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Author for correspondence: H.J. Buck, E-mail: hbuck@ioes.ucla.edu

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The politics of negative emissions technologies and decarbonization in rural communities

Holly Jean Buck[1,2]

[1]Cornell University, College of Agriculture and Life Sciences, Department of Development Sociology, Ithaca, NY 14850, USA and [2]Current contact: Institute of the Environment and Sustainability, University of California, Los Angeles, La Kretz Hall, Suite 300, Box 951496, Los Angeles, CA 90095, USA

Non-technical summary

Technologies and practices to remove carbon from the atmosphere ('negative emissions technologies') will be challenging to scale-up. Efforts to incentivize or govern their scale-up globally risk failing if they miss the social challenges. This paper analyzes prospective challenges for negative emissions through examining how decarbonization practices are evolving in one particular landscape: the Imperial Valley in southeast California, a desert landscape engineered for industrial agriculture. Based on semi-structured interviews and site visits, this paper examines how community actors have received, participated in, imagined or contested new energy technologies and climate practices, and draws out takeaways for negative emissions policy.

Technical summary

This article examines prospective challenges and opportunities for scaling up negative emissions technologies (NETs) through examining how decarbonization practices are evolving in one particular landscape: the Imperial Valley in southeast California, a desert landscape engineered for industrial agriculture. Local officials, community activists and business ventures are re-imagining the valley as a renewable energy landscape, some with interest in carbon-negative technologies. At the same time, aspects of this strategy for economic development via green energy are often contested. Based on semi-structured interviews and site visits, this paper examines how landscape-level actors have received, participated in, imagined or contested new energy technologies and climate practices. Through analyzing local perspectives on climate change and emerging energy technologies, the paper draws out three takeaways for the governance of NETs: (1) entrenched interests can play a role in shaping how particular NETs compete; (2) environmental justice concerns around NETs should be viewed as more than not-in-my-backyard-ism; and (3) incentives for NETs must be tailored to local contexts. The conclusion discusses two crosscutting challenges: the lack of institutions to build out new infrastructure and the challenge of generating narratives around invisible 'negative' emissions.

1. Introduction

The notion of 'negative emissions' first received sustained attention in the early 2000s, as part of the realization that carbon capture and carbon sequestration could be valuable in averting severe global warming [1]. Fast-forward 10–15 years, and the importance of negative emissions is even more striking. The majority of scenarios used in the Intergovernmental Panel on Climate Change (IPCC)'s fifth assessment report rely on negative emissions technologies to curb warming at 2 °C; in particular, the scenarios typically employ bioenergy with carbon capture and storage (BECCS) [2]. Essentially, these scenarios are pointing to the massive and widespread deployment of technological systems with heavy, capital-intensive infrastructure that has not been proven at scale. In many cases, they also imply vast land use and the repurposing of rural landscapes.

When NETs are extrapolated to the real scale they will need to be deployed at, just as when solar or wind are similarly extrapolated, it is clear that land use competition, competition for water and inputs, resistance to new roads and transmission lines, or impacts upon food prices [2–5] may all combine to create strong opposition. Some of these potential social challenges and friction points are difficult to identify when modeling and governance discussions take place on a global scale. This paper thus focuses on the people and stakeholders of rural landscapes, who would be the ones working on these carbon removal technologies and practices. The paper takes a landscape-level lens to explore the dynamics of nascent carbon sequestration practices, as well as the scale-up of renewables, which the paper argues can indicate potential challenges and opportunities for negative emissions.

Because NETs are not yet deployed – and, in fact, face an uncertain future – this paper turns to renewable energy as an analogue, examining the development of solar and geothermal as well as biofuels. This analysis is most applicable to BECCS, though direct air capture is also considered when useful. The paper considers renewables and biofuels to both be climate change technologies, as policy around their use has the explicit aim of mitigating climate change – at least in the context of California, where their rapid scale-up has been incentivized to meet climate targets.

