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"Fixing" Climate Change by Mortgaging the Future: Negative Emissions, Spatiotemporal Fixes, and the Political Economy of Delay

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Abstract: Models suggest that climate change mitigation now depends on negative emissions, i.e. the large-scale removal of carbon dioxide from the atmosphere. This assumption has been criticised in the climate policy literature for being unfeasible and unjust. This article asks how critical scholars can make sense of, and contribute to these debates. It suggests that negative emissions can be conceived of as a spatiotemporal fix that promises to defer the devaluation of fixed capital. But the negative emissions example also challenges us to broaden our conception of how the socioecological contradictions of capitalism can be "fixed". I outline three ways in which it does this by highlighting the significance of a predominantly temporal fix, the role of hegemonic, sociopolitical interventions involving multiple actors, and the possibility of safeguarding existing production processes. I conclude that spatiotemporal fixes to climate change should be seen as part of a wider political economy of delay in devaluing carbon-intensive accumulation processes.

Keywords: negative emissions, spatiotemporal fix, climate change mitigation, carbon dioxide removal, fossil capital, climate modelling

Introduction

Projections of how the world can avoid dangerous climate change are increasingly resembling science fiction. The IPCC's mitigation scenarios, for example, have almost completely come to rely on so-called "negative emissions" in order to meet the 2°C/1.5°C temperature targets of the Paris Agreement (Peters and Geden 2017; Schleussner et al. 2016; van Vuuren et al. 2017). This reflects the idea that climate change can no longer be addressed merely by reducing emissions, but that it will require the removal of vast amounts of carbon from the atmosphere as well. In most scenarios, between 400 and 1000 Gt CO_2 needs to be removed over the course of the 21st century (Minx et al. 2018), or about 20–50% of all greenhouse gases emitted over the past 200 years or so. The technology most favoured by models to deliver these negative emissions is called Bioenergy with Carbon Capture and Storage (BECCS) (Smith et al. 2016), a so far commercially unproven proposal to combine the cultivation of bioenergy crops (which, like all plants, sequester carbon from the atmosphere through photosynthesis) with their combustion for energy generation, and the capturing and long-term geological storage of the resulting CO_2 emissions.

The assumption that technologies like BECCS will deliver large-scale negative emissions is controversial, not in the least because implementing BECCS on the scale assumed by models would require a land area in the order of 7–25% of the planet's total agricultural land (Smith et al. 2016; Williamson 2016). This would inevitably lead to conflicts over land use, food production and biodiversity conservation (Anderson and Peters 2016; Buck 2018; Heck et al. 2018), with knock-on effects for food prices. If past experiences with carbon forestry and bioenergy projects are anything to go by, this burden would mostly fall on poor and vulnerable communities (Buck 2016), primarily in the global South, where land is cheapest and dissenting voices most easily marginalised (Fairhead et al. 2012; Leach and Scoones 2015). Implementing BECCS would also significantly increase demands for freshwater and fertiliser use (Minx et al. 2018; Smith and Torn 2013), and would need to resolve current uncertainties pertaining to the safe and long-term underground storage of carbon (Fuss et al. 2014), the level of emissions associated with land-use change (Harper et al. 2018), the economics of rapidly scaling up an as yet commercially unviable technology (Smith et al. 2016; Turner et al. 2018), and institutional, social and political barriers (Fuss et al. 2014; Meadowcroft 2013). Some scientists have argued that these concerns could largely be alleviated by relying on a "portfolio" of different technologies (Minx et al. 2018). Others however have concluded that the massive risks and uncertainties involved imply that proposed negative emission technologies (NETs) have "limited realistic potential" (EASAC 2018:1) and that the political mitigation agenda should therefore "proceed on the premise that they will not work at scale" (Anderson and Peters 2016:183).

Yet somehow, despite their apparent detachment from reality, there they are, at the centre of the IPCC's emission reduction scenarios and implicitly underpinning the stated ambition of governments to keep global warming to the targets agreed in Paris (Peters and Geden 2017; van Vuuren et al. 2017). A major concern is that the negative emissions concept is already playing a political role. It could provide a rationale to delay expensive, drastic emission cuts in the present, on the basis of a hypothetical option to remove excess carbon from the atmosphere in the second half of the 21st century (Anderson and Peters 2016; Beck and Mahony 2017). From an economic perspective indeed, negative emissions appear to be rather attractive, since they "allow higher total carbon emissions, and/or a later peak in emissions" (Gough and Vaughan 2015:2) and thereby seemingly enable a more gradual transition to a low-carbon economy (Meadowcroft 2013).

How should critical scholars make sense of these debates? In this article I want to argue that critical geographers have an important role laid out for them in providing a theoretically grounded critique of the political economy of negative emissions, as it is currently unfolding. The dynamics and contradictions of relying on carbon dioxide removal are well worth exploring in detail, and I want to suggest that we can identify important parallels with the various other ways in which capital is seeking to "solve" environmental crises. In embarking on this task, it is useful to distinguish between (1) negative emissions as material practice, as in the implementation of specific NETs, and (2) the discursive construction of negative emissions as a modelled, future solution to climate change. Since none of the proposed NETs currently exist at any meaningful scale, and are perhaps unlikely to ever materialise, the latter focus is for now the more pertinent one. As I elaborate below, the promise of future negative emissions already has concrete political economic implications in the present, and therefore warrants much closer scrutiny. The way these processes unfold in turn holds lessons for how we theorise the relation between capital and environmental change more generally.

