Considerations of justice in assessment and appraisal of negative emissions technologies

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Abstract

This paper draws on a recent global assessment of carbon dioxide removal (or negative emissions) technologies (NETs) undertaken by the author for Friends of the Earth in the UK. This paper presents a summary of results of the assessment, and the appraisal process. Alongside criteria such as cost and technical readiness, the review considered controllability, accountability and side effects.

It identified several justice implications arising from: the potential moral hazard in the development of NETs, the distribution (and potential limits to the overall availability) of geological storage for carbon dioxide, and the implications of competition for biological productivity for negative emissions.

The paper also reflects on the justice implications raised by the appraisal process and criteria, with reference to issues in justice theory, including capabilities, recognition, participation and deliberation. It concludes that a more explicit consideration of justice issues is essential for effective appraisal and governance of geoengineering.

1. Introduction

Past reviews of negative emissions techniques (NETs)[1] have focused on relatively few technologies (eg Socolow *et al* 2011; McGlashan *et al* 2010), or taken a broad approach to different options in a wider geoengineering context (Shepherd *et al* 2009). Most have applied a fairly narrow set of criteria, with particular emphasis on issues such as cost, efficacy, rapidity and technical readiness (Bellamy *et al* 2012). This reflects the typical analytical – expert nature of these studies. Where they have involved deliberative processes, these have been almost entirely with small groups of experts, rather than other stakeholders (Bellamy *et al* 2012).

The present study was also expert-analytic in nature, but sought to undertake a multi-criteria assessment of a comprehensive list (of around thirty) proposed techniques identified in the technical and theoretical literature. Following discussion with the client (Friends of the Earth) a shorter list of 14 techniques with significant technical potential was subjected to a deeper evaluation (see table 1 [2].

The appraisal process included some consideration of both procedural and distributional justice implications. Very little information on these was found in the literature. However when considering limiting factors to the deployment of NETs, justice implications were readily identified. On the other hand, there is fairly widespread consideration of the question of moral hazard in the literature, although rarely framed as a justice issue, despite its profound implications for intergenerational justice.

This paper briefly presents the findings of the assessment, then reflects on the criteria used, and discusses how justice might be more rigorously considered in future assessments of geoengineering techniques.

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1 NETs are means of withdrawing greenhouse gases from the environment such that atmospheric concentrations are reduced below the level that would have resulted without the NET. In the literature on geo-engineering (eg Shepherd *et al* 2009), they are often described as carbon dioxide removal (CDR).

2 Other techniques were also reviewed but are not included here because for various reasons their potential appears more limited, or very limited information was available on them. These included: mineral carbonation in autoclaves (Shuiling & Krijgsman, 2006), sea-water injection into basalts (Keleman and Matter, 2008), accelerated carbonation of mineral slag (Eloneva et al, 2007), direct air capture by use of fluidised beds (Nikulshina et al, 2009), electrodialysis (Eisaman et al 2009) or metal organic frameworks (Banerjee et al 2008; Wang et al. 2008), BECCS on biogas upgrading (Karlsson et al 2010) or biohydrogen production, ocean liming via electrochemical splitting (Rau 2008) or removal of HCl (House et al 2007), ocean fertilisation with iron (Shepherd et al 2010), use of GM crops for soil carbon management (Jansson et al 2010), cellulose aggregate concrete (Hemcrete, undated), and regenerative grazing (Lovell and Ward, undated).

2. Methodology and criteria for assessment

A review of approximately 30 different NETs found in the literature, which could contribute to meeting was undertaken in 2011[3]. Data was gathered from iterated web searches, mainly using Google Scholar, providing a large literature list, primarily from peer-reviewed or official sources. An initial scoping search was analysed to establish a categorisation of NETs, which was then populated with data from subsequent searches.