There are three key reasons to look at the scale-up of renewables when considering the scale-up of negative emissions. Firstly, renewables offer recent, direct experience in developing new infrastructure on the scale that negative emissions implies, and with the same moral rationale and climate policy component. Secondly, this article sees NETs not as distinct from renewables, but as an extension of the decarbonization process; it extrapolates from the current energy transition (in that mitigation aims to cut emissions to zero) towards net-negative goals. Negative emissions policy would be a continuation or add-on to current mitigation policy, and it is also developing in the context of mitigation efforts. It is not helpful to think of negative emissions in a discrete silo apart from decarbonization writ large. Thirdly, many NETs are energy-intensive, and they would have to be powered by carbon-neutral energy to actually be net-negative. Hence any scale-up of negative emissions implies a significant parallel expansion of renewables.

The analogy is not perfect. One major difference is that renewables generate a desirable good. The frame for carbon removal, on the other hand, is not entirely set: will it be set up within a market framing where negative emissions are seen as a 'good' that local producers can benefit from producing? Or will it be essentially pollution management and waste disposal? In actuality, some kind of hybrid between these seems likely – but a stronger emphasis on waste control may imply a different set of actors and dynamics driving its expansion, and hence, waste control might be an alternative useful analogy. However, because this rapid spread of renewables has already been experienced on a scale towards what NETs would require, and because this scale-up touches many more people than an isolated waste disposal site would, the analogies of biofuels and renewables seem the most instructive for this particular landscape. Notably, the object of study here is not just the 'technology' being deployed, but the scale and associated changes in land use and social dynamics.

The particular landscape examined is the Imperial Valley in southeast California, which has experienced a rapid growth of renewables in the last decade. This paper draws upon data from visits to biofuel and geothermal production sites, farms, laboratories and community meetings in the Imperial Valley, as well as 31 extended interviews with community members, businesses and scientists. Interviews were conducted from October–December 2016 in the Imperial Valley and adjacent Coachella Valley, with three from a pilot visit in July 2014. These interviews included questions about the future of the landscape in 2050, and touched upon many environmental and economic themes – some focused upon energy systems, and a few mentioned carbon removal explicitly, but most also discussed the future of agriculture, water rights, the restoration of the Salton Sea and other topics that respondents felt germane to their vision of the future landscape[i]. Perceptions of future agricultural production, infrastructure and land use are all relevant to the deployment of negative emissions and BECCS in particular, since BECCS would require a greater dedication of land and water to biofuel feedstock, and expanded infrastructure for carbon transport/storage.

In order to structure the discussion of the interviews, the theoretical background and value of the landscape lens is discussed first. Next, this particular landscape is introduced by way of discussing respondents' perceptions of climate change and energy futures, particularly since these are likely to impact their willingness to consider new climate-related technologies. Then, the body of the paper draws out three key lessons from looking at new decarbonization technologies in the Imperial Valley.

2. Theory and methods: the value of the landscape lens

Calculations of negative emissions potential are often presented on the global level. But the question who bears the responsibility for removing the carbon is elided from the global gaze, as is the question for whom the carbon is removed. If the idea is that negative emissions compensate for emissions in hard-to-mitigate sectors, such as aviation, iron and steel, or chemicals, it would likely result in rural landscapes sequestering carbon so that particular industries can continue to profit. Moreover, there is a moral case to be made that the responsibility for removal lies with high emitters in the global north (and potentially also with fossil fuel companies). The literature on negative emissions is indeed beginning to move from a more general, global discussion and beginning to address things like burden sharing under the framework of common but differentiated responsibilities [6] and national-level incentives [7], but there is still some way to go before discourse and policy on negative emissions reaches a true reckoning on this question of who exactly will be removing the carbon, and for whose benefit the carbon is removed.

