

1 **Accelerating the Carbon Cycle:**
2 ***The ethics of enhanced weathering***
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5
6 *Introduction*

7 National and global regulatory measures are required to control the effects of
8 anthropogenic climate change. In contrast to measures that incentivize lower emissions,
9 as well as substitute fossil fuels for alternative energy sources, geoengineering involves
10 interventions downstream from business-as-usual greenhouse gas (GHG) emissions.
11 One set of strategies—Solar Radiation Management (SRM)—manipulate other factors
12 determining the Earth’s temperature. Another set—Carbon Dioxide Removal (CDR), or
13 more recently Negative Emissions Technologies (NETs)—extract carbon from the
14 atmosphere itself. This can be achieved by using synthetic mechanisms to capture and
15 store carbon, or by enhancing or accelerating natural mechanisms that already do this.
16 The latter of these includes enhanced weathering—our focus—as well as afforestation
17 and other techniques.

18
19 In deciding which options to encourage and enact, policy-makers face not only
20 questions about efficiency and engineering, but also ethics. We provide an overview of
21 the ethical issues arising from NETs, particularly enhanced weathering, aiming to focus
22 on issues not already covered in detail elsewhere^{1,2}. Although the ethical considerations
23 are quite general, they interact with different techniques and strategies in different ways.
24 Furthermore, different ethical considerations are potentially in tension. Some ethical
25 issues turn in part on uncertainty about the effectiveness and consequences of enhanced
26 weathering, and so motivate further research; while others offer the opposite council, as
27 the development of enhanced weathering techniques might itself come at an ethical cost.

28
29 Silicate weathering—the process whereby silicate transforms into carbonate—affects
30 the global carbon cycle; as does the breakdown of carbon by aquatic biological agents,
31 and the transferal of terrestrial CO₂ into the oceans. Thus, the global carbon cycle’s
32 efficiency depends in part on terrestrial and aquatic biochemical composition. Although
33 on short time scales natural weathering processes are comparatively weak³, such
34 processes could be radically amplified, turning the Earth into a more efficient carbon
35 processor⁴. The basic biochemical processes involved are well understood⁵, and can be
36 studied at a local level⁶. Indeed, the basic notions are quite simple: given that global
37 carbon processing is in part driven by how much silicate is exposed to weathering,
38 increasing its exposure by dusting large amounts of the Earth’s surface with finely
39 ground, highly reactive, silicates would increase that processing, particularly if coupled
40 with biotic aids (such as certain plant varieties). The specifics are varied, from large-

1 scale terrestrial dusting^{7,8}, to incorporating industrial by-products⁹, to increasing oceanic
2 olivine¹⁰. Enhanced weathering techniques are sometimes considered to be a less
3 extreme option than SRM, and perhaps implementable at a relatively local level (we
4 shall emphasize this point below). Further, given that agricultural practices already alter
5 large sections of the Earth's surface in analogous ways (mineral fertilization to increase
6 soil alkalinity, soil tilling and liming, etc.), there is potential for enhanced weathering to
7 piggyback on existing practices. Finally, increases in oceanic alkalinity would
8 potentially come with the co-benefit of alleviating acidification and increasing biomass.

9
10 However, uncertainty about the global-scale efficiency and effects of enhanced
11 weathering is high. The reasons should be familiar: global systems are complex,
12 interconnected, and thus difficult to model. Even in comparison with SRMs, enhanced
13 weathering is understudied at global scales, and models are not well resolved¹⁰. Some
14 mineral outputs of enhanced weathering are potentially toxic at high concentrations.
15 Organic and inorganic CO₂ dynamics are coupled in complex ways¹¹, and it is unclear
16 how manipulating mineralogical composition will affect biological CO₂ absorption, and
17 *vice-versa*. The practical costs of locating (or generating), processing, and transporting
18 the large volumes of minerals required for large-scale enhanced weathering (to say
19 nothing of the production costs of biotic materials) are likely to be immense. The
20 possible side effects, both apparently beneficial and problematic, are voluminous¹⁰. For
21 more on the specifics of enhanced weathering, see the other papers in this collection.

22
23 In addition to these practical, theoretical, and empirical challenges, weighing the
24 advisability of enhanced weathering against other candidate strategies has ethical
25 dimensions. We highlight these, with a specific focus on the role of states, both because
26 this simplifies an already complex discussion, and because states are plausibly in a
27 position to both regulate and initiate strategies for mitigating and reducing climate
28 change, as well as entering into the kinds of international agreements required. Where
29 other reviews of the ethics have been general across geoengineering^{1,2}, we will focus on
30 the relationship between relatively general ethical considerations and the specific case
31 of enhanced weathering.

