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A directional dilemma in climate innovation

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ABSTRACT

One branch of the responsible innovation literature involves the direction of innovation: if the public or decision-makers can or should direct innovation, how should innovation be directed? This paper explicates a case study where directionality – the plurality of plausible values for innovation – is directly implicated. In this case, a key technology may require a strategy for innovation, but there are contrasting normative reasons to drive that innovation in different ways, reflecting two distinct moral values, 'effectiveness' and responsiveness to 'need'. In this case, carbon dioxide removal, these values may well conflict. Strategically deploying carbon dioxide removal in a cost-effective manner would tend to support siting it in regions where there are significant oil and gas operations. In contrast, strategically deploying carbon dioxide removal in response to need would tend to support siting it in regions where expected demand for the technology is required for development.

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Introduction

While it has been recognized that innovation can be guided by normative values (Stirling 2008a), there is insufficient discussion about how these values could conflict in practice (Papaioannou 2020a, 2020b). Consider the distinction between directing innovation (the processes driving change), the direction of innovation (the pathways orienting change) and the directionality of innovation (deciding how change should be oriented) (Stirling 2024). Roughly speaking, directing innovation concerns the various actors, structures and institutions that contribute to affecting how innovation develops. The direction of innovation includes pathways along which innovation can be directed; which processes drive innovation can influence, for instance, which subsequent options become available. Finally, the directionality of innovation responds to the various values or political processes that might influence how innovation is directed; are we concerned about a narrow form of innovative progress, or are we sensitive to a variety of values that could be relevant, troubling the notion of a single conception of progress?

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This paper focuses on the latter aspect: the directionality of innovation. When governments or decision-makers direct innovation as opposed to letting status quo structures determine its evolution, citizens might reasonably wish for this direction to reflect moral and normative considerations (Uyarra, Ribeiro, and Dale-Clough 2019). But where might these considerations come from and would adopting different values matter in practice? In terms of the directionality of innovation, are these values going to conflict? More subtly, are there cases where plausible values would conflict, lending support to a pluralistic account of directionality for innovation?

Intuitively, one might expect that innovation is unidirectional, as terms like 'progress' and 'development' suggest. Austrian economists famously argued that state intervention is self-undermining and that introducing plural values, especially in terms of social justice, will undercut innovation (Papaioannou 2024). However, this is harder to sustain when faced with challenges for which there is an overwhelming consensus to address, but for which there are a variety of ways to address it and these ways reflect distinct values.

The challenge this paper concerns itself with is climate change. This is not a minor, or cherry-picked example, but reflects a potentially existentially important threat (Kemp et al. 2022; Steel, DesRoches, and Mintz-Woo 2022; Steel, Mintz-Woo, and DesRoches 2023). Accepting, at least for the sake of argument, the common view that addressing climate change will require carbon dioxide removal (CDR) technology (Gambhir and Tavoni 2019), the question is are there plausible values that could guide innovation in CDR, and would these values conflict? If these values would conflict, this could lend support to the claim that directionality ought to reflect a plurality of values – and not be thought of as unidirectional. This also advances understanding of directionality by indicating that there are multiple values that moral theory could support that conflict in an important practical context.

The basic dilemma is as follows: a first strategy would be to use CDR to cost-effectively contribute to the mitigation of climate change, whereas a second strategy would be to deploy CDR in locations where it is most socially useful, in the sense of contributing to meeting needs and increasing development (Mintz-Woo 2022; Mintz-Woo and Lane 2021). The former would advocate deployment in whichever regions have the greatest prospects or likelihood of success (in practice, I suggest, this would be in regions where oil and gas operations are greatest, including regions in North America, northern Europe and the Middle East). The latter would advocate deployment in whichever regions have the greatest near-term demand or need for CDR (in practice, I suggest, this would be in regions where large amounts of fossil fueled infrastructure is locked in and development needs depend on that infrastructure, which especially includes regions in Asia). These strategies reflect ways innovation could be directed.[1] Furthermore, these values – cost-effectiveness and (responsiveness to) needs – are both morally important, but they support different strategies for deployment (Mintz-Woo 2023). Consequently, they also support different directions for innovation, showing practical upshots of applying concepts from innovation theories.

I believe that this dilemma could be relevant to a variety of actors, but most notably governments who are open to sharing technology with other countries, and public or private entities choosing where to fund CDR operations. Regardless of the processes driving these decisions (those 'directing innovation'), they may consciously or unconsciously align themselves with strategies reflecting different values.