In short, the global scale is insufficient to see the potential conflicts at work; we need to take up other scales as well. The scale examined in this paper is the landscape, defined as a place where ecological and social structures interact, larger than a farm but smaller than a region [8]. This paper draws from recent work in both geography and science and technology studies; in particular, work on rural development on landscape approaches to climate mitigation and adaptation, and energy geographies [9,10]. For example, Gavin Bridge and colleagues point out that for many, the low-carbon energy transition is experienced as the transformation of landscape. The concept of landscape is useful for understanding this transition because it calls attention to the interaction of natural, technical and cultural phenomena in a particular place, they write; it is also useful in understanding place attachment and emotional responses, as well as getting at these questions of 'which landscapes should be made, and who landscapes are for' [10].

Holism is a further reason to think in terms of landscapes: a landscape scale of analysis encompasses both ecological and political processes, as well as the feeling of the land. As Carol Hunsberger and colleagues argue, this unity encourages us to think holistically about how mitigation shapes the land, including ecological and social feedbacks in human and natural systems [8]. A landscape scale of analysis could also work counter to a logic of viewing landscapes in terms of their climatic attributes or carbon content, calling attention to what place means beyond the 'green gaze' of carbon, nutrient or hydrological flows [11]. The landscape view invites human habitation, embedding bodies in a context. Importantly, the landscape scale is broader than one site or case, which allows the analyst to go beyond the specifics of individual conflicts or events but still explore local contexts and

ways that sense of place interacts with emerging energy technologies [12].

Part of the value of this perspective here is to get away from seeing negative emissions 'technologies' as objects or artifacts that are deployed, but carbon removal as a practice that is done by laborers. There is another sense in which 'landscape' is relevant here; Rip and Kemp use the term 'socio-technical landscape' both literally and metaphorically to understand technological evolution [13]. Literally, the socio-technical landscape is travelled through, but metaphorically, it is a backdrop of opportunities and constraints – a backdrop that exerts influence, but which particular actors cannot change themselves in the short term [14]. The aim of this paper is to make visible the landscape, both literally and metaphorically; to understand deeper social and biophysical factors at work that might encourage or stymie the development of negative emissions here.

Hence, a landscape approach here denotes (1) coming to understand the processes of the geographic landscape, as well as the geographic realities and forms of it; (2) coming to understand the actors who live there, and the constraints and opportunities their socio-technical landscape offers as they navigate new climate change technologies. The method of semi-structured interviews, often held in working environments, as well as site visits, facilitate this approach. Site visits allow the researcher to better get a sense of the landscape and talk with its inhabitants – to see them at work, and be able to ask questions about their activities. Semi-structured interviews are another method that was selected in order to focus on the people who shape the landscape; they allow the researcher to take conversational diversions to better understand the reasons for the respondents' views of the future landscape. Finally, another benefit of the landscape approach is that it allows us to understand the deployment of landscape-altering technologies and practices not just in space, but also through time, as part of a continuation of the landscape's history. The temporal dimension is important for carbon removal, as it is imagined to unfold in time-scales of centuries.

3. Background: climate change and imagined energy futures in California's Imperial Valley

California can be seen as a favorable region for early adoption of negative emissions practices: it is a center for technological innovation, with progressive climate and energy policies, and it is an agricultural powerhouse. Within California, though, the Imperial Valley in the southeast is quite different from the urbanized coast, or even from more central agricultural regions. The valley is one the harshest landscapes in North America. It receives an average of three inches of rain a year, and summer temperatures routinely climb to 40–45 °C (∼105–115°F). Water is drawn here through 130 km (80 miles) of desert from the Colorado River via the All-American Canal, and so the valley is also a lush salad bowl, producing a significant portion of the nation's winter vegetables using the river that much of the American West depends upon. Because climatic conditions are already so harsh and dry, an observer from afar might think it is especially vulnerable to climate change. However, outside observers of the Imperial Valley understand its climate future quite differently than people who actually live there. These differences may underlie three surprises uncovered in the interviews regarding (1) the implications of warming; (2) the causes of warming; and (3) the role of renewable energy.