32
33 *i. Post-implementation scenarios*

34 Pak-Hang Wong¹² argues that the ethical debate over geoengineering misses important
35 ethical issues arising *post*-implementation. These include the responsibility for
36 continuation and monitoring, which he refers to together as 'the requirement of
37 maintenance'¹². Indeed, some enhanced weathering techniques require significant
38 infrastructure. And the best locations for implementation in terms of climate and
39 mineralogy lack existing agricultural systems to co-opt¹⁰. Further, ongoing monitoring
40 of the effects would be costly.

1

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

7

8 Many authors note the risks of any abrupt halt to certain geoengineering interventions
9 (although they usually have SRM rather than CDR in mind^{13,14,12,15}), a risk that becomes
10 more likely to materialize if responsibility for maintenance, once geoengineering
11 techniques have been implemented, is spread between groups. Wong argues that any
12 ethics of geoengineering must take a long-term perspective¹². Given that, generally
13 speaking, geoengineering measures are often presented as impermanent, stop-gap
14 measures, maintenance and removal costs must be considered alongside
15 implementation. It is not obvious, for instance, how long the effects of enhanced
16 weathering might last. If a decade has been spent adding vast quantities of silicate rock
17 to previously mineral-poor areas, what downstream effects would occur were we to turn
18 off the tap? In this regard SRM is likely more problematic than CDR, but the more
19 dramatic *vis-à-vis* scale and impact CDR interventions are, the less likely we are to be
20 able to predict and understand the implications of cessation. Post-implementation
21 scenarios, then, raise both ethical and empirical puzzles that remain unresolved.

22

23 *ii. Failures of collective action*

24 It is often thought that a Tragedy of the Commons (TOC) between states is a major
25 block to national and global action on GHGs. That is, the interests of each state
26 (business-as-usual or increasing emissions) come apart from what is in the interest of
27 states taken together (mutual restrictions to emissions). It is plausible that achieving
28 mutual restrictions, whatever the exact target, would not require equal action from all
29 states. Indeed, some states could take no action at all. This creates an incentive to be an
30 inactive state. If this is right, then there may be conditions under which a state could
31 take no action, while avoiding ethical culpability. Alternatively, states may be
32 culpable—e.g. for colluding in their collective failure to agree¹⁶. That a state may lack
33 culpability despite failing to do what is in the combined interests of states, applies to
34 enhanced weathering in two ways: firstly, to the decision to implement enhanced
35 weathering instead of reducing GHG emissions in a more straightforward way;
36 secondly, to the implementation and maintenance of enhanced weathering, as discussed
37 above.

38

39 Imagine that in the future, states are forced to implement NETs because of a prior
40 collective failure to negotiate the international agreement that would have solved the

1 TOC and allowed them to mitigate climate change *without* the use of NETs (or
2 geoengineering techniques more broadly). Particular states may not be culpable for this
3 failure, e.g. because taking unilateral action would not have made a significant
4 difference either to the concentration of GHGs in the atmosphere or to the agreement
5 being negotiated; or because they had reasonable, but ultimately mistaken beliefs about
6 what other states were willing to do^{17,18}. Other states may be culpable, e.g. because they
7 *caused* the failure.

8 Further, note that because NETs are processes that last through time¹² their maintenance
9 may itself create a TOC. This TOC may be international and hold between countries that
10 could share the burden of maintaining specific NET interventions; it may be domestic
11 but intergenerational, holding between successive governments of the same country; or
12 it may be both international and intergenerational—as in Gardiner’s ‘perfect moral
13 storm’¹⁹. The threat of a TOC for maintenance may be a sufficient reason to refrain from
14 deploying a specific NET, particularly due to high transition costs or risks from abrupt
15 cessation of the intervention (insofar as such risks exist). The possibility of a TOC for
16 maintenance depends in part on the cost of collective action, and thus the specifics of
17 the different kinds of NETs matter here. If enhanced weathering can be implemented at
18 relatively low costs it could be part of an overall response to climate change: especially
19 in partnership with existing agricultural practices (especially when contrasted with
20 SRM). However, establishing this requires significant research and moreover, as we
21 explain below, using enhanced weathering to avoid reducing GHG emissions (rather
22 than in combination with reductions) potentially creates a serious moral hazard.