Specifically, I propose that analysing the work that "promised" negative emissions (cf. Markusson et al. 2017) perform for, in this case, fossil capital helps further efforts to ecologise Harvey's (2001, 2007) notion of the spatiotemporal fix, as articulated in Ekers and Prudham's (2015, 2017, 2018) recent work on the socioecological fix (see also Castree 2008; McCarthy 2015; Surprise 2018). Most directly perhaps, the political economy of negative emissions puts in focus the underappreciated importance of the temporal dimensions of such fixes; that is, the various opportunities that exist to manage the *rate* at which socioeconomic upheaval occurs, and the way in which constructed visions of the future help defer crisis in the present. But the negative emissions example also highlights some of the ways in which fixes operate through capitalism's "other moments" (Harvey 2012), outside of the sphere of production or indeed the circuit of capital accumulation itself. I here particularly focus on the role that integrated assessment models (IAMs) have played in the emergence of the negative emissions concept. IAMs provide the foundation for the IPCC's mitigation scenarios and, as scientific exercises, are formally independent of corporate interests. Yet the economic assumptions that underpin these models closely align them with the logics of capital accumulation, making IAMs a key factor in explaining how the negative emissions concept appears to be emerging as a fix for the fossil fuel industry. IAMs in this way exemplify the (hegemonic) work that takes place outside of the circuit of capital accumulation to safeguard dominant interests and resolve crisis. Drawing out the implications of this, I argue, allows us to reframe the spatiotemporal fix concept as one component of, in this case, the wider political economy of delay in mitigating climate change.

In the next section I briefly summarise recent theorisations of an ecologised spatiotemporal fix, and then set out three interconnected ways in which capitalist reactions to climate change help advance these debates. I then apply this framework to a discussion of the negative emissions concept, drawing on a literature review and a recent example from the fossil fuel industry. The conclusion summarises the argument and elaborates the value of a broadened understanding of the ways in which capitalism seeks to "fix" its environmental crises.

Theorising a Spatiotemporal Fix to Climate Change

Critical scholars have long had an interest in the relation between capitalism and environmental change. In an effort to elucidate the internal ecological contradictions of capitalism as well as attempts to resolve them, some have turned to

David Harvey's notion of the spatiotemporal fix. Capital, Harvey (2007) famously argues, has an inherent drive to displace its internal contradictions by way of the processes of uneven geographical development. Tendencies towards crises of overaccumulation can be temporarily "fixed" by finding new outlets for surplus capital in geographical expansion and the production of new spaces of accumulation. The double meaning of "fixing" is important here, in that the temporary displacement and deferral of capitalist contradictions, through the production of space, necessarily relies on the creation of fixed capital; that is, capital "fixed" in space in the form of infrastructure, the built environment, machinery, etc. This however creates its own contradictions, because the inertia of fixed capital hampers capital's mobility, putting it at risk of devaluation in future crises (Harvey 2001, 2007).

The most elaborate case for an ecological reworking of these arguments comes from a special issue and two recent papers by Ekers and Prudham (2015, 2017, 2018), where they stress how efforts to temporarily offset the crisis tendencies of capital accumulation take place "through investments in landscapes that are simultaneously and always conjoined productions of space and nature" (Ekers and Prudham 2017:1371). The geographical expansion and spatial restructuring of production processes, Ekers and Prudham argue, is necessarily a socioecological process, a reworking of the metabolic relation with nature, even if it isn't always recognised as such. This means that the formation of fixed capital comes "in the guise of various socionatures [and] must be understood as an economic and extraeconomic, material and ideological process with valences that fuse capital accumulation, socioenvironmental change, and the conditions and experiences of everyday life" (Ekers and Prudham 2018:19). In tack with a by now vast literature on the commodification, marketisation and/or neoliberalisation of nature (Bigger et al. 2018; Castree 2010; Fairhead et al. 2012), Ekers and Prudham (2015) agree that such "socioecological fixes" increasingly take the form of stated attempts to render capitalism more sustainable; that is, through the expansion of markets for all kinds of "green" or "renewable" goods and services. This is arguably one of the more common ways in which an ecologised conceptualisation of the spatiotemporal fix has been deployed in the wider literature (e.g. Bryant et al. 2015; Bumpus and Liverman 2008; Holgerson and Malm 2015; McCarthy 2015), though Ekers and Prudham's argument shows that it need not be limited to that.

In much of this work, environmental crisis is conceived of as internal to the dynamics of capitalism, a socioecological contradiction that becomes expressed in political economic terms. Ekers and Prudham (2017) for example situate their argument within James O'Connor's so-called "second contradiction of capital", as does Castree (2008) in his disambiguation of different possible "environmental fixes". Briefly put, O'Connor (1997) argues that capitalism has a tendency to degrade and/or exhaust its own conditions of production, creating all sorts of socioecological problems that become barriers to further capital accumulation. The spatiotemporal fix in this way not only serves as a potential "solution" to overaccumulation, but also to the "underproduction" of nature. The continuous capitalist drive to seek out new resources and geographical spaces, in other words, is in part the logical and economically necessary result of capital's own tendency to deplete and pollute them.

