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How would phasing out U.S. federal leases for fossil fuel extraction affect CO_2 emissions and 2°C goals?

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ABSTRACT

Avoiding dangerous climate change will require a rapid transition away from fossil fuels. By some estimates, a phase-out of global fossil fuel consumption and production – particularly coal and oil – will need to be nearly complete within 50 years. Given the scale of such a transition, nations may need to consider a broad suite of policy approaches that aim not only to reduce fossil fuel demand – the current focus – but also constrain fossil fuel supply growth. In this paper, we examine the potential emissions implications of a supply-side measure under consideration in the U.S.: ceasing to issue new leases for fossil fuel extraction on federal lands and waters, and avoiding renewals of existing leases for resources that are not yet producing. Our analysis finds that under such a policy, U.S. coal production would steadily decline, moving closer to a pathway consistent with a global 2°C temperature limit. Oil and gas extraction would drop as well, but more gradually, as federal lands and waters represent a smaller fraction of national production, and these resources take longer to develop. Phasing out federal leases for fossil fuel extraction could reduce global CO_2 emissions by 100 million tonnes per year by 2030, and by greater amounts thereafter. The emissions impact would be comparable to that of other major climate policies under consideration by the Obama administration. Our findings suggest that policy-makers should give greater attention to measures that slow the expansion of fossil fuel supplies.

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1. INTRODUCTION

Avoiding dangerous climate change will require a rapid transition away from fossil fuels. By some estimates, global consumption and production of fossil fuels – particularly coal and oil – will need to end almost entirely within 50 years (Rogelj, Schaeffer, et al. 2015). The Paris Agreement on climate change approved last December asserted world leaders' commitment to strong climate action and urged countries to step up their efforts. While many countries are taking measures to reduce fossil fuel demand – from pricing carbon to promoting low-carbon energy sources – these policies are not advancing at the pace needed.

The need for swifter progress has led to growing interest in adopting supply-side measures as well, measures that more directly aim to slow further investment and growth in fossil fuel production and thereby enable a smoother, more rapid transition to a low-carbon future. In the U.S., one option on the table is to reduce or end the issuance and renewal of U.S. government leases for fossil fuel exploration and extraction on federal lands and offshore. The Obama Administration is considering changes to its coal leasing program in light of concerns about "whether the leasing and production of large quantities of coal… is consistent the Nation's goals to reduce greenhouse gas emissions" (BLM 2016b). The Administration could similarly take climate implications into account in its decisions regarding further federal leases for exploration and extraction of oil and gas resources, a large share of which are offshore.

This paper aims to shed light on the climate implications of future leasing decisions by examining how ceasing further leases would affect coal, oil and gas production, consumption, and global carbon dioxide (CO_2) emissions relative to a reference case. It also explores how such decisions might affect progress towards the goal set in Paris of keeping warming "well below 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5°C".[1]

The U.S. now produces more fossil fuels than ever. It ranks first in the world in oil and gas production, and second in coal production (BP 2015). Since 2010, U.S. fossil fuel production has grown by 20% in energy terms,[2] due in great part to technology advances in extracting oil and gas from tight and offshore resources (U.S. EIA 2015a). Increased production has helped natural gas eclipse coal as the top fuel for U.S. electricity production, slowing growth in CO_2 emissions (U.S. EIA 2015c). And despite current low oil prices, investment in fossil fuel extraction and trade infrastructure continues. For example, investments in new U.S. oil exploration and production infrastructure in 2015 amounted to $100 billion, which is down from an all-time high in 2014 but still among record levels, and is expected to be eclipsed again by 2018 (Rystad Energy 2015). Investments in capital-intensive, high-carbon fuel infrastructure can lock in long-term fuel supplies, while tying communities to fossil revenues, making it more difficult and expensive to later shift to a low-carbon pathway (Erickson et al. 2015).

About a quarter of all U.S. fossil fuels extraction (in energy terms), including two-fifths of all coal, occurs on federal lands and waters (U.S. EIA 2015a).[3] Producers obtain leases for these activities from the U.S. Department of the Interior (DOI) through bids and auctions, and pay fees, rents and royalties that are shared by the federal government and state and tribal governments (see Box 1).

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[1] See http://unfccc.int/paris_agreement/items/9485.php.

[2] For ease of comparison, much of the analysis in this paper presents coal, oil and gas production in energy equivalent terms, as quadrillion British thermal units (QBtu).

[3] Hereafter we refer simply to "federal lands" to encompass both lands and offshore areas that are subject to federal leasing provisions.

Box 1. Leasing and royalty practices for fossil fuels produced from U.S. federal lands and waters

The DOI administers fossil fuel production from U.S. federal lands and waters, as well as from lands where the federal government owns the sub-surface mineral rights but another entity owns the surface rights. DOI authority for administering onshore fuels originates from the Mineral Lands Leasing Act of 1920 and its subsequent revisions. For offshore fuels (i.e. those in federal waters), DOI authority originates from the Outer Continental Shelf Lands Act of 1953.

For onshore resources, the process for determining when and where leases occur is generally "bottom-up": interested firms identify eligible parcels and express their interest to the Bureau of Land Management (BLM), the DOI's implementing agency. For oil and gas, the BLM responds to interest by firms by holding a public lease auction, starting at a minimum of $2 per acre. If no bids are received, the land is offered to the first qualified applicant, with no requirement for a competitive bid. Initial leases are for 10 years.

For coal, a similar process called "lease by application" has been used for all federal coal (including in the Powder River Basin) since 1990. Companies propose specific parcels for sale; the BLM determines fair market value and the maximum amount of coal economically recoverable, and solicits sealed bids. The lease is then awarded to the highest bidder that meets or exceeds fair market value, for at least $100 per acre. Most leases are for parcels adjacent to existing mines (wholly new coal mines are rare), and typically receive only one bid, from the existing mining company. Initial leases are for 20 years.

Offshore oil and gas development is more top-down. DOI creates a five-year leasing plan that outlines a schedule of sales, including size and location of the proposed activities. The DOI's Bureau of Ocean Energy Management (BOEM) then publishes an announcement regarding the lease areas, in consultation with governors and local government officials of affected jurisdictions. Bids are solicited, and the lease is generally awarded to the highest bidder. Initial leases are for 5 years in waters less than 800 meters deep, 7 years in waters 800 to 1,600 meters deep, and 10 years in water depths greater than 1,600 meters.

For all fuels, onshore or offshore, the DOI will extend lease terms as long as the leasing firm continues to produce. In addition to the annual rental payments specified in leases, firms are responsible for future royalty payments of 12.5% of the sale price for onshore oil, gas, and surface coal; 8% for underground coal; and 18.75% (increased from 12.5% in 2007) for offshore oil and gas. The ONRR and BLM have been considering updating the royalty rates (and other associated terms), with the support of President Obama, as expressed in his 2016 State of the Union address.

Sources: Bureau of Land Management (BLM 2015); Congressional Research Service (Vann 2012; Vann 2014); Department of Interior (DOI 2012); Government Accountability Office (US GAO 2013); Office of Natural Resources Revenue (ONRR 2015b).

These leasing systems have been in place for generations, and they are a significant source of government revenue, including for local communities. However, government and civil society organizations are beginning to rethink these practices in light of climate and other concerns (BLM 2016b; The White House 2014). In his 2016 State of the Union address, on the heels of the Paris Agreement, President Obama announced his intention "to change the way we manage our oil and coal resources, so that they better reflect the costs they impose on taxpayers and our planet" (Obama 2016). Just days later, the DOI announced its intention to prepare a Programmatic Environmental Impact Statement (PEIS) of the federal coal program to, among other goals, consider "adjustments to the scale and pace of leasing", including the possibility of a "declining schedule consistent with the United States' climate goals and commitments" (BLM 2016b). Legislation has also been introduced in Congress to stop all future leasing activity (Merkley et al. 2015; Huffman et al. 2016). In addition, royalty regimes are being reexamined with an eye to eliminating apparent subsidies or possibly applying a carbon charge (Haggerty et al. 2015; Krupnick et al. 2015; BLM 2016a).

The debate about federal fossil fuel leases is complex, involving not only climate considerations, but also questions about broader environmental protection, government revenue, jobs, and the resilience of regional economies that now depend heavily on fossil fuel production (Haggerty 2014). Our analysis focuses on the climate implications, aiming to fill what we see as a critical knowledge gap.

Proposals to end or reform federal fossil fuel leases take what we call a *supply-side* approach to climate policy (Lazarus, Erickson, et al. 2015). Supply-side measures aim to complement demand-side measures, to ensure that energy and climate policies are more coherent and increase the likelihood of achieving climate goals. Yet the implications of supply-side policies remain poorly understood, as do their interactions with demand-side measures.[4] Until recently, few studies have assessed the CO_2 emissions impacts of supply-side policies – in stark contrast to the long history of demand-side analyses. Recent studies have examined the CO_2 emissions associated with past and current U.S. production (Stratus Consulting 2014) and with fossil fuel resources under federal jurisdiction (Mulvaney et al. 2015). Studies have also looked at the emission implications of specific infrastructure investments (e.g. coal export terminals) or of restricting or increasing production of specific resources (Power and Power 2013; Vulcan/ICF 2016).

Our paper builds on this growing literature, aiming to help answer key questions arising in the current debates over federal leasing. In particular, the paper:

- Reviews recent U.S. fossil fuel production and explores future trends (Section 2);
- Shows how future U.S. fossil fuel extraction might need to decline under a 2°C pathway, consistent with the Paris Agreement;
- Analyzes how fossil fuel production might be affected if the U.S. government stopped issuing new leases (Section 4);
- Estimates how a cessation of federal leasing might affect overall energy use and CO_2 emissions (Section 5), taking into account market responses; and
- Examines how a cessation of federal leasing would affect U.S. progress towards a 2°C pathway (Section 6).

This analysis may be useful to policy-makers who are considering how to manage the nations fossil fuel resources in a way that is, in Interior Secretary Sally Jewell's words, "consistent with our climate change objectives" (Jewell 2015; U.S. DOI 2016).

[4] For example, future federal coal leasing policy could complement or conflict with efforts to implement the CPP, as both will affect the pace and extent of a transition away from coal in the US power sector.

2. RECENT TRENDS AND OUTLOOK FOR U.S. FOSSIL FUEL PRODUCTION

U.S. fossil fuel production, which was relatively flat (in energy terms) for decades, has recently seen a substantial increase. Enabled by new technological developments for oil and gas extraction, especially hydraulic fracturing and horizontal drilling, production of these fuels has risen sharply in the last decade. The turnaround has been particularly dramatic for oil, which, after peaking in 1970, had been declining steadily until 2007. Since then, oil production has grown rapidly, overtaking the previous 1970 high (U.S. EIA 2015a). By contrast, coal production peaked around 2008 (U.S. EIA 2015a) and has since declined, due to global oversupply, slowing domestic and international demand, and competition from abundant, lower-cost natural gas supplies.

Table 1 displays fossil fuel production in the U.S. since 1990, by fuel, on federal and non-federal lands (see also Figure 1). The data show that, between 1990 and the mid-2000s, production on federal lands increased, while non-federal production decreased. Since then, however, these trends have reversed. Indeed, the vast majority of growth in U.S. fossil fuel production since 2005 has occurred on non-federal lands, with an increase of 20 QBtu (quadrillion Btu or "Quads"), while federal oil production grew by just 0.2 QBtu. (Federal gas production has declined by nearly 3 QBtu, and all coal production has declined.) As of 2014, an estimated 24% of all U.S. fossil fuels production occurred on federal lands and waters (U.S. EIA 2015a).

Table 1: U.S. fossil fuel production, 1990-2014, in quadrillion BTU

Fossil fuel production	1990	1995	2000	2005	2010	2014
Coal	**22.5**	**22.0**	**22.6**	**23.0**	**21.9**	**20.2**
Federal	6.1	8.0	9.3	9.1	9.2	8.1
Non-federal	16.3	14.0	13.3	13.9	12.7	12.1
Gas	**18.3**	**19.1**	**19.7**	**18.6**	**23.4**	**26.6**
Federal	6.6	6.8	7.3	6.2	5.2	3.6
Of which: offshore	*5.2*	*4.8*	*4.8*	*3.2*	*2.3*	*1.2*
Non-federal	11.7	12.3	12.3	12.3	18.2	22.9
Oil	**17.7**	**16.3**	**15.0**	**13.3**	**14.4**	**22.5**
Federal	3.0	3.6	4.4	4.4	5.2	4.6
Of which: offshore	*2.1*	*2.7*	*3.6*	*3.1*	*3.6*	*3.2*
Non-federal	14.7	12.7	10.6	8.9	9.2	17.9
Total	**58.5**	**57.4**	**57.2**	**54.9**	**59.7**	**69.2**
Federal	15.7	18.5	21.0	19.7	19.6	16.4
Non-federal	42.8	39.0	36.3	35.1	40.1	52.9

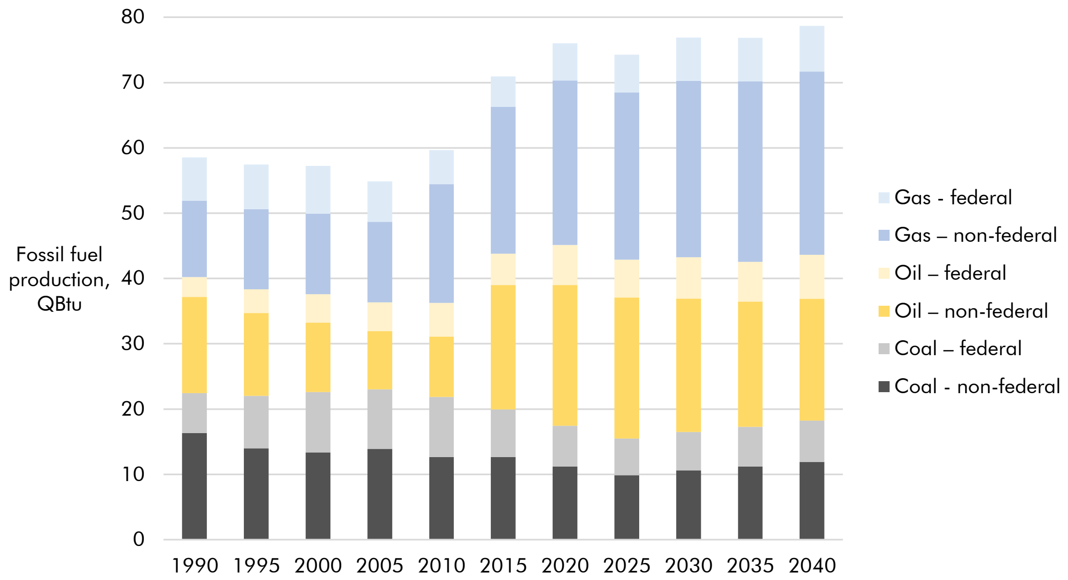
Source: SEI analysis based on ONRR (2015) and U.S. EIA (2015a).

