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Principles for aligning U.S. fossil fuel extraction with climate limits

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In order to avert the most extreme harms of climate change, the world must reduce net carbon dioxide emissions from all sources — especially fossil fuels — to zero by mid-century.

Introduction

In order to avert the most extreme harms of climate change, the world must reduce net carbon dioxide (CO_2) emissions from all sources — especially fossil fuels — to zero by mid-century. The Intergovernmental Panel on Climate Change has explored this challenge in extraordinary detail (IPCC 2018; IPCC 2014), and the world's countries have set zero net emissions as their collective goal in the Paris Agreement (UNFCCC 2015). As energy modelers have made clear, this transition must be led by a rapid and near-immediate decline in the use and production of fossil fuels (Rogelj et al. 2018; Riahi et al. 2017; IPCC 2018).

As one of the world's top fossil fuel producers, the United States is heavily implicated in this transition. And thankfully, some policy-makers in the U.S. have already anticipated the eventual wind-down of fossil fuels.

Though the current Trump administration is not so inclined, its predecessor — the Obama administration — clearly signaled a move away from fossil fuels. In the name of meeting national and global climate goals, it not only developed a comprehensive plan for moving away from fossil fuel consumption (The White House 2016a) but also took preliminary steps toward an eventual transition away from fossil fuel extraction (DOI 2016; BLM 2017). In particular, the U.S. Department of the Interior initiated efforts to incorporate the realities of climate change into policies surrounding fossil fuel production on public lands, which account for nearly one-quarter of U.S. CO_2 emissions (Merrill et al. 2018). Now, policy-makers in the 116th Congress are beginning to grapple with how a phase-out of fossil fuels might fit within a Green New Deal or other climate legislation (Barbier 2019; Natter and Dmitrieva 2019).

How should the U.S. align fossil fuel production with climate limits? This paper articulates three principles that lend structure to this challenging, but vital, task. These are, in brief, to: (1) reduce fossil fuel production at a pace consistent with climate protection; (2) accelerate the phase-out in economies that are the most resilient; and (3) safeguard human rights, cultural resources and the local environment in the process. Together, these principles can inform debate on an equitable phase-out of U.S. fossil fuel extraction.

The principles reflect not only the science and economics of how quickly global fossil fuels must be phased out, but also equity and other critical social dimensions. The phase-out of fossil fuel production will inevitably have substantial impacts on fossil-fuel-dependent local economies. Building a sufficiently robust political consensus demands that policy-makers take into account justice, equity and distributional fairness. A carefully planned phase-out of fossil fuel production that is grounded in equity not only helps ensure that the transition does not exacerbate inequality (Piggot et al. 2019); it may also stand a better chance of winning broad buy-in and, therefore, end up being more effective than a non-equitable approach (Fleurbaey et al. 2014; Green 2018).

Federal policy-makers could use these principles to help fulfil a goal, much like former President Obama's, of bringing the management of coal, oil and gas extraction in line with the U.S. government's stated climate objectives as committed under the Paris Agreement. The federal government has substantial jurisdiction over fossil fuel extraction (Ratledge et al. 2019). In addition to overseeing fossil fuel production on public lands, it also influences extraction through fossil fuel subsidies and infrastructure permitting decisions.

Subnational governments within the U.S. also shape patterns of fossil fuel extraction through land use and permitting; they can apply these principles immediately. In fact, there is already an active network of states and cities committed to climate action, and several states, including California and Colorado, that are debating how their oil and gas extraction futures may evolve under climate constraints.

To begin, we provide a short primer on why climate limits imply a global decline of fossil fuel production and what this means for the overall pace of winding down U.S. fossil fuel extraction. Next, we articulate the three guiding principles we have developed for winding down fossil fuel production. After introducing the principles, we use the examples of U.S. coal and oil extraction to broadly illustrate how resource managers could operationalize the principles. Finally, we close with a call for leadership and an outline of the next steps.

Climate limits mean winding down fossil fuels

Before delving into the specifics of U.S. fossil fuel extraction, it is important to first consider the broader picture: what degree and pace of a global wind-down of fossil fuel extraction is consistent with climate limits? This will inform what is required of the United States.

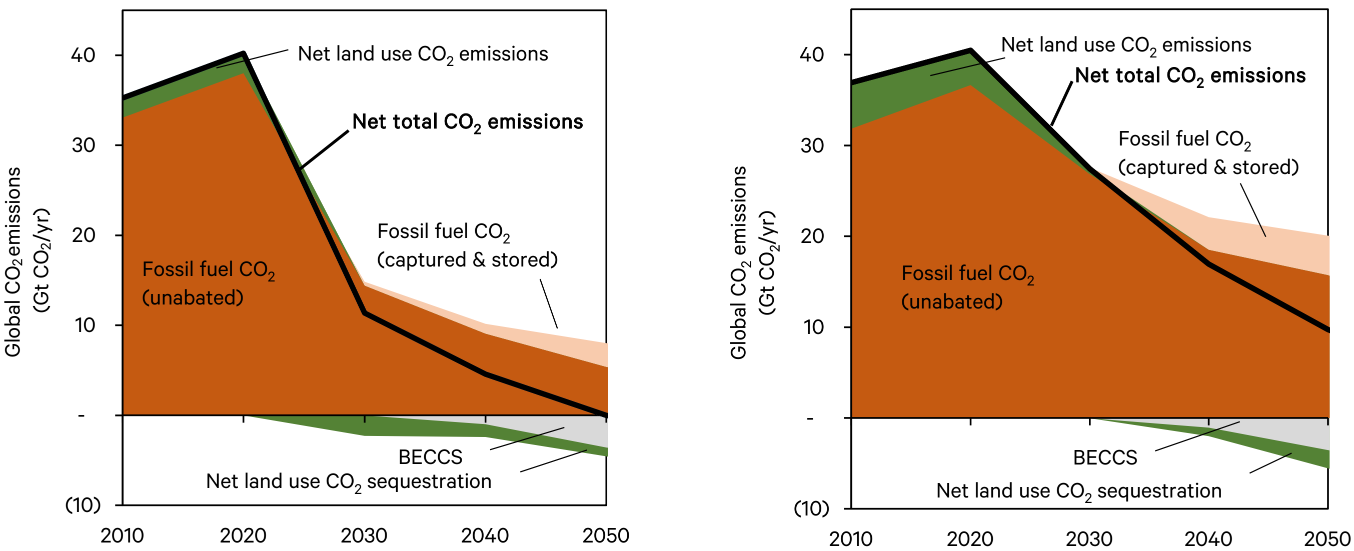
We suggest that a conservative interpretation of the Paris goals involves embarking on an emissions pathway that yields a high confidence of staying within the agreed-upon limits of 1.5°C and "well below" 2°C. Furthermore, in staying within those guardrails, there should be either no "overshoot" of the chosen temperature targets, or — at the most — overshoot that is time-bounded and limited (Schleussner et al. 2016; IPCC 2018).[1]

Figure 1 shows the required pace of global decarbonisation in order to limit warming above pre-industrial levels to 1.5°C with a 50% likelihood (left side) and within 2°C with a 66% likelihood (right side), based on the most recent IPCC modeling scenarios (Huppmann, Rogelj, et al. 2018). It is important to note this assumes a strategy with a 1-in-3 chance of failing to keep warming below 2°C; that is not, in our view, consistent with the spirit of the Paris Agreement, which held up this temperature threshold as a limit, not an aspirational goal. For the purposes of this analysis, however, we will take these 1.5- and 2-degree pathways as our benchmarks.

As seen in the black line, the IPCC models, in aggregate, show that global CO_2 emissions must peak virtually immediately, declining at an average rate of more than 10% per year (and reaching zero around 2050) to meet a 1.5-degree limit. To stay within the 2-degree limit, they must decline at about 4% per year for more than three decades. (By contrast, global CO_2 emissions over the last three decades have risen by an average of nearly 2% per year.)

Total global fossil fuel extraction for energy production must decline at roughly the same rate as CO_2 emissions, absent major new innovations in capturing CO_2 in ways that overcome social, ecological and economic constraints. (See Box.)

Figure 1. IPCC modeling scenarios that limit warming to 1.5°C (left panel) and 2°C (right panel) show CO_2 peaking by 2020 and then declining to below zero in the second half of this century.