23
24 But does a TOC in fact hold? Nicholas Stern²⁰ and Fergus Green²¹ (the latter more
25 forcibly) argue that radically reducing emissions does not, contrary to received wisdom,
26 put states into a TOC, because of the nature of the co-benefits that would accrue from
27 doing so. If states, or at least *particular* states, could be reducing emissions and
28 obtaining co-benefits all the while freeing up resources for additional welfare, but are
29 not doing so, then they wrong their citizens, whose interests they are supposed to serve.

30
31 *iii. Distribution of risk, externalities, and redress for damage*

32 Some NETs might displace risk from those deploying them onto others. This
33 displacement can be spatial and temporal: onto people in future generations, or people
34 living in other countries²². This is likely for enhanced weathering: the most effective
35 areas for deployment are the hot, wet climes of the tropics, so the (often severely
36 underprivileged) people living there would be exposed to the risk of unintended
37 consequences, such as toxic by-products from increased silicate weathering.

38
39 Such risks are one kind of ‘negative externality’; in general, negative externalities are
40 costs borne by those other than the technology’s implementers. Externalities may be

1 positive. Countries in drier, colder climates would likely reap the benefits of lower carbon
2 levels, less acidic seas, and higher biological production from large-scale enhanced
3 weathering implemented in tropical zones; ocean-based increases in biomass would
4 surely not respect national borders, so that were the US (let us imagine) to implement
5 such measures in their territorial waters, the effects would be felt in Mexico. Risks can
6 be negative externalities when they cross borders (or generations) in the same way²².

7
8 One ethical question is whether it is permissible to implement techniques that impose
9 risks on others without their having a say, in particular when they may not even benefit
10 from the techniques' desired initial effects; another is how such risks should be
11 distributed among candidate recipients and managed so as to minimize them. If
12 enhanced rock weathering were implemented by the UK Government, for example, and
13 that had consequences that caused serious damage, who would be responsible for
14 repairing—or compensating for—that damage? Ethical considerations potentially
15 require those nations that implement the technologies and benefit from them to absorb
16 (or compensate for) the relevant externalities and materialized risks. (On the ethical
17 obligations of those countries that benefit from geoengineering, see Heyward²³.)

18
19 Issues of post-implementation, collective action, and redress for damage are all
20 exacerbated by uncertainty. Although reducing or removing uncertainty will not fully
21 resolve the ethical issues, it would certainly clarify them. As such, these ethical points
22 encourage further consideration and research into enhanced weathering techniques.
23 However, other ethical considerations push in the other direction, to which we now turn.

24
25 *iv. 'Dirty Hands' — or, arming the future*

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

36
37 From a categorical perspective, choosing dirty hands is impermissible. But those who
38 take a less categorical view of morality may see it as laudable. It is not easy to do
39 something others, here both nations and individuals, may consider unethical, but doing
40 it to secure a better outcome is somewhat heroic. Of course, all of this is mere hypocrisy

1 if a government claims that the reason for doing something unethical is that otherwise *it*
2 will do something even more unethical. Governments have control over what they do,
3 and in that case the answer is easy: do neither! The harder question involves doing
4 something unethical to prevent *someone else* from doing something worse (or
5 something worse from happening).

6
7 An argument along these lines has been made by Paul Crutzen²⁶, and is criticized by
8 Stephen Gardiner²⁷. Gardiner refers to it as the 'arm the future' argument. It goes like
9 this. Reducing emissions would be best. We are not doing much to reduce emissions,
10 and that will probably continue. At some point, people will be faced with a terrible
11 choice: geoengineering, or catastrophe. Obviously, geoengineering is better than
12 catastrophe, so those people should choose it. Without the research, that choice is
13 unavailable. So, we should do the research²⁷. Gardiner's main objection to this argument
14 is that current governments still have control over whether it is true that 'we're not doing
15 much to reduce emissions', and that 'that will probably continue'. It is up to us whether
16 we take more radical action to reduce emissions in a way that will not force anyone into
17 the position of having to use geoengineering techniques—whether SRM or
18 CDR/NETs—to avoid catastrophe. For as long as this remains true (and for as long as
19 individual countries are not 'off the hook' because of collective action problems),
20 Gardiner's criticism is persuasive.