In recent scenarios, the U.S. Department of Energy projects that U.S. oil and gas production will continue to increase, and coal production will continue to decline. Figure 1 displays both historical (as in Table 1) and future domestic fossil fuel energy production through 2040, as drawn from the U.S. Energy Information Administration's *Clean Power Plan* scenario (U.S. EIA 2015b). This scenario assumes implementation of the Clean Power Plan, which was finalized in October 2015 (U.S. EPA 2015c), and is expected to lead to continued declines in coal use and production over the next decade, followed by a slow rise nearly to current levels.[5]

We use the EIA's Clean Power Plan scenario as the reference case for our analysis. We consider this scenario, among several the EIA developed for its Annual Energy Outlook (see Box 2), to be closest to a "business as usual" case, given finalization of the Clean Power Plan in October 2015, and the assumption of no further policy action or unforeseen technological advancement. (In Appendix A, we consider another reference case without the Clean Power Plan.)

We split the EIA's scenario into fractions extracted on federal vs. non-federal land by assuming that fuel- and region-specific shares of federal (vs. non-federal) production remain constant at recent (2014) levels.[6]

Figure 1: Historical and future U.S. fossil fuel production, 1990–2040



Source: SEI based on ONRR (2015) and U.S. EIA (2015a; 2015b), assuming implementation of the Clean Power Plan.

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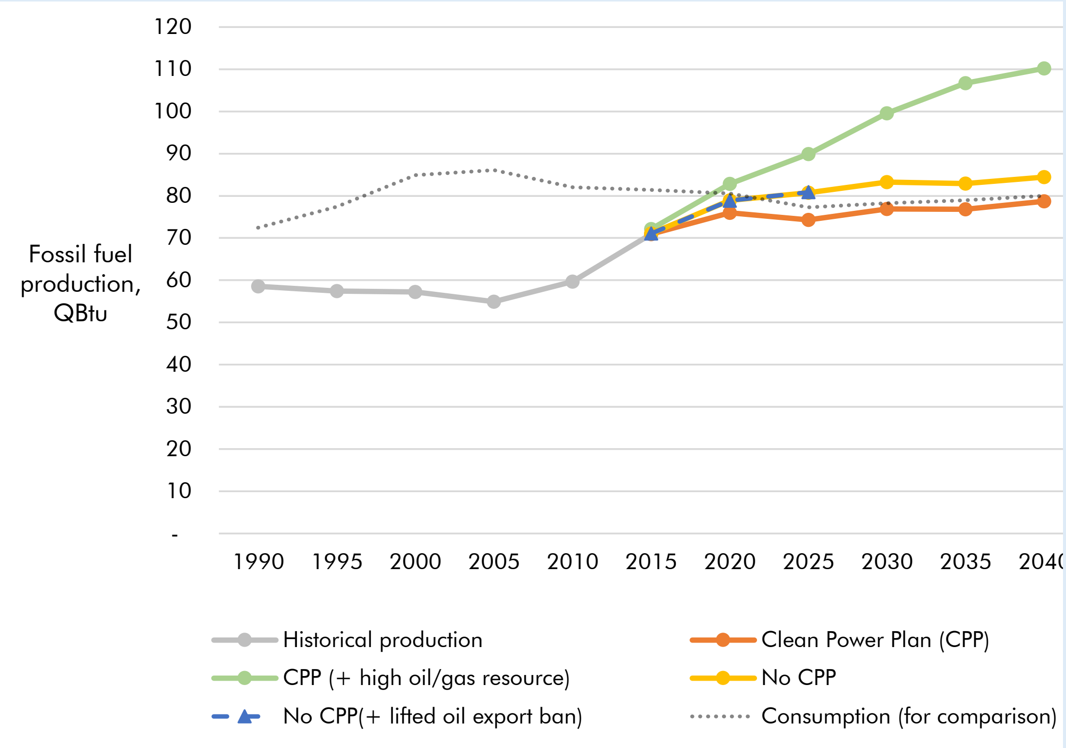
[5] At the time of this analysis, EIA had conducted an analysis of the draft Clean Power Plan, but not the final plan as placed into law. EIA staff told us in early 2016 that *Annual Energy Outlook 2016* will include the final Clean Power Plan in the reference case, but it was not available in time to inform our analysis. The EIA Clean Power Plan scenario does not extend CPP targets beyond 2030 (the last target date specified in the current plan) and thus emissions begin to rise thereafter. As several aspects of the final Clean Power Plan differ from the draft version, EIA's yet-to-be-released forecasts of fossil fuel production under the final rule could differ from those used here.

[6] We do this by dividing DOI data on federal production (ONRR 2015) by EIA data on total (federal and non-federal) production (U.S. EIA 2015a). We then apply these ratios to forecast region- and fuel-specific production estimates in the Clean Power Plan scenario of the EIA's Annual Energy Outlook (US EIA 2015b).

Box 2: Alternate EIA scenarios of future U.S. fossil fuel production, 1990–2040

The EIA has developed a number of scenarios to explore how U.S. fossil fuel production may evolve (U.S. EIA 2015b; U.S. EIA 2015c). The chart below shows the results of four of these other scenarios, chosen to reflect a wide range of possible outcomes. In addition to the Clean Power Plan case (our study's reference scenario), the scenarios include the lifting of the oil export ban (finalized in late 2015), the possibility of higher future oil and gas production than anticipated, and the possibility that the Clean Power Plan is not implemented (the rule had not yet been finalized at the time of the mid-2015 EIA analyses used here, and it is under legal challenge).

In the EIA assessment, the Clean Power Plan leads to a 20% decline in coal production in 2040 relative to the case without Clean Power Plan, and thus to a decline in overall fossil fuel production. Further advances in oil and gas extraction technology could also result in U.S. fossil fuel production being as much as 40% greater in 2040 than would otherwise be the case, due to even greater increases in oil (70%) and gas (50%) production that also lead to a drop in coal production (20%) due to greater competition from gas.



Source: U.S. EIA (2015b; 2015c).

3. U.S. FOSSIL FUEL PRODUCTION IN A 2°C WORLD

At the Copenhagen Climate Change Conference in 2009, which President Obama attended, world leaders embraced the long-term goal to keep global warming below 2°C above pre-industrial levels.[7] The Paris Agreement further raised ambition, with governments striving to keep warming "well below" 2°C, and agreeing "to pursue efforts to limit temperature increase to 1.5°C".[8] Even with large-scale deployment of bioenergy and carbon capture and storage technologies, scientific assessments show that limiting warming to 2°C, and avoiding dangerous climate tipping points, will require a rapid phase-out of fossil fuels around the world (Rogelj et al. 2011; IPCC 2014; Raupach et al. 2014).

The Paris Agreement makes no reference to fossil fuel *production*, nor is it reflected in the national commitments embedded in the agreement – but clearly, at a global level, producing more fossil fuels is not consistent with simultaneously trying to reduce their use. Yet it is also unclear how production should be phased down: Which countries should curtail production, of what fuels – coal, oil, or gas – and at what rate? For example, would only the most economically attractive resources be extracted, in keeping with emissions constraints and declining fossil fuel demand and prices? Or would political or equity considerations influence where remaining fossil fuel resources might be produced (Lazarus and Tempest 2014; Raupach et al. 2014)?

Though these questions are relatively unexplored, two studies provide scenarios of coal, oil and gas production in a 2°C world with enough detail to estimate how much of that production might occur in the United States. One, the International Energy Agency's *World Energy Outlook*, charts a 2°C ("450") scenario for regional fossil production through 2040 (IEA 2015). The other, published in the journal *Nature*, identifies a least-cost pathway for fossil fuel production under a 2°C scenario through 2050 (McGlade and Ekins 2015).

Each study has its merits and limitations for understanding U.S. fossil fuel production levels consistent with a 2°C goal. The *Nature* study uses a more stringent (and common) definition of a 2°C scenario – one that maintains a 66% chance of limiting warming to this level. It specifies fossil production for the U.S., but may underestimate it, since the study uses a data set from 2010 that misses much of the subsequent boom in U.S. oil and gas production capacity.[9] Accordingly, this scenario may represent a *low* scenario for U.S. fossil fuel production in a 2°C world, at least for oil and gas. (It also does not reflect global equity considerations that might suggest less-developed countries should be allowed to produce a greater share of the total.)

The IEA study starts with 2013 data, and thus better captures the U.S. boom in oil and gas production capacity. However, it uses a weaker definition of a 2°C scenario – a 50% chance of keeping warming below 2°C – and therefore does not curtail fossil fuel production and consumption as rapidly.[10] Together, these factors suggest that IEA's ("450") scenario may a *high* scenario for U.S. production in a 2°C world.

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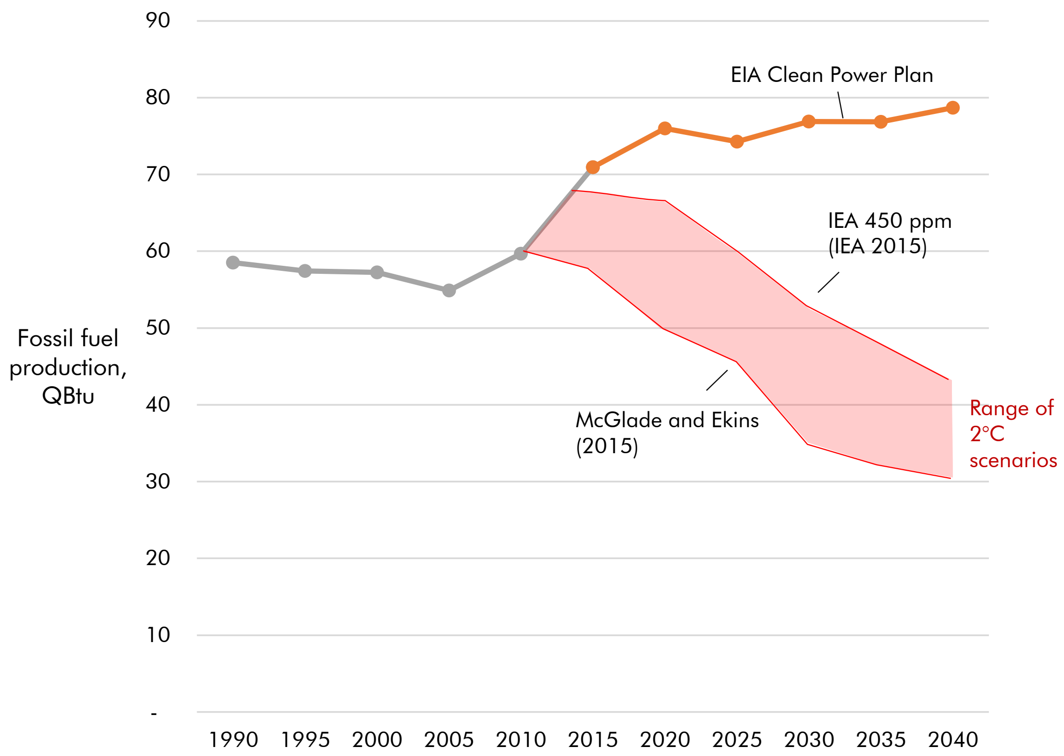
[7] See http://unfccc.int/meetings/copenhagen_dec_2009/meeting/6295.php.
[8] See http://unfccc.int/paris_agreement/items/9485.php.
[9] We thank Drs. McGlade and Ekins for providing the U.S. extraction pathway from their analysis.
[10] The IEA reports findings for U.S. fossil fuel production in its New Policies Scenario, but not in its 2°C 450 Scenario, for which it reports fossil fuel production only for OECD Americas, a grouping that includes Canada, Chile, Mexico and the U.S. To impute U.S. results for the 450 Scenario, we adjust the findings for OECD Americas according to the ratio of U.S. to OECD Americas production in the New Policies Scenario. For example, in the New Policies Scenario, U.S. fossil fuel production comprises 91% of OECD Americas coal production in 2040, 50% of oil production, and 71% of gas production, and so we approximate U.S. production in the 450 Scenario as these same fractions of OECD Americas production in IEA's 450 Scenario. Were the marginal source of U.S. resources

Figure 2 shows the projected levels of U.S. fossil fuel production out to 2040 from these two studies, compared with our reference scenario, the EIA's Clean Power Plan case. Between them, these studies suggest **that to be consistent with a 2°C goal, the U.S. would need to cut aggregate fossil fuel production by 40–60% from current levels by 2040**, instead of an anticipated increase of 11% under the Clean Power Plan scenario.

Although scientific understanding of 1.5°C pathways is limited, U.S. fossil fuel production in a 1.5°C world would almost certainly be lower than in the 2°C scenarios. Studies suggest that cumulative global fossil fuel consumption between now and 2050 must be about 40% lower to meet a 1.5°C vs. a 2°C goal (Rogelj, Luderer, et al. 2015; Baer et al. 2013).

Figure 2: 2°C scenarios of U.S. fossil fuel production, 1990–2040



Source: SEI analysis based on U.S. EIA (2015a; 2015b), IEA (2015), and McGlade and Ekins (2015).

to be more or less expensive than the respective marginal sources in other OECD America countries, this approximation could over- or under-estimate, respectively, the cost-efficient level of U.S. production.

4. THE EFFECT OF FEDERAL LEASING DECISIONS ON FOSSIL FUEL PRODUCTION

To bring U.S. fossil fuel production more closely in line with a 2°C production pathway, the DOI could phase out leasing and/or provide incentives to reduce fossil fuel production on public lands. The DOI intends to consider such measures, at least for coal, as parts of its upcoming review of its coal program (U.S. DOI 2016; BLM 2016b).

To inform these and related discussions, in this section we look at how fossil fuel production would be affected if the DOI stopped issuing new leases for fossil fuel extraction on federal lands and waters, and did not renew any leases on resources that are not yet producing when each lease comes up for renewal.[11]

We look at what such a lease phase-out policy might mean for fossil fuel production on federal lands, and consider how this compares with what might be required to meet the 2°C goal. Except for the restrictions on leasing, we assume that all other factors, such as broader economic trends and policy actions, proceed as in the EIA's Clean Power Plan scenario.

4.1 Approach

Before we can analyze the effect of leasing reform on future fossil fuel production, we need to understand trends in expected leasing activity in the absence of any changes to leasing policy. We start with our reference case projection of future fossil fuel production on federal lands and waters, as shown in Figure 1. We then further analyze it to estimate what fraction of production would come from new or renewed leases (that DOE could decide not to issue) instead of existing leases (which must be renewed as long as they are producing).