First, despite significant media coverage that warns that drought will imperil agriculture, some residents do not see water shortages as threatening the agricultural future of the valley, because the Imperial Irrigation District has senior water rights to a significant portion of Colorado River water (its entitlement is 3.1 million acre-feet, or approximately 70% of California's allotment). A few respondents were worried about climate impacts upriver, and Lake Mead in particular – because when Lake Mead drops to a critical level, drought contingency plan requirements could be implemented. This will decrease California's allotment of Colorado River water, and farmers in the Imperial Irrigation District will feel those cuts. But in general, since the landscape is not directly dependent upon local rain but upon engineering and distant water sources, water is often seen first in terms of political battles and allocation challenges. Moreover, the already-extreme heat may contribute to lukewarm concern: "The heat is a real thing, but it's one of those things that people just think, 'Okay, this is how it is in the valley'" (R2). On the other hand, some people wondered about the ability of the body to actually tolerate such high temperatures. Farm workers are particularly vulnerable; employers provide minimal protections such as shaded resting places and water breaks. In short, people are already adapting to extreme conditions, so in a sense they must just pile on more adaptation: more cooling centers, more air conditioning, more grit and endurance.

In the Imperial Valley, as in many rural regions, some residents are skeptical of anthropogenic global warming. Farmers in particular are attuned to variability in weather, and some question whether climate observations just reflect natural variability. As one farmer asked: "Is it just a drought that we're in, a drought cycle? That certainly has changed the climate; that's for sure. Is it man-made? I don't know. There are a lot of different thoughts on that … You go to look at tree rings, back 2000 years, you see cycles that are very similar to what we have today" (R18). Moreover, some growers do not just see the science as uncertain – they see the climate change discourse as politically motivated. "Lookit, they've raised a lot of money through carbon taxation, they changed the way people live, which was really the goal in the first place. It's all about money. They've done it" (R3). If landowners do not believe in the link between CO_2 emissions and warming, or if they believe changes in climate are being used for political ends, they may be less likely to support NETs. Previous studies of landowner adoption of cellulosic feedstock, for example, found social factors to be a large factor in producer decision-making [5].

Despite the mixed concerns about climate change, visions of renewable energy in the Imperial Valley are thriving[ii]. Local development officials celebrate the valley's natural blessing: 360 days of sunshine a year, a 1° slope on most lands, and the geothermal resources of the Salton Sink. The first geothermal production began in 1982, and there are now 21 plants in operation in the area, interspersed with fields and solar farms. The potential for solar here is 42,000 MW, enough to power 31 million homes [15]. California requires that utilities have 50% of their portfolio in renewable energy by 2030 (the Renewables Portfolio Standard, or RPS), and coastal utilities are buying from massive Imperial County solar and wind projects to fulfill their renewable energy mandate. In a region with 25% unemployment, the prospects of economic growth seem promising: as one county supervisor put it, "Renewable energy is going to give Imperial County a shot in the arm" [16]. Local agencies are actively promoting development of this '21st century gold' in the region.

Five renewable projects funded with $470 million of American Recovery and Reinvestment Act financing also helped the growth of renewables here, as did a new high-power transmission line to San Diego [17].

Many see the benefits of participating in the renewables boom – while at the same time critiquing the perspective held by some outsiders that their desert landscape is full of empty land for solar, or that mega-projects are the answer. Some citizen scientists and local entrepreneurs view the landscape as a place to experiment with new forms of energy. One nongovernmental advocate describes working towards a scientific collective of technology companies involved with renewables, algae, biofuels, desalination and water quality projects for wetland habitat (R14). Another vision is for a demonstration area where companies can learn from each other: "'Where's the hydrogen?' It's over there. 'Where's the solar testing area?' It's over there, and there's 20 different solar companies that are trying to be more efficient than the other one, and be more productive" (R4). These visions are not strictly entrepreneurial, but lean towards landscape transformation: "What would it do when you have an arid desert that now is lush green, and all the mangroves there are sequestering carbon on a regular basis, and all of the animals there are only there because you have created a new habitat for them?" (R4).