Source: Author analysis of all IPCC scenarios categorized as meeting a 1.5-degree limit with a 50% probability and a 2-degree limit with a 66% probability (Huppmann, Rogelj, et al. 2018). This chart shows the median of model outcomes in each year, drawing from methods in Anderson and Peters (2016). As composite scenarios, neither panel represents a single, internally consistent scenario.

1 As stated by the IPCC (2018): "Overshoot trajectories result in higher impacts and associated challenges. Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of carbon dioxide removal (CDR) at rates and volumes that might not be achievable given considerable implementation challenges."

THE RISKS OF COUNTING ON NEGATIVE EMISSIONS TECHNOLOGIES

Development of CO_2 capture and storage (CCS) at a very large scale could in principle prolong the wind-down of global and U.S. fossil fuel production. However, widespread adoption of carbon dioxide removal technologies that would trap CO_2 or pull it out of the air remains highly speculative, due to major social, ecological and economic barriers. Of all negative emissions options, IPCC models lean most heavily on bioenergy production with CCS (or "BECCS") because this approach can not only remove carbon from the atmosphere (through tree and plant growth) but also displace fossil fuel use when the bioenergy is combusted or otherwise converted to energy. (For this reason, carbon sequestration through tree and plant growth alone offers less long-term potential, as shown in the green "wedge" in Figure 1.)

Yet the success of such technologies at a global scale relies on heroic assumptions about land availability and optimistic inferences about the carbon cycle (Kartha and Dooley 2016; Anderson and Peters 2016; Dooley et al. 2018). Indeed, in the IPCC model scenarios that keep warming within 2°C, the median amount of carbon captured at bioenergy facilities is 10 Gt CO_2 per year by the end of this century. That would be extraordinarily difficult to attain given competing uses for land and the attending ecological, economic and social constraints.[2] The IPCC (2018) cautions that large-scale reliance on carbon dioxide removal "is subject to multiple feasibility and sustainability constraints."

Given these uncertainties in CCS and other forms of negative emissions — as well as in the pace of reduction in gases other than CO_2 — staying within warming limits would require an especially cautious approach to fossil production. For example, policy-makers should plan on fossil fuel production for energy to decline at least as fast as the total (gross) CO_2 emissions from fossil fuel combustion, before negative emissions are captured and stored (e.g., the highest lines depicted in Figure 1.) An even less precarious approach would suggest that efforts to meet climate limits should "proceed on the premise that [negative emissions] will not work at scale" (Anderson and Peters 2016). Hence, fossil fuel production for energy should decline by the rates of net CO_2 emissions in Figure 1, or at least 4% per year on a sustained basis for a 66% chance of meeting a 2-degree limit.

The specific rate for different nations will vary. While science and economics can inform a global pathway towards zero net emissions (or the closely related concept of a carbon "budget", which is the cumulative amount of CO_2 allowed relative to a given climate objective), any differentiation of rates of phase-out among territories necessarily involves considerations of equity.

For two reasons, the U.S. should be among the countries that wind down fossil fuel production the fastest, faster even than the global rates depicted in Figure 1. First, the U.S. is one of the world's top fossil fuel producers – both historically and currently (BP 2018) — and therefore has already gained a disproportionate global share of the economic value associated with fossil fuels. Second, its robust economy is not heavily reliant on fossil fuel extraction. The share of fossil fuel extraction in U.S. GDP is among the lowest in the world – especially for oil, where profits from oil extraction comprise just 0.1% of U.S. GDP compared to about 1% on average across the globe (Lange et al. 2018).

2 The upper, biophysical limit for bioenergy potential has been estimated at ≈250 Exajoules (EJ) per year (Haberl et al. 2013), which would require a doubling of current human biomass harvest (all crops, feedstock and other materials). This suggests the potential for serious social, economic and ecological constraints (Searchinger and Heimlich 2015; Haberl et al. 2013). While some estimates of bioenergy potential in mitigation scenarios are well within this upper limit (Erb et al. 2012; Kraxner et al. 2013), many are close to or exceed it (GEA 2012; Humpenöder et al. 2014; Kriegler et al. 2013). Some prominent studies estimate as much as double this amount would be needed (IPCC 2000; Smeets et al. 2007), with the overall range of projections reaching as high as 1,000 EJ/year (Smith et al. 2014). Creutzig et al. (2015) note that beyond 100 EJ/year, there is decreasing agreement on the *sustainable* technical potential of bioenergy.

Principles to guide a U.S. fossil fuel wind-down

As a wealthy, industrialized nation that is also a top fossil fuel producer, the United States has an obligation to wind down fossil fuel production faster than the rest of the world. But the U.S. is a diverse nation in terms of natural resources, economies and cultures. How do we translate the national target for winding down fossil fuels into a coordinated plan that takes into account this diversity? Our goal is to provide a structure that helps policy-makers and other stakeholders to answer that question.

We articulate three guiding principles for winding down U.S. fossil fuel extraction. The principles described here can help inform considerations about where fossil fuel production should be wound down the quickest. Fossil fuel resource managers in the U.S. (e.g. at state-level departments of natural resources or at federal-level regional offices of the Bureau of Land Management) can use these principles to inform an approach to ramping down fossil fuel production in line with climate limits.

Principle 1: reduce fossil fuel production at a pace consistent with climate protection

Our first suggested principle relates to consistency with climate protection. As described above, meeting globally agreed climate limits will require a rapid and sustained winding down of fossil fuel use and production.

As a wealthy, industrialized nation that is also a top fossil fuel producer, the United States has an obligation to wind down fossil fuel production faster than the rest of the world.

This phase-out, based on IPCC analysis of climate scenarios, is the core of Principle 1. To meet a 1.5°C climate limit (with 50% likelihood), fossil fuel production should decline by about 10% per year. Meeting a 2°C limit (with 66% likelihood) would require fossil fuel production to decline about 4% per year. Consistency with climate protection therefore demands that resource managers plan for U.S. fossil fuel production to reduce at rates at least that fast.

Principle 1 has some precedent in the U.S. government's approach to resource management. Under the Obama administration, the Department of the Interior (DOI) planned to consider a "declining schedule" of coal production consistent with climate limits, making "judicious use of the land" as well as striving for "balanced and diverse resource uses that takes [sic] into account the long-term needs of future generations" (Vann 2012). These considerations suggest that the federal government can, and has already taken preliminary steps to, manage public lands in ways that would move it closer to reducing fossil fuel production at a pace consistent with climate protection.

It may also make sense to move even faster where fuels are the most carbon-intensive and costly, all else being equal. In general, getting the most energy value per unit of CO_2 would suggest that the most carbon-intensive fuels should be used the least, which in turn would suggest that a coal phase-out proceeds the fastest, oil nearly as fast, and gas close behind (Huppmann, Kriegler, et al. 2018). That said, consideration of GHGs other than CO_2, including highly potent methane (CH_4) associated with gas production, may suggest a faster phase-out of gas than included in most current assessments (Alvarez et al. 2018). Considering carbon intensity would also suggest prioritization within a particular resource type; for example, some oil deposits, such as oil sands, are especially carbon-intensive and should therefore be phased out especially quickly (Masnadi et al. 2018).

Getting the most economic value out of each unit of CO_2 may also suggest that — within each fuel type — fuels that are the most costly and therefore economically marginal would be phased out faster. Taking this into consideration would suggest a faster phase-out for assets with the highest marginal production cost for a given quality fuel (Fæhn et al. 2017).

Principle 2: accelerate the phase-out where economies are most resilient

This second principle relates to the resilience of communities to cope with a change in their economic structure, particularly when that structure is highly dependent on fossil fuel extraction. (Below we mainly use the term *communities* for simplicity, but the principles can be applied from community-level to sub-national region to country scale, even as the policy tools may differ at each level.)

More specifically, we assert that extraction should wind down more rapidly in communities that are more resilient to such a transition. As noted in the prior section, given the United States' economic strength and its role as a top fossil fuel producer, fossil fuel extraction must begin winding down immediately across the nation. However, that wind-down need not occur at a uniform pace across its diverse fossil-fuel-producing regions. Phasing out extraction more rapidly in highly resilient communities allows more time and resources for a well-managed, controlled phase-out in communities that are less able to adapt.

There are multiple components to resilience. One obvious and important factor is the relative dependence of communities on a region's fossil fuel employment and available alternatives (Pollin and Callaci 2018). Assessments of economic dependence should also include employees indirectly supported by the industry (e.g. in service industries) and residents reliant on pensions and other forms of industry-provided support.