In the following section ('Two values for innovation'), I introduce two specific normative values that could be relevant for innovation broadly, or climate innovation specifically: 'cost-effectiveness' and (responsiveness to) 'need'. The first has to do with maximizing the effectiveness of technology relevant to cost and the second has to do with developing technology that responds to the needs of vulnerable groups. In the next section ('A sample directional dilemma in climate innovation'), I explain how these sample values generate a directional dilemma with plausible strategies for directing innovation aimed at different geographical regions with different goals. The dilemma is meant to demonstrate that there are plausible normative values with distinct practical implications. In the next section ('Objections'), I discuss some objections and ways around this dilemma. I offer some final thoughts in the last section ('Conclusion').

Two values for innovation

Many scholars take green innovation to be a major issue for socio-technical change over the coming decades as we attempt the transition to a greener society and economy (Köhler et al. 2019; Perez 2015). In this green technology context, innovation is being rethought not only as a market-driven phenomenon, but also as a reflexive or directed process (Papaioannou 2020b).

Not only is the climate transition of interest with respect to this reflexivity, it is also important in the sense of potentially being a key hinge point for our species. Due to the speed of approaching changes in innovation, and the intended pace of transition, small changes in innovation direction could have impacts which are large and rapid. This dependence underscores the importance of responsibly guiding innovation. In turn, this justifies careful consideration of normative values, where values are axioms that guide moral judgment or policy choice and normativity involves doing the right things without reference to the ends in question (Stirling 2008a).[2]

First, a standard picture of climate mitigation is that the goal for various technologies is to cost-effectively contribute to the expected reduction of carbon dioxide (and other greenhouse gases) in the atmosphere. This goal can be supported in a variety of ways, including responding to environmental injustice: those in the global south threatened by climate change contributed disproportionately little to the problem, whereas those who potentially stand to benefit contributed disproportionately to the problem. It can also be supported by considering the estimated benefits to reducing emissions (for instance, as measured by the social cost of carbon), which are global common goods and often outweigh the benefits of emitting.

The general point is that we might want to direct scientific and technological innovation in order to cost-effectively contribute to that global goal. If following this value, one would want innovation to contribute to emissions reductions relative to the cost or effort involved in the innovation. That is, we might promote the normative value of:

> *Effectiveness*: If innovation were to be directed in terms of cost-effectiveness, then that would mean prioritizing innovation that generates the best prospects for the overall effectiveness of that science or technology relative to the costs of innovation.

In the climate context, effectiveness could refer to expected (global) mitigation potential of that scientific or technological innovation relative to cost, which one could choose to proxy as the volume of sequestered carbon per cost unit (optimizing for greatest stock) or the rate of sequestered carbon per cost unit (optimizing for greatest flow).

Note that this assumes that addressing climate change is itself normatively important. Indeed, I am assuming this, since cost-effectiveness is a value given that what is being promoted cost-effectively is itself of value. What is relevant here is that, if it is granted that it is morally important to address climate change, we need a value that reflects that not every contribution to a goal (e.g. addressing climate change) is (equally) worthy. One salient way of considering options is to rank them in terms of how cost-effective they are. This seems especially salient when it comes to technological options, where, in uncertain contexts, options with good prospects – cost-effective options in expected terms – compete with other options for research and development resources.

Second, the direction of innovation generates certain kinds of winners or losers, with different parties standing to be benefitted or harmed depending on which technologies succeed (Lenzi, Schübel, and Wallimann-Helmer 2023).[3] We might consider which innovation is demanded by particular populations, especially vulnerable populations (or, conversely, what types of innovation vulnerable populations object to). When avoidable, it is unjust to make choices that further disadvantage already vulnerable populations, and this claim is robust to a variety of theories of distributional justice.[4]

For instance, Rawls (1999) argues that justice requires fairness, which is what basic rules or structure would be agreed to in a population if they did not know which roles they would play in society. In other words, he claim that, if individuals were choosing the basic rules of society, but did not know who they would be (e.g. in terms of socioeconomic or gender or professional roles), then the rules that they would choose would be fair, rules which would constitute justice. Influentially, he argued that deviations from equal distributions were permissible, but only in cases where the least well-off individuals were better off than they would have been with equal distributions, since everyone would be concerned about being worst-off and would not agree to rules where the worst-off were further disadvantaged. This kind of normative justification could support innovation which protects the needs or demands of those already vulnerable. There are a variety of ways of thinking of needs in normative contexts (Pölzler 2021), such as these needs could be for the kinds of subsistence that gives rise to what Henry Shue (1980) calls 'basic rights'. This picture is strengthened in the innovation context by the claims of Buchanan, Cole, and Keohane (2011), who point out that, even if there are a variety of theorists with different substantive normative starting points, they might converge on justice requiring that innovation benefit those in greatest need (especially if that need is extreme).