In short, there are a few different ways to imagine the future climate-energy landscape, from mega-projects for export to smaller, community-driven projects. At times, these visions clash. Expanding the use of renewables and adding in new negative emissions practices to decarbonize to net-negative is likely to further exacerbate the tensions between visions of development. In the following section, three specific lessons brought up by recent experiences with decarbonization technologies are discussed.

4. Results: lessons for NETs

4.1. Vested interests can shape competition between technologies

No technology emerges upon a blank slate. NETs – potentially used together in a portfolio approach or series of 'wedges' to remove carbon – may face both influence from existing energy technology regimes, as well as competition with each other. Two examples around biofuels and renewables in the Imperial Valley illustrate this, and they will be briefly discussed in turn.

BECCS implies a massive scale-up of biofuel feedstock production, and while it is typically assumed that advanced feedstocks would power the BECCS supply chain, the challenges of this are often glossed over. The Imperial Valley is considered an area favorable for biofuel feedstocks due to its abundant sunlight and cheap water, though as of yet it has not been a major producer[iii]. The efforts that are moving forward are in a first-generation feedstock, sugarcane. Until 2017, there was no cane processing facility in the valley, but California Ethanol & Power's large processing facility is about to come online, which is projected to catapult sugarcane to Imperial County's third most valuable product [21].

Algae, a more 'advanced' fuel, faces an uncertain future. Over the past decade, companies garnered sizable grants from the Department of Energy, such as Kent Bioenergy's project utilizing microalgae for carbon sequestration and greenhouse gas abatement; companies like Carbon Capture sprouted up, with their algal ponds to be later sold or rented to Synthetic Genomics, General Atomics and so on. There are now empty raceways among the desert scrub. Algae companies have since pivoted to other non-fuel products such as nutriceuticals and food dyes.

Key reasons for algae's fail to scale include the collapse in oil prices and the lack of sustained national-level government support for R&D – the cultivation of this industry required coherent and long-term energy policy beyond the local or regional scales. However, the story of algal biofuels' slow start also relates to choices made between algae and other biofuel feedstocks. For example, one biofuel scientist explained that research into cellulosic ethanol started 20–30 years ago, "but it became very clear to everybody in science four years ago, five years ago that cellulosic ethanol was going nowhere. That we had spent a billion dollars in research in the previous five years and got nowhere…" (R29)[iv].

Vested interests can allow certain technologies to rise at the expense of others. This narrative of cellulosics indicates that vested scientific interests are able to keep going on a committed research path even without successes. Moreover, being committed to one research trajectory can come at the expense of researching something else. Investing in the wrong idea can be costly.

A second example from the renewable scale-up in California also illustrates tensions between different technologies and their actor-interest groups as different approaches to decarbonization mature. Geothermal presently isn't cost-competitive with cheap solar, which benefits from tax credits; one geothermal expert called it "a very, very unlevel playing field." Utilities love solar, this expert explained, because transmission lines are used by solar for six hours a day, and they have to fill up the other 18 hours in the day with electricity that they can generate from their own generators with incredibly cheap gas – while still charging the same prices (R9). In other words, solar and fossil fuels are working in a complementary fashion to the detriment of geothermal. In a sense, solar was able to scale-up so rapidly because of cheap fossil fuels – at the expense of other renewable options. A different policy design could have given geothermal a greenhouse gas offset credit to make it more competitive (R9). But at present, as pointed out by a solar developer, the cost of geothermal has been steady for 20 years while the cost of solar has dropped by 90%: "Why would anybody want to sign up for expensive geothermal when you can get cheap solar?" (R5).

