutual restrictions to emissions). It is plausible that achieving mutual restrictions, whatever the exact target, would not require equal action from all states. Indeed, some states could take no action at all. This creates an incentive to be an inactive state. If this is right, then there may be conditions under which a state could take no action, while avoiding ethical culpability. Alternatively, states may be culpable—e.g. for colluding in their collective failure to agree [16]. That a state may lack culpability despite failing to do what is in the combined interests of states, applies to enhanced weathering in two ways: first, to the decision to implement enhanced weathering instead of reducing GHG emissions in a more straightforward way; second, to the implementation and maintenance of enhanced weathering, as discussed above.

Imagine that in the future, states are forced to implement NETs because of a prior collective failure to negotiate the international agreement that would have solved the TOC and allowed them to mitigate climate change *without* the use of NETs (or geoengineering techniques more broadly). Particular states may not be culpable for this failure, e.g. because taking unilateral action would not have made a significant difference either to the concentration of GHGs in the atmosphere or to the agreement being negotiated; or because they had reasonable, but ultimately mistaken beliefs about what other states were willing to do [17,18]. Other states may be culpable, e.g. because they *caused* the failure.

Further, note that because NETs are processes that last through time [12] their maintenance may itself create a TOC. This TOC may be international and hold between countries that could share the burden of maintaining specific NET interventions; it may be domestic but intergenerational, holding between successive governments of the same country; or it may be both international and intergenerational—as in Gardiner's 'perfect moral storm' [19]. The threat of a TOC for maintenance may be a sufficient reason to refrain from deploying a specific NET, particularly due to high transition costs or risks from abrupt cessation of the intervention (insofar as such risks exist). The possibility of a TOC for maintenance depends in part on the cost of collective action, and thus the specifics of the different kinds of NETs matter here. If enhanced weathering can be implemented at relatively low costs it could be part of an overall response to climate change: especially in partnership with existing agricultural practices (particularly when contrasted with SRM). However, establishing this requires significant research and moreover, as we explain below, using enhanced weathering to avoid reducing GHG emissions (rather than in combination with reductions) potentially creates a serious moral hazard.

But does a TOC in fact hold? Nicholas Stern [20] and Fergus Green [21] (the latter more forcibly) argue that radically reducing emissions does not, contrary to received wisdom, put states into a TOC, because of the nature of the co-benefits that would accrue from doing so. If states, or at least *particular* states, could be reducing emissions and obtaining co-benefits all the while freeing up resources for additional welfare, but are not doing so, then they wrong their citizens, whose interests they are supposed to serve.

4. Distribution of risk, externalities and redress for damage

Some NETs might displace risk from those deploying them onto others. This displacement can be spatial and temporal: onto people in future generations, or people living in other countries [22]. This is likely for enhanced weathering: the most effective areas for deployment are the hot, wet climes of the tropics, so the (often severely underprivileged) people living there would be exposed to the risk of unintended consequences, such as toxic by-products from increased silicate weathering.

Such risks are one kind of 'negative externality'; in general, negative externalities are costs borne by those other than the technology's implementers. Externalities may be positive. Countries in drier, colder climes would likely reap the benefits of lower carbon levels, less acidic seas and higher biological production from large-scale enhanced weathering implemented in tropical zones; ocean-based increases in biomass would surely not respect national borders, so that were the USA (let us imagine) to implement such measures in their territorial waters, the effects would be felt in Mexico. Risks can be negative externalities when they cross borders (or generations) in the same way [22].

One ethical question is whether it is permissible to implement techniques that impose risks on others without their having a say, in particular when they may not even benefit from the techniques' desired initial effects; another is how such risks should be distributed among candidate recipients and managed so as to minimize them. If enhanced rock weathering were implemented by the UK Government, for example, and that had consequences that caused serious damage, who would be responsible for repairing—or compensating for—that damage? Ethical considerations potentially require those nations that implement the technologies and benefit from them to absorb (or compensate for) the relevant externalities and materialized risks. (On the ethical obligations of those countries that benefit from geoengineering, see Heyward [23].)

Issues of post-implementation, collective action and redress for damage are all exacerbated by uncertainty. Although reducing or removing uncertainty will not fully resolve the ethical issues, it would certainly clarify them. As such, these ethical points encourage further consideration and research into enhanced weathering techniques. However, other ethical considerations push in the other direction, to which we now turn.

5. 'Dirty hands' or arming the future

Is a government ever permitted to do something unethical because doing so will prevent *even more unethical* consequences? In this section, we assume for the sake of argument that NET measures come at some ethical cost, e.g. by creating moral hazard, by placing us in a dominating relationship with nature, or by creating opportunity costs—perhaps implementing NET will mean not doing some other valuable action, like alleviating poverty. In the case at hand, the question is whether a government would be permitted to choose enhanced weathering in a straight choice between that and business-as-usual emissions. Whether having 'dirty hands'—purposefully performing an unethical action to avoid some even less ethically desirable outcome—is impermissible is often cashed out in terms of how 'categorical' we take ethical claims to be [24,25].