Table 1: The Negative Emissions Techniques subjected to detailed assessment

Category	*Technique*	*Description*
Mineral	Soil mineralisation	The addition of silicate minerals to soils (or surface water) to accelerate the natural process of carbonation of such minerals through dissolution both in the soil and in runoff (Shuiling & Krijgsman, 2006; Köhler *et al*. 2010).
	Magnesium cement	The replacement of carbonate in cement with a magnesium oxide from magnesium silicate, which combines with atmospheric CO_2 while setting (Vlasopolous, 2010).
	Biochar	Storing partially combusted organic matter (char) in soil by burial, preventing the return of biotic carbon to the atmosphere via decomposition. The char can be created from organic matter by pyrolysis or gasification, either of which provides some bioenergy (Shackley & Sohi, 2011).
Pressurised	Direct Air Capture (supported amines)	Adsorption of CO_2 directly from the atmosphere using amines in a solid form, suspended on a branched framework, through which air is pumped, or circulated by wind. The CO_2 is recovered by washing in vacuum, pressurised and injected into geological storage (Lackner 2009, Eisenberger *et al* 2009).
	Direct Air Capture (Wet Calcination)	Capture of CO_2 directly from the atmosphere using wet scrubbing systems based on calcium or sodium cycling technology. The CO_2 is recovered by calcining, pressurised and injected into geological storage (Keith et al, 2006, Baciocchi et al 2006, Socolow et al 2011).
	BECCS (Combustion)	Carbon dioxide is captured from the emissions from combustion of bioenergy sources. Because bioenergy is nominally carbon neutral, capture of the majority of combustion emissions creates a net negative emission across the bioenergy cycle (from plant growth to energy utilisation) (Karlsson *et al* 2010).
	BECCS (Ethanol/BLG)	As for BECCS (Combustion), but the CO2 is captured at an earlier, fuel conversion stage such as ethanol fermentation or black liquor (wood pulp effluent) gasification (Karlsson *et al* 2010).
Oceanic	Ocean Liming	The addition of calcium hydroxide (Kheshgi, 1995) or calcium bicarbonate solution (Rau & Caldeira, 1999 and Rau, 2011) to ocean surface waters, accelerating uptake of CO_2 from the atmosphere, and enabling the ocean to hold a higher total CO_2 store (Jenkins *et al* 2010).
	Ocean Fertilisation	Increasing ocean productivity through addition of limiting nutrients such as iron, phosphate or nitrogen, with the expectation that dead biological matter will sink into the deep ocean and add to stored carbon there. There is great uncertainty over the effectiveness of these proposed techniques (Shepherd *et al* 2009).
Biotic	Forest management	Increasing forest area by planting new forest or extending agro-forestry on suitable land, and /or enhancing management of existing natural and plantation forests to maximise the carbon sink.
	Wetland restoration	Rewetting and restoration of peatlands, tidal salt marshes and mangrove swamps to enhance anaerobic storage of dead organic matter (Parish *et al* 2008; Chmura *et al* 2003).
	Soil management	'No-till' agriculture to reduce the loss of carbon through oxidation when ploughing, thus enhancing the natural soil sink (Lal et al 2004; or organic soil management, using manures and composts to increase the levels of soil organic content (Azeez, 2009).
	Timber use in construction	Increased use of harvested timber in long-life construction applications, thus increasing the store of carbon in the built environment.
	Biomass burial	Burial of harvested biomass in anaerobic conditions (on land) or in the deep ocean (Zeng et al, 2011; Strand and Benford, 2009).

3 The full report and detailed spreadsheet of the assessment can be found at https://sites.google.com/site/mclarenerc/research/negative-emissions-technologies

A few semi-structured telephone or face-to-face interviews were conducted with researchers and policy experts in the field to explore emerging conclusions about particular technologies, rankings and policy approaches.

Seven broad criteria – identified in the process of the scoping search - were used to evaluate the techniques (see Box 1). These were applied consistently to fourteen techniques with selected according to apparent capacity and information availability.

Box 1: Assessment Criteria

Technical capacity and scalability: The technique can make a significant contribution to the overall level needed, and does not run into technical limits or become increasingly difficult or expensive at large scale. Ideally the technique should show economies of scale.

Controllability: Use of the technique can be controlled, in particular such that it can be halted if unforeseen negative impacts arise. Moreover, choices about deployment should be under the control of democratic institutions rather than being proprietary or corporate controlled.

Accountability: The impacts of the technique should be capable of being adequately measured and accounted for.