Entrenched interests (such as the utility companies, in this case) can have a role in developing the commercialization strategies for new technologies. When it comes to scaling up NETs, there may be similar roles for entrenched fossil fuels, at least when it comes to direct air capture. First, the main markets right now for the captured carbon are enhanced oil recovery. Second, CO_2 to fuel with lower carbon intensity (as a type of fuel encouraged by California's Low-Carbon Fuel Standard) is the commercialization strategy of direct air capture startup Carbon Engineering [23] and may figure into the plans of others. Although these approaches can reduce net greenhouse gas emissions, this does not meet the long-term objectives when it comes to net-negative emissions.

These examples of policy choices between competing technologies illustrate how important it is to both (1) honestly consider technical barriers when choosing which technologies to invest in; and (2) think critically about the roles of vested interests in promoting particular approaches. In assessing NETs, analysts often seem to assume that the most efficient technology will be rationally chosen, or the one with the least 'side effects' – but these examples illustrate that vested interest groups may shape the playing field as much as the technical potentials for decarbonization will.

4.2. Environmental justice concerns: more than NIMBY-ism

While renewables have a rosy-green image, both environmental activists and farmers have issues with the way solar has been rolled out in the Imperial Valley. In the words of one environmentalist, "It's ridiculous to build solar projects 100 miles away [from San Diego], or 150 miles in the case of LA, from where the energy's going to be used, because then you have to destroy a whole bunch more desert with these high-power transmission lines, which are ugly and ruin the wildness of the desert. Absolutely crazy" (R22). The alternative, the activist points out, is to stop building remote projects and relocate production locally, explaining that "San Diego could be energy independent if we used all our parking lots and rooftops and public buildings and abandoned landfills, and right around the city, create the renewable energy in the microgrids right where people live" (R22).

The resistance to these energy projects can sound like aesthetic complaint or not-in-my-backyard-ism, but it should not be dismissed as mere NIMBY-ism, as it is shot through with environmental justice concerns. First, local people have to bear the harms from the development. As a community advocate explained, the energy companies put in power which all flows out, and the solar installations scrape the desert and break up the soil underneath, "and then we have these episodes of wind now where all this dust is blowing. … We see our hospitals with acute respiratory disorders in newborns and the elderly. Somehow, again, the word to me is immoral that this is happening and somehow our decision makers feel like they can't do what they need to do with this" (R10).

Second, benefits – both financial and energy – are flowing elsewhere. Part of the objection is the economic impact: solar only brings a few jobs, which are well-paid but often temporary, and so the economy of the whole community can change. Solar installations are perceived to have less jobs associated with them (when accounting for indirect jobs like equipment repair, supplies, etc.) Farmers, too, have questions about who benefits and who loses from these megaprojects. It's not an entirely economic matter – it has to do with the loss of a way of life, and an identity; an ongoing loss that solar is seen as one part of. In a video with 41,000 views, which garnered 692 tearful and angry emojis, a farmer shows up at an Imperial County Board of Supervisors meeting with several boxes of the last cantaloupes from what used to be a ranch, and is now the Iris solar project: "The ground my family's farmed for 50–60 years, which is some of the best farm ground … there was hundreds and hundreds of people working out there last winter; I've got a hundred people out there today – this is the last crop off that ground" [24]. In the Imperial Valley, there are just 400–500 landowners (many of whom live on the coasts), and farmers rent their fields. When their landlords switch to solar, they have no recourse. There is also an urban/rural divide here; some in the agricultural community do not appreciate these lands being used for powering big cities.

Crucially, the opposition to renewables is not to the technologies themselves, but in the occasionally place-blind ways they are being implemented. Legislation at the state level attempts to address the issue of how disadvantaged communities can benefit from the renewables scale-up, such as California's 2016 Assembly Bill 1550, which builds on earlier legislation to require that 25% of the revenue from California's cap-and-trade system be spent on projects located in and benefiting disadvantaged communities. If these measures are successful, they may suggest a way to distribute benefits from new negative emissions infrastructures.