Another important consideration is what financial support can be made available. Certain regions already have programs in place for skill development and economic diversification. For instance, Partnerships for Opportunity and Workforce and Economic Revitalization (POWER) is a congressionally funded initiative that supports strategic economic investments in communities negatively impacted by the changing economics of coal, particularly in Appalachia. More broadly, a just transition will require substantial investment in fossil-fuel-extraction based communities, such as workforce retraining and revenue replacement for local governments to fund basic services (Haggerty et al. 2018).

Beyond economic considerations, there are also important social and cultural components to resilience (Carley, Evans, Graff, et al. 2018). Transitions are likely to be most successful where they involve local communities in shaping their post-fossil-fuel economies (Muttitt and Kartha 2019). Important factors in a community's capacity for transition include the extent to which they understand their alternative local economic futures and accept the changes to come (Haggerty et al. 2018).

In total, this resiliency principle attempts to gauge and account for the *capacity* of a community to undertake an effective and equitable transition out of fossil fuel production. It recognizes that different communities will be expected to contribute to the low-carbon energy transition in different ways, depending on their capacity to do so.

Principle 3: safeguard human rights, cultural resources and the local environment

Principle 3 recognizes that, in many places of the world — including the United States — there have been conflicts between fossil fuel extraction and human rights, culture and environmental health (Greenberg 2018; Epstein et al. 2011).

For example, any region where extraction impinges on the rights of Indigenous people, including free, prior and informed consent, would suggest a faster wind-down of fossil fuel development. Areas that pose a high risk to public health and safety — such as regions with poor safety and reclamation records, or areas with high levels of pollution — would also wind down more rapidly. Additionally, extraction that disrupts ecosystems and leads to habitat fragmentation, particularly areas with high conservation value, would be prioritized.

Regions where these conflicts are the greatest would see a faster, more urgent wind-down of fossil fuel production, so as to minimize harm.

Applying the principles

These principles lend structure to policy debates on how to articulate a "declining schedule" for U.S.-wide fossil fuel production, including how that schedule might be applied across different fuels and reserves, as well as within individual basins.

The first step is to operationalize each of the principles. There are multiple different variables that may be used; some may be more relevant than others for a particular fuel or region. This process — as well as the ultimate implementation of any resultant plan — should be done in conjunction with a wide array of stakeholders. This mirrors many processes already in place, such as environmental impact assessments and the BLM's resource management planning processes. Thus, there is already a solid foundation for this type of stakeholder engagement.

Applying the principles requires assessments of multiple variables across different scales. However, it need not be especially complicated or data-intensive, particularly in assessing the relative pace of a fossil fuel basin's wind-down or who should have access to significant transition support.

To illustrate, we briefly apply the principles to the case of U.S. coal and U.S. onshore oil. This analysis is meant to illustrate how resource managers might operationalize the principles; it is not a comprehensive analysis (that is, it does not capture all the outcomes of implementing these principles) and should be not taken as a road map or prescription for a U.S. phase-out of fossil fuel extraction. (The case studies are presented in greater detail in Appendices A and B.)

Coal case study

Global coal production must drop precipitously to stay within the 1.5°C and 2°C guardrails (IPCC 2018). As noted previously, we would expect the U.S. to phase out its coal production even more rapidly.

U.S. coal production is concentrated in two dominant areas: the Powder River Basin in the west (especially the state of Wyoming), and the Appalachian Basin in the east (especially West Virginia, Kentucky and Pennsylvania). Smaller amounts of coal are extracted in the Midwestern United States, and in a handful of states in the Rocky Mountain region of the West (e.g., Colorado and Utah). All coal-producing regions must begin to decline production immediately, but which areas should decline most rapidly?

This is where the principles are a useful guide for structuring policy debate and decision-making. We start with Principle 1, which directs our attention to carbon intensity and resource cost. From this view, Appalachian coal could be a priority for phase-out because it generally carries a high cost (measured in terms of either dollars per ton or per unit of energy) (Morris 2016).

Principle 2 then focuses our attention on community resilience. When measured in terms of gross domestic product, the U.S. economy is the world's strongest; however, there is tremendous intra-national variation in wealth, economic diversification and adaptive capacity. Principle 2 suggests more rapidly phasing out fossil fuel production in the most resilient communities, to enable a more controlled, planned transition for communities more dependent on extraction. A transition in any coal community will no doubt be difficult, but a planned transition that is anticipated, and eased with wise policies, can help usher a community more smoothly into its post-extraction future.

There are multiple ways of capturing resilience. Employment and economic activity are two important fiscal considerations. Using this lens, Principle 2 again focuses attention on Appalachian coal as a priority for phasing out. Even though it is one of the dominant coal-producing basins in the U.S., only 2% of Appalachia's employment and 8% of its economic activity is based directly on coal (see Appendix A).

Finally, Principle 3 concerns human rights, cultural and ecological concerns. Available research strongly indicates that coal mining poses numerous threats to human rights and the environment (Epstein et al. 2011; Greenberg 2018). Appalachian coal mines are among the most regular sites of mine accidents, according to data by the Mine Safety and Health Administration (MSHA 2018). Data suggest that there are roughly six accidents per 100 mine employees each year in Appalachian mines, compared to one accident per 100 mine employees in Powder River Basin mines. The Illinois basin also has a higher accident rate, as well as higher sulfur content. For these reasons, it may also be prioritized (see Appendix A). A more comprehensive assessment would also consider air pollution levels and attributable rates of chronic disease, other forms of surface and groundwater contamination, and mercury exposure incidents that we do not address here.

Environmental damage is also particularly marked in Appalachia as a result of the extensive use of mountaintop removal. While all surface mining impacts the landscape, mountaintop removal is particularly destructive; it damages streams, increases erosion and results in deforestation. Furthermore, Appalachia is a biodiversity hotspot (Epstein et al. 2011), raising the level of concern.

Briefly applying the three principles to U.S. coal suggests that all coal production regions should begin a phase-out immediately, and that Appalachian coal may be prime for an especially rapid phase-out. The Illinois basin also garners attention for its relatively high impact on public safety and the environment.

Onshore oil case study

Meeting the Paris Agreement's upper limit of 2°C, let alone 1.5°C, requires that global oil production peak within just a few years, declining sharply by 2030 (IPCC 2018). As for coal, Principle 1 suggests that a phase-out of U.S. oil production begin immediately. The question next is: what extraction zones should phase out most rapidly?

Principle 1 provides an initial guide by directing us to carbon intensity and resource cost. Certain oils require more energy to extract, and, as a result, have a higher carbon intensity (Gordon et al. 2015). Principle 1 suggests prioritizing the phase-out of the most carbon-intensive oils, such as heavy oils and those whose production emits large quantities of methane (Masnadi et al. 2018).

One of the most carbon-intense oils in the U.S. is the heavy oil in California's San Joaquin basin, especially in the Midway Sunset field, according to an assessment by Gordon et al. (2015). Midway Sunset has an overall, "well-to-wheels" GHG emissions intensity of over 700 kg of CO_2 equivalent per barrel crude. To put this number in perspective, Canada's Athabasca oil sands in Alberta have an intensity of about 730 kg of CO_2 equivalent (e) per barrel, and the world average is about 500 kg CO_2e per barrel (Gordon et al. 2015). Other oils from the San Joaquin basin, such as from the South Belridge field, also have a carbon intensity of well over 600 kg CO_2e per barrel. Principle 1 would imply that the San Joaquin basin should undergo a rapid phase-out of oil extraction.

Principle 1 also suggests that areas of the country that are newly developing or expanding oil production should be carefully considered. These expansions may make an ultimate transition to a low-carbon pathway more challenging, since they are clearly inconsistent with Principle 1's climate limits and lock in new oil production (Erickson et al. 2015). From that perspective, the Permian basin in Texas and southeastern New Mexico, where oil production is set to rise, should be a priority.

Principle 2 concerns resilience. As in the case of coal, oil regions with more diversified economies are more resilient and thus able to wind down extraction more quickly. Several major U.S. oil-producing basins are in regions where oil revenue makes up less than 10% of local GDP. They include the Niobrara basin in Colorado and Wyoming (3%), the Anadarko basin in Oklahoma and Texas (8%), and the San Joaquin basin (3%) (see Appendix A for details).