21
22 It is worth emphasizing that we need not choose between enhanced weathering and
23 reduced GHGs: insofar as NETs are relatively cheap, relatively low-impact ways of
24 mitigating the effects of increased carbon emissions, they may be a natural *partner* to
25 more traditional strategies. Relatedly, it is not obvious that there is bright red line, on
26 one side of which GHG emissions reduction is a plausible strategy, the other side of
27 which geoengineering is the only way forwards. Plausibly, the situation is more
28 complicated, and some desirable scenarios combine the two.

29
30 However, insofar as we choose to emphasize NETs at the expense of reducing GHGs
31 (that is, there are opportunity costs), or insofar as emphasizing such after-the-fact
32 technological solutions lowers the urgency of reducing GHGs, a choice is being made
33 about the extent to which ongoing natural systems such as the carbon cycle will depend
34 on human technology. It strikes us as important that this choice is seen as such. This
35 naturally leads to considering the possible moral hazards of developing NETs.

36 37 *v. Moral hazard*

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

40 The notion of 'moral hazard' comes from economics, and is the idea that 'people with

1 insurance may take greater risks than they would do without it because they know they
2 are protected^{28,29,30,31}. Applied to NETs, the moral hazard is that because countries have
3 the 'safeguard' available of removing carbon with NETs (not to mention reducing the
4 temperature with SRM), they may diminish their efforts to reduce GHG emissions in
5 other ways.

6
7 Of course, whether geoengineering measures actually pose a moral hazard depends on
8 whether we should think of them as 'insurance'—back-up plans to be used only in cases
9 where the primary plan fails—or as legitimate primary plans. To dip briefly into fantasy,
10 imagine that enhanced weathering techniques had developed to the stage that the
11 planet's rate of carbon processing was, in effect, under our immediate and fine-grained
12 control. Under these conditions, what reasons would we have for lowering our GHG
13 emissions? Here, enhanced weathering is not merely a stopgap, but an ongoing part of
14 planet management (although, as we discuss below, the dominating position of humans
15 in this scenario may yet be problematic). If it is a legitimate primary plan, then there is
16 no reason to frame the issue as involving moral hazard. There would not be anything
17 morally hazardous about countries diminishing their efforts to reduce GHG emissions.

18
19 How should we think about the implementation of NETs compared with straightforward
20 efforts to reduce emissions, e.g. by cutting consumption, switching to clean energy
21 sources, investing in public transport infrastructure while raising taxes on private
22 vehicle usage, transforming fossil fuel and agricultural industries into alternative
23 sustainable industries, and so on? The most persuasive argument for conceiving of
24 (certain kinds of) SRM and CDR techniques as creating 'moral hazard' involves their
25 *safety*. Efforts to reduce emissions in the way just mentioned are generally safe, and
26 often involve co-benefits. Caution is required here: although there are clear health
27 benefits in encouraging people in developed countries to drive less, there are economic
28 costs involved in dramatic changes to consumption and production, which often fall on
29 the most vulnerable. However, these costs are, in a sense, the kinds of costs we are used
30 to. In contrast, some SRM and CDR strategies are far from safe (it has even been
31 suggested that afforestation is problematic³²). This worry is less pressing for less
32 ambitious forms of enhanced weathering.

33
34 The combination of the possibility of moral hazard and uncertainty generates something
35 of a dilemma. If the Royal Society Report is correct, then more research is required to
36 decide whether or not various strategies in fact present moral hazards. However, if they
37 do, then that research should not be done, as often doing the research, and making a
38 technology available, are coupled²⁹.

39 *vi. International governance*

40 Enhanced weathering, at the scale required to genuinely make emissions 'negative', will

1 have to be administered globally and will therefore have global impacts and carry global
2 risks. For example, enhanced rock weathering requires the dusting of huge tracts of land
3 with finely ground rock silicate. That land may lie outside the country implementing the
4 technology, and may have impacts on everyone (via its general effects on the climate
5 system), and on those in the countries whose land is dusted (e.g. effects on those
6 populations' respiratory health)—and indeed on those in bordering countries if the rock
7 silicate crosses borders via wind currents. NETs therefore require appropriate global
8 governance^{22,23,29,28}.

9
10 One of the five 'Oxford Principles' requires 'public participation in geoengineering
11 decision-making', another requires 'governance before deployment'^{33,34,35}. The Royal
12 Society notes:

13
14 '...a flexible framework for international regulation is needed. [...] In general however, any future
15 improvements to the regulatory context should be democratic, transparent, and flexible [...] and
16 should discourage unilateral action'²⁸.