In observing that "the warming of the atmosphere will inevitably destroy people, places, and profits, not to speak of other species life", O'Connor (1997:166) himself saw climate change as one example of this second contradiction of capitalism. Many scholars have since followed him in this, including Ekers and Prudham (2015). In the remainder of this section I want to offer some thoughts on the conceptualisation of climate change that emerges from this, and more specifically on what it implies for how we think of the various capitalist fixes to it. I here raise three main points that I then substantiate in more detail in the discussion on negative emissions below. Throughout this text I mostly focus on "capital" in general to convey the idea that the fossil fuel-dependent regime of accumulation continues to be dominant, but this of course in no way implies a homogeneity of capitalist interests and attitudes towards climate change. Different sectors and economic interests will be, and already are affected differently. While the fossil fuel industry arguably stand to lose most, examples from the renewable energy sector or the emergence of "catastrophe bonds" (Johnson 2013) make clear that for an increasing number of capitalist actors, climate change is an economic opportunity more than anything else.

First, it is well established that environmental crises do not necessarily lead to economic crisis directly, but that they are mediated by social and political processes. Indeed, O'Connor (1997:164–165) acknowledges as much by stressing that "the state places itself (or mediates) between capital and nature, with the immediate result that the conditions of capitalist production are politicized". The relation between the environmental conditions of production and capitalist social relations therefore poses "sociopolitical and ideological questions first, and socioeconomic questions only secondarily" (1997:165). We can thus identify a number of different, if closely intertwined processes through which climate change leads to a crisis for capital, and therewith to the need for a spatiotemporal fix. Most obviously perhaps is the fact that emission-induced changes to biophysical and atmospheric conditions will (and to some degree already do) directly impact agricultural yields and general productivity, damage infrastructure, increase insurance costs, etc. As Malm (2017) rightly points out, however, it will be a long time still before capital is affected by these effects in any systemic way, and climate change will have wreaked disaster and devastation on those most vulnerable long before it does. Particularly from the perspective of fossil fuel capital, the arguably more immediate problem posed by climate change is the social and political reactions against it, i.e. its indirect effects as a consequence of the actions of environmental movements and the various efforts by authorities to put a price on carbon, subsidise renewables, etc., a set of processes that together threaten the devaluation of existing fixed fossil fuel capital.

That climate change as a crisis of/for capital in this way takes on multiple forms is commonly recognised by scholars. McCarthy (2015) for example analyses large-scale renewable energy development as socioecological fix and notes how the barriers to profitability emerge not just from rising temperatures but from growing activism and, following Wainwright and Mann (2013), a looming crisis of legitimacy. Similarly, Surprise (2018) discusses stratospheric aerosol injection—a proposed geoengineering strategy—as a potential "preemptive" fix to a climate crisis defined in both biophysical and political economic terms. Despite this, such accounts then commonly go on to conflate these multiple expressions of the climate crisis when outlining the capitalist fixes it spurs. Yet the differentiated dynamics of the crisis are of conceivable importance in shaping the exact reactions of capital, and I therefore want to suggest that they are worth distinguishing between. Note that this need not involve resurrecting a dualism between society and nature—evidently the biophysical and political economic do thoroughly intersect, especially in the case of climate change. The two however are not the same, and conflating them is unhelpful for understanding the various forms that capitalist crises take (see also Malm 2017). How different interests respond to climate change will depend in part on what form the crisis takes for them; that is, on the *extent* to which it is mediated by social and political processes.

In this sense it matters quite a lot if the conditions of production are undermined directly by rising sea levels, by increased insurance costs as a result of more extreme weather events, or by political demands for radical mitigation. It is hard to argue with rising sea levels, hence companies confronted by this will in a very immediate sense need to spatially restructure production processes. But where the crisis takes a more overt political form, as it does with environmental regulation or a crisis of legitimacy, the options are significantly broader. It *is* possible to argue with governments, hence to seek and fix the "problem" of regulation without necessarily providing fixes to the underlying biophysical dimensions of climate change. The various efforts by fossil fuel companies to lobby governments, weaken regulation, discredit science and fund denialist media campaigns (Klein 2014; Oreskes and Conway 2011) are in this sense just at one extreme of the range of possible forms that capitalist fixes to climate change can take. Indeed, to the extent that the crisis plays out primarily in the sociopolitical sphere, it is arguably sufficient to be *perceived* as addressing the underlying problem, without this necessarily needing to be reflected in reality (cf. Buck 2012; Markusson et al. 2017). The documented efforts of companies "greenwashing" their image can in this sense reasonably be conceived of as an attempt to fix a crisis of legitimacy. While this is a step away from Harvey's original ruminations on the spatiotemporal fix, I would argue that it is the logical extension of his argument to a wider range of space/nature and time reorganisations. As Ekers and Prudham (2018) also note, any fix is simultaneously an ideological and hegemonic project. The inevitably multiple and mediated character of environmental crisis in this sense points to the need for an appreciation of spatiotemporal fixes as not just the organisation of absolute space, but also as the production and restructuring of social space and its various (political) representations (cf. Harvey 2006; Lefebvre 1991).