Resistance and promotion of new infrastructures may not map onto familiar narratives, as another example shows. A Native American group in this area had been attempting to install wind turbines on reservation land – land which had no utilities, no grid, no telephone infrastructure – but faced resistance by both the Forest Service and by environmentalists concerned about golden eagles.

> "We are protectors of the environment, the golden eagle is a spiritual entity for the tribe. It has great power with the tribe. And we would not engage in a project that would harm or intend to harm or would cause harm to the golden eagle population. We took golden eagles for ceremonies for thousands of years and choose not to do so now. But that we would be opposed by environmentalists, environmental organizations, for the potential take of even one golden eagle over a 20 year operating span of a wind project, which is a green energy project, which displaces carbon-based energy, which is a net positive and greenhouse gas reduction and supports climate change, is really difficult for us to understand. Development takes many forms" (R23).

In the view of this local official, non-tribal people tend to use tribal lands "as mitigation banks for their own adverse development" (R23). Negative emissions projects could face this same concern – that rural lands, as well as lands belonging to indigenous groups, may be used as places that allow carbon to be burned elsewhere.

4.3. Social acceptability of new climate technologies varies by culture

A third takeaway from looking at new climate and energy technologies in the Imperial Valley is that social acceptability issues blossom unevenly, and not everything that is contestable will be contested. Does it make sense to use Colorado River water to grow bioenergy for export – or, potentially, for negative emissions? The water footprint of biofuels, and cane in particular, has received attention when it comes to large-scale land acquisitions in the developing world and trade in virtual water [25–27]. Here, alfalfa and other hay grasses are major crops, with a significant volume shipped to China and the Arabian Peninsula, so there is already a large water export – one could argue that it might as well go to biofuels than to cows overseas. Farmers who were asked about this virtual water trade countered with questions about the balance of trade and the embedded water content of electronics produced in China. Moreover, one farmer pointed out that the Imperial Irrigation District is currently underusing its allotment, so the unused water could be used by new sugarcane production (R18). These questions around water and land are the kinds of questions that can come up when envisioning BECCS at scale. Another potential social issue is genetic modification – it seems likely that BECCS on a scale large enough to make a difference in global warming would involve genetically modified feedstock or genetically modified enzymes in production. However, GMOs have not been a key social issue in the Imperial Valley to date. In short, there are ways in which negative emissions practices may have greater social license in an area such as this one, even when some landowners may be skeptical about anthropogenic global warming. In what conditions this goes beyond social license to social support is a bigger question, and initially getting NETs off the ground will be quite difficult.

Policymakers will need to create incentives for negative emissions that address the needs of multiple local contexts.

5. Conclusion: climate policy for NETs must take stock of the landscape level

By examining how biofuel feedstock production and renewables are expanding, we can glimpse how a landscape of overlapping carbon removal practices in this valley could emerge in the coming decades. Whether this landscape features a good quality of life for people and other organisms depends very much on the policy choices made to bring NETs to scale. This analysis has brought many types of challenges to the fore: financing challenges and technical barriers, landholder adoption, environmental justice concerns and broader social acceptance issues of the underlying technologies. Some of these challenges can be addressed by smart policy design, but some are fundamentally cultural and will be more difficult to address through 'governance' efforts at macro scales. An important point is that while some of these issues are 'local', they can't simply be placed in a box of 'local issues' that people working on the global or other scales can simply ignore or delegate to the local scale. Many of these concerns that are evident when examining the local are actually best addressable on state or national scales, such as the challenges to investing in new facilities and helping them cross the gap from demonstration-scale to commercial-scale, or properly incentivizing landowner adoption. At the same time, global action is likely needed to catalyze national or regional action.