Side effects: The technique should not have unacceptable or unsustainable negative impacts. Ideally it will offer social, environmental or economic co-benefits.

Energy requirement: The technique should be relatively energy efficient, and have the potential to be run using renewable energy sources or low grade (waste) heat.

Status: The technique should be at least theoretically proven, and ideally well advanced into laboratory or field trials to give a reasonable degree of confidence regarding its performance on the other criteria identified.

Cost: High cost is not necessarily a reason to exclude a technique from consideration, but lower costs would mean earlier and more widespread use may be practical, and impose less burden on taxpayers for the same level of abatement.

2. Summary of findings of assessment

The overall assessment of the main options considered is summarised in Table 2 below. The NETs assessed are at various stages of development (mostly confined to the laboratory, or indeed in many cases, theory). Those close to deployment are typically very limited in scale (with an estimated capacity well below 3Gt-CO_2 pa) and face greater challenges in measuring and accounting for carbon stored than the less well developed direct capture techniques. All the techniques with high potential capacity are expected to remain high cost (at least $250 per ton CO_2) and require access to either or both geological storage, and a significant supply of renewable energy. A practical strategy towards NETs will therefore involve construction of a mixed package if abatement rates in the 10-30Gt-CO_2 pa range are to be achieved[4].

The energy demand of NETs is likely to remain a major obstacle in several cases, and means that NETs are unlikely to be deployed in preference to point-source mitigation measures. An effective net carbon balance for several options, particularly for direct air capture, depends on the widespread availability of low-carbon heat or electricity.

Few NETs involve side effects so severe as to rule out their use. Ocean fertilisation with iron might fall into

4 Based on the difference between two IPCC SRES scenarios (A1B: atmospheric CO_2 approx 700ppm in 2100 and B1: atmospheric CO_2 approx 550ppm in 2100)(IPCC, 2000) and James Hansen's indicative safe level (350ppm CO_2) (Hansen *et al* 2008). These two reductions, (350 ppm and 200 ppm) taken over 50 years, imply an average global rate of negative emission of 32-52 Gt- CO_2 pa[4]. Alternatively if mitigation rates follow a scenario of delivery of the Copenhagen pledges followed by 80-95% reductions in Annex 1 countries and around 55% reductions elsewhere by 2050 (Lowe *et al* 2010) concentrations might be restricted to around 500 ppm by 2100, requiring a total negative emission of 1200Gt-CO_2 (24Gt pa over 50 years) to achieve 350 ppm. Even with very aggressive mitigation including a phase out of unabated coal use by 2030 (Hansen *et al* 2008) there is still a residual negative emission required in the order of 400Gt-CO_2 (50 ppm, or 8 Gt pa over 50 years).

this category, but is also largely ruled out by the serious uncertainties over its effectiveness and measurability. But many have side effects that should constrain their use: particularly biotic techniques that would divert biological productivity from other vital ecosystem services. It should be noted that these constraints have been considered in estimating the potential capacity shown in Figure 3, and in table 2 the traffic light system then assesses whether that level of capacity could be achieved.

Almost all the options involved face issues of governance in terms of who controls them: either as a result of land ownership (for the biotic techniques) or the control of patents (for most of the rest).

Figure 2 below sets out schematically, a possible scenario and package of NETs. It is based on IPCC SRES A1B adapted in line with the analysis of Lowe *et al* (2010), combined with a roughly 1200Gt CO_2 cumulative package of NETs (averaging 24Gt CO_2 pa for 50 years), estimated as necessary to achieve 350 ppm.

The package includes most terrestrial biotic techniques, air capture, BECCS, ocean liming but not fertilisation, soil mineralisation and magnesium cement. NETs are assumed to be introduced in 2030, with a 40 year roll out to rates in 2070 which match the levels shown in Figure 3 below. The package would require more than 540Gt of storage by 2100, exceeding conservative estimates of availability, but well within the IPCC's 'likely' estimate.