17
18 The problem, of course, is that we do not have international democratic institutions in
19 place: by which we mean, institutions that in some sense give *every* potentially affected
20 individual a voice in decision-making. Not all countries are democratic, and even those
21 that are often fail to consult with their citizens before making important decisions. Even
22 if we ignore this 'democratic deficit' and focus only on groups of state representatives,
23 e.g. parties to the UNFCCC, there is still a problem of efficacy. Parties met 20 times
24 since 1992 and accomplished very little³⁶. The Paris Agreement is something of an
25 exception; but parties' current pledges are unlikely to sum to the Agreement's stated
26 goal. How, then, should we think about the prospects of global governance of large-
27 scale NETs into the indefinite future?

28
29 If there is no institution for (genuine) global democracy, then it is hard to see how
30 global governance of geoengineering could be feasible. If it is not feasible, then the
31 requirement cannot be met, and at its most dramatic, this means either scrapping the
32 requirement, or scrapping geoengineering. Of course, which of these we should do
33 depends on the severity of the risks, which are a lot worse for certain kinds of SRM
34 approaches than for certain kinds of NETs. Even within NETs, some are riskier than
35 others: cloud treatment and enhanced weathering involve more risk and uncertainty than
36 'blue carbon' (that is, capture from oceanic and coastal ecosystems) habitat restoration.
37 The greater the uncertainty and the worse the risks, the less acceptable it is to make
38 global interventions without appropriate global governance. For NETs with lower risks,
39 and about which there is less uncertainty, governance by the UNFCCC may represent
40 the best compromise between political feasibility and moral desirability.

41

1 *vii. The 'hubris' objection*

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

5
6 There is a less sensible and a more sensible version of this worry. The less sensible
7 version says that in intentionally manipulating the climate at the scale proposed for
8 some NETs, we would be 'playing God'; it is not *our place* to intervene on the climate at
9 that scale. A fallacy lurks here: the idea that there is some 'natural' state of the world and
10 humans' place in it that ought to be protected against change. Whatever is 'not natural' is
11 somehow also bad, with the corollary that whatever is natural is somehow also good.
12 This is demonstrably false: nature contains plenty of terror (natural disasters, violent
13 killing, starvation and suffering) and there are artificial goods (like medical advances, or
14 the internet). This is not to mention that the distinction between 'natural' and 'non-
15 natural' is itself difficult to draw in a compelling way. This same objection has been
16 waged against abortions, stem cell research, the genetic modification of food, cloning,
17 and so on. There is little to recommend it.

18
19 The more sensible version of the objection suggests that there are better and worse ways
20 in which humans might relate to the environment—and that standing in a relation of
21 *domination* over it is especially problematic. Certain interventions upon the climate
22 system do seem to put humans into a dominating relationship with nature. For example,
23 in implementing NETs instead of choosing to make radical cuts to our consumption
24 practices, we move away from an appropriate balance between humans and the natural
25 environment (Confucians emphasize the importance of this kind of balance³⁷). Here
26 'playing God' is better understood as exercising inappropriate levels of control over the
27 natural world.

28
29 *Conclusion*

30 The complexity of the technologies, systems, and measures involved in combating
31 anthropogenic climate change raise difficult scientific and engineering challenges, but
32 there are significant ethical dimensions as well. In the case of enhanced weathering, in
33 comparison to other geoengineering measures, there is at least the possibility of a
34 reduced cost, reduced impact way of decreasing atmospheric carbon, with positive
35 knock-on effects such as decreased oceanic acidity. However, uncertainty about these
36 factors make relying on such possibilities difficult. Moreover, the ethical considerations
37 are not exhausted by uncertainty: issues of responsibility and governance are pressing,
38 and if enhanced weathering presents a moral hazard, it is not obvious whether we
39 should attempt to resolve that uncertainty in the first place. Ethical considerations
40 further highlight the distinction between less ambitious NETs, best seen as supplements

1 to traditional GHG emissions reduction, and more ambitious, extensive approaches. The
2 former are less effective alone, but present less moral risk. The latter require
3 significantly more caution. Our aim has not been to resolve such issues, but to argue
4 that ethical concerns have a place alongside empirical, political and social factors as we
5 consider how to best respond to the critical challenge that anthropogenic climate change
6 poses.