From a categorical perspective, choosing dirty hands is impermissible. But those who take a less categorical view of morality may see it as laudable. It is not easy to do something others, here both nations and individuals, may consider unethical, but doing it to secure a better outcome is somewhat heroic. Of course, all of this is mere hypocrisy if a government claims that the reason for doing something unethical is that otherwise *it* will do something even more unethical. Governments have control over what they do, and in that case the answer is easy: do neither! The harder question involves doing something unethical to prevent *someone else* from doing something worse (or something worse from happening).

An argument along these lines has been made by Paul Crutzen [26], and is criticized by Stephen Gardiner [27]. Gardiner refers to it as the 'arm the future' argument. It goes like this. Reducing emissions would be best. We are not doing much to reduce emissions, and that will probably continue.

At some point, people will be faced with a terrible choice: geoengineering or catastrophe. Obviously, geoengineering is better than catastrophe, so those people should choose it. Without the research, that choice is unavailable. So, we should do the research [27]. Gardiner's main objection to this argument is that current governments still have control over whether it is true that 'we're not doing much to reduce emissions', and that 'that will probably continue'. It is up to us whether we take more radical action to reduce emissions in a way that will not force anyone into the position of having to use geoengineering techniques—whether SRM or CDR/NETs—to avoid catastrophe. For as long as this remains true (and for as long as individual countries are not 'off the hook' because of collective action problems), Gardiner's criticism is persuasive.

It is worth emphasizing that we need not choose between enhanced weathering and reduced GHGs: insofar as NETs are relatively cheap, relatively low-impact ways of mitigating the effects of increased carbon emissions, they may be a natural *partner* to more traditional strategies. Relatedly, it is not obvious that there is a bright red line, on one side of which GHG emissions reduction is a plausible strategy, the other side of which geoengineering is the only way forward. Plausibly, the situation is more complicated, and some desirable scenarios combine the two.

However, insofar as we choose to emphasize NETs at the expense of reducing GHGs (that is, there are opportunity costs), or insofar as emphasizing such after-the-fact technological solutions lower the urgency of reducing GHGs, a choice is being made about the extent to which ongoing natural systems such as the carbon cycle will depend on human technology. It strikes us as important that this choice is seen as such. This naturally leads to considering the possible moral hazards of developing NETs.

6. Moral hazard

In the last section, we assumed that NETs are ethically costly. In the next three, we consider reasons why this might be true.

The notion of 'moral hazard' comes from economics, and is the idea that 'people with insurance may take greater risks than they would do without it because they know they are protected' [28, p. 78; 29, p. 166] (see also [30,31]). Applied to NETs, the moral hazard is that because countries have the 'safeguard' available of removing carbon with NETs (not to mention reducing the temperature with SRM), they may diminish their efforts to reduce GHG emissions in other ways.

Of course, whether geoengineering measures actually pose a moral hazard depends on whether we should think of them as 'insurance'—back-up plans to be used only in cases where the primary plan fails—or as legitimate primary plans. To dip briefly into fantasy, imagine that enhanced weathering techniques had developed to the stage that the planet's rate of carbon processing was, in effect, under our immediate and fine-grained control. Under these conditions, what reasons would we have for lowering our GHG emissions? Here, enhanced weathering is not merely a stopgap, but an ongoing part of planet management (although, as we discuss below, the dominating position of humans in this scenario may yet be problematic). If it is a legitimate primary plan, then there is no reason to frame the issue as involving moral hazard. There would not be anything morally hazardous about countries diminishing their efforts to reduce GHG emissions.

How should we think about the implementation of NETs compared with straightforward efforts to reduce emissions, e.g. by cutting consumption, switching to clean energy sources, investing in public transport infrastructure while raising taxes on private vehicle usage, transforming fossil fuel and agricultural industries into alternative sustainable industries, and so on? The most persuasive argument for conceiving of (certain kinds of) SRM and CDR techniques as creating 'moral hazard' involves their *safety*. Efforts to reduce emissions in the way just mentioned are generally safe, and often involve co-benefits. Caution is required here: although there are clear health benefits in encouraging people in developed countries to drive less, there are economic costs involved in dramatic changes to consumption and production, which often fall on the most vulnerable. However, these costs are, in a sense, the kinds of costs we are used to. In contrast, some SRM and CDR strategies are far from safe (it has even been suggested that afforestation is problematic [32]). This worry is less pressing for less ambitious forms of enhanced weathering.

The combination of the possibility of moral hazard and uncertainty generates something of a dilemma. If the Royal Society Report [28] is correct, then more research is required to decide whether or not various strategies in fact present moral hazards. However, if they do, then that research should not be done, as often doing the research, and making a technology available, are coupled [29].