Table 2 : A high level assessment of obstacles to deployment of NETs

NET	Capacity / scalability	Accountability	Side effects	Energy requirement	Status	Cost
Soil mineralisation with olivine	amber	red	amber	amber	amber	green
Magnesium Silicate Cement	amber	amber	green	green	green	green
Biochar – pyrolysis	amber	amber	amber	green	green	amber
Biochar – gasification	amber	amber	amber	green	amber	amber
Supported amines for direct air capture	green	green	green	amber	red	red
Wet calcination for direct air capture	green	green	green	red	red	red
BECCS – combustion / co-firing	green	green	amber	amber	amber	amber
BECCS – ethanol fermentation	amber	green	amber	amber	green	green
BECCS - black liquor (BLG) / pulp	amber	green	amber	amber	amber	green
Ocean liming (calcination)	green	amber	amber	amber	red	green
Ocean fertilisation (macro-nutrients)	amber	red	amber	green	red	amber
Forest restoration / management	amber	amber	green	green	green	green
Habitat restoration: peatlands and other wetlands	amber	amber	green	green	green	green
Soil management (eg No-till practices)	amber	red	green	green	green	green
Timber use in construction	red	green	green	green	green	green
Tree burial in anaerobic conditions	amber	amber	amber	green	amber	amber

Key: red = serious obstacle or problem, may not be overcome
amber = significant obstacle, or unknown
green = challenges are relatively small, and probably surmountable