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18 19 **References**

- 20 [1] Preston, C. J. (2013). Ethics and geoengineering: reviewing the moral issues raised by solar radiation
21 management and carbon dioxide removal. *Wiley Interdisciplinary Reviews: Climate Change*, 4(1), 23-37.
22
23 [2] Corner, Adam., & Pidgeon, Nick. 'Geoengineering the Climate: The Social and Ethical Implications',
24 *Environment Magazine* 52/1 (2010), pp. 24-37.
25
26 [3] Peters, G. P., Marland, G., Le Quéré, C., Boden, T., Canadell, J. G., & Raupach, M. R. (2012). Rapid
27 growth in CO₂ emissions after the 2008-2009 global financial crisis. *Nature Climate Change*, 2(1), 2-4.
28
29 [4] Köhler, P., Hartmann, J., & Wolf-Gladrow, D. A. (2010). Geoengineering potential of artificially
30 enhanced silicate weathering of olivine. *Proceedings of the National Academy of Sciences*, 107(47),
31 20228-20233.
32
33 [5] Hartmann, J., & Kempe, S. (2008). What is the maximum potential for CO₂ sequestration by
34 “stimulated” weathering on the global scale?. *Naturwissenschaften*, 95(12), 1159-1164.
35
36 [6] Hartmann, J. (2009). Bicarbonate-fluxes and CO₂-consumption by chemical weathering on the
37 Japanese Archipelago—application of a multi-lithological model framework. *Chemical Geology*, 265(3),
38 237-271.
39
40 [7] Schuiling, R. D., & Krijgsman, P. (2006). Enhanced weathering: An effective and cheap tool to
41 sequester CO₂. *Climatic Change*, 74(1-3), 349-354.
42
43 [8] Taylor, Lyla., Quirk, Joe., Thorley, Rachel., Kharecha, Pushker., Hansen, James., Ridgwell, Andy.,
44 Lomas, Mark., Banwart, Steve., & Beerling, David. 'Enhanced weathering strategies for stabilizing

- 1 climate and averting ocean acidification', *Nature Climate Change* 6 (2016), pp. 402-406.
- 2
- 3 [9] Renforth, P., Manning, D. A. C., & Lopez-Capel, E. (2009). Carbonate precipitation in artificial soils
4 as a sink for atmospheric carbon dioxide. *Applied Geochemistry*, 24(9), 1757-1764.
- 5
- 6 [10] Hartmann, J., West, A. J., Renforth, P., Köhler, P., De La Rocha, C. L., Wolf-Gladrow, D. A., ... &
7 Scheffran, J. (2013). Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric
8 carbon dioxide, supply nutrients, and mitigate ocean acidification. *Reviews of Geophysics*, 51(2), 113-
9 149.
- 10
- 11 [11] Jones, D. L., Dennis, P. G., Owen, A. G., & Van Hees, P. A. W. (2003). Organic acid behaviour in
12 soils—misconceptions and knowledge gaps. *Plant and Soil*, 248 (1-2), 31-41.
- 13
- 14 [12] Wong, Pak-Hang. 'Maintenance Required: The Ethics of Geoengineering and Post-Implementation
15 Scenarios', *Ethics, Policy and Environment* 17/2 (2014), pp. 186-191.
- 16 [13] Burns, William. 'Climate Geoengineering: Solar Radiation Management and its Implications for
17 Intergenerational Equity', *Stanford Journal of Law, Science & Policy* (2011) pp. 38–55.
- 18
- 19 [14] Svoboda, Toby., Keller, Klaus., Goes, Marlos., & Tuana, Nancy. 'Sulfate Aerosol Geoengineering:
20 The Question of Justice', *Public Affairs Quarterly* 25/3 (2011), pp. 157–179.
- 21
- 22 [15] Preston, C. J. (2016), 'Climate Engineering and the Cessation Requirement: The Ethics of a Life-
23 Cycle', *environ values*, 25/1: 91–107.
- 24
- 25 [16] Goodin, Robert. 'Excused by the Unwillingness of Others?' *Analysis* 72/1 (2012), pp. 18-24.
- 26
- 27 [17] Lawford-Smith, Holly. 'Benefiting from Failures to Address Climate Change', *Journal of Applied*
28 *Philosophy* 31/4 (2014), pp. 392-404.
- 29
- 30 [18] Lawford-Smith, Holly. 'Unethical Consumption and Obligations to Signal', *Ethics & International*
31 *Affairs* 29/3 (2015), pp. 315-330.
- 32
- 33 [19] Gardiner, Stephen. *A Perfect Moral Storm* (Oxford: Oxford University Press, 2011).
- 34
- 35 [20] Stern, Nicholas. 'Economic Development, Climate, and Values; Making Policy', *Proceedings of the*
36 *Royal Society B* 282 (2015), pp. 1-9.
- 37
- 38 [21] Green, Fergus. 'Nationally Self-Interested Climate Change Mitigation: A Unified Conceptual
39 Framework', *Centre for Climate Change Economics and Policy, Working Paper No. 224*. July (2015), pp.
40 1-44.
- 41
- 42 [22] IPCC. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the
43 Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.).
44 (IPCC: Geneva, Switzerland, 2014).
- 45
- 46 [23] Heyward, Clare. 'Benefiting from Climate Geoengineering and Corresponding Remedial Duties: The