To estimate future leasing activity for oil and gas, we draw from an extensive database of U.S. oil and gas fields that estimates economics and production from each field over time (Rystad Energy 2015). From this database, we estimate the shares of fuel-, region- and year-specific U.S. production that would arise from existing (already producing), renewed (not yet producing), or new leases, and apply these ratios to our EIA-based reference scenario.[12]

For coal, we estimate future lease dynamics using industry data and guidelines. In particular, we assume that producers will seek new leases at a rate that maintains reserves at a level equal to 15 years of expected production.[13] This is roughly the ratio observed in recent years,[14] and is consistent with ranges, typically 10–20 years, reported by the U.S. Geological Survey (Pierce and Dennen 2009) and coal industry consultants (Miller and Bate 2011). Starting from estimates of existing reserves of federal coal (explained further below), we then assume that producers will seek new leases at rates that maintain reserves equivalent to the next 15 years of expected production (from federal lands) in our reference scenario. We further assume that producers do

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[11] This closely resembles what seven U.S. Senators proposed in the Keep It in the Ground Act of 2015 (Merkley et al. 2015). It also resembles a permanent version, for all fuels, of the temporary moratorium on new coal leasing implemented by the DOI in early 2016 (U.S. DOI 2016). We assume that in all cases, the moratoria would not affect leases that are already producing fuels, as these leases would automatically continue.

[12] More specifically, we use shares of *Field*, *License* and *Open* asset designations in Rystad's Base scenario. For oil, we calculate and apply the ratios separately for each year of production for oil from lower 48 offshore deposits (which is strongly federal), in the Rocky Mountain and Dakota states (also strongly federal), natural gas liquids, and all other crude.

[13] Where expected production follows the reference scenario as in Figure 1.

[14] Based on analysis of production (ONRR 2015), reserves (Miller and Bate 2011) and lease (Headwaters Economics 2015) data.

not wait to begin mining their newly acquired leases, but extract the same fraction of these new stocks each year as they do of existing stocks.[15]

To estimate starting reserves for the Powder River Basin, we rely on a coal industry report that estimated year-end 2010 reserves of 5.8 billion short tons[16] (Miller and Bate 2011). Outside the Powder River Basin, we rely on a U.S. Government Accountability Office report that estimated year-end 2012 reserves of 0.9 billion short tons (U.S. GAO 2013). We then update these sources to 2015 by debiting the totals based on subsequent actual annual production (ONRR 2015) or incrementing them based on new lease inflow since (Headwaters Economics 2015). In total, this process yields an estimate of total federal coal reserves of 7.1 billion short tons as of the end of 2015.[17]

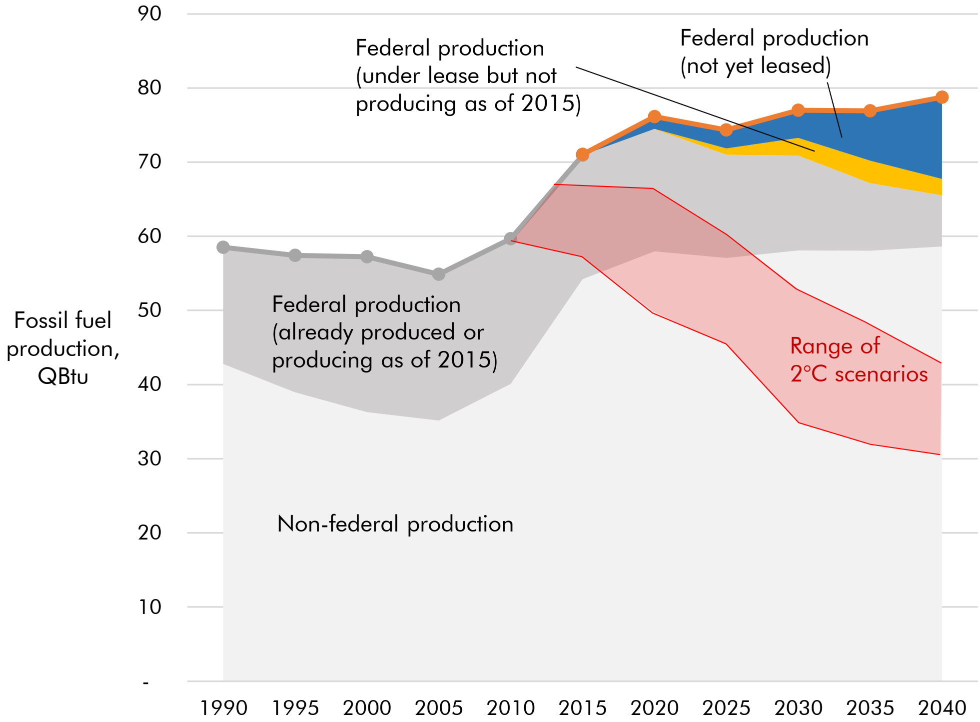
4.2 Overall results

In total, our analysis indicates that, of expected federal fossil fuel production in 2040 (20 QBtu), about two-thirds (13 QBtu) is either not yet under lease or is under lease but not yet producing.[18] Figure 3 shows historical and forecast U.S. fossil fuel production by status of federal lease.

Note especially that, under a 2°C pathway (red shading, just as in Figure 2), U.S. production will need to drop at some point to levels below what is expected on non-federal lands alone. This point comes sooner (after 2017) under McGlade and Ekins' (2015) 2°C scenario, and not until after 2025 under the IEA's less stringent pathway (IEA 2015). However, in either case these findings suggest that, at some point in the next two decades, there is potentially no need for federal fossil fuels in a 2°C pathway. This is not to suggest, however, that under a 2°C pathway, all U.S. fossil fuel production could, or should, shift wholly to non-federal lands; rather it simply illustrates a 2°C pathway will likely require a drop in production far exceeding what is expected from federal lands.

[15] Collectively, these assumptions imply that producers from federal lands do not draw down their existing stocks at faster than normal levels. If they did so, they could conceivably maintain production levels through 2035 (under a Clean Power Plan reference case), after which production from federal lands would cease entirely.
[16] Most U.S. coal production data are given in short tons, while CO_2 emissions are usually given in metric tons, or tonnes. For clarity, we consistently use "short tons" to refer to the U.S. weight measure, and "tonnes" or Mt (million tonnes) or Gt (gigatonnes, or billion tonnes) when referring to CO_2.
[17] This estimate is lower than that reported for 2012 by the GAO, 9.0 billion short tons, for two reasons. First, the GAO describes that its estimate for Wyoming, 8.0 billion short tons, is high by an unknown amount because it includes coal in mines that is not ultimately saleable, because it is along property boundaries or is left in place for structural mine support (U.S. GAO 2013). Second, the inflow of new coal leases since 2012 has been smaller than mine production (ONRR 2015; Headwaters Economics 2015).
[18] As explained in Box 1, the DOI will extend leases as long as the leasing firm continues to produce – but it can refuse to renew leases for resources that are not producing.

Figure 3: Historical and forecast U.S. fossil fuel production, 1990–2040, in energy terms, by status of federal lease



Source: SEI analysis based on ONRR (2015), U.S. EIA (2015a; 2015b), assuming implementation of the Clean Power Plan.

Of the prospective federal fossil fuels from areas not yet leased or producing (orange and dark blue areas in Figure 3), about half is coal. Cumulatively, an estimated 70 QBtu of coal extracted between 2016 and 2040 from federal lands has not yet been leased, whereas 40 QBtu of oil and 30 QBtu of gas has either not yet been leased or is in leases that are not yet producing and are subject to renewal.[19] Findings specific to each fuel follow below.

4.3 Coal

Figure 4(a) shows the significant role that coal from newly leased federal lands could play over the next 25 years. Most of the federal coal in already-leased reserves will be extracted by 2040, with the majority of federal coal coming from new leases by 2030.[20]

Cumulatively between 2016 and 2040, 4 billion short tons (70 QBtu) of federal coal will be extracted (mostly, but not exclusively, in the Powder River Basin) from lands not yet under lease. This represents an estimated 7 Gt CO_2 of emissions once the coal is combusted.

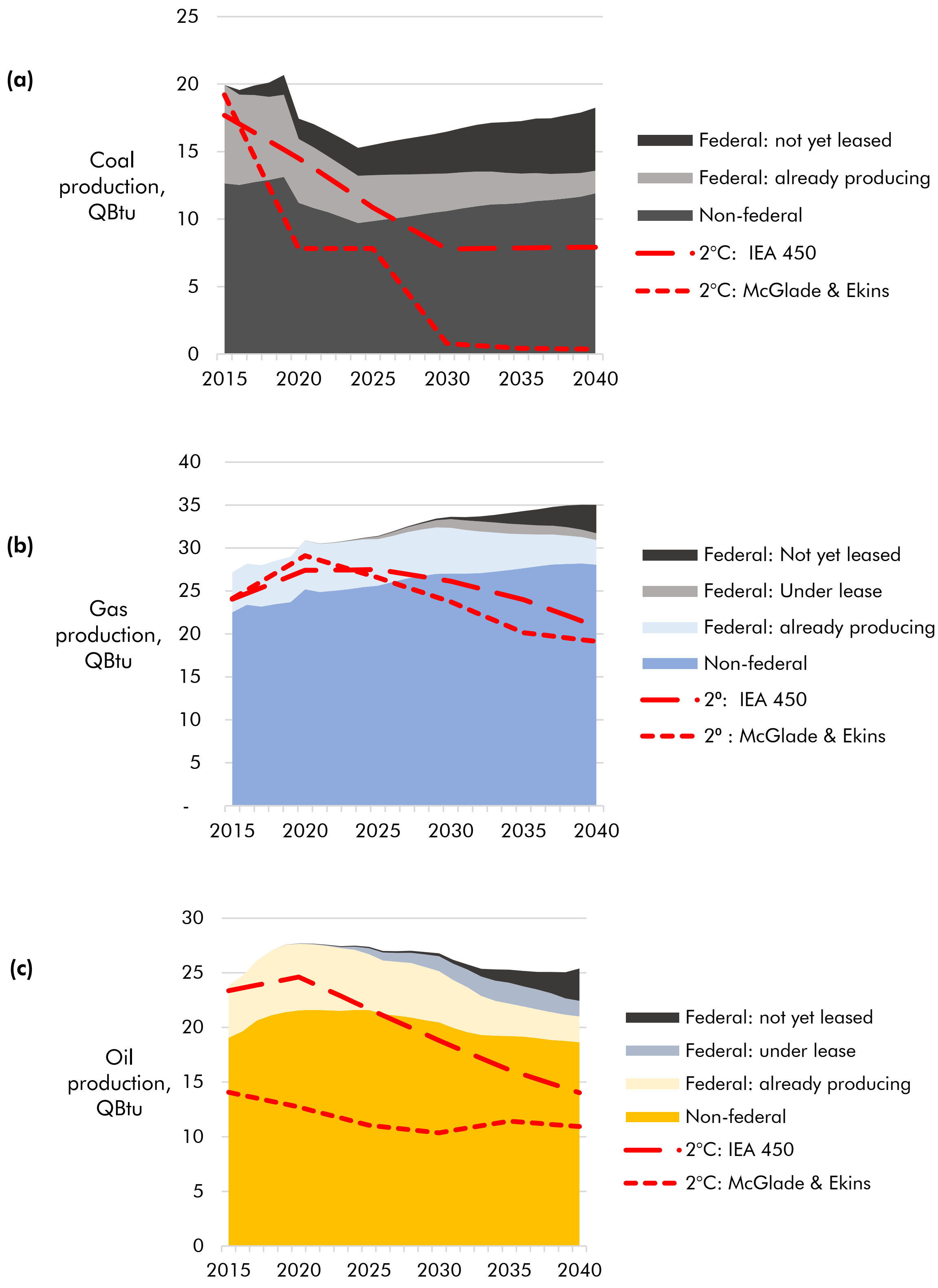
Under the reference case, total U.S. coal production drops sharply after 2020, then rebounds gradually such that, in 2030, the U.S. produces about 16 QBtu of coal. In a cost-efficient 2°C scenario, however, U.S. coal production would likely need to keep declining rapidly, by more

[19] We could not find data on lands leased for coal but not yet producing. Because the production on coal lands could be seen as trivial (i.e., very little infrastructure is needed to extract a minimal amount of saleable coal and therefore prove the lease), we assume that no coal extraction could be avoided by not renewing leases because leaseholders could easily prove production and avoid the non-renewal.

[20] This finding is based on the assumption that producers draw from existing and new leases at the same proportional rates.

than half: to 8 QBtu annually under IEA's 2°C scenario by 2030, or 1 QBtu under McGlade and Ekins's 2°C scenario. Compared with these 2°C scenarios, reference case U.S. production is on pace to substantially over-produce coal, such that both federal and non-federal coal supply would need to be reduced to attain a pathway consistent with 2°C.

Figure 4: Future U.S. fossil fuel production in reference case (by status of federal lease) and under 2°C scenario, 1990–2040



4.4 Gas

As shown in Figure 4, of all three fossil fuels, gas has the lowest fraction (less than one-fifth) produced from federal lands and waters. Roughly half of this gas is from lands in Rocky Mountain states, especially Wyoming and Colorado. About a third is from offshore deposits, almost all of which are in the Gulf of Mexico.

Gas (and oil) projects tend to have longer lead times than coal, as companies must first conduct exploratory drilling and put wells or offshore platforms in place. (By contrast, new federal coal leases are often next to existing mines and can be accessed readily with existing equipment.) Accordingly, changes to leasing practices for gas may take many years to affect production. In our analysis, new leases produce only a negligible quantity of gas before 2030. Existing (but not yet producing as of 2015) leases could produce slightly more gas in the near term (e.g. rising to 15% of production by 2030), but their importance diminishes in the longer term.

Between now and 2040, the reference case sees an estimated 30 trillion cubic feet (30 QBtu) of gas will be extracted from federal lands and waters not yet under lease or that are under lease but have not yet started producing. This represents 2 Gt CO_2 of emissions once the gas is burned. About two-thirds of this is likely to be from offshore deposits, indicating the growing role of offshore sources of gas. And although most of the offshore gas is still expected to come from Gulf sources through 2040, Pacific and Atlantic sources (notwithstanding the Obama administration's recently announced cancellation of mid-Atlantic lease sales) could take on increasing roles over time, making up 10% of offshore production in 2040 (up from 1% today, all in the Pacific). In the reference case, U.S overall (federal and non-federal) gas production rises gradually through 2040. By contrast, under the 2°C scenarios considered here, U.S. gas production would instead level off and peak in the next 10 years, then decline steadily to about 20 QBtu in 2040, indicating that the role of gas as a "bridge" fuel between coal and renewables in a 2°C world is short-lived. This finding is consistent with that of other studies (Lazarus, Tempest, et al. 2015; Davis and Shearer 2014).