Second, and closely related to the point above, even if we agree that environmental crisis is internal to capitalism, it does not necessarily follow that the crisis will primarily manifest itself in the sphere of production, or that this is where efforts to fix it need to be situated. For understandable reasons, scholars commonly focus on capital's pursuit of new or expanded forms of value production in response to crisis, as witnessed for example in discussions on market environmentalism (Brockington and Duffy 2010; Castree 2008; Dempsey and Chiu Suarez 2016; Lohmann 2011). Harvey's (2007) account however allows for a broader conceptualisation than that. Surprise's (2018) discussion of stratospheric aerosol injection (SAI) is illustrative here in that it conceives of a spatiotemporal fix that, were it ever to materialise, would occur at least in part outside of the circuit of capital accumulation. Increasingly, Surprise shows, private capital is funding the research and development of SAI as a potential "safety valve" measure to help cool the planet, or at least slow down the rate at which it is warming. Yet it is scientists and/or governments that would ultimately need to do the "fixing", and they would do so on a planetary rather than on a company scale, by intervening directly in the (atmospheric) conditions of production. There are in this process little or no new forms of accumulation involved, but there are potentially massive gains to be had for existing forms of value generation. As Surprise (2018:13) notes, the implementation of SAI "could enable a less abrupt devaluation of fossil fuel infrastructure and assets … and thus allow existing fossil fuel infrastructure to continue (however temporarily) generating, circulating, and realizing value". I think there are two important take-aways from this example that I elaborate in the discussion on negative emissions below. First, Surprise's analysis suggests that spatiotemporal fixes need not operate through the "normal" circuits of capital accumulation, but that they could equally do so through the wider array of institutions and social actors that are co-constitutive of capitalist hegemony—its superstructure if you will. Second, the SAI example demonstrates that capitalist fixes to environmental crisis can occur, at least in theory, by preventing the devaluation of *existing forms of value creation* as much as through geographical expansion or the emergence of novel forms of accumulation.

Finally, climate change confronts us with the important temporal dimensions of the spatiotemporal fix. While Harvey (2007) demonstrates that fixing the contradictions of capital accumulation consists of the combined geographical displacement and temporal deferral of those contradictions, most scholars have primarily focused on the former, with crisis deferral often treated as the logical consequence of spatial restructuring, rather than a strategy in itself. Indeed, many authors, including Harvey (2001), commonly refer to the "spatial fix", dropping the temporal reference and therewith at least flagging a primary concern with spatial dynamics. There are however clear reasons for giving the temporal components of the fix closer attention. As Ekers and Prudham (2018) point out, fixed capital investments come with their own temporal dynamics in that they tend to have a long turnover time, while simultaneously also decreasing the turnover time of circulating commodity capital. While this can temporarily take the heat out of an overaccumulation crisis, it also exposes those investments to the risk of devaluation. No less important, I propose, are the opportunities for a temporal fix outside of the circuit of capital accumulation, not just as a way to decrease the turnover time of capital but to mitigate *the rate of fixed capital devaluation* itself. Surprise (2018:12) again provides a useful example. SAI, he notes, serves as a fix to the "temporal disjuncture" that capital confronts between the biophysical and the financial/economic dimensions of climate change. This crisis can be displaced in time "through the production of atmospheric space"; that is, by the deployment of geoengineering techniques that "intentionally manage" the rate of climatic change. The devaluation of fixed fossil fuel capital is in this account potentially alleviated by intervening directly in atmospheric conditions.

While I think Surprise's (2018) account is important, I want to suggest that we can push the idea further. If we acknowledge that climate change as a crisis of/for capital comes in more direct biophysical and more mediated regulatory/socio-political forms, then there are multiple levels at which (temporal) fixes can operate. Concretely, there are at least two different ways in which the devaluation of fixed fossil fuel capital can be deferred or slowed down. The first, and the one Surprise (2018) is concerned with, consists of (geoengineered) attempts to slow down the rate at which the planet is warming. The second is to intervene instead at the level of regulation; that is, of the political mediation of climate change, in an effort to manage the rate of *decarbonisation.* Again, the indefatigable efforts by fossil fuel interests to undermine or weaken possible climate policy are obvious examples here and need no elaboration, though temporal deferral operates in more subtle ways as well. As I have argued elsewhere, market mechanisms such as carbon trading in many ways fulfil the same function (Carton 2016, 2017). While this temporarily fixes the regulatory problem, it does little to solve the underlying challenge posed by increasing greenhouse gas emissions. However, if, as I would argue, climate change currently presents capital with a social-political crisis, and not yet (primarily) with a direct biophysical one, then this need not be of immediate concern. There are from this perspective plenty of opportunities for capital to try and "fix" climate change *concerns* while simultaneously perpetuating the problems posed by a rapidly warming planet. Evidently, this poses enormous challenges for those of us concerned with climate change as more than just a crisis for capital. Recent debates on negative emissions illustrate these dynamics, and it is to this discussion that I now turn.

Going Into Carbon Debt: Negative Emissions as Spatiotemporal Fix

Multiple Crises, Multiple Fixes: Fixing Climate Concerns Without Mitigating Climate Change

Climate change is a problem of cumulative greenhouse gas emissions, amassing in the atmosphere at a rate that exceeds their reabsorption and/or degradation through geological, biological and chemical processes. Within certain confidence intervals, a given accumulation of emissions correlates to a given level of future warming. To predict how much CO_2 can still be emitted before a certain temperature limit is reached, scientists often make use of so-called "carbon budgets". To keep warming below 1.5°C for example, the remaining carbon budget over the period 2016–2100 is estimated at –175 to 475 $GtCO_2$ (Rogelj et al. 2018). This corresponds to at most 13 years of current annual emissions, and stands in stark contrast to the 2900 $GtCO_2$ or so that are embedded in known fossil fuel reserves (McGlade and Ekins 2015). Logically then, the vast majority of reserves appear "unburnable" (cf. Carbon Tracker Initiative 2012) if climate goals are to be met. McGlade and Ekins (2015:187) for example estimate that "a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused" in order to meet the 2°C target, let alone the 1.5°C one.