7. International governance

Enhanced weathering, at the scale required to genuinely make emissions 'negative', will have to be administered globally and will therefore have global impacts and carry global risks. For example, enhanced rock weathering requires the dusting of huge tracts of land with finely ground rock silicate. That land may lie outside the country implementing the technology, and may have impacts on everyone (via its general effects on the climate system) and on those in the countries whose land is dusted (e.g. effects on those populations' respiratory health)—and indeed on those in bordering countries if the rock silicate crosses borders via wind currents. NETs therefore require appropriate global governance [22,23,28,29].

One of the five 'Oxford Principles' requires 'public participation in geoengineering decision-making'; another requires 'governance before deployment' [33–35]. The Royal Society notes:

> ...a flexible framework for international regulation is necessary. [...] In general however, any future improvements to the regulatory context should be democratic, transparent, and flexible [...] and should discourage unilateral action [28, p. 39].

The problem, of course, is that we do not have international democratic institutions in place: by which we mean, institutions that in some sense give *every* potentially affected individual a voice in decision-making. Not all countries are democratic, and even those that are often fail to consult with their citizens before making important decisions. Even if we ignore this 'democratic deficit' and focus only on groups of state representatives, e.g. parties to the UNFCCC, there is still a problem of efficacy. Parties met 20 times since 1992 and accomplished very little [36]. The Paris

Agreement is something of an exception; but parties' current pledges are unlikely to sum to the Agreement's stated goal. How, then, should we think about the prospects of global governance of large-scale NETs into the indefinite future?

If there is no institution for (genuine) global democracy, then it is hard to see how global governance of geoengineering could be feasible. If it is not feasible, then the requirement cannot be met and at its most dramatic, this means either scrapping the requirement or scrapping geoengineering. Of course, which of these we should do depends on the severity of the risks, which are a lot worse for certain kinds of SRM approaches than for certain kinds of NETs. Even within NETs, some are riskier than others: cloud treatment and enhanced weathering involve more risk and uncertainty than 'blue carbon' (that is, capture from oceanic and coastal ecosystems) habitat restoration. The greater the uncertainty and the worse the risks, the less acceptable it is to make global interventions without appropriate global governance. For NETs with lower risks, and about which there is less uncertainty, governance by the UNFCCC may represent the best compromise between political feasibility and moral desirability.

8. The 'hubris' objection

The hubris objection to the implementation of global NETs in response to anthropogenic increases in carbon emissions accuses its implementers of excessive arrogance or self-confidence.

There is a less sensible and a more sensible version of this worry. The less sensible version says that in intentionally manipulating the climate at the scale proposed for some NETs, we would be 'playing God'; it is not *our place* to intervene on the climate at that scale. A fallacy lurks here: the idea that there is some 'natural' state of the world and humans' place in it that ought to be protected against change. Whatever is 'not natural' is somehow also bad, with the corollary that whatever is natural is somehow also good. This is demonstrably false: nature contains plenty of terror (natural disasters, violent killing, starvation and suffering) and there are artificial goods (like medical advances or the Internet). This is not to mention that the distinction between 'natural' and 'non-natural' is itself difficult to draw in a compelling way. This same objection has been waged against abortions, stem cell research, the genetic modification of food, cloning and so on. There is little to recommend it.

The more sensible version of the objection suggests that there are better and worse ways in which humans might relate to the environment—and that standing in a relation of *domination* over it is especially problematic. Certain interventions upon the climate system do seem to put humans into a dominating relationship with nature. For example, in implementing NETs instead of choosing to make radical cuts to our consumption practices, we move away from an appropriate balance between humans and the natural environment (Confucians emphasize the importance of this kind of balance [37]). Here, 'playing God' is better understood as exercising inappropriate levels of control over the natural world.

9. Conclusion

The complexity of the technologies, systems and measures involved in combating anthropogenic climate change raises difficult scientific and engineering challenges, but there are significant ethical dimensions as well. In the case of enhanced weathering, in comparison to other geoengineering measures, there is at least the possibility of a reduced cost, reduced impact way of decreasing atmospheric carbon, with positive knock-on effects such as decreased oceanic acidity. However, uncertainty about these factors make relying on such possibilities difficult. Moreover, the ethical considerations are not exhausted by uncertainty: issues of responsibility and governance are pressing, and if enhanced weathering presents a moral hazard, it is not obvious whether we should attempt to resolve that uncertainty in the first place. Ethical considerations further highlight the distinction between less ambitious NETs, best seen as supplements to traditional GHG emissions reduction, and more ambitious, extensive approaches. The former are less effective alone, but present less moral risk. The latter require significantly more caution. Our aim has not been to resolve such issues, but to argue that ethical concerns have a place alongside empirical, political and social factors as we consider how to best respond to the critical challenge that anthropogenic climate change poses.

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