Fiscal policy may also yield variation in resilience and adaptive capacity. For example, oil-producing states invest varying shares of production tax revenue into dedicated long-term funds as a buffer against volatility (Headwaters Economics 2014). Such trusts could potentially support long-term planning and economic diversification.

Finally, Principle 3 takes into account negative impacts on human rights and key natural resources. There are certain areas that emerge where these threats are particularly acute. Alaska's North Slope, where oil extraction threatens Indigenous subsistence, is one such area. There is concern that onshore drilling on the North Slope threatens the habitat of caribou, which the Gwich'in Indians rely on for food and clothing (National Research Council 2003). Although uncertainty remains as to the precise impact of oil development on caribou, there is broad agreement that industrial development disrupts typical behavioral patterns (Dyer et al. 2001; Johnson and Russell 2014; Plante et al. 2018). Moreover, given the gravity of the threat to Indigenous rights, uncertainty is a compelling reason to err on the side of caution and prioritize winding down extraction on Alaska's North Slope. At the same time, we must recognize that there are Alaska Native corporations that support oil and gas development. It is important to keep in mind that Indigenous communities are diverse, often with nuanced approaches to extraction. This is a tension that we will return to later in this paper.

Applying Principle 3 to oil also returns our attention to the San Joaquin basin in California. The myriad public health impacts associated with oil extraction are significant, and have been shown to be elevated for those living in close proximity to wells (Field et al. 2014; McKenzie et al. 2012). It is also important to consider who is impacted. Frequently, communities of color and low-income neighborhoods bear a disproportionate burden. In 2014, Hispanics or Latinos made up 45% of people living within one mile of an oil or gas well in California, compared with 35% statewide (Srebotnjak and Rotkin-Ellman 2014). Most California oil production also is in areas that the state has already identified as being disproportionally burdened by pollution (Erickson et al. 2018). This is what advocates refer to as the "double jeopardy" of environmental injustice: those who are already vulnerable given social, economic and political variables are also at greater risk for environmental contamination (Morello-Frosch et al. 2001).

In sum, this brief assessment points to a rapid phase-out of oil production across the U.S., and especially in California's San Joaquin basin. This is a region where the three principles are in alignment: 1) its oil is highly carbon-intense and costly; 2) oil revenue makes up a relatively small share of local GDP; and 3) there is a tremendous opportunity to advance environmental justice by rapidly winding down extraction. Furthermore, addressing areas where oil production is currently set to expand, such as the Texas Permian basin, may also be a high priority.

Discussion

This brief analysis provides an illustration of how resource managers might operationalize our three guiding principles, as well as underscores the larger point that this need not be a data-intensive or complex process.

The accessibility of this process is important not only from a policy-maker or departmental-capacity perspective, but also from a stakeholder engagement perspective. The success of planning and implementing a phase-out hinges on broad-based, meaningful engagement with a diverse range of stakeholders, including local, regional and federal governments, businesses, civil society organizations, tribal representatives, and impacted communities.

The public has an important role to play in determining how to put the principles into practice. That includes working with decision-makers to identify what factors are relevant for a given extraction region and how to assess them. Transitions are most successful when they have the full participation of those impacted (Muttitt and Kartha 2019). Moreover, equity is as much about process as it is about outcome; it is vital that the process, as well as the plan, is fair, equitable and just.

Public engagement is also vital for mediating between the different principles when tensions emerge — and they will emerge, as this paper's cursory exercise reveals. For example, Principle 2 might appear to be in tension with Principle 1. Clearly, the rapid wind-down of a region's fossil fuel production may be warranted by climate limits, while also stressing the abilities of many communities to adjust their economies. What is the appropriate course when those communities that produce the most carbon-intense and expensive fuels are also the least resilient? Communities that are deeply entangled with fossil fuel production and do not have the resources to adapt should not bear a disproportionate burden of transition costs. However, distributing those costs equitably and securing transition support will require meaningful engagement between decision-makers at different scales, from the national level to the local level.

Applying Principle 3 to the case of oil reveals another possible area of tension. While the Gwich'in tribe is concerned that drilling on the North Slope may negatively impact caribou, some Alaska native corporations support and benefit from oil and gas development. Such tensions also emerge in coal regions. For example, the Northern Cheyenne Tribe and the Crow Tribe — located in close proximity geographically — take very different positions on coal (Volcovici 2017). The Northern Cheyenne Nation has gone so far as to sue to stop coal mining on federal land, whereas members of the Crow Tribe are advocating for coal exports in order to access new markets for coal and expand extraction (Hansen 2017; Indianz.Com 2017). Intra-group tension and differing interests are not limited to tribes. This will likely feature in all communities and is a core reason that meaningful stakeholder engagement is vital to developing and implementing a wind-down in fossil fuel extraction. As noted in the discussion, stakeholder engagement is already built into many of our planning processes at the national, state and regional level. These can serve as a foundation.

In addition, there may also be interaction effects between the principles that require public engagement to mediate. For example, fossil fuel extraction sites and regions that rate as high priorities under Principle 3 — due to high levels of air and water pollution, or the infringement of Indigenous rights— may

OPPORTUNITIES FOR APPLYING FOSSIL FUEL WIND-DOWN PRINCIPLES ON U.S. FEDERAL LANDS

Federal lands are a major source of fossil fuels produced in the U.S.: they produce 40% of all coal, over one-fifth of all oil, and about one-sixth of all gas (U.S. EIA 2015), together representing nearly a quarter of total U.S. CO_2 emissions (Merrill et al. 2018). On these lands, the U.S. Department of the Interior (DOI) has clear authority and discretion to stop or phase out licenses to produce oil, coal and natural gas. Although DOI is currently pursuing the opposite approach in the name of "energy dominance", several aspects of DOI's mandate and prior work make it the natural starting point to examine how resource managers could implement a declining schedule of U.S. fossil fuel production.

Most pertinently, in 2016, DOI released a "Scoping Report" that considered how to manage a coal phase-out; this was background research to support an eventual Programmatic Environmental Impact Statement (PEIS) for the Bureau of Land Management (BLM)'s coal program (BLM 2017; BLM 2016). The Report examined, among other things, how the existing Resource Management Plan process could be used to decrease fossil fuel production.

Broadly speaking, Resource Management Plans specify which areas of onshore U.S. federal lands will be made available for leases to extract coal, oil or gas. In principle, no areas need be made available for fossil fuel leasing, if fossil fuel extraction is considered a threat to the quality of other ecological resources or uses. Since the connection between fossil fuels and increasing climate-related damages is strong (Reidmiller et al. 2018), this argument would not seem difficult to make. Furthermore, there is some precedent for removing large quantities of federal lands from fossil fuel leasing due to a large-scale ecological concern (Pidot 2018). (Options that are less ambitious than ending new leasing are discussed in the BLM Scoping Report, including market-based solutions such as increasing competition among firms bidding for new leases and royalty "adders" based on the social cost of carbon; these options are less consistent with the framework in this paper.)

Offshore fossil fuel leasing is managed through a different but analogous process that sets out five-year leasing plans. The Department of the Interior is not obligated to lease oil or gas for development in these leasing plans. Furthermore, a President may permanently remove areas from leasing under the Outer Continental Shelf Lands Act (OCSLA), as President Obama did for much of the U.S. Arctic, citing climate change as a rationale (The White House 2016b). While the authority of a subsequent President to reverse a withdrawal under OCLSA is currently in litigation, there is no dispute over a President's authority to withdraw further areas.

be less economically resilient (Principle 2) than other regions, and therefore have even greater needs for new economic diversification and development.

More complex modeling and extensive data may also be valuable in some instances. For the purposes of this exercise, we focused on the fiscal component of resilience — however, truly capturing community resilience requires considering multiple dimensions. This includes not only quantitative economic data, but also quantitative and qualitative data on governance, institutional capacity, and identity (Carley, Evans, Graff, et al. 2018; Carley, Evans and Konisky 2018).

Furthermore, resource managers would also benefit from more and better models for how to undertake successful transitions (Strambo et al. 2019). The literature on how to evaluate resilience and support fossil-fuel-producing communities in the midst of energy transitions is growing rapidly (Carley, Evans, Graff, et al. 2018; Green 2018; ITUC 2017; Piggot et al. 2019; Strambo et al. 2019). Still, there are relatively few examples of successful past transitions to draw from — at least not transitions that were fostered by policy and aiming to alleviate adverse impacts.