More practically, we might also refer to the Brundtland Commission, which defined sustainability as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development 1987). This account of sustainability also supports directing innovation towards development and deployment that supports responsiveness to needs.

In short, the resultant picture foregrounds the circumstances of vulnerable populations and their demands or requirements. If following this value, one would want innovation to help address the deprivation or demands of vulnerable populations. That is, we might address the moral importance of:

> *(Responsiveness to) need*: If innovation were to be directed in order to respond to need, then that would mean prioritizing innovation that helps address the expected deprivation or demands of especially vulnerable populations.

In the climate context, regions and populations that have especially stringent needs include those which have built and locked-in fossil-intensive infrastructure, like coal power plants, which is economically or developmentally costly to wind down. Many theories of justice converge on the moral importance of nurturing development in vulnerable regions, especially in a world with highly unequal access to resources (Buchanan, Cole, and Keohane 2011). Innovation that allows these regions to, for instance, offset emissions from built and locked-in infrastructure more cheaply or easily would be hugely valuable to them.

These normative values, at least in the climate context, respond to a variety of distinctions (Mintz-Woo and Lane 2021). For instance, short-term justice considerations would be more focused on (currently) vulnerable populations, and so support developmental objectives. Long-term justice considerations would be more focused on the climatic threats which are currently mitigable, and so support increasing our long-term mitigable capacity. Another example is the ways that these values are initiated. As noted above, needs are determined more in a bottom-up, regional manner whereas cost-effectiveness tends to be called for by top-down, global planners. In the real world, these dichotomies are much less distinct than in principle, but these normative values do tend to push in contrasting directions.

The normative values of cost-effectiveness and need respond to, roughly speaking, the expected success of innovation for generally socially valuable ends and the contribution of innovation to address the specific challenges of vulnerable populations. Both of these values are plausibly of normative importance, but the following section indicates how they might conflict in practice. Despite what may appear to be a unified goal in climate innovation, different normative values may inform different directions for innovation – with diverging outcomes for socio-technical futures (Köhler et al. 2019; Papaioannou 2020a; Pel 2016).

A sample directional dilemma in climate innovation

Having distinguished between the normative values that innovation directionality might reflect [i.e. cost-effectiveness and (responsiveness to) need] in principle, it is worth considering how they might diverge in practice. The purpose of this exercise is to demonstrate, firstly, that normative values guiding innovation direction can justify distinct trajectories for some actual technologies; and, secondly, that it is worth attending to normative values in the context of directionality for innovation. In other words, not only are the variety of normative values of theoretical interest, they could make a major difference in strategically directing innovation – even within potentially pivotal contexts for the climate transition. This is especially important because one might intuit that innovation is unidirectional or one might impute one's own favored values to society or policy-makers instead of trying to grapple with the complexity of understanding a variety of values.

The context of this dilemma is the climate transition, which will involve a vast portfolio of new policies and technologies. However, one significant part of this portfolio which is sensitive to innovation would be 'carbon dioxide removal' (CDR) technology [(also known as 'negative emissions technologies' (NETs)]. Carbon dioxide removal involves removing carbon dioxide (CO_2) from the atmosphere and durably storing it in reservoirs.[5]

The reason CDR can be expected to be a significant part of the portfolio is twofold. First, it is heavily relied upon by integrated assessment models in least-cost modeling of future energy pathways (e.g. Galán-Martín et al. 2021; Minx et al. 2018). Even if we manage to reduce our emissions significant by reducing consumption and changing energy sources, it looks like CDR is needed to get to Paris Agreement targets. Moreover, very large amounts of CDR are needed according to various modeling exercises.