4.5 Oil

Slightly more than one-fifth of current and expected U.S. oil extraction is from federal lands and waters. Thus, in contrast to coal, the impact of federal leasing through 2040 is more modest.

Leasing practices for offshore oil, especially in the Gulf of Mexico, could have the largest impact on federal oil extraction, since the Gulf is the source of about 70% of federal oil in the reference case. Most of the remaining oil comes from federal lands in Western states, including New Mexico, Wyoming and North Dakota.

As for gas, the longer lead times for oil projects – especially offshore oil – mean that new leases do not have much impact on oil production until after 2030. However, as production from existing fields declines more rapidly in later years, the importance of new leases grows.

Between 2016 and 2040, the reference case sees an estimated 7 billion barrels (40 QBtu) of oil will be extracted from federal lands and waters that were not under lease as of 2015, or had not yet started producing. This would equal 3 Gt CO_2 of emissions once the oil is burned (primarily as vehicle fuel). Over half of this oil is from offshore deposits in the Gulf of Mexico that are already under lease, which indicates that lease *renewal* rather than new leasing practices are likely to be the major determinant of federal oil production through 2040.

Overall, across both federal and non-federal lands and waters, U.S. oil production in the reference case peaks around 2020 at around 28 QBtu, then declines gradually to about 25 QBtu. By contrast, in the IEA 2°C scenario, U.S. oil production would peak at around 25 QBtu and then decline more rapidly, to less than 20 QBtu by 2030; in McGlade and Ekins' 2°C scenario, U.S. oil production would begin declining immediately, to less than 15 QBtu in 2020.

Table 2 summarizes the findings of our analysis of coal, oil, and gas production scenarios, especially the amount of federal fossil fuel extraction that might be avoided by cessation of new leases and by not renewing existing, non-producing leases.

Table 2: U.S. federal fossil fuel production in reference case and quantities avoided by ceasing new leases and not renewing non-producing leases, 1990–2040, in QBtu

Federal fossil fuel production	2015	2020	2025	2030	2035	2040
Coal	**7.3**	**6.2**	**5.6**	**5.9**	**6.1**	**6.3**
Avoided from non-renewals	–	–	–	–	–	–
Avoided from cessation of lease sales	–	(1.5)	(2.2)	(3.1)	(3.9)	(4.7)
Avoided (total)	–	(1.5)	(2.2)	(3.1)	(3.9)	(4.7)
Avoided, as % of reference case		(24%)	(40%)	(53%)	(64%)	(74%)
Gas	**4.6**	**5.7**	**5.8**	**6.6**	**6.7**	**7.0**
Avoided from non-renewals	–	(0.0)	(0.3)	(1.0)	(1.1)	(0.8)
Avoided from cessation of lease sales	–	(0.0)	(0.1)	(0.3)	(1.6)	(3.3)
Avoided (total)	–	(0.0)	(0.4)	(1.3)	(2.7)	(4.1)
Avoided, as % of reference case		(0%)	(6%)	(19%)	(40%	(59%)
Oil	**4.8**	**6.1**	**5.8**	**6.3**	**6.1**	**6.8**
Avoided from non-renewals	–	(0.0)	(0.6)	(1.4)	(1.9)	(1.4)
Avoided from cessation of lease sales	–	(0.0)	(0.1)	(0.3)	(1.2)	(3.0)
Avoided (total)	–	(0.0)	(0.7)	(1.6)	(3.1)	(4.4)
Avoided, as % of reference case		(1%)	(12%)	(26%)	(51%)	(65%)
Total	**16.7**	**18.0**	**17.2**	**18.8**	**18.8**	**20.1**
Avoided from non-renewals	-	(0.0)	(0.9)	(2.4)	(3.0)	(2.2)
Avoided from cessation of lease sales	-	(1.5)	(2.4)	(3.6)	(6.7)	(10.9)
Avoided (total)	-	(1.6)	(3.3)	(6.0)	(9.7)	(13.2)
Avoided, as % of reference case		(9%)	(19%)	(32%)	(52%)	(66%)

Source: SEI analysis based on sources described in prior charts.

5. REDUCTIONS IN CO_2 EMISSIONS FROM RESTRICTED LEASING

The prior section examined how fossil fuel production would be affected by ceasing new leases and not renewing existing, non-producing leases. In this section, we assess what this reduction in fuel extraction might mean for energy use and global CO_2 emissions.

We characterize these impacts on a net basis, meaning that we estimate the change in global CO_2 emissions *after* taking into account how other fuels may substitute for the federal fuels no longer extracted. Accordingly, our analysis directly addresses the potential for carbon leakage, or the whack-a-mole" phenomenon, that has characterized much of the debate around limiting fossil fuel extraction (Roberts 2015; Lazarus, Erickson, et al. 2015). Specifically, we quantify how, in response to reduced supply of federal fossil fuels:

- **Other non-federal fuels of the same type could substitute,** such as if coal from private, tribal, or state lands replaces coal no longer extracted from federal portions of the Powder River Basin. In oil markets, other supplies could come either from non-federal domestic sources, or from other global oil producers.
- **Different fossil fuels could substitute,** such as if, in response to a drop in coal production, U.S. power systems instead used more natural gas for power generation.

We apply economic tools commonly used to assess fuel markets. In each case, these tools consider that a cut in production is a shift in the supply curve for the fuel. Other producers, and consumers, then respond by consuming more or less of different fuels based on the resulting changes in prices. This approach situates our analysis in the broader economic literature on supply and demand for energy, and allows for a relatively straightforward quantification of the potential CO_2 effects, since the carbon contents of each fuel (coal, gas, and oil) are well known.[21] However, these tools are incomplete, as they do not capture the potential broader political or economic implications of what would be a high-profile climate measure taken by a major world economy. For example, were the prospective leasing restrictions by DOI to lead other decision-makers or investors to similarly move away from expanding fossil fuel supply, the impacts could be far greater. We will return to this possibility later in the discussion.

We conduct our analysis for the two energy resources – coal and oil – for which reduced federal leasing is likely to have the greatest implication on global CO_2 emissions. We do not consider the net CO_2 impact of reduced federal leasing for gas: as described in Box 3, it is not clear that changing the availability of natural gas would have a significant impact on CO_2 (or total greenhouse gas) emissions, either positive or negative.

We focus on net CO_2 emissions impacts in a specific year, 2030, as it serves as a common reference year for future climate action and commitments in the UN climate negotiations, including the Paris Agreement.

In Section 4, we developed estimates of the impact of fossil fuel extraction from federal lands (Table 2) if the DOI were to cease issuing new leases for coal or oil extraction and stop renewing non-producing leases as they come due.[22]

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[21] We do not conduct analysis of the change in CO_2 emissions associated with extracting, processing, or transporting each resource because these impacts are generally small compared to the emissions associated with combustion of the resulting fuel.

[22] As explained in Box 1, lease terms for oil are 10 years onshore or 5, 7, or 10 years for offshore (depending on water depth). It is possible that, should these leases (not producing as of 2015) start producing before the end of the lease term, they would be "held by production" and, by law, automatically renewed. In such a scenario, the estimates

Box 3. Changing the supply of gas has little impact on net CO_2 and GHG emissions

The decision to use coal or gas in power generation depends on the relative price and availability of these fuels, as well as their non-fossil alternatives, such as renewable power. The CO_2 implications of changes to gas supply are highly dependent on these dynamics, as well as on economy-wide effects on energy prices and overall energy use.

A number of studies have looked at the relative balance of these effects in assessing the CO_2 implications of increased availability of gas in the U.S. (Lazarus et al. 2015). Some indicate a slight CO_2 benefit of increased gas availability (Newell and Raimi 2014; Shearer et al. 2014; US EIA 2014), especially if gas tends to displace coal power. Other studies indicate a slight net increase in CO_2 emissions is possible, due increased energy use and displacement of low-carbon energy (Brown, Krupnick, and Walls 2009; US EIA 2014).[1] A model comparison exercise by the Energy Modeling Forum suggests, on average, no significant CO_2 emissions impact over the next few decades, as the "scale" effect of increased overall energy use largely offsets the "substitution" effect of shifting away from coal (Energy Modeling Forum 2013). Studies looking at gas supply internationally have come to similar conclusions (Lazarus et al. 2015; McJeon et al. 2014).

Given the findings of these studies, we do not ascribe a net CO_2 emissions impact to decreased leasing of federal natural gas resources, at least for the time scale we focus on here (through 2040). That said, the leasing decisions considered in this analysis would play out well beyond this time scale. Over the longer-term, natural gas is more likely to compete with low-carbon energy sources, especially if nations such as the U.S. and China continue to move away from coal. Thus, while reduced leasing of federal natural gas resources may have little effect on global CO_2 emissions over the next two decades, it could help in easing the longer-term transition to a low-carbon economy.

The effect of expanding natural gas supply on greenhouse emissions other than CO_2 will depend on other factors, namely, how much of methane (CH_4), a greenhouse gas many times more potent than CO_2, leaks to the atmosphere. Methane leakage can occur during fuel extraction (e.g. conventional or unconventional production, including fracking), transportation (e.g. via pipelines), or distribution (e.g. to homes and businesses via metal or plastic pipes.) At leakage rates most commonly suggested in the literature, methane leakage is unlikely to counteract the GHG emissions balance of natural gas relative to other fuels when that gas is used in most stationary energy applications, such as power generation or heat provision (Lazarus et al. 2015).[1] Some suggest that leakage rates and impacts could be much higher (Howarth 2015), especially for shale gas, though such estimates have yet to be widely accepted. We therefore consider that restricting leasing would not have a substantial net GHG emissions impact, just as we do not ascribe it a net CO_2-only impact, though we note that further efforts are needed to address methane leakage in natural gas production and distribution.[1]

5.1 Coal

U.S. coal markets are particularly complex, given the stock of coal power plants, many of which were built (or were substantially rebuilt) with boilers designed for a specific grade (or even supplier) of coal, thereby limiting the possibilities for substitution among coals from different suppliers (Joskow 1987; Haggerty et al. 2015). For example, a power plant built for the uniquely low-sulfur, sub-bituminous coal from the Powder River Basin may not be able to switch to other coal, at least not without major retrofits (e.g. to coal processing or pollution controls, or

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of avoided production due to non-renewals in Table 2: could be too high and, accordingly, also the estimates of CO_2 impacts in this section. However, nearly all of the production expected from already-held (but not-yet-producing) leases is from offshore oil, and very little of this is expected to start producing before 2025 in Rystad Energy's assessment (Rystad Energy 2015). With a maximum lease term of 10 years, most of these leases would be expected to come up for renewal before 2025, and therefore be subject to non-renewal.

potentially, a complete rebuild of the boiler). A simple model of supply and demand, by treating each ton of coal as equivalent in a competitive market, could miss these dynamics and thus likely overestimate the tendency for other coal, with much different characteristics, to substitute for the drop in federal coal. For this reason, a model that represents the costs and fuel requirements of specific power plants and coal resources has distinct advantages that here outweigh the lack of transparency that a simpler model might provide.

Therefore, to assess the response of the U.S. power market to a drop in domestic coal supply, we look to a recent study (which we refer to as the "Vulcan study") that analyzed how changes to federal leasing practices would affect coal consumption and power-sector CO_2 emissions in the U.S. (Vulcan/ICF 2016). It is the most recent and comprehensive study we identified that looks at changes to U.S. coal supply, and it is also the most closely aligned with the focus here on coal from all federal lands.[23] It uses the Integrated Planning Model, IPM, a tool also used by the U.S. Environmental Protection Agency (EPA). Furthermore, it takes into account the impact of the Clean Power Plan as well as the specific, power-plant-level dynamics – such as coal grade requirements and the cost of pollution control technologies or other plant retrofits – that would constrain substitution of other coals for the drop in federal coal.[24]

We summarize the results of the Vulcan study in terms of net decrease (or increase) in fuel consumption per unit drop in coal production in the year 2030.[25] The study found that, under the Clean Power Plan, each QBtu of coal no longer supplied (due to lease restrictions) to domestic power markets would be replaced by 0.64 QBtu of other coal, for a net drop in national coal consumption of 0.36 QBtu. Electricity production would remain virtually unchanged, such that gas consumption would increase 0.23 QBtu to make up for the lost coal-based electricity. (Gas power generation is more efficient than coal, thus less gas would be needed to provide an equivalent amount of electricity).[26]

Were the Clean Power Plan not in place, the Vulcan scenario found a larger effect: a net drop in 0.69 QBtu coal for every federal QBtu cut (with gas increasing 0.35 QBtu).

Table 3 summarizes these market responses. The effect under the Clean Power Plan is smaller, as the Plan would already lead power producers who can replace coal with low-cost alternatives

[23] Other studies reviewed, including the "North Fork" study (USFS et al. 2015) and the Tongue River Railroad study (OEA 2015), looked at a particular coal going to a more limited market.

[24] As described in the EPA's documentation of the IPM Model, (U.S. EPA 2013), IPM aggregates existing actual power plants into a smaller number of "model plants" with similar characteristics, each of which is modeled individually. For example, IPM models about 759 coal-fired "model plants" to represent 1,003 actual existing coal-fired plants.

[25] The Vulcan study analyzed over a dozen cases that varied in terms of policy considered (royalty rate increases and leasing restrictions), whether and how the Clean Power Plan might be implemented (mass vs. rate basis), and base case assumptions regarding future resource costs (Base Case A vs. Base Case B). To characterize the reduced coal and increased gas consumption per unit of gross drop in coal production (as in Table 3), we looked at the impact of a phasing out coal production by increasing coal prices (by imposing the social cost of carbon on royalty rates), assuming: a) the Clean Power Plan is implemented using a "mass-based" approach in which each state pursues a fixed CO_2 emissions target but can trade emissions allowances with other states in regional trading programs; b) fuel and renewable cost projections consistent with the EPA's analysis of the final Clean Power Plan (Base Case B). The Vulcan study also modeled a simpler (and total) phase-out of federal fossil fuel production between 2028 and 2037 due to cessation of new lease issuance, but we do not consider that case here because it uses an older, "Base Case A" with higher renewables costs than forecast by EPA, and because it takes a more simplistic approach to lease phase-out.