All that said, this brief analysis highlights some areas worthy of focus and greater attention. An application of the three principles draws attention to Appalachian coal as one possible area to prioritize. Similarly, there is a strong rationale for prioritizing a phase-out of oil extraction in California's San Joaquin oil basin and for avoiding further new development in areas poised to expand extraction, like the Permian basin in Texas and New Mexico. This is not intended as a policy prescription, as our analysis was presented as an example, not a comprehensive assessment. The goal is simply to demonstrate that the principles can lend structure to a debate that is otherwise perceived as so unwieldy it is likely to be put off.

Conclusions

It may seem that now is an inopportune time to write about a fossil fuel phase-out, when large parts of the U.S. federal government have been running in an entirely different direction. And yet the rapidly changing climate — and mounting evidence of the need for urgent action — demands, in our view, that we begin thinking through how to manage a fossil fuel production phase-out in ways that are rapid, effective and equitable.

This working paper introduces a topic that, though critical for managing a transition to a low-carbon economy, has not been widely examined. Namely: how should society decide which regions will be the first — and the fastest — to leave their fossil fuels undeveloped, and forego the socio-economic contribution from extracting coal, oil and gas?

The question of how the United States should manage a wind-down of fossil fuel production is not one that we — or any group of policy researchers — are qualified to answer. That will require a democratic dialogue — one that engages impacted communities, trade unions, state and local governments, resource managers, and other key stakeholders. But our hope is that the principles that we outline here provide a useful structure for guiding such dialogue.

In the absence of such proactive dialogue, those with power — chiefly, the fossil fuel industry (and allied governments) — will provide their own answer to the question of who gets to extract and how much. Alarmingly, that answer could well be the status-quo. The long-term energy outlooks of major fossil fuel companies predict that extraction will continue at near-current rates, putting society and ecosystems at risk of collapse from runaway climate change.

Fossil fuel resource managers are increasingly ready to explore options for reducing coal, oil, and gas production, and the momentum is growing. As recently as 2017, the U.S. Department of the Interior considered how to approach a "declining schedule" of U.S. fossil fuel production. It may do so again in the coming years, which will provide the opportunity to use federal leadership to begin a fossil fuel wind-down on federal lands in line with climate limits (See Box).

Several countries — including New Zealand, France and Spain — are already winding down new exploration and production, providing more certainty to their oil and gas industries (Erickson et al. 2018). Within the U.S., California and other U.S. states are exploring whether and how to limit fossil fuel production on climate grounds, while striving towards a "just transition" for affected communities.

U.S. federal and state agencies have the opportunity to shape the direction of climate and energy policy. The Department of the Interior, the Department of Energy and the Environmental Protection Agency — as well as the analogous departments at state governments throughout the country — can articulate national and regional strategies for the long-term wind-down of U.S. fossil fuel production (coupled with transition support). They can also lead the way by phasing out fossil fuel extraction from lands owned by the public.

As the world's largest historic CO_2 emitter and fossil fuel producer, the U.S. must take on a leadership role in aligning fossil fuel production with climate limits.

Appendix A: Applying the principles to the wind-down of U.S. coal and onshore oil

Case study 1: U.S. coal

Here we evaluate how the principles described above could be put into practice for articulating, and ultimately implementing, a wind-down of U.S. coal extraction.

As noted in the main body of this paper, U.S. coal production is located mostly in the Powder River Basin in the west (especially Wyoming) and the Appalachian Basin in the east (especially West Virginia, Kentucky and Pennsylvania) (see Table A-1).

Table A-1. Top coal producing-basins and states in the U.S.

Basin	Major State(s)	Production, 2016 (million tons)	Percent from federal land
Powder River Basin	Montana, Wyoming	319	78%
Appalachian Basin	West Virginia, Kentucky, Pennsylvania	206	0%
Illinois Basin	Illinois, Indiana	72	0%
Gulf Coast Basin	Texas	45	0%
Williston Basin	North Dakota, Montana	28	17%
Uinta/Piceance Basin	Colorado, Utah	18	38%
Greater Green River Basin	Colorado, Wyoming	17	44%
All other		22	n/a
Total (million tons)		**728**	**40%**

Source: SEI analysis based on data from the U.S. Energy Information Administration (2017; 2018c) and U.S. Office of Natural Resource Revenue (2018)

Applying Principle 1 to coal: U.S. wind-down begins immediately

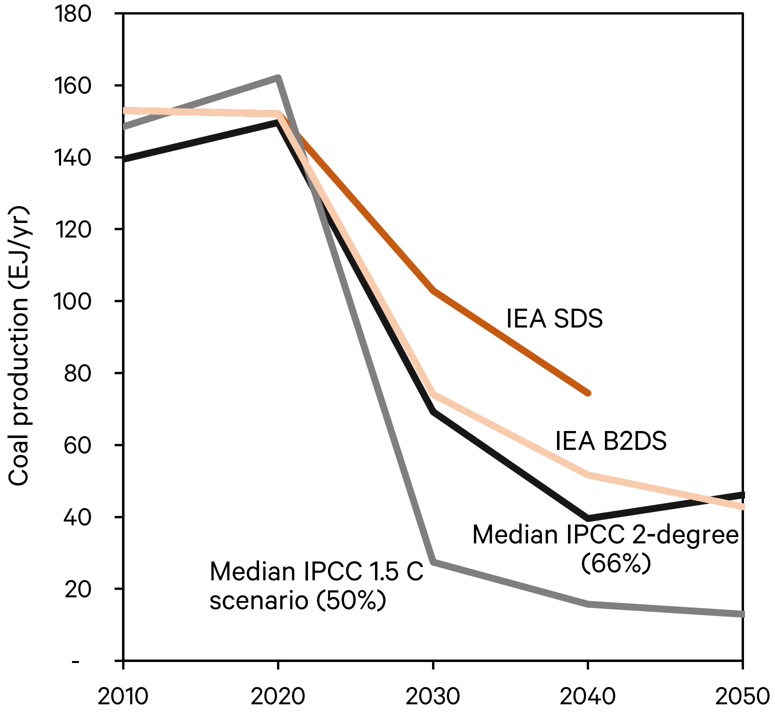
To understand the pace of an exit from U.S. coal, we start with recent scenarios for global coal production compiled by the Intergovernmental Panel on Climate Change, or IPCC (Huppmann, Kriegler, et al. 2018), supplemented with those from the International Energy Agency (IEA 2017a; IEA 2017b) (Figure A-1). These scenarios show global coal declining immediately and sharply. To meet a 1.5°C limit, global coal production would need to decline by 80% in the next decade; it would need to decline by more than half to stay within a 2°C limit. We would expect this decline to be even more immediate and marked for the United States.

Principle 1 further suggests a faster phase-out for particular regions or types of coal in the United States. Chiefly, Appalachian coal could be a priority for a phase-out, with dedicated transition support. Appalachian coal is generally higher cost (measured as either dollars per ton or per unit of energy) and yields fewer profits than other coal. For this reason, it is already economically vulnerable. Recent experience in the U.S. suggests that this vulnerability has already threatened the region's coal (Morris 2016).

Certain coal deposits in the west contain metallurgical coal, which is used in steelmaking. At present, there are few replacements for metallurgical coal available at scale. This suggests that any phase-out of metallurgical coal may proceed more slowly. However, use of this type of coal currently accounts for less than 10% of U.S. coal consumption and production (U.S. EIA 2017).

In summary, Principle 1 suggests that all U.S. coal used for energy production would need to be phased out rapidly, and that an even faster transition in Appalachia could be warranted.

Figure A-1. IPCC 1.5°C and 2°C scenarios show global coal production dropping precipitously.
Lines here indicate the median coal production in each year, across all scenarios in the IPCC's 1.5°C scenario database, that have a 50% chance of meeting the 1.5°C limit without overshoot and a 66% chance of meeting the 2°C limit without overshoot. The peach line displays IEA's Beyond 2°C (B2DS) scenario, itself designed to meet the 2°C limit with a 66% chance.



Applying Principle 2 to coal: U.S. economy resilient, even as individual regions are less prepared

The U.S. economy is both among the world's strongest, when measured by gross domestic product (GDP), and among those least dependent on coal mining. Coal extraction accounts for only 0.04% of U.S. employment (see Table A-2). Additionally, the U.S. does not have urgent energy access needs, as do many poorer countries.