This is *not* to say that CDR is the best option, all things considered. In many cases, it is risky, expensive, and energy-intensive (Lenzi 2018; Shue 2018). However, the claim here is not that it is always justifiable, merely that it is reasonable to consider as part of a climate responsive portfolio (where our focus should be how to balance risks (Jebari et al. 2021), not on aiming for perfect responses) and that we ought, therefore, to consider alternatives to simply letting CDR follow market demand (Lenzi, Schübel, and Wallimann-Helmer 2023).

Second, not only is the expected market demand very significant, the capacity for CDR to meet that demand is highly sensitive to socio-technical innovation. That is because the expected quantum of CDR over the coming decades is very high – but its current capacity and maturity are very low. That suggests that whether CDR is able to play the role that it is required to in modeled pathways is not locked-in; the success of this outcome is contingent upon sufficient innovation today and in the coming decades.

Thus, I focus on this technology for both the reason that the expected demand is great (and, potentially, pivotal for the overall success of climate transition technology portfolio) and the reason that the success of CDR depends on the way that innovation occurs. In other words, I would claim that this is not an arbitrary or unimportant example, but an especially crucial one for addressing the challenge of climate change.

Before explaining the dilemma, it is worth explaining varieties of CDR. CDR involves capturing carbon from the ambient air (the capture side) and storing it, usually in geological structures (the storage side), which is the focus of the dilemma.[6] The forms of CDR most relevant in this context are Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS) (Gambhir and Tavoni 2019). These forms can share the same options on the storage side, but differ significantly on the capture side. The former, BECCS, involves burning biomass (e.g. fast-growing grasses or kelp) in order to generate energy while capturing the carbon from smokestacks. The latter, DACCS, involves running large volumes of ambient air by chemicals (called 'sorbents') which capture the carbon. BECCS risks increasing demand for cropland and, potentially, the price for certain crops. Since DACCS works on the ambient air, it can in principle be located anywhere – except it is highly energy-intensive so would ideally be located in places where large amounts of renewable energy are available. Unlike BECCS, it would not require productive land and could be located in arid or unproductive regions (e.g. deserts). BECCS, in contrast, has the potential advantage of both removing carbon from the ambient air and being an energy source.

Regardless of which CDR option is either successful or deemed most appropriate on the capture side, the storage side of fixing that carbon also reflects innovation which can be directed. In particular, innovation might be directed on the storage side by effectiveness considerations, considering which activities are likely to produce the greatest (sustainable) capacity to store carbon dioxide relative to cost. Alternatively, innovation might be directed by need-based considerations, considering which regions or communities might have the greatest expected demand, especially when development is considered.

This brings us to the directional dilemma which interests me here, one which can apply on the capture side, but is most pronounced on the storage side. The two normative values, cost-effectiveness and need, generate a dilemma because, in the real world, these directions would suggest very different strategies for CDR storage development and deployment.[7]

With respect to effectiveness, one would want to develop and deploy where there are the most cost-effective prospects for successful storage capacity. The importance of 'expectation' or 'prospects' in this context is that developing storage capacity is risky and expensive (Lane, Greig, and Garnett 2021). Large amounts of investment have to be put into understanding the geology and capacity of a potential site, with expensive tests which take time (very roughly speaking, three to ten years can be spent on determining if a potential site is suitable). In short, investment can occur on various sites, but it is very difficult to know whether a site will actually perform as expected. Due to the time lag, waiting to commit until potential sites are well-understood risks the storage capacity coming online too late to be useful for responding to near-term climate threats. In this context, to increase the likelihood that storage will actually be developed and available in a timely manner, it could be strategically justified to only develop sites that have good prospects, justifying a focus on effectiveness. This could track, inter alia, places where there is greater geological storage understanding and where human resources and skills are greatest (Lenzi, Schübel, and Wallimann-Helmer 2023). Those places tend to be where there are large extant oil and gas operations, e.g. Canada, the United States, northern Europe, and various regions in the Middle East. In these places, we can expect that innovation would be most likely to succeed where there is a lot of (literal) groundwork and skills that increase the likelihood of successful development.