- 1 Case of Unforeseeable Harms', *Journal of Applied Philosophy* 31/4 (2014), pp. 405-419.
2
- 3 [24] Smart, J.J.C, & Williams, Bernard. *Utilitarianism - For and Against* (Cambridge: Cambridge
4 University Press, 1973).
5
- 6 [25] Morrow, David. & Svoboda, Toby. 'Geoengineering and Non-Ideal Theory', *Public Affairs Quarterly*
7 30/1 (2016), pp. 83-104.
8
- 9 [26] Crutzen, Paul. 'Albedo Enhancement by Stratospheric Sulphur Injections: A Contribution to Resolve
10 a Policy Dilemma?' *Climatic Change* 77 (2006), pp. 211-219.
11
- 12 [27] Gardiner, Stephen. 'Is 'Arming the Future' with Geoengineering Really The Lesser Evil? Some
13 Doubts About Intentionally Manipulating the Climate System', Stephen Gardiner, Dale Jamieson, Simon
14 Caney, & Henry Shue (Eds.) *Climate Ethics: Essential Readings* (Oxford: Oxford University Press,
15 2010).
16
- 17 [28] The Royal Society. *Geoengineering the climate: science, governance and uncertainty*. Royal Society
18 Policy Document 10/9, September 2009.
19
- 20 [29] Gardiner, Stephen. 'Some Early Ethics of Climate Geoengineering: A Commentary on the Values of
21 the Royal Society Report', *Environmental Values* 20/2 (2011), pp. 163-188.
22
- 23 [30] Corner, Adam., & Pidgeon, Nick. 'Geoengineering, climate change scepticism and the 'moral hazard'
24 argument: an experimental study of UK public perceptions', *Philosophical Transactions of the Royal*
25 *Society* 372 (2014), pp. 1-14.
26
- 27 [31] National Research Council. 2015. "Climate Intervention: Carbon Dioxide Removal and Reliable
28 Sequestration." Washington, DC. doi:10.17226/18805.
29
- 30 [32] Heck, V., Gerten, D., Lucht, W. et al. (2016), 'Is extensive terrestrial carbon dioxide removal a
31 'green' form of geoengineering? A global modelling study', *Global and Planetary Change*, 137: 123–130.
32
- 33 [33] Rayner, Steve., Redgwell, Catherine., Savulescu, Julian., Pidgeon, Nick., Kruger, Tim.
34 'Memorandum on draft principles for the conduct of geoengineering research', *House of Commons*
35 *Science and Technology Committee Enquiry into The Regulation of Geoengineering* (2009). Online at
36 <http://www.geoengineering.ox.ac.uk/oxford-principles/history/> accessed 27th July 2016.
37
- 38 [34] Rayner, Steve., Heyward, Clare., Kruger, Tim., Pidgeon, Nick., Redgwell, Catherine., Savulescu,
39 Julian. 'The Oxford Principles', *Climatic Change* 121 (2013), pp. 499-512.
40
- 41 [35] The Economist. 'We all want to change the world', *April 3rd - 9th* (2010).
42
- 43 [36] Kunzig, Robert. 'Fresh Hope for Combating Climate Change', *National Geographic*, October 15th
44 (2015).
45
- 46 [37] Wong, Pak- Hang. 'Confucian environmental ethics, climate engineering, and the "Playing God"

1 argument', *Zygon* 50/1 (2015), pp. 28-41.