[26] Given the much higher average efficiency of gas-fired electricity generation, this amount of gas is sufficient to nearly completely substitute for lost coal-based electricity (i.e. nearly all of the substitution is by gas not renewables), e.g. as shows in Exhibit 118 of the Vulcan study (Vulcan/ICF 2016)

to do so, leaving coal generation mostly in places where the relative cost of alternatives is high. As a result, in response to a drop in federal coal, these remaining coal-fired power systems would shift more heavily to other coal supplies, as from the Illinois Basin and Appalachia. (It is also possible that other, non-federal Powder River Basin coal could substitute, were large new mines to be developed on state, tribal, or private lands, though the Vulcan study does not appear to envision such projects being economic at scale to replace the forgone federal coal.)[27] Another reason that the effect under the Clean Power Plan is smaller in the Vulcan analysis is because of interactions between the leasing restrictions and provisions that states must meet specific emission rate goals. To the extent these goals – or more accurately, the policies and measures states put in place to achieve them – are "binding", and states allow for interstate trading of allowances and credits, further CO_2 emission reductions beyond those required by the Clean Power Plan may be more difficult to achieve. While increases in coal prices spurred by restricted leasing would lead to further decreases in coal-based generation and emissions, those decreases could be offset by increased gas-based generation and emissions. They could also be offset by reductions in renewable power or energy efficiency, due to the added "headroom" under the cap and associated decreases in allowance or credit prices within and across states (to the extent that state and regional trading is adopted).

Table 3: Change in net consumption of coal and gas per 1 QBtu decrease in gross production of coal, QBtu basis

	Clean Power Plan case (Reference scenario)		No Clean Power Plan Case (Alternative reference scenario)	
	Coal	**Gas**	**Coal**	**Gas**
Domestic market	-0.36	0.23	-0.69	0.35
Export market	-0.30	0.07	-0.30	0.07

In principle, this effect could be so strong as to nearly eliminate any CO_2 emissions reductions from leasing restrictions under the Clean Power Plan. This could happen, for example, if the state emission rate goals assigned by EPA under the Clean Power Plan were "binding" for all states, fully determining power sector CO_2 emissions. A fully binding outcome for the Clean Power Plan is not foreseen in the Vulcan analysis used here. If future renewables or gas power costs were to be greater than currently foreseen by the EPA, then the likelihood of such an outcome would increase – a possibility we consider in the sensitivity analysis in Appendix B.

For exports, which are not described in detail in the Vulcan study, we develop and apply a simple model of supply and demand, similar to prior approaches (Power and Power 2013). The EIA expects exports of steam coal, including from federal lands in the Powder River Basin, to rise slowly but steadily over the next two decades. Producers in the Powder River Basin are particularly looking to emerging economies in East and Southeast Asia, especially Korea, where coal demand is still expected to increase (Considine 2015; Leaton et al. 2014; IEA 2015).

Information on the price elasticity of coal demand in Korea and Southeast Asia is sparse, however (Leaton et al. 2014). We assume that, in the long term, this market is roughly as price-

[27] For example, were the Otter Creek mine on state and private lands in Montana or the Big Metal Mine on Crow Reservation lands to be developed, the coal supply curve could "flatten", facilitating coal substitution beyond that foreseen in the Vulcan study, decreasing the net effect on coal consumption in Table 3.

responsive as Chinese power systems were during their period of rapid growth (Jiao et al. 2009), for an elasticity of demand of -1.12. We assume that the Pacific Coal market is highly competitive, with substantial low-cost supplies from Indonesia and Australia (Aldina 2013), for elasticity of supply of 2.6. Together these assumptions imply that each QBtu of U.S. coal no longer exported to Asian power markets would be replaced with 0.7 QBtu of other coal, for a drop in net coal consumption of 0.3 QBtu (Table 3).[28] Given the limited supply of gas in Asia to substitute, gas would not fully offset this net drop in coal. Based on a meta-analysis of fuel substitution research (Stern 2012), we find that natural gas in these markets would increase by 0.07 QBtu, only partially substituting for the drop in coal consumption.[29]

We now apply the ratios in Table 3 to the gross drop in coal production from cessation of lease issuance (Section 4) to yields estimates of net change in coal and gas consumption. First, however, we make two adjustments to our estimates of the gross drop in coal production.

The first adjustment is simply to exclude metallurgical coal, such as for use in iron and steel mills. Though this coal is much higher-value than coal for energy production (steam coal), it has smaller CO_2 emissions implications. This is because metallurgical coal has few, if any, readily available low-carbon alternatives, so reducing its supply would be unlikely to affect CO_2 emissions substantially. We assume that 7% of the coal extracted goes to metallurgical, not power, markets, based on national averages from the U.S. EIA (2015b).

The other adjustment involves additional deposits of coal that may be affected by leasing restrictions since in some instances cutting the availability of *federal* coal would also constrain the accessibility or profitability of mining adjacent *non-federal* coal. This could especially be the case in Wyoming, as hundreds of relatively small plots of state lands are entirely contained within federal parcels (Luppens and Scott 2015). These non-federal parcels may not be accessible or economic to extract if federal leasing were restricted (a similar situation may exist with some private lands). The Vulcan study, for example, estimates the associated reduction in non-federal coal to be as much as half the reduction in federal coal (Vulcan/ICF 2016), magnifying the effects of federal lease restrictions. Here, we assume, based on a review of U.S. EIA (2015a) and ONRR (2015) data, that non-federal coal makes up about one-sixth of federal production in Wyoming, and so we increase our estimates of the drop in coal supply from Wyoming by this fraction. (We do not adjust the drop in coal production from other states.)

Together, these adjustments result in an estimated cut in coal supply in 2030 of 2.9 QBtu to domestic markets and 0.3 QBtu to export markets relative to our Clean Power Plan reference scenario.

Applying the ratios in Table 3 to these totals yields estimates of the impacts on net consumption of coal and gas in energy terms (Table 4). Applying standard carbon contents for coal and gas

[28] We assume an elasticity of demand of -1.12 (Jiao et al. 2009) and an elasticity of supply of 2.6, as imputed from Wood Mackenzie's coal supply curve (Aldina 2013) at expected consumption levels. Together, and using the equation $E_d/(E_d-E_s)$ as from basic microeconomics (Perloff 2007) and prior studies (Power and Power 2013; Erickson and Lazarus 2014), suggests a net effect on consumption of 0.30. See the next section, on oil, for further discussion of this equation.

[29] We estimated the ratio of increased gas consumption to drop in coal supply by introducing two adjustments to the equation described in the prior footnote. The adjustments are the elasticity of substitution between coal and gas (E_{cg}) and the starting ratio of gas to coal consumption (Q_g/Q_c), and are applied as follows: $(E_d+E_{cg})/(E_d-E_s)*Q_g/Q_c$. We use Table 4 of Stern's (2012) meta-analysis to estimate E_{cg} in Korea as 1.4. The IEA estimates that the ratio of gas to coal consumption in OECD Asian countries (such as Korea and Japan) in 2030 will be 0.9, and we use this as Q_g/Q_c. Were the consumers of exported U.S. coal instead countries with more coal and less gas, such as China or India, the ratio of gas to coal could be much lower and, therefore, also the extent of substitution of gas for coal.

(IPCC 2006) yields estimates of the emissions increases or decreases for each fuel in each market (also in Table 4).[30]

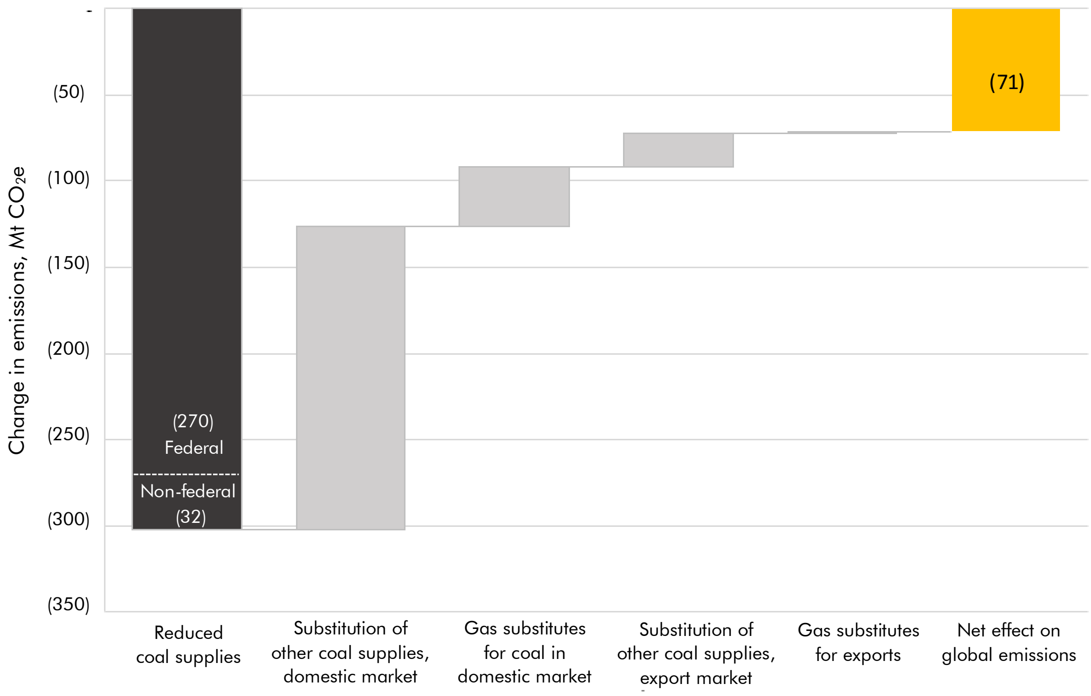
Table 4: Change in net consumption of coal and gas in response to decreased coal production, 2030

	Clean Power Plan Case		No Clean Power Plan Case	
	Coal	**Gas**	**Coal**	**Gas**
Energy content (QBtu)				
Domestic market	(1.03)	0.66	(3.33)	1.67
Export market	(0.09)	0.02	(0.10)	0.02
Total	(1.12)	0.68	(3.43)	1.69
Carbon content (Mt CO_2)				
Domestic market	(99)	35	(318)	88
Export market	(8)	1	(10)	1
Total	(107)	36	(328)	90

In our reference case, assuming Clean Power Plan implementation (Table 4), we find that leasing restrictions would reduce CO_2 emissions in 2030 from coal by about 107 Mt CO_2, but increased use of gas would increase emissions by about 36 Mt CO_2, resulting in a net reduction of 71 Mt CO_2. Figure 5 illustrates the individual effects that add up to this net reduction. As shown in the chart, leasing restrictions lead to a drop in coal extracted in federal or adjacent lands in 2030 equivalent to 300 Mt CO_2. Increased production in the Illinois Basin and (to a lesser extent) Appalachia makes up for about 60% of the lost coal production from federal and adjacent lands. Increased coal prices also lead to some substitution by gas in domestic power systems. Substitution also occurs in export markets, by gas and other coal supplies from countries such as Australia and Indonesia. The net reduction in CO_2 emissions, after accounting for all of these effects is, as stated above, 71 Mt CO_2 in 2030

[30] We do not conduct analysis of the change in CO_2 emissions associated with extracting, processing, or transporting each resource because these impacts are generally small compared with the emissions associated with combustion of the resulting fuel.

Figure 5: Impacts of decreased coal production on coal and gas markets, 2030, under the reference (Clean Power Plan) case, CO_2 basis



5.2 Oil

Oil is used primarily in transport, with more than half of current and expected future global oil used as transport fuel, especially for cars and trucks. The remaining portion is split among the industry, buildings and power sectors, though uses in buildings and power are expected to decline (IEA 2015). The oil market is also highly global, with oil readily traded among countries, and substantial infrastructure in place to do so. The U.S. both imports and exports oil, and world and domestic oil prices very closely track each other (U.S. EIA 2016).

For this reason, we expect that changes in U.S. oil production would affect an integrated global oil market, an assumption also made by many other analysts that have looked at changes in U.S. oil supply (Bordoff and Houser 2015; Rajagopal and Plevin 2013; Allaire and Brown 2012; Metcalf 2007; IEc 2012). Though in the past the oil market could be strongly influenced by cartel behavior among a small number of producers, many analysts now see the market as more likely to behave competitively (The Economist 2016; U.S. EIA 2016), meaning that increases or decreases in supply do translate into shifts in prices and, in turn, consumption.[31]

Accordingly, we model the impact of federal leasing policy on the global market as a shift in the global supply curve, just as in our prior assessment of oil markets (Erickson and Lazarus 2014). Assuming the decline in supply is small relative to this global market, the resulting change in consumption can be modeled as a direct function of the change in production, using

[31] A shift in supply will only affect consumption if it is not offset by a shift by another large producer, such as a cartel in the Middle East.

elasticities of demand (E_d) and supply (E_s) (Erickson and Lazarus 2014) and from basic microeconomics (Perloff 2007), using the following equation:[32]

$$\Delta Consumption \cong \frac{E_d}{E_d - E_s} * \Delta Production \tag{1}$$

Consistent with our prior work, we use a mid-range estimate of the long-run elasticity of world crude oil demand of -0.2 based on a literature review (Hamilton 2009), and within the range, from -0.072 to -0.3, found by a more recent review (Bordoff and Houser 2015). For the elasticity of supply, we use a value of 0.25 from Rystad Energy's oil supply curve for the year 2030.[33]

Applying these elasticities to equation (1), we estimate that, for each unit of production cut, other oil supplies will substitute for 0.56 QBtu, and that net oil consumption will drop by 0.44 QBtu (Table 5). This result is unaffected by Clean Power Plan implementation, since the law has little impact on oil consumption.

Table 5: Change in net consumption of oil and substitute fuels per unit decrease in gross production of oil, QBtu basis[34]

	Oil	Substitutes (biofuels, gas and electricity)
Global market	(0.44)	0.22

Some of this drop in oil consumption will be made up by alternative transport fuels, while some will represent a reduction in overall transportation energy use due to increased vehicle efficiency, transport mode shifts, or other measures. In the long term, other transport fuels (beside oil) may become viable alternatives at scale, including biofuels, compressed natural gas (CNG), or electricity. However, little information exists on the long-term elasticities of substitution between oil and these other transport fuels (Faehn et al. 2016). Furthermore, deployment of these other fuels and their corresponding vehicles will depend not only on fuel economics, but also on national policies (U.S. EIA 2013). Therefore, we look to the International Energy Agency's *World Energy Outlook 2015* (IEA 2015) to inform our estimates of substitution effects. A comparison of *World Energy Outlook 2015* scenarios suggests that, over the next few decades, the effect of price-induced decreases in oil consumption may be split roughly evenly between lower overall energy use and increased use of substitute fuels.[35] As

[32] This equation is the same one as that used to model the response to coal exports as described previously. We describe it here for oil in more detail since the flow of oil from U.S. public lands and waters to the global market is many times greater than the flow of coal from public lands to the Pacific coal market.

[33] We measure the slope of Rystad Energy's oil supply curve for 2030 at the expected equilibrium consumption level (99.5 mbpd), and use that to calculate the elasticity. In this range of the cost curve, offshore oil producers in Mexico and Malaysia, and tight oil producers in the U.S., are dominant, suggesting that these could be the marginal producers for oil supply in 2030.