This essentially means that vast amounts of fossil fuel assets risk becoming stranded on the road to climate change mitigation (Surprise 2018). This would entail a fixed capital devaluation of epic proportions and can rightly be seen as the capitalist crisis that commentators have described it as. But note that this crisis *for capital* does not follow directly from the biophysical conditions associated with a changing climate. It is a crisis that first and foremost exists in socially mediated form, meaning that the direct "threat" comes from increasing social demands for mitigation and the political drive towards regulation rather than from increasing temperatures or rising sea levels. This is directly reflected in the way fossil fuel companies articulate the problem. Shell, for example, one of the world's largest oil and gas companies, in its 2017 annual report for the first time acknowledged that climate change poses a risk to its operations (Shell 2018a). Yet it nowhere mentions actual climate change as a problem; rather, it is "rising climate change *concerns*" that are the issue, because they "have led and could lead to additional legal and/or regulatory measures which could result in project delays or cancellations, a decrease in demand for fossil fuels, potential litigation and additional compliance obligations" (Shell 2018a:13). As I discussed above, it is well worth taking seriously this distinction between the social articulation of climate change and its biophysical basis, given how it speaks directly to the different fixes that are, and can be pursued. Among others it suggests that one does not necessarily need to mitigate climate change at all in order to fix (i.e. displace and defer) the crisis of legitimacy that it produces.

The negative emissions concept illustrates this. Negative emissions take the carbon budget concept to its inevitable conclusion, by accounting not just for carbon "expenditures" (i.e. emissions), but also a range of proposed carbon "incomes". This idea takes its inspiration from a number of biological (e.g. photosynthesis) and chemical (e.g. weathering of rocks) processes that remove CO_2 from the atmosphere, and imagines that these could be deployed at a massive scale in order to make a limited carbon budget stretch further. The aforementioned BECCS is one example of such negative emissions technology (NET), but there are many others, including afforestation, soil carbon sequestration, direct air capture, enhanced weathering of rocks, etc. Because of the scale at which these technologies would need to be implemented, and the fact that their commercial and technological viability is in many cases unknown, models assume that NETs will only be operational at scale in the second half of the century. Essentially, this means that the negative emissions concept acts as a debt mechanism: the carbon budget for the first half of the 21st century can be extended on the basis of the assumption that large amounts of carbon will be removed in the second half (Geden 2016, 2018; Parson 2017). As Geden (2018:381) puts it, integrated assessment modellers have in this way "adopted the standard approach pursued by most governments instead of disciplining them: run huge deficits, betting on payback by future generations".

The significant, negative social and environmental consequences that one could expect with the actual implementation of some NETs have already been alluded to in the introduction. The negative emissions *concept*—as modelled in IAMs—however has concrete implications already now (Beck and Mahony 2018). By enabling a pathway to the 2°C target in the face of a tight carbon budget, it helps preserve a sense of normality in climate policy, fostering the notion that current policy commitments are appropriate and sufficient, that ambitious climate targets are still within reach and that governments are putting in place adequate measures to achieve them (Anderson and Peters 2016; Beck and Mahony 2017; Geden 2016; Pielke 2018). As Larkin et al. (2018:692) note, "IAM outputs risk delivering overly optimistic, unrealistic and potentially flawed message about future change [in which] challenging, but incremental energy policy is sufficient to deliver on the Paris Agreement". The negative emissions concept in this way helps in "masking political inaction" (Geden 2016:794) and serves to legitimise mainstream climate policy in the face of 30 years of institutionalised delay. It does this without any NETs actually being implemented, indeed, irrespective of whether they will ever be implemented at all, but merely on the basis of its promised future arrival by climate models (Geden 2016; see also Markusson et al. 2017). Despite their so-far immaterial form, negative emissions help to pre-empt a crisis of political legitimacy by seemingly answering calls for ambitious climate action, all the while deferring the most difficult questions to the future.

When Models Go Travelling: The Political Economy of an Anticipated Future

While these are important points, I believe critical analysis can and should do more than illuminate the work that negative emissions do in narrowly political terms. There is a clear need here to scrutinise the full implications for the political economy of climate change mitigation, by asking whose interests are served by a scientific focus on negative emissions, and what work the concept performs within a capitalist system that is still fundamentally dependent on fossil fuel extraction, production and combustion. Climate policy does not express itself in a social and economic vacuum, but comes with vested interests, power relations, allegiances and assumptions. Any "policy-performative" science—of which the IPCC is an example (Beck and Mahony 2018)—inevitably inserts itself in these dynamics. In this sense it is not just weak climate policy that is being maintained by the invocation of negative emissions, but crucially also the carbon-intensive economic processes that it is supposed to regulate. What is being sustained and legitimised in this broader sense is a regime of capital accumulation centred around the continued use of fossil fuels, at the precise moment when it is facing a legitimacy crisis due to increasing social concerns for climate change.