Within the U.S., areas with diversified economies have an even higher capacity to move away from a dependency on coal mining, especially if infrastructure for workforce retraining programs, access to capital, and community reinvestment are made available to these areas.

For example, even as the Appalachian basin produces a large share of the nation's coal, it is one of the regions least dependent on the coal industry for employment and economic activity. Basin-wide, only 2% of the region's employment and 8% of its economic activity is based directly on coal (see Table A-2). Note that the very high share of coal revenue of GDP in the Powder River Basin (and perhaps other basins, too, e.g. Williston) is partly a function of the revenues not staying in those local communities. In other words, the revenue from the sale of the coal goes to out-of-region owners and activities rather than contributing to local GDP.

At the same time, particular counties within Appalachia are more dependent on coal than the region as a whole. For example, coal accounts for as much as one-fifth of local employment in Boone County and Wyoming County in West Virginia. This highlights the importance of attending to local variation in economic activity, as well as the need for supportive policies and resources in regions that are particularly dependent on extraction (Pollin and Callaci 2018).

Other coal basins — such as the Illinois Basin, the Greater Green River Basin, and the Gulf Coast Basin — also have diversified economies where coal represents less than 10% of each region's employment and economic activity.

Table A-2. Coal as share of local economy by basin

Basin	Production, Million short tons, 2016	Coal employment, 2016	Employees per million tons, 2016	Coal share of local employment, 2016	Coal revenue as share of local GDP, 2016	Accidents per employee
Powder River Basin	319	5,907	18	15%	99%	0.01
Appalachian Basin	206	31,530	153	2%	8%	0.06
Illinois Basin	72	6,109	85	2%	10%	0.05
Gulf Coast Basin	45	2,222	50	2%	4%	0.02
Williston Basin	28	1,272	45	12%	31%	0.01
Uinta / Piceance Basin	18	1,685	92	5%	23%	0.02
Greater Green River Basin	17	1,869	107	4%	7%	0.03
All other	22	3,451	155	n/a	n/a	n/a
Total	**728**	**54,045**	**74**	**0.04%**	**0.1%**	**0.04**

Source: SEI analysis based on data from the U.S. Energy Information Administration (2017), MSHA (2018), BLS (2018), and BEA (2018) (see Appendix B for more on data and methodology)

Without question, the transition in any coal community would be difficult, even for those with other economic opportunities in the region. A carefully managed decline, however, is much less difficult than one that is disruptively and haphazardly unleashed upon a community through unmitigated market forces. A just transition requires investment in these communities, such as workforce retraining and revenue replacement for local governments to fund basic services (Haggerty et al. 2018).

Coal mining is often deeply intertwined with the community's cultural identity. In areas where mining has existed for generations, this identity is particularly well-established and the decline of the industry is keenly felt. Coal companies may even purposefully construct or reinforce that identity to further their own interests (Bell and York 2010; Carley, Evans and Konisky 2018; Haggerty et al. 2018; Lewin 2019). However, a historical reliance on extractive industries should not condemn these communities to insecure jobs in a declining sector. The costs of the transition out of coal production can be borne fairly, by those actors with the most capacity and responsibility to fund a clean transition.

Applying Principle 3 to coal: multiple human rights and environmental infractions suggest an even more rapid phase-out in some areas

As described in the main body of this report, available research strongly indicates that coal mining poses numerous threats to human rights and increases environmental stressors (Epstein et al. 2011; Greenberg 2018), particularly in Appalachia and the Illinois basin. Additional considerations not mentioned previously include the particular characteristics of that region's coal, such as sulfur content and mercury abundance. These can vary between and within basins, as can practices for addressing these risks and broader coal mining practices. Practices for capturing methane releases also likely vary among basins and mines.

It is also possible that lands used for coal mines could be put to more socially or economically productive uses. Federal lands in particular require consideration of multiple uses, a factor that may therefore have special implications for how western coal is assessed under this framework. For example, rather than extraction, the federal government could lease federal land for renewable energy development or grazing; federal land may also provide recreational opportunities and contribute to an outdoor economy.

Lastly, engagement with local Tribes can further clarify potential impacts on their cultural resources and rights (including applicable treaties). Although there are Indigenous communities that have emerged as vocal opponents to fossil fuel extraction, they are by no means a monolith. For example, the Northern Cheyenne Tribe and the Crow Tribe — located in close proximity geographically — take very different positions on coal (Volcovici 2017). The Northern Cheyenne Tribe has gone so far as to sue to stop coal mining on federal land, whereas members of the Crow Tribe are advocating for coal exports in order to access new markets for coal and expand extraction (Hansen 2017; Indianz.Com 2017). Meaningful engagement is necessary to identify and mediate diverse interests.

Summary assessment

This brief assessment is captured in Table A-3. This assessment is intended to be illustrative rather than comprehensive, and blank spaces here should not be taken to mean a lack of priority. That said, even a cursory investigation sheds light on areas of possible prioritization. Namely, each of the three principles directs attention to Appalachia as a critical region for more research and investigation.

Table A-3. Preliminary assessment of U.S. coal basins against principles.

Basin	Principle 1 – Reduce at a pace consistent with climate protection	Principle 2 – More rapid phase-out in more resilient communities	Principle 3 – Safeguard human rights and environment
Powder River Basin and vicinity		Fewer people employed per ton of coal mined	
Appalachian basin	Higher cost of coal extraction	Coal represents low share of regional employment and economic activity	High accident rate High ecological cost, e.g. mountain-top mining
Illinois Basin		Coal represents low share of regional employment and economic activity	High accident rate High sulphur coal
Gulf Coast Basin		Coal represents low share of regional employment and economic activity	
Williston Basin			
Uinta/Piceance Basin			
Greater Green River Basin		Coal represents low share of regional employment and economic activity	

This assessment is intended to be illustrative rather than comprehensive, and blank spaces here should not be taken to mean a lack of priority.
Source: SEI analysis.

Case study 2: U.S. onshore oil

Meeting the 2°C, let alone 1.5°C, temperature limits of the Paris Agreement requires that global oil production peak within just a few years, declining sharply by 2030 (IPCC 2018). As noted, the difficult question is where to phase out production most rapidly.

This case study applies the three principles advanced in this paper to onshore oil drilling in the U.S. For the purpose of this demonstration, we have limited our attention to onshore oil given the relative ease in quantifying direct economic dependence. In particular, we examined the seven most productive onshore oil basins in 2016, listed in Table A-4. Together, these seven basins accounted for 83% of onshore oil extracted in 2016. The principles could certainly be extended to offshore drilling.

Table A-4. Top oil-producing basins and states in the U.S.

Basin	Major State(s)	Production, 2016 (million barrels)	Percent from federal land
Permian	Texas, New Mexico	739	1%
Eagle Ford	Texas	457	0%
Bakken (Williston)	North Dakota, Montana	385	7%
North Slope	Alaska	179	0%
Niobrara (Green River/Powder River)	Colorado, Wyoming	158	9%
Anadarko	Oklahoma, Texas	149	0%
San Joaquin	California	141	7%
All other		442	n/a
Total (million barrels)		**2,651**	**6%**

Source: SEI analysis based on data from the U.S. Energy Information Administration (2017; 2018c) and U.S. Office of Natural Resource Revenue (2018).

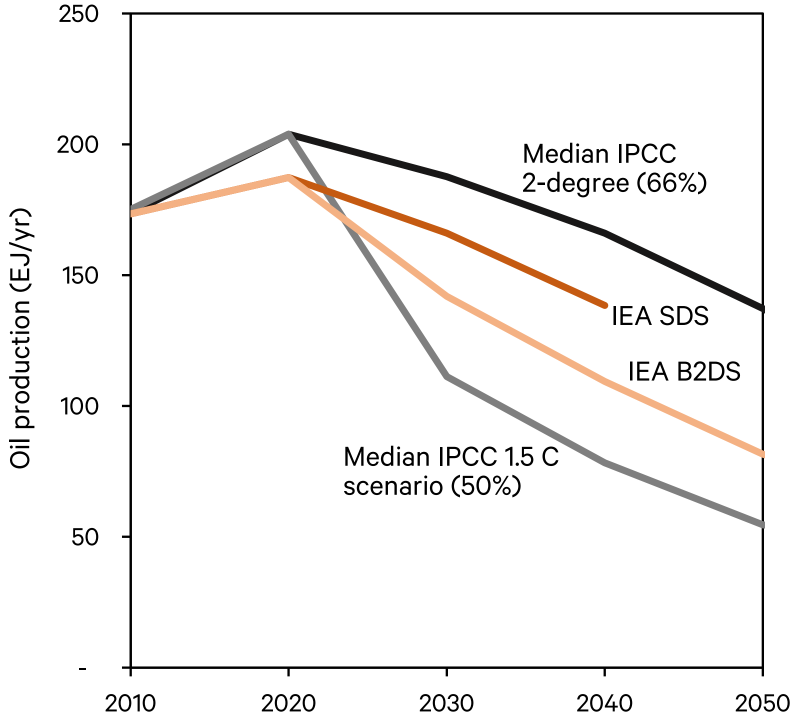
We consider each principle in turn, identifying core concerns and possible tools for operationalizing. Next, we zoom out to examine lessons for U.S. onshore oil extraction as a whole.