With respect to needs, while there are many scenarios where demand for CDR might be relevant, here is a salient one. Suppose that emissions reduction targets are viewed as important (either because they become international legal hard constraints or because there is sufficient pressure from peer nations or from local citizenry that they are viewed effectively as political constraints).[8] In this scenario, roughly speaking, large amounts of built infrastructure (e.g. fossil fuel plants) might be incompatible with these constraints, since this kind of infrastructure is a major contributor to emissions. This presents governments with a difficult choice. On the one hand, they might have to prematurely shut down this infrastructure (infrastructure which in the case of many developing countries is newly built) to meet these constraints, thus costing the operators and economy significant resources and potentially slowing or retarding development. Note that this need not only be financial cost of those underwriting this infrastructure, it might also include energy interruptions that affect the capabilities of local populations. On the other hand, they might keep this infrastructure and the developmental benefits thereof, but fail to meet their emissions targets, undermining global action on climate change. However, if CDR technologies can be used to offset or capture the emissions generated by this infrastructure, and are available to these governments (whether on a subsidized or technological transfer basis), that allow them to avoid such a difficult choice. Of course, this is a hypothetical scenario, but scenarios of this type might well demonstrate the importance of CDR options for countries to retain development in the face of climate goals. And it is not wholly speculative; IPCC (2006, 5.20) guidance suggests that CO_2 reductions can be included in national greenhouse gas inventories, where cross-border operations have the reductions being reported in the capture side nation. This suggests that CDR operations in these developing countries could offset some of the emissions associated with extant built infrastructure. In short, the economic and developmental needs of a nation might depend on whether CDR is an option for that nation.

In order to implement the importance of needs, it could be informative to consider metrics like the ratio of expected demand to current oil and gas operations. This is because the question is not the absolute size of expected or demanded operations, but the comparison of the demands to current activity. This indicates how big CDR would need to be relative to (related, but distinct) current oil and gas operations. Work by Lane, Greig, and Garnett (2021) suggests that, given an IEA 2°C scenario, developing regions like India and China would require much more carbon storage ('injection capacity') than current oil and gas operations, suggesting that the growth in demand is very sizeable relative to these current operations. This is due to growing population and growing fossil fuel demand which could require CDR. In Europe and the United States, in comparison, the expected need for storage is only a fraction of existing oil and gas operations, suggesting more of a shift in types of operations than rapid expansion from a small base.

This evidence suggests if innovation were directed in accordance with need in developing regions, then that would prioritize development of CDR capacity in places like India and China. This is for both reasons: these regions both have massive expected growth in CDR storage relative to current oil and gas operations (meaning that they would need to grow this capacity rapidly) and have major fossil fuel intensive infrastructure, especially in the energy sector (meaning that they face the choice of prematurely shutting down infrastructure, undermining developmental objectives or risking their climate targets). Responding to developmental needs, therefore, would prioritize development and deployment of CDR in regions like these Asian ones.

This dilemma demonstrates that responding to these different normative values can generate different foci and directions for innovation in actual circumstances. This also suggests that these values generate different directions for an important contemporary innovation challenge. While it has not been discussed *how* innovation could be directed to reflect these values (which would involve, inter alia, economic, social and policy support (Papaioannou 2020b)), this case clearly illustrates that these different directions would make a material difference in a key socio-technical issue of our time.

Objections

The purpose of this project is not to demonstrate that one way of directing innovation is more justifiable than another. It is to point out that there are plausible normative values that would justify different ways of directing innovation in order to demonstrate that directing innovation is not only of theoretical interest, but practically relevant.

However, one might wonder if there are ways around this dilemma or, if it cannot be avoided, which is the 'better' value to adopt. I discuss these in turn, starting with objections to this being a genuine dilemma before turning to objections to the specified values.

A first type of objection is that the dilemma is not real (or not 'forced'). After all, it is not a *logical* truth that CDR ought to be directed on either an effective or a needs-based rationale. An objector might even ask why CDR development and deployment be directed at all? Perhaps the objector might be skeptical about directed innovation in general or perhaps the objector might be skeptical in this particular instance.

With respect to the point that these need not conflict in all cases, this is certainly true. There are many cases where addressing need dovetails with making cost-effective choices. The purpose of explicating *this* case is to demonstrate that, sometimes, they *do* conflict. As some would say, this is meant to be a constructive proof.