Consider again the example of Shell. In spring 2018, the company published a new energy transition scenario that it calls "Sky", in which it presents its most ambitious vision of a low-carbon future. Sky raises the bar compared with two earlier scenarios, which were not compatible with the Paris Agreement. Shell points out that these scenarios are not predictions, but that they are meant to "challenge executives' perspectives on the future business environment" (Shell 2018c:68). They are also used in developing the company's own energy transition strategy. In this Sky scenario, Shell envisions a future in which warming is kept well below 2°C while still being able to "thrive" as an energy company (Evans 2018). It assumes that demand for coal has already peaked, that oil demand will peak around 2025, and demand for gas around 2040. The fossil fuel demand curves in this scenario however drop gradually, so that oil demand in 2050 still equals about 78m barrels (about 85% of today's demand), and 50–60m barrels by 2070 (Ward 2018). The result is that in Shell's vision of the world in 2070, total emissions from fossil fuels still equal 16.5 $GtCO_2$, or slightly less than half of those today. How can this be compatible with keeping temperature increases to well below 2°C? The answer, in large part, is negative emissions. Shell assumes that by 2050, carbon dioxide removal will be rapidly scaling up, and that by 2070 the world will have reached "net-zero emissions" through the large-scale deployment of carbon capture and storage (CCS) and NETs, primarily BECCS. In the Sky scenario, those remaining 16.5 $GtCO_2$ are entirely offset by the capture and sequestration of emissions in direct CCS plants, by "the use of carbon for materials", and "by captured CO2 from an expanded bioenergy system" (Shell 2018c:61). According to the company, this would need to involve the use of 10,000 large CCS installations (Shell 2018c). To reduce emissions even further would then require additional measures. In reaction to the recent 1.5°C IPCC (2018) report, Shell's CEO, Ben van Beurden, announced what strategies the company foresaw to stay within the 1.5°C target: "What we think can be done," he said, "is massive reforestation. Think of another Brazil in terms of rainforest" (Vaughan 2018).

From a political economy perspective, the inclusion of negative emissions in this scenario fulfils a clear purpose. It allows any real efforts to be deferred until after 2030 and therefore allows Shell to gradually diversify/alter its business model despite the urgency of climate change. Negative emissions in this way invoke a future in which ambitious mitigation appears consistent with the argument that "[f]rom 2018 to around 2030 ... the potential for dramatic short-term change in the energy system is limited, given the installed base of capital across the economy and available technologies" (Shell 2018c:23). In parallel with any other spatiotemporal fix then, negative emissions help address the threat of a sudden devaluation of existing fossil fuel assets. Indeed, negative emissions would allow *all* of Shell's existing fossil fuel reserves to be utilised. The company's 2018 energy transition report, which sets out a concrete transition strategy and which is underpinned by the Sky scenario, notes that Shell will be able to produce "80% of our current proved oil and gas reserves ... by 2030 and only around 20% after that time" (Shell 2018b:37). There is, as the company clarifies, very little risk of any stranded assets even in its most ambitious transition scenario (Shell 2018b). In highlighting this, Shell effectively addresses the "climate concern" risk it identifies in its 2017 annual report and puts its shareholders at ease. A NETs-dependent climate scenario, in other words, provides Shell with a (temporary) solution to the financial risk of increased demands for climate action, and it does so without necessitating any substantial restructuring of production processes in the near-term. The fix exists entirely in a scientifically grounded refutation of the idea that fossil fuel use needs to be decreased in the short term in order to mitigate climate change, which one could assume Shell and other fossil fuel majors will be eager to highlight in response to future political challenges. The only space that is produced or restructured in this effort, is an abstract, hypothetical, and future one. It is a largely discursive fix in response to a socio-political crisis.

As an analysis by Carbon Brief points out, Shell's scenario is rather optimistic about future energy demand, but otherwise generally consistent with state-of-the-art scenario modelling, where the use of negative emissions is ubiquitous. In fact, Shell's scenario is on the lower end of assumptions of how much negative emissions will be deployed by the end of the century (Evans 2018). Here, then, is an example of a fossil fuel company that, using an entirely accurate application of the kind of modelling that underpins IPCC scenarios, is able to justify the full extraction of its reserves on the basis of a scientifically accepted, though highly improbable assumption that future technologies will be able to compensate for this. The inclusion of NETs in emission scenarios, in other words, is already providing the fossil fuel industry with valuable services. How is this possible? How did IAM outcomes come to be so compatible with the interests of the fossil fuel industry? This is a conundrum that cannot be understood merely by focusing on the "fixing" that occurs within the immediate circuit of capital accumulation. It also requires scrutiny of the scientific and political work that enables such fixes to occur, work that is therefore co-constitutive of efforts to prevent widespread capital devaluation.

In our case, this includes attention to the logics and mechanisms of integrated assessment modelling itself. Now, scientific knowledge production is of course an inherently political exercise (Turnhout 2018). As Turnhout et al. (2014:583) note, "dominant political discourses compel scientists to create assessments that work within these discourses", which involves the articulation of problems that are legible to, and the proposal of solutions compatible with, dominant political and economic logics. The production of models is no different and if anything merely goes further in shrouding ideological assumptions behind seemingly technical and objective processes (Beck and Mahony 2018; Demeritt 2001; Mahony and Hulme 2018). As it turns out, the specific assumptions that underpin IAMs are highly consequential for the kind of scenarios that are produced. Most importantly perhaps, IAMs, as the IPCC (2014:422) itself points out, "tend towards normative, economics-focused descriptions of the future". They are optimisation models that focus on "minimiz[ing] the aggregate economic costs of achieving mitigation outcomes, unless they are specifically constrained to behave otherwise" (IPCC).

Until the IPCC's (2007) fourth assessment report, this prioritisation of cost-efficient mitigation meant that very few of the scenarios produced by IAMs were compatible with keeping temperatures below 2°C, let alone 1.5°C (Tavoni and Socolow 2013; van Vuuren et al. 2007). The stabilisation of greenhouse gas concentrations at low levels was largely deemed to be economically unfeasible. When policy makers agreed on 2°C as the political target and subsequently asked modellers to come up with scenarios that would be compatible with this, this posed a substantial challenge (Parson 2017; Tavoni and Socolow 2013). The only way in which the modelling community could meet this request *within their cost-efficiency framework* was by including hypothetical NETs, such as BECCS (Dooley et al.