Figure 2: Schematic contrasting mitigation and NETs in a 350 ppm scenario

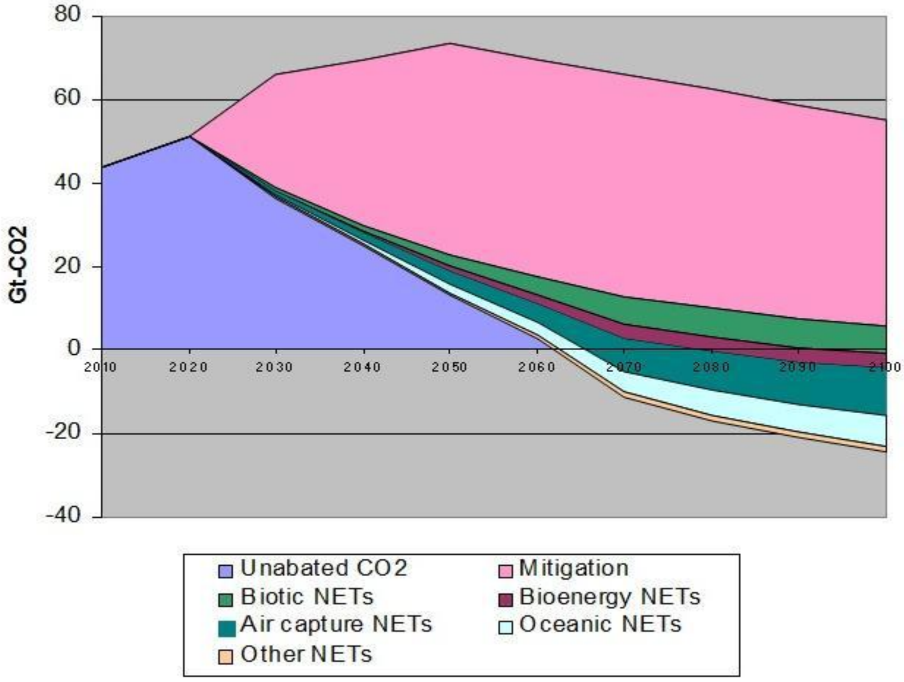

Figure 3: Provisional global assessment of NETs: scale, cost and readiness

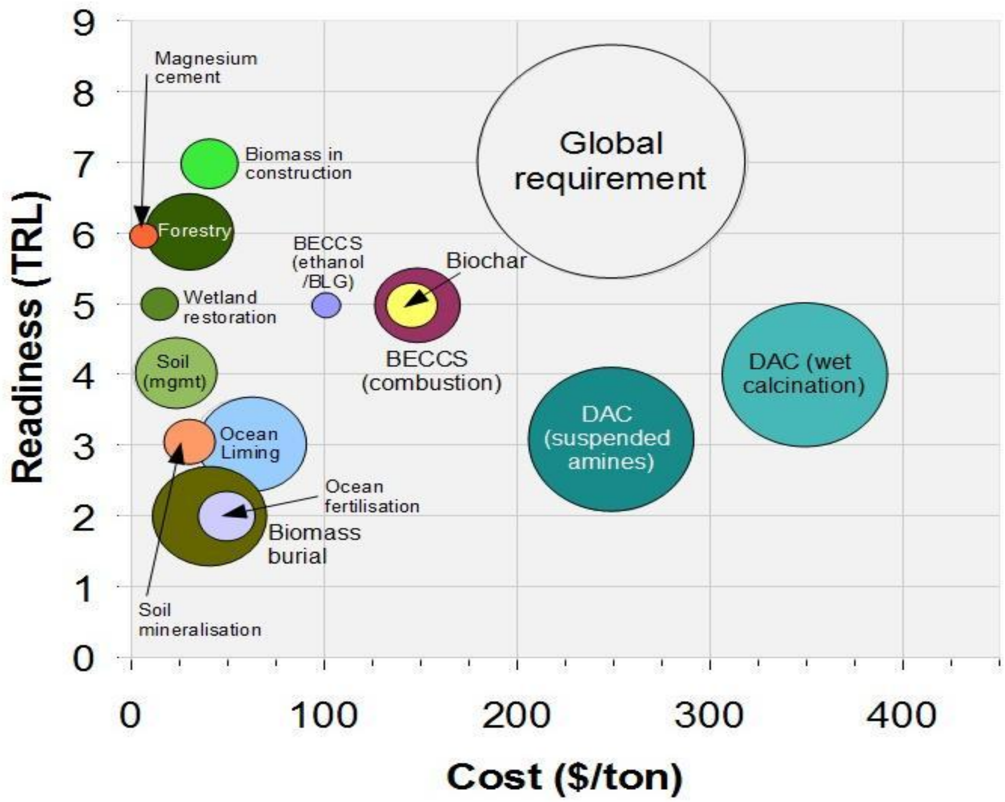

Figure 3 illustrates the estimated global capacity, costs and readiness of NETs. The bubbles are equivalent in size to the estimated annual global capacity, and they are located against axes of technical readiness (where higher = more ready), and cost. The costs, represented here as single figures rather than ranges, should be treated as at best indicative[5]**.**

3. Justice and negative emissions technologies

The appraisal did identify a number of justice concerns, but before considering the aspects of the development and deployment of NETs that might raise such concerns, this section briefly reviews theoretical approaches to justice in an effort to help understand what we might be trying to identify or measure. Justice is multidimensional and can be approached from many different perspectives, so it is instructive to consider the theoretical framework.

Justice theory

Contemporary justice theory is largely rooted in the work of John Rawls (1972) and is focused on questions of distributive justice – the extent to which individuals enjoy fair access to 'goods', and avoid unfair exposure to 'bads'. There are of course, a wide range of principles of justice in political science, from the egalitarian to the libertarian, via various forms of utilitarian.

Both Rawls own approach – using the concept of the 'original position', and the work of Amartya Sen (2009) which emphasises public reasoning, suggest that fair approaches to distribution rely to at least some extent, on public participation and deliberation in the determination of 'fairness'.

Sen and Martha Nussbaum (2001) build on distributive justice theory with the concept of capabilities, which turns the focus of theory away from 'goods and bads' to the ability for human flourishing that results from the pattern of goods and bads (and other necessary capabilities). This approach allows for a more careful consideration of different needs and vulnerabilities (Walker 2011). It also suggests a foundation for duties of justice, based in the capability to take action to prevent or rectify injustice (Sen, 2009).

The distributive justice of geo-engineering might relate to side-effects of the techniques used (including cots and energy consumption) or to the relative distribution of the impacts of climate change that are reduced or remain, and the capabilities and vulnerabilities of those affected.

Justice theory can be extended beyond conceptions of distribution in at least two directions. The first is ***procedural justice*** – the question of how decisions might be made fairly. There are several consistent principles in procedural justice provisions in law and administration (McLaren 2012b), among which participation is often emphasised in justice theory, both as a capability itself, and as an essential criterion of a fair process (Schlosberg, 2007). A full consideration of procedural justice needs to extend across the whole development chain for a technology, and benefits from a whole systems perspective (McLaren, 2012a).