[34] As described in the text, we assume 30% of the substitute fuel is biofuels (50% cut in GHG-intensity relative to oil), and the remainder is electricity and gas (same GHG-intensity as oil).

[35] We estimate this half-half split by looking at the response to oil and other fuel demand in IEA's Low Oil Price scenario relative to their New Policies Scenario. Figure 4.5 of *World Energy Outlook 2015* indicates that for each increase in oil consumption in the Low Oil Price scenario, about half is from higher demand and half is from less fuel switching away from oil (the substitution effect is slightly less than half in earlier years, slightly more in later

shown in Table 5, we apply this 50:50 ratio and estimate that for each 0.44 unit drop in oil consumption, the use of substitution fuels will increase by 0.22 units.

We further assume, again drawing from a comparison of *World Energy Outlook 2015* scenarios, that 30% of the fuels that substitute will be biofuels.[36] Though future production methods of biofuels remain in development, we assume that they will be half as GHG-intensive as petroleum-based fuels, on a life-cycle ("well to wheels") basis, and reflecting a higher penetration of second-generation and advanced biofuels in the future.[37]

Beside biofuels, the other fuels that substitute are natural gas (e.g. CNG in vehicles) and electricity (i.e. in electric vehicles). However, these fuels are not yet foreseen to offer, in aggregate across the globe through 2040, substantial GHG emission benefits for transportation uses relative to oil. This is because natural gas (methane) leakage during fueling erodes what would otherwise be a CO_2 benefit of gas (Alvarez et al. 2012). Electric vehicles, though they can bring substantial CO_2 benefits in regions adding low-carbon electricity, can increase net CO_2 emissions if the source of electricity is coal. On average, the IEA finds that, in its reference (New Policies) case, one effect does not clearly outweigh the other (IEA 2015), and so we assume, for simplicity, that *in aggregate*, there is no net CO_2 effect in substituting electric for petroleum-fueled vehicles.

Based on these assumptions about the GHG balance of biofuels, gas, and electricity, we estimate that the carbon-intensity of this alternative fuel mix is 85% of the carbon-intensity of oil-based fuels. Were the alternative fuels to be lower-carbon, such as renewable electricity or sustainable, second- or third-generation low-GHG biofuels, then the GHG benefits of reducing oil supply and, in turn, consumption, could be much greater, a possibility we explore further in the sensitivity analysis in Appendix B.

Applying the ratios in Table 3 to the gross oil production cuts from Table 2: (1.6 QBtu) yields estimates of the net increase or decrease in oil and its substitutes (Table). Further applying standard carbon contents of oil (IPCC 2006) yields estimates of net changes in CO_2 emissions.

As shown in Table , cutting oil production from federal lands reduces global CO_2 emissions in 2030 from oil consumption by 54 Mt CO_2, and leads to an increase in CO_2 emissions from other fuels of 23 Mt CO_2, for a net emissions benefit of 31 Mt CO_2. (Again, Appendix B provides sensitivity analysis.)

Table 6: Change in net consumption of fuels in response to lower oil production, 2030

	Oil	Substitutes (biofuels, gas, and electricity)
Energy content (QBtu)		
Global market	(0.73)	0.36
Carbon content (Mt CO_2)		
Global market	(54)	23

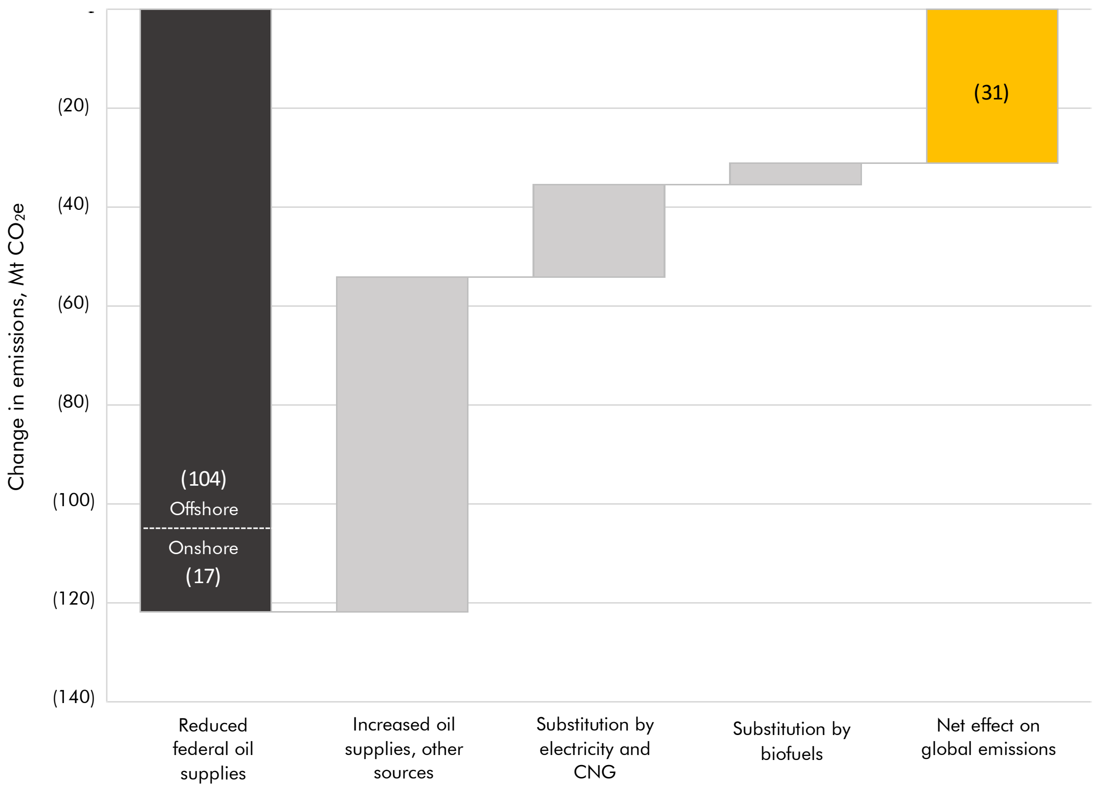
years). For our analysis, we assume the same dynamic would apply for decreases (rather than increase) in oil consumption.

[36] We derive this by comparing changes in (non-bunker-fuel) global transport energy demand for 2030 in the New Policies Scenario versus the Current Policies Scenario in the *World Energy Outlook 2015* (IEA 2015)

[37] The most widely used biofuel in the U.S., ethanol from corn, offers only modest (if any) GHG emission reductions relative to petroleum fuels, but sugarcane and other cellulosic ethanol and advanced biofuels still under development could cut the CO_2-intensity of fuels substantially (U.S. EPA 2010).

Figure 6 shows the individual effects that result in this estimated reduction. Leasing restrictions lead to a drop in oil extracted from federal lands and waters in 2030 equivalent to 120 Mt CO_2, 85% of which is from offshore oil leases not renewed or issued. Increased production in other global supplies makes up for more than half the lost federal oil production. Increased oil prices also lead to some substitution by other fuels: electricity, CNG and biofuels. The net reduction in CO_2 emissions, after accounting for all of these effects is 31 Mt CO_2 in 2030, as noted above.

Figure 6: Impacts of decreased oil production on oil and substitute fuel markets, 2030, under the reference (Clean Power Plan) case, CO_2 basis



5.3 Summary and discussion

Table 7 summarizes the net CO_2 emissions impacts of the cuts in coal and oil production. In total, we find that, by ceasing to issue new and renewed leases for fossil fuel extraction from federal lands and waters, the DOI could reduce net CO_2 emissions by about 100 Mt per year by 2030. Annual emission reductions could well increase over time, as federal fossil fuel production becomes even more dependent after 2030 on yet-to-be issued leases. Furthermore, over time, consumers are likely to be more sensitive to increased fossil fuel prices (Bohi 2013).

Table 7: Change in net consumption of fuels, 2030, in Mt CO_2

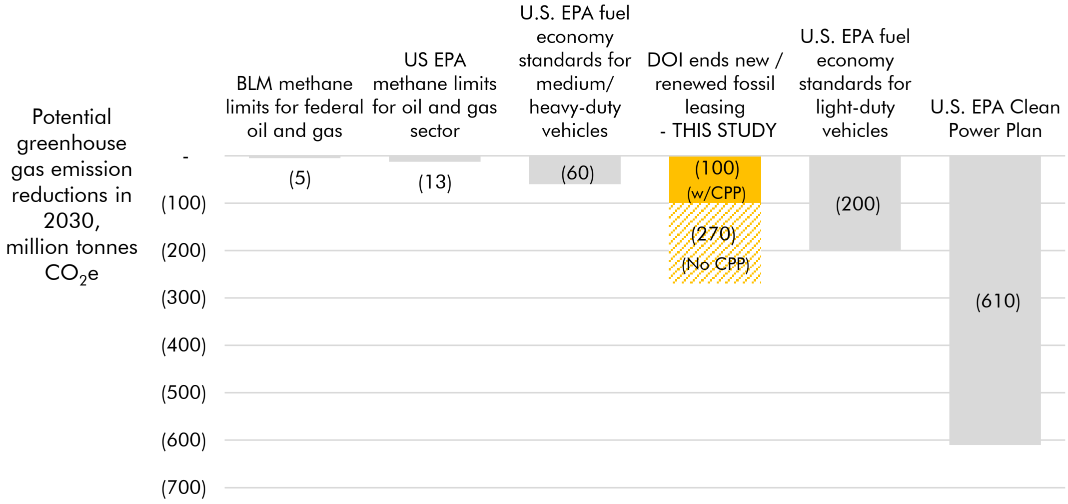
	Clean Power Plan Case			No Clean Power Plan Case		
	Impact on same fuel	**Impact on substitute fuel(s)**	**Net**	**Impact on same fuel**	**Impact on substitute fuel(s)**	**Net**
Coal						
Domestic market	(99)	35	(64)	(318)	88	(230)
Export market	(8)	1	(7)	(10)	1	(8)
Subtotal	(107)	36	(71)	(328)	90	(238)
Oil						
Global market	(54)	23	(31)	(54)	23	(31)
Total	(160)	58	**-100**	(380)	110	**-270**

Note: Figures may not add to totals due to rounding.

Our findings on the CO_2 emission savings that could result from leasing restrictions (100 Mt CO_2 per year in 2030 with the Clean Power Plan) are comparable to the savings from prominent policy initiatives of the Obama administration. As shown in Figure 7, the EPA's most recent proposed standards for light- and medium-/heavy-duty vehicles are expected to yield 200 Mt and 70 Mt in CO_2 savings, respectively, in 2030. The reduction from leasing restrictions is considerably greater than either the emission reductions that the EPA expects to achieve through regulation of the oil and gas industry's own (sector-wide) emissions, or what the BLM expects to achieve from methane restrictions on oil and gas operations on federal land.[38] Only the Clean Power Plan is expected to yield significantly greater emission benefits than potential federal leasing restrictions. In other words, cessation of new and renewed leases could make an important contribution to U.S. climate change mitigation efforts.

[38] In addition to the magnitude of greenhouse gas emissions reductions, planners may also consider cost-effectiveness as a criterion. From that perspective, one might prefer to phase out high-cost fossil resources first, which may or may not be federal resources. (For example, deepwater oil is often considered a high-cost oil resource; Powder River Basin coal, however, is generally considered lower-cost coal.)

Figure 7: Comparison of the potential global GHG emissions impact of federal leasing reform and other U.S. government policies, 2030



Source: SEI analysis. Estimate of emission reductions other policies adapted from BLM (2016a) and U.S. EPA (2012; 2015a; 2015b).

Several uncertainties underlie our analysis. We address an important one – the potential reversal of the Clean Power Plan – by conducting our analysis both with and without this policy in place. We find, in this case, that not issuing new leases for coal production could be an important complement to the Clean Power Plan, since ending leasing could phase down federal coal production and, should the Clean Power Plan not be implemented, reduce emissions by 270 Mt CO_2 in 2030. This amounts to nearly half of the 610 Mt in CO_2 savings that the EPA estimates the Clean Power Plan would achieve in that year.

Our findings are also particularly sensitive to the response of producers and consumers to changes in energy prices that would result from reductions in fossil fuel supply. For example, should coal producers on federal (or non-federal) lands respond to lease restrictions by more rapidly drawing down their reserves, perhaps in anticipation of broader and more ambitious efforts to address U.S. CO_2 emissions,[39] the impact in 2030 could be less than we estimate, though in later years, emission reductions could be greater.[40] On the other hand, should cessation of federal leasing send a market signal that leads to further tightening of finance for the coal industry, already in trouble, then coal production could decline even more rapidly. Similarly, should coal power plants be less able to substitute other sources of coal for the Powder River Basin and other federal resources, as at least one analysis has suggested (Haggerty et al. 2015), then the CO_2 emission reductions could be greater, as even more power systems would switch to lower-emissions resources such as gas or renewables.

Similar uncertainties affect our estimate of oil market impacts. This estimate is dependent on the responsiveness of other oil suppliers to lower U.S. federal supplies in global markets. Our analysis uses a relatively steeply sloping supply curve (from Rystad Energy) in 2030, with relatively high-cost producers on the margin, such as less-profitable tight oil and offshore-

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[39] This would be a manifestation of what some have termed the "green paradox" (Sinn 2012).

[40] Vulcan/ICF's (2016) analysis would seem to indicate that this could occur, as producers of federal coal respond to lease restrictions by essentially maintaining (or slightly increase) production over the next decade, only to stop entirely by 2040.

producers. If oil production were to experience another surge of unexpected technological advancement, then the supply curve could "flatten" and reduce the impacts of lower federal oil production. Or if future oil production were constrained by unexpected resource declines (such as faster than expected decline rates from tight oil fields), slower technological progress, or other countries taking similar measures to slow future oil production, then the net CO_2 emissions impact could be even greater.

To understand the potential impact of these uncertainties, as described in detail in Appendix B, we conduct sensitivity analysis around several of the most important parameters in our analysis: the sensitivity of producers and consumers to shifts in supply and price. At one end of the spectrum, were fossil fuel markets and energy technologies to proceed unencumbered by climate policy, the world might see continued abundance of lower-cost fossil fuel supplies and slower development of low-carbon alternatives (such as renewable power or low-carbon vehicles). In a higher-carbon world, restrictions on federal fossil fuel supply could have less of an impact than we estimate here – as little as 4 Mt CO_2 in 2030 under our reference scenario. Restricting supply would have little impact on energy prices (due to higher supply elasticities), and fuel consumers would have fewer cost-competitive alternatives (as reflected in lower demand elasticities).