Applying Principle 1 to U.S oil: Winding down investment in new U.S. oil supplies begins immediately, with a clear priority to further phase-out existing carbon-intensive and expensive California oil

As with the coal case study, here we also start with global pathways for a fossil fuel phase-out drawn from the IPCC (Huppmann, Kriegler, et al. 2018), supplemented with those from the International Energy Agency (2017a; 2017b).

These scenarios, shown in Figure A-2, show global oil use and production peaking in the very near term, and dropping at a median rate of about 1% per year globally under the IPCC's 2-degree scenarios, and 6% per year under the IPCC's 1.5-degree scenarios.

Figure A-2. IPCC and IEA scenarios show global oil production peaking in the very near term.
Lines here indicate the median oil production in each year, across all scenarios in the IPCC's 1.5°C scenario database, that have a 50% chance of meeting the 1.5°C limit without overshoot and a 66% chance of meeting the 2°C limit without overshoot. The peach line displays IEA's Beyond 2°C (B2DS) scenario, itself designed to meet the 2°C limit with a 66% chance.



For context on these rates of decline, the IEA has estimated that the world's already existing oil fields — if not drilled further — would decline at a rate of about 8% per year (IEA 2018). That is only slightly faster than the decline rate of about 6% per year under a 1.5-degree scenario, as shown in Figure A-2. This means that ceasing new oil exploration and development would help attain climate goals, and that there is very little (if any) room under a 1.5-degree limit for new investment to maintain oil supply. This finding stands in stark contrast to U.S. government and oil industry expectations about continued growth, driven especially by the Permian Basin in Texas and New Mexico (U.S. EIA 2018a).

Other considerations for deciding which oils to prioritize for a phase-out include carbon intensity and resource cost. Certain oils require more energy to extract, and, as a result, have a higher carbon intensity, as described in the main body of this report. Different oils are also used for an ever-growing set of products, with varying carbon footprints. Consequently, taking into account the full life-cycle impacts — from extraction to refining to combustion — there is a wide range of greenhouse gas (GHG) intensities for different oils (Gordon et al. 2015). Principle 1 suggests prioritizing the phase-out of the most carbon-intensive oils, such as heavy oils and those whose production emits large quantities of methane (Masnadi et al. 2018).

In addition to carbon intensity, Principle 1 further implies a rapid wind-down for higher cost and higher risk oils, on the theory that those oils have fewer profits to "lose" under a low-carbon transition, and may lead to stranded assets if not otherwise restricted. By that standard, most new (not yet discovered) oil developments, especially those offshore, are riskier, with high breakeven oil price economics. These new developments — as well as select onshore fields (again, as in California's San Joaquin basin) — could be priorities for leaving undeveloped (Erickson et al. 2016; Erickson and Lazarus 2018).

Applying Principle 2 to U.S. oil: diversified economies enable accelerated transitions

At the core of Principle 2 are justice and fairness for the communities that are dependent, to varying degrees, on extraction. Although it is important to start phasing out extraction across all communities in order to prevent further carbon lock-in, and to reach a pathway consistent with limiting warming "well below" 2°C or to 1.5°C, Principle 2 argues that fairness requires accelerated transitions in the extraction zones that are most economically resilient. This allows less resilient communities that are highly dependent on fossil fuel extraction more time for a somewhat slower, managed transition.

As in the case of coal, oil regions with more diversified economics are more resilient and thus able to wind down extraction more quickly. Major oil-producing basins where oil revenue makes up less than 10% of local GDP include the Niobrara, Anadarko, and San Joaquin basins (3%, 8%, and 3%, respectively) (see Table A-5). Note that the very high share of oil revenue in the GDP in Alaska's North Slope (and likely also in the Permian, Eagle Ford, and Bakken regions) likely is in large part a function of the revenue not staying in the local communities. In other words, the revenue from the sale of the oil goes to out-of-region owners and activities rather than contributing to the local GDP.

Table A-5. Oil as a share of the local economy by basin

Basin	Production, Millions of barrels, 2016	Oil revenue as share of local GDP, 2016
Permian	739	37%
Eagle Ford	457	41%
Bakken	385	85%
North Slope	179	>100%
Niobrara	158	3%
Anadarko	149	8%
San Joaquin	141	3%
Total	**2,209**	**15%**

Source: SEI Analysis based on data from the U.S. Energy Information Administration (2017; 2018b; 2018d) (see Appendix B for more on data and methodology)

Principle 2 also implies phasing out production more quickly and halting new development in areas with alternative economic options. The community of Paonia in Colorado's North Fork Valley offers one example. Paonia forged a new economic reality after experiencing a coal-related boom-bust cycle. Known for its wineries, boutiques and galleries, it now has a vibrant tourist industry. It is also home to Solar Energy International, which trains solar panel technicians, and hosts extensive organic agriculture (Colman 2018; Hood 2017). However, the area is now facing the prospect of a surge in oil and gas development. The Trump administration posted 2,800 acres of federal land in the North Fork Valley for sale on October 26, 2018 (BLM 2018; Webb 2018) . If the availability of new lands for oil development leads to new extraction, that could threaten Paonia's burgeoning new industries. Principle 2 would suggest additional protection for extraction-dependent communities that have already initiated economic diversification, be that accelerated wind-downs or protection from new development.

Applying Principle 3 to U.S. oil: human rights and environmental injustice heighten attention on North Slope and the San Joaquin basin

Broadly, Principle 3 prioritizes rapidly phasing out oil extraction that violates human and Indigenous rights, threatens public health or safety, or threatens key natural resources.

There are certain areas that emerge where these threats are particularly acute. As noted, Alaska's North Slope, where oil extraction threatens Indigenous subsistence, is one such area. Offshore drilling has pushed bowhead whales, which the Iñupiat Eskimos have hunted for hundreds of years, further offshore.

This has increased both the risk to hunters and of spoilage (National Research Council 2003). There is concern that onshore drilling on the North Slope threatens the habitat of caribou, which the Gwich'in Indians rely on for food and clothing (National Research Council 2003).

The Greater Chaco Canyon area offers another example where extraction threatens human rights and unique cultural resources. It falls in the San Juan Basin, which spans northwest New Mexico and southwest Colorado. The basin produces primarily gas, but crude oil extraction is gaining momentum (Natural Gas Intelligence n.d.). Chaco Canyon, filled with remnants of Indigenous architecture and artifacts dating from 850 to 1250 A.D., is described as "the most significant cultural site in the United States" (Moe 2017). As a National Park and UNESCO World Heritage Site, Chaco Canyon itself is protected. However, the Greater Chaco Canyon area is not. There is concern that drilling, particularly hydraulic fracturing, near Chaco Canyon could destroy irreplaceable artifacts that scientists and local experts are still mapping and recovering (Moe 2017). The Navajo Nation has vocally opposed drilling near Chaco Canyon, which includes some of the only remaining undeveloped land in the San Juan Basin (Manus et al. 2018). In March 2018, BLM cancelled a proposed lease sale for parcels near Chaco Canyon amid protests. However, it may again offer such parcels for lease after completing a cultural analysis (BLM 2018). There is also the more nuanced challenge that most of the tribal land in this region is "split estate": the Navajo Nation owns the surface rights, while the federal government owns the mineral rights (Thompson 2018).[3]

Principle 3 also directs our attention to health and safety impacts. This includes both acute and chronic impacts. One acute threat is the risk to those living along rail corridors and pipelines, which Burton and Stretesky (2014) suggest is a human rights issue. Transporting crude oil — a flammable liquid — is inherently risky. Following incidents in Quebec, Alabama, and North Dakota, many expressed concern that Bakken crude may pose an elevated risk relative to other crude oils (de Place and Abbotts 2014; Gold 2014). Although uncertainty remains, Bakken crude has been shown to have higher mean true vapor pressure when compared to a collection of oils stored at the U.S. Strategic Petroleum Reserve, which suggests higher volatility (Lord et al. 2015).