Questions of procedural justice in geoengineering might relate to the governance of deployment, but also of research and development. They could relate for instance to ownership, intellectual property and any benefits arising.

The second is in the concept of ***recognition***. In this approach it is argued that much injustice arises from failures to respect or recognise individuals, groups or their interests, and thus failure to enable their effective participation in society (Schlosberg, 2007; Young, 1990). In considering geoengineering and justice we should, for example consider whether the interests of future generations are appropriately recognised. Schlosberg (2007) also extends the scope of recognition to non-human species and ecological systems.

5 To allow some degree of comparison of scale a 'global indicative' need bubble of 30Gt CO2 has been included. The placing of this is <u>not</u> representative of a 'need' for any specific cost or readiness.

Justice implications of NETs

In examining the various proposed NETs, many of these theoretical issues were identified.

Some techniques may raise specific distributional issues related to the deployment of the technology – for example possible threats to specific fisheries from downstream impacts of ocean fertilisation or localised chemical pollution from air capture devices. But in general the justice issues raised by NETs are more generic.

Climate change is often, and logically, framed as an issue of ***climate justice***. The negative impacts of rising sea levels, higher temperatures and changing weather patterns are typically felt most acutely by already disadvantaged groups, with little capacity to adapt, and who have contributed least to the causes of climate change. The capabilities approach helps us understand this injustice better.

But this does not mean that by definition any measure capable of reducing the extent or effects of climate change will therefore also enhance justice. It should only take a moment's thought regarding nuclear power to recognise that a source of low carbon energy (for example) could generate severe injustices in other respects (impacts of uranium mining, waste management etc). Such impacts can be significant both in terms of distributional justice and procedural justice (McLaren 2012a).

NETs are equally capable of raising serious justice issues. The ***energy requirements*** of NETs are one route. Indeed if direct air capture were to be powered by nuclear electricity, the increased energy demand would result in even elevated nuclear cycle impacts. Even use of additional renewable energy would not be free of justice implications (both distributional and procedural), although in this case the intergenerational injustices of either climate change or nuclear power would not arise (McLaren 2012a).

Insofar as NETs generate a ***moral hazard*** for decision makers, they raise further justice issues. If mitigation is delayed because of the perceived availability of NETs (or other geoengineering techniques), then additional climate impacts could arise, distributed across space and time. Moral hazard could perhaps be construed as a failure of recognition, in this case, of the interests that future generations might be assumed to have in a more precautionary approach.

The more tightly limited the availability of resources the more severe related distributional justice concerns tend to be. NETs are subject to potential limits in several regards. Constraints on the practical availability of ***geological storage*** are clearly plausible, and have raised concerns in some countries regarding the potential for CCS (CCC, 2011). This leads to a fundamental intergenerational justice question – should and will adequate storage space be reserved for NETs, given their unique ability to withdraw CO2 from the atmosphere, or will it be exploited (even 'squandered') on CCS to enable continued use of fossil fuels?

Constraints to the deployment of NETs also arise in the limited availability of ***sustainable bioproductivity*** for use in BECCS, biochar or other biotic techniques (see eg Woolf et al 2010). In this case the most obvious justice impacts are those which could arise if bioproductivity is diverted to NETs from other valued uses, such as food, fuel, shelter etc. There are clearly related issues of recognition for those groups and species reliant on alternative used of bioproductivity.

Limits to the deployment of NETs raise further ***procedural questions*** about who controls the technology and decides on where and how it is used, and distributional questions about the outcomes that arise. For example, one of the emerging companies seeking to bring its NET to market is openly hypothesising that it might sell negative emissions to, for example, a luxury car manufacturer, allowing the vehicles to be marketed as 'zero carbon' for a relatively small increment in price[6]. The general principle that (limited) NETs may be purchased as offsets for emissions that might be otherwise expensive or unpopular to mitigate creates distributional concerns for those groups (or countries) unable to afford NETs.