By contrast, in a lower-carbon world, where other countries take similar steps to limit fossil fuel supply and renewable power and alternative vehicles are even more available, the impacts of federal leasing policy could be greater. Fewer coal and oil producers would be able to step in to make up for the lower supply from U.S. federal lands (lower supply elasticities), and consumers would more readily respond to the price impacts by shifting to lower-carbon alternatives (higher demand elasticities). In such a case, the impact of U.S. leasing restrictions under the reference (Clean Power Plan) case could be twice as high as estimated – 210 Mt CO_2. Appendix B describes the assumptions that lead to these low- and high-end results.

Our analysis has thus far focused on overall CO_2 emissions impacts, without specifying the jurisdictions where these impacts would occur. The territorial emissions accounting system currently used under the UN climate regime only accounts for emission reductions that occur within each country's own boundaries, creating a political disincentive to adopt climate policies that would yield a large share of their benefits abroad (Erickson and Lazarus 2013).

In this context, it is notable that in our reference case, 30% of the estimated emissions benefit in 2030 of avoiding new federal fossil fuel leases and renewals would occur outside the U.S. Moreover, the majority of the emissions benefit of reduced U.S. oil production in particular would occur in other countries, due to the global nature of oil markets. If reductions in emissions are evenly spread, proportionate to projected oil consumption in 2030, then of the 31 Mt of CO_2 reductions, 5 Mt CO_2 in savings would occur in the U.S., and 26 Mt CO_2 in other countries.

In contrast, because domestic coal markets and prices are relatively distinct, and because most U.S. coal remains in the country, we project that nearly 90% of the emissions benefit of reduced coal supplies would occur within U.S. borders. Still, while the impact we calculate for export markets for 2030 is relatively small (reduction of 7 Mt CO_2), the long-term effect may be more significant if these countries are making enduring decisions regarding power infrastructure, and so U.S. leasing restrictions may also help avoid lock-in of long-lived coal-using infrastructure.

It is important to note that while the incremental emissions impact of reduced leasing over the next two decades is non-trivial, the broader, long-term implications with respect to global climate objectives would be more profound. As shown in Section 4, new leases begin to account for a majority of federal fossil fuel production only after 2030, as production from existing leased areas begins to play out. Thus, the incremental emissions impact will be far greater in the longer run.

In addition, a cessation of new federal leases would send a strong signal to other countries, encouraging them to take similar steps. Based only on the straightforward economic tools used here, we estimate that in such a case, with global fossil fuel supply more constrained and low-carbon renewables more available, the impact could be at least twice as high: 210 Mt CO_2 in 2030 alone.

Taken together, reduced government licensing and support for fossil fuel production could also help avoid further carbon lock-in in terms of investment in both fossil fuel-using and -producing infrastructure. Phasing out of federal oil supply could help accelerate the development of low-carbon transport options (such as electric vehicles powered by low-carbon electricity). Leases for offshore oil production, estimated to supply as much as three-quarters of U.S. federal oil (chiefly from the Gulf of Mexico), may be especially important as offshore oil production, with its high capital costs, is a key contributor to carbon lock-in, increasing the cost of meeting climate goals and making it harder to transition away from oil later (Erickson et al. 2015).

Finally, by ceasing new leases, the U.S. government would put fossil fuel production on a path to ending completely sometime in the second half of this century. That would be consistent with a long-term goal adopted in the Paris Agreement to achieve net zero greenhouse gas emissions from human activities later in the century, consistent with having a likely chance of keeping warming below 2°C (or 1.5°C).[41]

[41] The agreement says "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty", which translates to net zero emissions.

6. CONCLUSIONS

Our analysis suggests that future leasing practices in federal lands and waters will play an important role in U.S. efforts to achieve its climate protection goals. Under a business-as-usual scenario, where federal leasing continues unabated, U.S. fossil fuel extraction will continue to rise through 2040, with 40% of coal and a quarter of overall fossil fuel production occurring in federal lands and waters. Should the Clean Power Plan survive legal and legislative challenges, overall coal production is likely to drop. Gas and oil production, however, (assuming a rebound in global oil prices) will likely continue upward, at least in the short term. By 2040, the U.S. could be producing 11% more fossil fuel energy and 7% more fossil fuel carbon than it does today.

At the Paris Climate Change Conference, the U.S. and other governments reaffirmed their commitment to keep warming within 2°C, further noting an intention to pursue a limit of 1.5°C. These goals would appear to call for a far different path for future U.S. fossil fuel production. As we illustrate in Section 3, **a cost-efficient pathway to meeting the 2°C commitment could require total U.S. fossil fuel energy production to decline by 40–60% from current levels by 2040**, and even more so for a 1.5°C goal. The percentage decline would be steeper for coal, and less so for gas, though production of all three fossil fuels would need to drop substantially over this period.

The U.S. has been a world leader in fossil fuel *consumption*, and the country has used this position to play a pivotal role in climate policies that seek to reduce fossil fuel *demand*. The U.S. is also a world leader in fossil fuel *production*, and could play a similar role for fossil fuel *supply*. By taking actions to curb investment in future fossil fuel supply infrastructure, federal policy-makers could limit carbon lock-in, limit the potential for asset stranding, and complement the policies needed to reduce fossil fuel use, such as the Clean Power Plan. In particular, modifying federal policies for leasing lands and waters for fossil fuel extraction – for example, by increasing royalties or removing lands or waters from future availability – could be an important element of a more comprehensive U.S. strategy aimed at fulfilling its long-term climate commitments.

In this paper, we have examined the potential energy and emissions implication of a decision to cease all new leases and non-producing lease renewals for fossil fuel production on federal lands and waters. Our main findings are that such an action could:

- **Send national coal production on a declining pathway**, potentially to levels more consistent with a 2°C pathway for U.S. coal extraction. Such an action could leave 4 billion short tons of federal coal in the ground that otherwise would be combusted between now and 2040, equivalent to about 7 Gt of CO_2 emissions.
- **Take longer to play out for oil and gas extraction**, as many oil and gas projects, especially offshore, have substantially longer lead times from lease approval to full production. Stopping leases for these fuels could leave an estimated 7 billion barrels of federal oil (3 Gt CO_2) and 30 trillion cubic feet of federal gas (2 Gt CO_2) undeveloped between now and 2040.
- **Yield a net CO_2 emissions reduction in 2030 of 100 Mt CO_2** (relative to reference case levels), substantially more than other U.S. policies under consideration focused on fossil fuel extraction and on par with flagship policies of President Obama's Climate Action Plan, such as fuel standards for cars and trucks. Roughly 70 Mt CO_2 of the impact in 2030 would be from reduced coal emissions (especially in the U.S.). We find that the effect of ceasing new coal leases could range from virtually none (were gas generation to increase even more strongly) to 140 Mt CO_2 (were other coal supplies to be more limited and renewables able to fully substitute for reduced coal). The

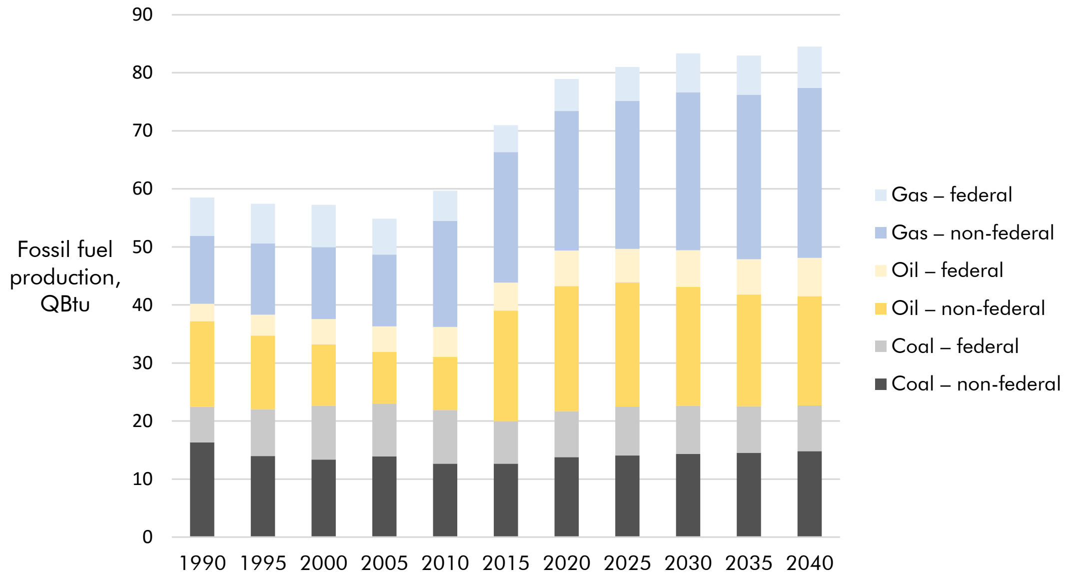
remaining decrease of 30 Mt CO_2 results from reduced global oil consumption resulting from an end to new leases and renewals (for non-producing areas) for oil production (largely off-shore), an effect that could similarly range from 4 Mt CO_2 to 64 Mt CO_2, depending on other policies put in place internationally. These emissions impacts would likely increase over time, as new, not-yet-issued federal leases comprise an even greater fraction of national fuel production after 2030.

Many nations are pursuing actions that reduce the demand for fossil fuels, including commitments ("intended nationally determined contributions") registered in the Paris Agreement and the policies that support them. Few nations, however, are pursuing actions to limit fossil fuel supply. Given the goal of limiting warming to 2°C (or 1.5°C) and the corresponding need to transition rapidly away from fossil fuels, many more policy measures need to be on the table than are currently considered. Our analysis here indicates that measures directed at fossil fuel supply – such as a phase-out of leasing federal lands and waters for fossil fuel extraction – could be an important complement to other measures designed to reduce fossil fuel consumption.

APPENDIX A: RESULTS FOR CASES WITHOUT THE CLEAN POWER PLAN

In the main body of this paper, we consider the EIA's Clean Power Plan scenario as the reference case for our analysis of U.S. fossil fuel production. In this appendix, we instead present findings for a reference case without the Clean Power Plan.

Figure A-1: Historical and forecast U.S. fossil fuel production, 1990–2040, case without the Clean Power Plan



Source: SEI analysis based on ONRR (2015) and U.S. EIA (2015a; 2015b), assuming the Clean Power Plan is not implemented.

Figure A-2: Historical and forecast U.S. fossil fuel production, by status of federal lease, 1990–2040, case without the Clean Power Plan

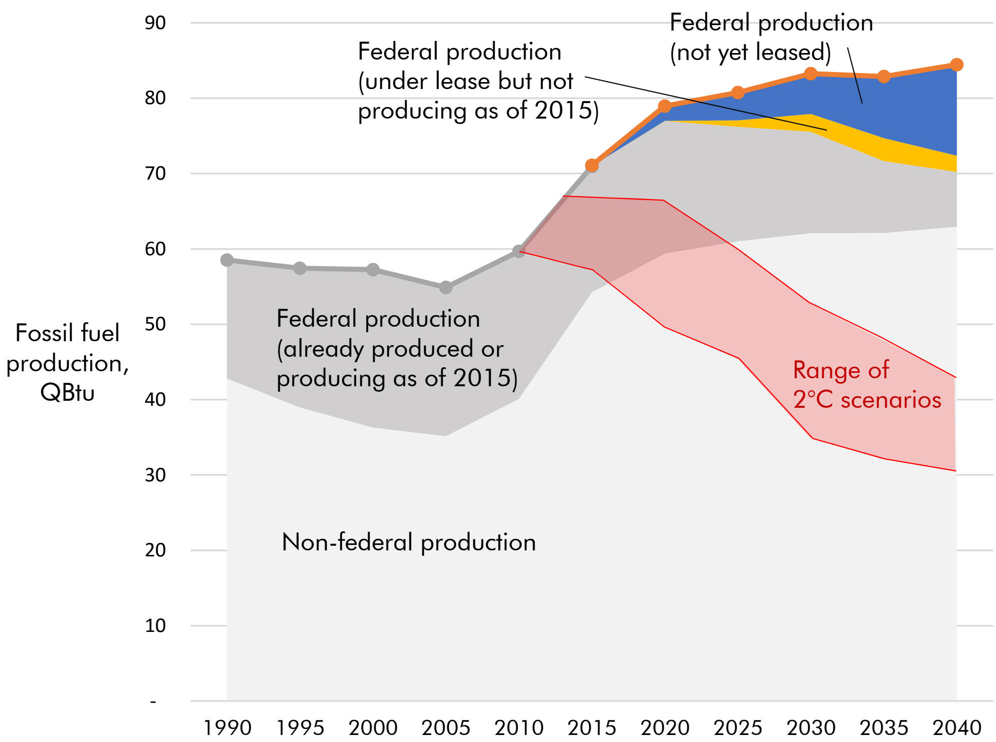
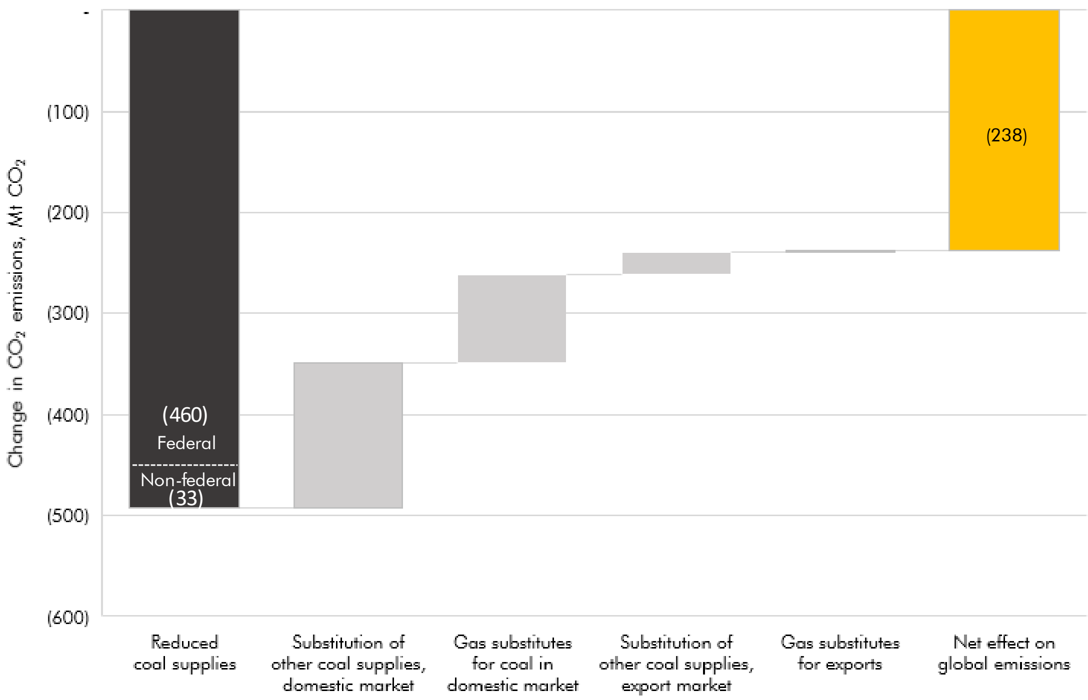