With respect to the question about why directionality is relevant, I believe that there are two responses or justifications for directing innovation in this instance. First, in the absence of direction, market forces have already revealed what will happen: CDR, mostly in the form of carbon capture and storage, will not be used for storage of hydrocarbons, but instead to facilitate extraction of *more* hydrocarbons, in the form of enhanced oil recovery (EOR). EOR refers to a set of methods where carbon and water are injected into oilfields to increase the pressure on crude oil, allowing it to more effectively be extracted. The reason why more carbon capture and storage, in the absence of direction, would lead to more EOR is simply that EOR is profitable: it is using sequestration to increase yields and production. CDR aimed primarily at storage and contribution to climate mitigation is a form of waste or pollution control; it is not inherently revenue-generating. So in the absence of direction (or other appropriate incentives), there is no reason for profit-seeking companies to engage in it. In other words, much of the current use of carbon storage is to *increase* oil extraction, increasing emissions in the system, as opposed to storing carbon and decreasing emissions in the system.

Second, at a more strategic level, in the absence of direction, we should expect that CDR will be insufficient or deployed in the wrong geographical regions to make a meaningful difference to either cost-effectiveness *or* need. Deploying CDR for effectiveness requires policy and institutional support, which is unlikely to arise through market forces (Lane, Greig, and Garnett 2021). In contrast, deploying CDR to tackle needs is likely to require some technology transfers or subsidies in order to make it accessible in the developing world. Once again, these require political will and strategic vision in order to occur. In the absence of these, developing countries may face the difficult choices between meeting the energy and financial needs of their populations and meeting their climate goals.

A second type of objection is that this is not a real dilemma since we might be able to develop and deploy CDR in order to promote both values. For instance, perhaps we can transfer CDR technology to some developing countries in order to meet developmental goals and simultaneously look for storage sites that have the best prospects.

While I agree that, ideally, we would be able to promote both values, I am less optimistic that, in practice, this could be done. For one thing, CDR is massively expensive so trying to fund everything (in the absence of sufficient carbon prices, say) would carry significant financial costs. For another thing, there might be associated political costs as well. Investments in storage capacity by the developed world in the developing world are risky investments where the benefits (the reductions in emissions) would accrue to those developing countries (otherwise, they would not be able to get the developmental benefits of keeping their fossil fuel intensive infrastructure operational). A risky bet which has upside to a foreign country might be politically difficult to swallow.

However, there is one way that the tension between these two options could be dissolved. Perhaps it could be possible to separate the capture and storage sides, i.e. to capture the emissions where they are most useful for promoting developmental objectives and shipping them to geological storage sites which are most cost-effective or where the marginal injection rate is highest.[9] The infrastructure for such ambitious operations is not yet present, but if it were that would be excellent in terms of potentially allowing us to address multiple values. In the absence of the resources or political will for such an option, however, the dilemma remains.

A third type of objection, assuming the dilemma remains, is that we ought to prioritize one value over another. First, we can consider cost-effectiveness. One might want to defend cost-effectiveness for a variety of reasons: (1) the relevant resources are predominantly revenue from citizens, who might want their governments to use the revenue to get the most (climate) benefits that they could with the resources; (2) climate change is a massively pressing problem and we need to limit its size and impacts before dealing with other challenges; or (3) the benefits of reducing climate change are massive, both intra- and intergenerationally, so we ought to try to promote those kinds of common goods.[10]

Second, we can consider needs. One might also want to defend an appeal to needs for a variety of reasons: (1) Rawls and other theorists point to the normative important of meeting basic needs; (2) the kinds of resource or technology transfer suggested could enhance global distributive justice; or (3) those at risk from losing access to fossil fuel intensive infrastructure already are disproportionately poor in global terms as well as less responsible for climate change in causal terms.[11]

My response here is straightforward: while some might think that one of these values is obviously more important than the other, I do not believe it is obvious how to compare them. Furthermore, I suspect that I am not alone, and that reasonable people could disagree on the relative strengths of these considerations.

Another point worth making here is epistemic. One might think that the best solution to such value conflicts is to argue about them (as philosophers would say, at the first-order or normative level): perhaps those who see a more utilitarian orientation in the cost-effectiveness value and those who see something more egalitarian or justice-oriented in the responsiveness to needs value might think that it is useful to argue about which of these theories is correct (or more justifiable). My (perhaps pessimistic) view is that such disputes are unlikely to be conclusive, on the weak inductive grounds that such disputants have argued for hundreds of years with little resolution on the overall truth of the theories. However, that does not mean that the normative project is ill-formed. Instead, I believe that the same skills are relevant to discerning the practical conclusions that are theoretically robust, in the sense of being supported by more than one theory (or principle), with more acceptance indicating more robustness (cf. Beebee 2018, for a similar view).