The control of geoengineering ***intellectual property*** by private organisations raises similar concerns, with particular procedural questions that arise because corporate bodies are subject to lower standards of procedural justice (in most societies) than governments and state agencies.

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6 http://www.carbonengineering.com/wp-content/uploads/2011/04/CarbonEngineering-AirCaptureFAQ.pdf

4. Discussion and further questions arising

This assessment of NETs has identified a fairly diverse collection of justice implications. Justice theory can help us understand and categorise these.

However to be useful in the assessment process, it would be helpful to be able to compare and contrast different impacts in such a way as to quantify their significance, or at least rank them. There are no obvious 'units' of justice. Distributive justice can be measured in economic terms using indicators of inequality such as the Gini coefficient, but in other respects justice is not measurable. This does not mean it is unknowable.

The questions are further complicated by the challenge of attributing responsibility for the potential justice impacts arising from changed climatic and weather patterns subsequent to a combination of climate change and geoengineering, such as first elevated and then depressed precipitation.

One option for future development may be to use a deliberative form of public engagement, ideally involving groups likely to be affected, to rate or rank different justice impacts or outcomes, and indeed also to weight them in relation to the other criteria considered. Such procedures are fraught with philosophical and methodological differences. But if assessment of NETs and other geoengineering techniques is to assist with the prioritisation of research and development, then some form of comparison is essential.

Unfortunately much of the justice literature does not address comparative justice, focusing rather on ideal models or conceptions of justice. Indeed many distributional justice theorists argue that concepts of international justice are meaningless, because there is no common cultural reference point or democratic polity within which rules of justice can be negotiated. Sen's work on a capabilities approach to justice is an honourable exception. Sen (2009) argues that social choice theory, although by definition subject to incompleteness, can help us understand the comparative justice merits of different outcomes, measured in terms of capabilities.

However, in their review of different assessments Bellamy *et al* (2012)suggest that more reflexive consideration of the methods and framing of assessments could usefully focus on making their inputs broader (through deliberative involvement of stakeholders) and their outputs more open (recognising the need for continued discussion and consideration of relative assessments from different perspectives). This would suggest that too great an effort put into quantifying justice might be counter-productive, and that the inclusion of effective participative deliberation should be the priority for improvement of the assessment.

This conclusion is also reflected in the understanding of geoengineering as a 'post-normal' science (Funtowitz and Ravetz 1992). Participation and deliberation introductes new perspectives and even new epistemologies, which can challenge the implicit (and explicit) framings and assumptions of empirical expert reviews. Ideally a participatory approach should be used to identify the criteria used in appraisal (and if only a selection of techniques is to be appraised, then also to help select the short list, so as to avoid the risks of arbitrary selection and framing (Bellamy *et al* 2012).

By this token, the role of deliberation, however, should extend beyond geoengineering appraisal into the governance of geoengineering research (and development). Deliberation is both an instrumental means to identify and evaluate justice considerations, and a practical tool which enhances the procedural justice of the process.

In the assessment, the criterion of controllability also proved difficult to measure. But considering the issue highlighted further questions of justice and governance, such as the degree to which NETs might further raise concern about the role of private corporations in climate policy. While some techniques – like tree planting or peatland rewetting - are simple and widely available, and some others (notably Cquestrate (Jenkins *et al* 2010)) are being developed in a deliberately open fashion, the majority of NETs are likely to be subject to multiple patents. Most of the technological development – especially around direct air capture - is being undertaken by venture capital funded university spin-offs in the USA. There is limited effort to claim a public share in the intellectual property arising even from publicly funded research. A better defined measure of controllability in this respect would be valuable for future assessment, and would, like justice, benefit from a participatory means of defining the criterion.

Future work might also benefit from a more rigorous and reflexive consideration of both the overall terminology used and the categorisations applied. Existing and proposed public engagement work (Pidgeon et al) might help with evaluation of the relative framing effects of terms such as negative emissions techniques (or technologies), carbon dioxide removal, geoengineering, climate engineering and climate remediation[7]. The most scientifically objective language will not necessarily be the most neutral in framing issues for the public, or indeed for the researchers involved.

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