2018). Because IAMs apply a discount rate (typically 5%) to future costs (van Vuuren et al. 2017); because negative emissions de facto allow the short-term extension of the carbon budget; and because assessing the costs of any technology implemented half a century from now is necessarily speculative, NETs have a distinct economic advantage over more immediate emission reduction strategies (Minx et al. 2018). The inclusion of negative emissions in IAMs, in other words, was the direct result of a cost-minimisation exercise (Parson 2017), of efforts to uphold the idea that significant mitigation is still achievable in a cost-effective way. A rejection of negative emissions in IAMs would by definition require far more radical short-term mitigation to meet the 2°C/1.5°C targets (see van Vuuren et al. 2018), and therewith much more significant short-term capital devaluation.

In a world where capital accumulation is still largely dependent on fossil fuel use, it should not come as a surprise that efforts to minimise mitigation costs and prioritise continued economic growth tend to maximise the value that can be extracted from current fossil fuel-dependent production processes. Connecting IAMs to the deferral of fixed fossil fuel capital devaluation, then, is the ideology of neoclassical economics. The economisation of emissions accounting that has permeated mainstream scenario modelling is evident not just in the invocation of the carbon debt idea (Geden 2016), but in the prioritisation of cost-effectiveness as a seemingly neutral method to arbitrate between alternative climate futures. In a very direct way, Shell's projections of a 2°C-compatible future in which all of its fossil fuel reserves can be utilised are made possible by the economic assumptions that underpin the IPCC's emission scenarios; that is, by the hegemony that neoclassical economics enjoys in integrated assessment modelling. This, I think, puts science on the map as an important arena in which the conditions for a spatiotemporal fix to climate change are co-produced. By their internalisation of cost minimisation, IAMs unintentionally serve as vehicles for the reproduction of existing socioecological relations. The efforts of modellers to stay within the boundaries of what is economically feasible aid capital in averting the threat that more radical emission reductions would pose to fossil fuel assets, and as such serve to mediate the risk of devaluation.

Delayed Mitigation, or the Tendential Decrease in the Rate of Decarbonisation

From what I have presented so far, it should be clear that the main mechanism by which negative emissions operate as a fix is through the temporal deferral of mitigation action; that is, through efforts to make the rate of decarbonisation compatible with the realisation of existing fixed (fossil fuel) capital. The extent to which this is an incipient if not already existing effect of the negative emissions concept itself is hotly debated in the literature, and mirrors broader discussions on the risks of geoengineering. The debate is commonly framed in terms of the "moral hazard" or "mitigation deterrence" that negative emissions give rise to, with scholars vehemently disagreeing on whether it exists or not (McLaren 2016). The problem is most commonly framed in pure political terms, as the concern that "decision makers may reduce mitigation effort, believing climate engineering [or negative emissions in this case] to represent adequate insurance against climate risk" (McLaren 2016:596).

Minx et al. (2018:13) point out that in IAMs, mitigation deferral is a demonstrable and widely recognised consequence of the inclusion of negative emissions: "the introduction of NETs in cost-optimising mitigation scenarios reduces the costs of long-term mitigation but *impedes early emissions reductions*". As discussed above, this outcome is integral to IAMs' preference for cost-optimal solutions (Tavoni and Socolow 2013). The dispute supposedly exists in whether mitigation is, or will be deferred in *practice*, outside of models. Yet if we recognise that models do not just "carr[y] with it beliefs and values about the world it is seeking to describe" (Mahony and Hulme 2018:410) but actively help bring that world into being (Beck and Mahony 2017); that by operating within the hegemonic logics of neoclassical economics, IAMs inadvertently serve to delineate possible climate futures, and thereby reproduce dominant socioecological relations, values and beliefs, then a strict distinction between model and real world makes little sense. This is all the more so if we step away from the focus on climate policy, and consider the broader political economy of integrated assessment modelling. The Shell scenario clearly blurs the boundaries between modelled and real world practices. If a fossil fuel company can make use of IAMs to make the case, to its shareholders, for the compatibility of its operations with a well below 2°C world, then negative emissions already have real-world consequences.

The mitigation deferral problem thus points to a necessary problematisation of the various dynamics that give science a contributing role in "fixing" rather than resolving the climate crisis. It demands greater attention, not in the least from critical social scientists, to *how* scenario modelling and research into NETs is carried out; to the specific processes that seem to align the in-built assumptions of IAMs with the economic interests of fossil fuel companies. A crucial part of this alignment appears to be the construction, by IAMs, of seemingly robust projections of the future. It is highly significant in this sense that the only way in which the dominant constellation in climate policy—between the combined pursuit of cost-efficiency and the ambition to keep temperatures below 2°C/1.5°C—still seems workable is by deferring its internal contradictions to the next generation, by laying claim to that projected but unlikely future. More work remains to be done in understanding—and challenging—the implications of this temporal fix.