In this context, even if there is a conflict between two prima facie values – which I believe is true in my sample Directional Dilemma – one can glean a more constructive conclusion: two very different values support the development of CDR, making that conclusion (somewhat) theoretically robust.

However, for practical application, my view is that the determination of which of these two values should be prioritized could reasonably be a site of democratic contention. I do not think normative theory tells us that one of them is more fundamental than the other; however, normative theory allows us to diagnose their importance and the way that they conflict.

In any case, if an objector thought that one value is more important than another, that would not undermine my primary point, which is that *plausible* values that might determine the direction of innovation for a concrete and potentially important technology can point to contrasting directions, with different strategies for development and deployment. In other words, regardless of how one thinks it best to resolve the situation, this example demonstrates that directing innovation can be subject to difficult dilemmas.

Conclusion

Technological responses to climate change are and need to be part of the climate policy and action portfolio. However, these technological responses ought to be strategic and responsive to our goals and values. Innovation direction of this sort might seem to be straightforward, but this paper illustrates how, in a concrete circumstance, it can be complicated. In particular, how innovation is directed ought to be explicitly aligned with particular values – and this matters because different values may yield different directions for innovation. This opens or helps justify exploring the space for a plurality of values in directionality for innovation.

The overall intention of introducing this prototypical directional dilemma for climate innovation is to demonstrate that selecting explicit normative values can matter. It is not only important for us to recognize this in a conceptual or theoretical manner, although that is important. It also matters materially and practically, even in technological contexts which are massively consequential, such as with climate change.

Notes

1. Note that one feature of CDR is that the location of innovation and the location of application cannot easily be decoupled. Since storage is site-specific, the innovation processes are largely dependent on the (geophysical) features of the storage location. As Malhotra and Schmidt (2020) point out, this highly ‘customized’ characteristic of CDR means that innovation is more challenging than with mass-produced low-carbon technologies. Also note that the physical location of CDR is important, since the IPCC National Greenhouse Gas Inventory guidelines (IPCC 2006, which was the first National Greenhouse Gas Inventory to discuss CDR) indicate that, for cross-border operations, the location where the capture occurs is where the relevant emissions credits are inventoried (5.20).
2. Many normative discussions in moral philosophy operate in terms of consequentialism, deontology and virtue ethics. I purposefully intend to avoid these accounts, since they tend to silo audiences. My hope is that the values I consider here are, at least in principle, of interest to people regardless of which of these first-order normative theories they tend to endorse.
3. Indeed, climate change itself might involve a variety of winners or losers, with different associated demands of justice (Mintz-Woo and Leroux 2021).
4. For an introduction to distributional justice in a broader justice landscape, cf. Zimm et al. (2024).

5. I focus on geological reservoirs, since these are usually taken to be the most understood and easiest to scale storage technological options (little to no innovation is required in order to store carbon in trees and other living matter). Other potential reservoirs are terrestrial, e.g. trees or grasses, and ocean, especially deep ocean sediment. These are plausibly less sensitive to innovation directionality, so are less effective illustrations of the points being made here.
6. As mentioned above, CDR actually covers a wide variety of options, and not all of them match this schema. For instance, afforestation and reforestation (tree planting) is sometimes thought of as CDR even though the carbon is not sequestered by human processes. My analysis focuses on BECCS and DACCS, since these are also key technologies but are more sensitive to innovation than is the case with afforestation and reforestation.
7. This dilemma arises assuming that innovation can be directed to a limited extent or with finite resources. If there are infinite resources, then both of these normative values could be promoted; obviously, in the real world, that is never the case.
8. The mechanisms whereby citizens affect transitions or require certain kinds of climate policy are beyond the scope of this paper, but are complex and multifaceted (Köhler et al. 2019).
9. Note that this distribution of burdens is compatible with the guidance provided by IPCC (2006).
10. One might also want to go on the offensive against directing innovation on the basis of needs in this context: developing countries only face these hard choices because they invested in fossil fuel intensive infrastructure. They shouldn't have done that, and the financial benefits they expected from this infrastructure are unjust or unjustified.
11. One might also want to go on the offensive against directing innovation on an effectiveness basis in this context: the fact that some countries could have better prospects for storage development and deployment reflects historical inequities (e.g. in oil and gas development and human capital development) which are undeserved and not a good basis for current decision-making.

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