Beyond the challenges mentioned above, there are two crosscutting issues that complicate the deployment of NETs at climate-significant levels. The first crosscutting issue is that NETs imply vast new infrastructure in a world that's already built out, and in which infrastructure is increasingly contestable. This contestability is something to be celebrated in many respects, but it also makes it more difficult to make sweeping transitions to new systems that require land or changes in land use, especially when many of the agencies dealing with land management have mandates that focus them on restricting use. As one local official put it:

> "In our world – and perhaps California is more pronounced than the rest of the country – we have a number of government agencies whose mission it is to protect the environment and other agencies who, increasingly, are focused on protecting the environment. But most of the agencies and organizations, at least the official ones, are designed to say, "No," and they're not designed to do something. They're designed to stop some things from being done. … That's very different than probably 1935 or 1955, where government agencies in this country did things like built Hoover Dam, or big freeways, or a big piece of infrastructure. Those served purposes and had major impacts, environmental impacts, cultural impacts and others. Well, the pendulum has certainly swung…" (R16).

On a national level, there are a few agencies such as ARPA-E (the Department of Energy's Advanced Research Projects Agency – Energy), which are mission-driven to make something happen, but they are few and far between. There are many agencies that have a role in R&D – no less than five federal agencies in a recent policy review [7] – but how to go beyond demonstration-scale is murkier. The newly politicized world of infrastructure, in combination with the lack of institutions that have a strong mandate to build out new systems, mean that the institutional landscape is bleak for supporting NETs.

Proposing new institutions brings up the issue of bottom-up support, and a second crosscutting challenge is the issue of narrative. Even for people who are not climate skeptics, negative emissions are by definition some invisible thing; it can be difficult to get a widespread coalition of actors involved with a narrative about the benefits of a 'negative' commodity or waste disposal service, where the landscape is transformed but the object of the transformation itself is occluded. A recent bestselling book (and probably the only one on carbon removal to reach a wide audience), *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*, critiques this language used by scientists: "This term has no meaning in any language. Imagine a negative house, or a negative tree… This is another example where climate-speak removes itself from common parlance and common sense" [28]. I would suggest that (1) the academic terminology of 'negative emissions' may want to be dropped in favor of terms that embrace the emergent cultural currents around drawdown and climate change reversibility; and (2) scientists work to make carbon flows more visible. Advanced monitoring technology might help make visible the invisible, especially if it could gamify the carbon removal somehow. Governance of negative emissions should focus on monitoring and verification not just at the national level, but also at the level of individual landowners, both to spread awareness of carbon removal and to help landowners profit from sequestration activities in the future.

This sketch of negative emissions in one particular landscape makes it possible to see the contours of biofuels, on-farm sequestration and renewables as part of an agro-energy negative emissions system. At the same time, the examples here illustrate the tensions or failures that can arise when environmental sociotechnical imaginaries are selected from afar – such as large-scale solar installations or investment in cellulosic biofuels – without engagement from the people who will be living with these practices and infrastructure. If a negative emissions agro-energy system is difficult to manifest here, in an industrialized, high-tech, progressive economy like California, it's time to rethink what work 'negative emissions' is actually doing. Oliver Geden describes how carbon removal technologies have had the effect of "masking the growing inconsistency between political talk, decisions and actions" [29]. If this has in fact become the point of negative emissions, empirical social science research and speculative exercises such as this one can help point to the inconsistency, so we can be honest about the future.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/sus.2018.2.

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Notes

i Interviewees are referred to numerically, along with a descriptor of their choosing. See Supplementary Material for a list of interviewees and interview questions.

ii This should not surprise, as support for renewable energy research in the US tends to be strong even when belief in anthropogenic global warming is low [18].

iii Whether there is local carbon sequestration potential in the underlying Salton Trough is unclear from the geological literature [19] and no bioCCS plant is planned, so it is not meant to be suggested that biofuels for BECCS would definitely be grown in this valley. California's Central Valley appears more promising for co-locating biomass and carbon storage [20]

iv Dale writes about the slow scaling of cellulosics, discussing difficulties in pre-treatment at scale (the lignin in plants is difficult/expensive to break down), but also pointing to upstream issues such as biomass storage and the cost of setting up supply chains [22]. Farmers have no commodity markets to participate in for residues and think of supplying residues as a distraction from their work of growing food.

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