Table A-1: U.S. federal fossil fuel production in reference case (no Clean Power Plan case) and quantities avoided by cessation of new lease sales and non-renewals of non-producing leases, 1990–2040, in QBtu

Federal fossil fuel production	2015	2020	2025	2030	2035	2040
Coal	**7.3**	**7.9**	**8.4**	**8.3**	**8.0**	**7.9**
Avoided from non-renewals	–	–	–	–	–	–
Avoided from cessation of lease sales	–	(1.9)	(3.8)	(4.9)	(5.5)	(5.9)
Total avoided production		(1.9)	(3.8)	(4.9)	(5.5)	(5.9)
% of reference case production		(25%)	(45%)	(59%)	(69%)	(75%)
Gas	**4.6**	**5.5**	**5.8**	**6.7**	**6.7**	**7.1**
Avoided from non-renewals	–	(0.0)	(0.3)	(1.0)	(1.1)	(0.8)
Avoided from cessation of lease sales	–	(0.0)	(0.1)	(0.3)	(1.6)	(3.4)
Total avoided production		(0.0)	(0.4)	(1.3)	(2.7)	(4.1)
% of reference case production		(0%)	(6%)	(19%)	(40%)	(58%)
Oil	**4.8**	**6.1**	**5.8**	**6.3**	**6.1**	**6.6**
Avoided from non-renewals	–	(0.0)	(0.6)	(1.4)	(1.9)	(1.4)
Avoided from cessation of lease sales	–	(0.0)	(0.1)	(0.3)	(1.2)	(2.9)
Total avoided production		(0.0)	(0.7)	(1.6)	(3.1)	(4.3)
% of reference case production		(1%)	(12%)	(26%)	(51%)	(65%)
Total	**16.7**	**19.6**	**20.0**	**21.3**	**20.9**	**21.6**
Avoided from non-renewals	–	(0.0)	(0.8)	(2.4)	(3.0)	(2.2)
Avoided from cessation of lease sales	–	(2.0)	(3.9)	(5.4)	(8.3)	(12.1)
Total avoided production		(2.0)	(4.8)	(7.8)	(11.3)	(14.3)
% of reference case production		(10%)	(24%)	(37%)	(54%)	(66%)

Figure A-3: Impacts of decreased coal production on coal and gas markets under the case without the Clean Power Plan, CO_2 basis, 2030



APPENDIX B: ADDITIONAL SENSITIVITY ANALYSES

The analysis of market impacts and net CO_2 emissions impacts in Section 5 focuses on results of a central case, considered either with or without the Clean Power plan in place. That central case foresees coal and oil markets responding in ways consistent with current assessments by Rystad Energy, Wood Mackenzie, the International Energy Agency, and the U.S. Energy Information Administration. However, energy markets could also evolve in other directions, whether due to new policy developments (e.g. more or less-stringent climate policy) or other economic or technical developments (e.g. more or less-constrained fossil fuel resources.)

In this appendix, we look at how the net CO_2 impact might change were markets to evolve in different directions. We look especially at the prospective impact of U.S. federal fossil fuel leasing policy under cases where world leaders pursue either a lower-carbon or a higher-carbon world than the current pathway.

In the lower-carbon world, other countries also take similar measures to limit or otherwise move away from fossil fuel extraction, and to increase even further the availability of low-carbon power and other fossil-fuel demanding technologies. In this low-carbon world, coal and oil supply curves are steeper (lower elasticity of supplies), because fewer projects are brought online, not just in the U.S. but also in other major fossil-fuel producing countries poised for expansion (e.g. oil in Brazil, Russia, Canada, Nigeria, Norway). Demand curves are flatter (elasticities of demand are more strongly negative, and elasticities of substitution are higher) because consumers of oil, such as vehicle owners, can more readily purchase electric or other low-carbon-fueled vehicles, and power providers can more readily build and integrate renewable electricity.

By contrast, in the higher-carbon world, just the opposite conditions are present. Fossil fuel production from other U.S. and international resources can expand readily, and so the decline in federal coal (largely Powder River Basin) and federal oil could be made up by other producers with little impact on fuel prices. On the demand side, a high-carbon world would see consumers who are less sensitive to price, as higher-carbon power systems and lifestyles are "locked in", with low-carbon alternatives that are less available and more costly.

Below we explore the implications of these other energy market conditions for each of the energy markets analyzed in this report: the global oil market; the domestic coal market; and the export coal market.

Sensitivity analyses for global oil market

Table B-1, below, displays sensitivity analysis for oil markets. These cases explore variation in the elasticity of supply from 0.1 to 1 and elasticity of demand from -0.072 to -0.3, both as in a recent literature review and analysis (Bordoff and Houser 2015). The cases also explore variation in the emissions intensity of the fuels that would substitute for oil, based on a higher-carbon fuel mix that is no better than petroleum-based fuels (whether that is petroleum, first generation biofuels, or fossil-powered EVs) and a lower-carbon fuel mix as seen in the IEA's 450 scenario.[42]

[42] Specifically, we define the lower-carbon fuel mix here based on the transport fuels that substitute for oil in the IEA's 450 scenario: 60% biofuels, 30% gas, and 10% EVs. At a GHG savings of 50%, 0%, and 100%, respectively, this leads to a fuel mix that is 40% better than petroleum fuels.

Table B-1: Sensitivity in oil market analysis, 2030

			Elasticity of:		Change in net consumption of oil and substitute fuels per unit decrease in gross production of oil		Emissions intensity of substitute fuel, expresses as ratio of oil-based fuel			Net CO_2 emissions impacts		
	Drop in oil production (Qbtu)	Carbon content of crude, Mt CO2 / Qbtu	Supply (Es)	Demand (Ed)	Oil: Ed/(Ed-Es)	Substitutes: (Half of drop in oil)	**Higher-carbon**: First gen biofuels, fossil-powered Evs	**Base case:** 30% second-gen biofuels, two-thirds gas and EVs	**Lower carbon**: 60% second-gen biofuels, 30% gas, 10% renewable-powered Evs	Higher-carbon fuel mix	Base case fuel mix	Lower-carbon fuel mix
	(a)	**(b)**			**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**a*b* (c+d*e)**	**a*b* (c+d*f)**	**a*b* (c+d*g)**
Lower-carbon world	1.6	74.5	0.1	(0.3)	(0.75)	0.38	1.00	0.85	0.60	(46)	(52)	(64)
	1.6	74.5	0.1	(0.2)	(0.67)	0.33	1.00	0.85	0.60	(41)	(47)	(57)
	1.6	74.5	0.1	(0.072)	(0.42)	0.21	1.00	0.85	0.60	(25)	(29)	(36)
	1.6	74.5	0.25	(0.3)	(0.55)	0.27	1.00	0.85	0.60	(33)	(38)	(46)
Base case	1.6	74.5	0.25	(0.2)	(0.44)	0.22	1.00	0.85	0.60	(27)	(31)	(38)
	1.6	74.5	0.25	(0.072)	(0.22)	0.11	1.00	0.85	0.60	(14)	(16)	(19)
	1.6	74.5	1	(0.3)	(0.23)	0.12	1.00	0.85	0.60	(14)	(16)	(20)
	1.6	74.5	1	(0.2)	(0.17)	0.08	1.00	0.85	0.60	(10)	(12)	(14)
Higher-carbon world	1.6	74.5	1	(0.072)	(0.07)	0.03	1.00	0.85	0.60	(4)	(5)	(6)

Our base-case estimate of the global emissions impact of restricted federal leasing for oil is 31 Mt CO_2, as described in the main text and shown in Table B-1. The sensitivity analysis indicates that, in a higher-carbon world with relatively unconstrained oil supplies and little demand response, the impact could be as little as 4 Mt CO_2. By contrast, in a low-carbon world where other countries take similar steps to limit oil supply and consumers are more price-sensitive with regard to fuel price, the emissions impact could be twice as high, 64 Mt CO_2.

Sensitivity analyses for the domestic coal market

Table B-2 displays sensitivity analysis for domestic coal markets under the case of the Clean Power Plan. For transparency and to better enable comparison to other studies, we conduct our sensitivity analysis here using a simple, elasticity-based approach, using the same equation (equation 1) used for the global oil market and the coal export market. (By contrast, our base case results for the domestic coal market were derived from a run of the IPM model of the U.S. power market.)

To first demonstrate the application of the elasticity-based model to the domestic coal market, we construct a "parameterized base case", using only elasticities, that mimics the results derived from the IPM model. For this case, we use the mid-range long-term elasticity of demand from a recent analysis of long-term markets for PRB coal (Fulton et al. 2015) of -1.5. We derive an elasticity of supply from the same coal supply curve, itself constructed by Wood Mackenzie, that the EPA uses in its version of the IPM model (U.S. EPA 2013), and assuming reference levels of domestic coal consumption. This value is 2.5. Lastly, we assume that gas substitutes fully for any lost coal-based electricity, as Vulcan's IPM-based study (Vulcan/ICF 2016), and that gas power plants operate at an efficiency 1.5 times that of coal-based power (IEA 2014). Using this parameterized model, we calculate net CO_2 impact of 65 Mt CO_2, essentially equal to the full model results (64 Mt CO_2) presented in Section 5 of the main report and repeated in Table B-2.

With this parameterized model faithfully matching the base case, we use it to examine a sensitivity case for a lower-carbon world. We characterize coal demand in a lower-carbon world based on the higher end of the demand-response, elasticity -2, estimated by the same recent analysis of long-term markets for PRB coal used for the parameterized base case (Fulton et al. 2015), and where lower-carbon fuels are much more available and where coal supply is more constrained. Further, in a lower carbon world, the substitute fuels would be low-carbon renewables, not gas, and so we assume that no gas substitutes.[43] In the lower-carbon world, coal supplies would be even more constrained than under the Clean Power Plan (and not just from federal sources), and so we use a lower elasticity of supply of 2.

For the higher-carbon world, we take two approaches. One, as above, is to use an elasticity-based approach. Here, we use a much lower elasticity of demand, -0.13, derived from EIA's own assessment (U.S. EIA 2012). This value reflects the dynamics of the domestic power market in the previous decade (2005–2010), prior to the growth in domestic low-cost natural gas.[44] We use an elasticity of supply of 5 to reflect a more abundant domestic coal market characterized by a flatter supply curve.

The other approach assumes that the Clean Power Plan is fully "binding", meaning that it is the rule's state-specific targets (and corresponding compliance pathways established by the states) that reduce power-sector CO_2 emissions in each trading region to levels below what they would be in the absence of the rule. In such a case, any increase in coal prices resulting from leasing restrictions would have no effect on CO_2 emissions, since any further decreases in coal consumption would be met by equal (in CO_2 terms) increases in gas consumption, as spurred by increases in allowance prices (under mass-based trading) or credit prices (under rate-based trading), and which would also partially displace renewables.

The Clean Power Plan may be most likely to be fully binding if states adopt a national, rather than regional, trading system, since a national system would equalize the costs of compliance and eliminate the possibility that any one state or trading region exceeded its target. The national system would also need not to exceed the targets. The likelihood of this outcome could increase were renewables costs to be higher than currently expected (or gas costs lower). Were renewables costs to be lower, including due to extension of the federal renewable tax credits, this outcome could be less likely.

Table B-2: Sensitivity in coal market analysis, Clean Power Plan case, 2030

		Carbon contents, Mt CO_2/Qbtu		Elasticity of:			Relative market shares	Change in net consumption of coal and gas per unit decrease in gross production of coal		Net CO_2 emissions impacts
	Drop in coal production (Qbtu)	Coal	Gas	Supply (Es)	Demand (Ed)	Substi-tution	Starting ratio of gas to coal	Coal	Gas	
	(a)	(b)	(c)					(d)	(e)	a*(b*d+c*e)
Lower-carbon world	2.87	95.5	53.0	2.0	(2.0)	--	--	(0.50)	-	(140)
Base case	2.87	95.5	53.0	--	--	--	--	(0.36)	0.23	(64)
Parameterized "base case"	2.87	95.5	53.0	2.50	(1.5)			(0.38)	0.25	(65)
Higher-carbon world	2.87	95.5	53.0	5	(0.13)	0.20	1.5	(0.03)	0.02	(4)
Higher-carbon world (w/ CPP binding)	2.87	95.5	53.0	--	--	--	--	0	0	0

[43] This is equivalent to assuming an elasticity of substitution equivalent to the opposite of the elasticity of demand, or 2, which is, like the elasticity of demand, at the upper end of that found by empirical studies (Stern 2012).

[44] EIA reports an average U.S.-wide elasticity of demand for coal of -0.11. Further, they report an average elasticity of substitution between gas and coal of 0.17. They report an "adjustment parameter" of 0.82 that they state can be used to construct long-term elasticities. We therefore use an adjusted elasticity of demand of -0.11/0.82= -0.13 and an adjusted elasticity of substitution of 0.20. We use the elasticity of substitution to estimate the response of

Together, these sensitivity cases display how the impact of restricting federal coal leasing could have much greater or much less impact than we estimate. For example, in a lower-carbon world where coal supply is more constrained and power systems are more sensitive to changes in coal prices (in part because renewable power is more readily available), the impact of restricting leasing could be more than twice as great: an estimated 140 Mt CO_2. By contrast, were other supplies of coal to be much less constrained, such as if non-federal coal in the Montana portion of the Powder River Basin (or Illinois Basin or Appalachian coal) were able to readily substitute for the lost federal coal, and if power systems are not very sensitive to coal price (as in the past decade), than the impact of restricted leasing could be very little – only 4 Mt CO_2. The impact could even be zero, were the Clean Power Plan to be fully binding.

Sensitivity analyses for export coal market

We estimate the emissions impact of restricting federal coal leasing on coal export markets is less, approximately 7 Mt CO_2, at least given export quantities as foreseen by EIA. As a result, we do not conduct a detailed quantitative sensitivity analysis here. Instead, we observe simply that in a high-carbon world, plentiful alternative coal supplies from either non-federal suppliers in the Powder River Basin (as above) or other coal exporters or own-markets (e.g. Australia, Indonesia, and China) would be available, and could relatively easily substitute for the lost federal PRB coal. Furthermore, with the constrained gas markets in rapidly expanding power markets in Southeast Asia, switching to alternate fuels may also be constrained, such that the impact of declining exports of federal coal could be less. By contrast, in a low-carbon world, other supplies would be constrained, and renewables more available, and the impact could be greater than 7 Mt CO_2.

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