Towards a Critique of the Political Economy of Delay

Negative emissions have variously been called "an unjust and high-stakes gamble" (Anderson and Peters 2016:183), "a kind of magical thinking" (Geden 2016:794) and "science fiction—like a light saber, incredible but not real" (Pielke 2018:33). Much in these critiques rings true. Negative emissions problematically extend the carbon budget concept to allow for the creation of debt, where an overdraw in the near term is justified by a scientific elaboration of how this will be compensated for later in the century (Geden 2016). The result is the economisation of emission reduction pathways, the invocation of something uncannily like a mortgage mechanism in which a "carbon loan" is funding current carbon-intensive capital accumulation, while the wellbeing of future generations—and the poor in particular—serves as collateral. This occurs on the basis of assumptions that seem unrealistic and naïve at best, and that logically emerge out of a modelling exercise that is skewed against more radical near-term emission cuts, while largely ignoring social, political and broadly defined environmental considerations.

The political repercussions of this are significant. Important concerns have been raised about how NETs-dependent climate scenarios help maintain a semblance of normality in the face of woefully inadequate political efforts to tackle the climate crisis. Most significantly perhaps, the promise of negative emissions could act as a deterrent to more radical near-term action. Yet negative emissions do more than just shore up the unsteady foundations of climate policy. Examining whether and how the "moral hazard" plays out in practice requires us to move beyond a narrowly defined political arena, to open up the black box of climate policy and unpack the different political economic dynamics it contains. In scrutinising the implications of negative emissions, we thus need to ask whose interests are being defended by an appeal to future carbon dioxide removal. For whom or what are negative emissions buying time? I have argued that answering these questions requires attention to the wider "political economic life" of integrated assessment models, and the narrowly economic assumptions that underpin them. Further research is needed to determine the extent to which various interest groups are (not) mobilising the methods and outcomes of IAMs, in discursive and material ways, in order to legitimise continued fossil fuel-dependent accumulation. The example of Shell however illustrates that at least in one instance negative emissions have already moved beyond the realm of science and climate policy, to where they fulfil a very concrete function for capital: dispelling the perceived risk of stranded assets and thereby seemingly making the continued extraction of fossil fuels compatible with climate change mitigation.

Negative emissions in this example serve as a spatiotemporal fix to the socio-politically mediated climate crisis that fossil capital faces, a crisis in which increasing concerns for climate change threaten fixed capital devaluation through calls for regulation, litigation and the suppression of fossil fuel consumption. Notably, this is a fix that works defensively, not through new forms of commodification, but by doubling down on existing accumulation strategies and attempting to shape, in a direct way, the (sociopolitical) conditions of production. Notably also, the fix is largely a promissory one, based on the hypothetical deployment of NETs rather than their actual existence (cf. Markusson et al. 2017). In a sense then, the fix here operates through the mobilisation of a specific vision of the future as a way to legitimise and reproduce the present. The production and restructuring of spatial relations in response to capitalist crisis is complemented by a distinctively temporal strategy, by the invocation of an improbable certainty about *future* socio-spatial relations. The spatial fix in this way finds its logical corollary in the production and restructuring of *future* space into which current production processes can be extended.

In this, the negative emissions example illustrates the merits of extending prevailing approaches to analysing spatiotemporal fixes. Not only does it signal the underappreciated importance of the temporal dimension, it also underscores the value of giving the ideological and hegemonic components of the fix their due attention (cf. Ekers and Prudham 2018). If we accept O'Connor's (1997) idea that the relationship between capital and nature is necessarily sociopolitically mediated, then this process of mediation needs to be given closer consideration in the fix literature. Doing so, I have argued, suggests that the contradiction between socioecological crisis and fixed capital investments need not be resolved solely through the expansion or restructuring of new spaces of accumulation; that is, in the sphere or production. The various acts of mediation itself, be they within or outside the circuit of capital accumulation, can create opportunities for "fixing". It is this role that IAMs fulfil, as calculative devices that incorporate, enact and reproduce hegemonic worldviews, values and power relations (cf. McElwee 2017), and it is in this light that we can cast other forms of knowledge production and policy making as well. Spatiotemporal fixes are in this sense part of a wider political economy of "fixing", a constellation of sociopolitical practices that serve to reinforce and reproduce existing socioeconomic relations. This involves a range of different actors, mobilises strategies that are defensive as well as expansive in character, and operates through both temporal and spatial processes. Such a broadened agenda for research on the spatiotemporal fix need not distract from the more specific way in which it was originally conceived of by Harvey (2001, 2007), or compromise the concept's theoretical coherence. Rather, I think, it fruitfully situates the "original" fix within a larger analytical concern for the conditions that enable capital's responses to crisis; that is, for the various sociopolitical practices that facilitate capital's movements from one place to another and at times seem to underwrite its resilience in the face of adversity.

At least in the case of climate change, such an inclusive approach seems needed to satisfactorily understand why mitigation currently falls so far short of what is needed; why despite the overwhelming evidence on the catastrophic impacts of climate change, including but certainly not only for capital, fossil fuel-dependent production processes are able to persist. Answering these questions requires a conceptualisation of capitalist crises that are contained and deferred not just in the sphere of production, but by virtue of a wider set of hegemonic socioecological relations. Together, these relations constitute what one could call the political economy of delay, a constellation of economic, political, cultural and everyday practices that in numerous ways serve to postpone the necessary devaluation of fixed fossil fuel capital. In this article I have focused on the way this process operates through the ideology of cost optimisation that has become central to the logic of integrated assessment modelling, but a fuller understanding would also need to account for, among others, the neoliberal dynamics of environmental governance and the grip that carbon-intensive consumption maintains on social behaviour and cultural preferences. Critical geographers possess the requisite tools to link these various moments of social reproduction together and problematise the kind of developments of which the negative emissions concept provides such an acute example.

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