The myriad public health impacts associated with oil extraction are significant, and health impacts have been empirically shown to be elevated for those living in close proximity to wells (Field et al. 2014; McKenzie et al. 2012). This is unsurprising, as the oil and gas industry is a major emitter of a range of volatile organic compounds (VOCs) (Epstein 2017; Allen 2016; Brantley et al. 2015; Field et al. 2014). This includes hazardous air pollutants like benzene, a known carcinogen. VOCs are also linked to ozone, which can aggravate lung diseases like asthma and emphysema. Oil drilling further poses a threat to water and soil quality. Contamination can occur from leaks and spills, as well as during wastewater transportation, storage and disposal (Akob et al. 2016; Cozzarelli et al. 2017; Ingraffea et al. 2014; Jackson 2014; Lauer et al. 2016). The risk of contamination is especially pertinent in the case of unconventional drilling, given concerns regarding the toxicity of hydraulic fracturing fluid (Colborn et al. 2011; Elliott et al. 2017).

How do we identify areas to prioritize public health given the widespread impacts? This is where an environmental justice lens can help identify priorities for accelerated wind-downs (O'Rourke and Connolly 2003). Recent statistical methods, such as California's CalEnviroScreen 3.0 and the Environmental Protection Agency's EJSCREEN, can provide integrated measures of cumulative health impacts and social vulnerability that enable policy-makers to identify communities experiencing this "double jeopardy" (Huang and London 2012) at both the state and national level. Principle 3 would suggest prioritizing wind-downs in those sites where public health threats are magnified by other forms of marginalization and disempowerment.

Finally, Principle 3 urges policy-makers to consider conservation, beyond that necessary to minimize human rights impacts. Oil drilling requires clearing vegetation for both the well pads themselves, as well as the roads and other infrastructure necessary to support drilling. This disrupts ecosystems and leads to habitat fragmentation (Brittingham et al. 2014). For example, oil and gas development has severely impacted the sagebrush ecosystem and its iconic greater sage grouse (Aldridge and Boyce 2007; Green et al. 2017; Walker et al. 2007). High-volume hydraulic fracturing is especially disruptive, given that it takes both more land and water than conventional drilling (Brittingham et al. 2014).

3 Opposition to oil and gas development has at times been a source of tension within the Navajo community (Begay 2017).

Principle 3 would suggest phasing out extraction and limiting drilling in areas with high conservation value. How can resource managers operationalize high conservation value? Belote and his colleagues (2017) offer one possible approach. Building on the work of other land conservation scientists, they conducted a spatial assessment that overlays four critical metrics for determining conservation value: ecological integrity, ability to establish a connected network of habitat, whether the area is representative of ecosystem diversity, and biodiversity hotspots. Taken together, these four variables are key factors in determining adaptive capacity (Dawson et al. 2011; Gillson et al. 2013; Martin and Watson 2016; Schmitz et al. 2015). Their analysis reveals large swaths of land with high conservation value in the western U.S., including currently unprotected land with high ecological integrity.[4]

It is important to note that the ability to neglect the human and environmental costs of extraction often makes it possible for fossil fuel sources to be considered cost-effective. These same fossil sources may well not be marketable were these costs internalized by, for instance, mandating environmental and public health abatement measures, requiring the reinvestment of benefits, ensuring enforcement of all laws and regulations, and imposing appropriate penalties for violations.

Summary

In reviewing how each principle applies to the case of oil extraction in the U.S., national trends begin to emerge as to which areas should be prioritized in developing a national supply-side policy to phase out fossil fuel extraction. It also becomes clear that, given the degree of variation within basins, there is a role for deeper regional-level analysis. This will be an important supplement for any national-level strategy. However, it also indicates that even lacking the political will for a national strategy, there is tremendous value in regional leadership and building regional extraction wind-down policies.

As in the coal case study, Table A-6 is a preliminary assessment of how the principles above could be put in practice. It is intended to be illustrative rather than comprehensive, and readers should understand that blank spaces here should not be taken to mean a lack of priority.

Table A-6. Assessment of U.S. oil basins against principles.

Basin	Principle 1 – Reduce at a pace consistent with climate protection	Principle 2 – More rapid phase-out in more resilient communities	Principle 3 – Safeguard human rights and environment
Permian	May represent priority given rapid investment in new oil fields		
Eagle Ford			
Bakken			Potentially higher transport risk
North Slope			Threatens Indigenous subsistence
Niobrara		Oil represents low share of economic activity	
Anadarko		Oil represents low share of economic activity	
San Joaquin	Extremely high GHG intensity	Oil represents low share of economic activity	Pollution concentrated in communities of color

This assessment is intended to be illustrative rather than comprehensive, and blank spaces here should not be taken to mean a lack of priority.
Source: SEI analysis.

Lastly, note that this is a case study, not a policy recommendation. There are no doubt additional considerations associated with each of the three principles that regulators must take into account when developing a wind-down plan for oil production, and these considerations will become more evident

4 Critical regions in the eastern U.S. also emerge out of Belote et al.'s (2017) analysis, including the Southern Appalachian Mountains and Cumberland Plateau, the Allegheny Plateau of Pennsylvania, the Southeastern Coastal Plain, the Sand Hills of Nebraska, the Ozark and Ouachita Mountains, east Texas and central Louisiana, Northern Minnesota and Wisconsin, and the Northern Appalachians of New England.

with regional assessment and engagement. Robust engagement with a diverse range of stakeholders would help shed light on specific local concerns. That said, it is nonetheless a useful illustration of the types of concerns that each principle brings to the table and the implications for how to prioritize areas for a rapid wind-down.

Appendix B: Data and methodology

To understand the regional economic character of coal- and oil-producing basins, we compiled data on production, employment, prices and GDP for counties within our study area (presented in Table A-2 and Table A-6). We used United States Geological Survey (USGS) and Energy Information Administration (EIA) data to associate coal- and oil-producing counties, respectively, with each basin and aggregated county-level statistics on a basin level.

Coal data

For Table A-2 on coal as a share of the local economy, we use the figures for coal employment and coal production to derive the number of employees per million tons of coal extracted. We use Mine Safety and Health Administration (MSHA) data for mining employment figures and compare that to Bureau of Labor Statistics (BLS) data for total employment in order to find the coal share of local employment.

In exploring the importance of coal revenue to the community, we compare regional coal revenue to the regional GDP. This is less than ideal, mainly because we do not have a robust means of estimating regional GDP that ensures consistency with our method for estimating coal revenue.

To estimate coal revenue, we simply multiply a county's known coal production by the best estimate of coal price we could identify -- the county, state or U.S. average price for coal, depending on what level of specificity was available. This part is fairly straight-forward, and the total for a region (e.g., the Appalachian Basin) can be estimated by adding up all the major coal-producing counties.

For regional GDP, the calculation has more uncertainty. We essentially downscaled state GDP figures according to county personal earnings data, using the following equation:

$$GDP_{c,y} = \frac{GDP_{s,y}}{Personal\ Income_{s,y}} \times Personal\ Income_{c,y}$$

Where c = county, s = state and y = year (Barreca et al. 2012). (The Bureau of Economic Analysis has proposed collecting county-level data on GDP, which will be quite revealing once available.)

The main limitation in our method is that it assumes that GDP scales from state to county level with personal income. This relationship would not be as valid if, for example, a substantial portion of the earnings from coal mining were not retained in the county where the coal was extracted, but instead taken outside that county. (In such cases, our estimate of county GDP would be too low, meaning that our estimate of the share of fossil revenue as a share of local GDP would be too high.) This is very likely the case in some circumstances: for example, in comparing regional coal mining revenue to regional GDP, we see some large numbers particularly in the Powder River Basin.

Accident rates were derived from MSHA accident reports, then divided by the number of mining employees in each basin.

Oil data

We used the same method for calculating regional GDP for oil as for coal (described above), and with the same notable limitations. We calculated oil revenue using EIA's (2018b) Domestic Crude Oil First Purchase Prices by Area for 2016.

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