Emissions from fossil fuels produced on US federal lands and waters present opportunities for climate mitigation

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Abstract
Between 2005 and 2019, a quarter of US fossil fuel production came from federal lands and waters. We estimate that the extraction, transportation and combustion of these fuels resulted in emissions equivalent to roughly 1.4 billion metric tons of carbon dioxide equivalent per year. To better understand their future role in the US emissions profile, we use publicly available data and machine learning to model coal, oil and natural gas production on federal lands and waters to 2030, and calculate associated life cycle climate emissions. We estimate that total emissions from fossil fuels produced on federal lands and waters decline 6% below 2019 levels by 2030; and note that absent additional policy, further reductions may be challenging as some of the cheapest fossil fuels occur on federally owned lands and many are effectively subsidized.

Keywords Energy policy · Climate policy · Climate change · Federal lands · Machine learning

1 Introduction

The US government is one of the world’s largest energy asset managers, responsible for administering fossil fuel development on over 2.4 billion acres of onshore and offshore subsurface mineral rights (United States Bureau of Land Management 2020; US Bureau of Ocean Energy Management 2020). Between 2005 and 2019 over 27% of US oil, gas, and coal production came from federal lands and waters (US Office of Natural Resources Revenue (ONRR) 2020; US Energy Information Administration (EIA) 2020a). We estimate that...
emissions associated with this historic extraction averaged 1,408 million metric tons of carbon dioxide equivalent MMTCO\textsubscript{2}e per year, nearly a quarter of annual US greenhouse gas (GHG) emissions since 2005 (US Environmental Protection Agency (EPA) 2021). Despite their sizeable contribution to the US greenhouse gas profile, emissions from fuels produced on federal lands and waters have not been tracked and reported on an annual basis. Increasing transparency of historic and projected trends from federally managed lands and waters is important for developing domestic climate and energy policy, particularly as many aspects of federal mineral leasing and production can be regulated directly by the Department of the Interior without Congressional approval (Leshy 2019; Pleune et al. 2020; Krupnick et al. 2016).

While the US government has acknowledged the large share of national emissions stemming from fuels produced on federal lands and waters, agencies have neglected to track emissions in a comprehensive manner that is annually updated or transparent to the public. The exception came from a one-time report published by the United States Geological Survey (USGS) in 2018 (Merrill et al. 2018). The USGS found that life cycle emissions from coal, oil and natural gas produced on federal lands and waters accounted for 1,279 MMTCO\textsubscript{2}e, 22.4% of US energy emissions, in 2014, the last year covered in their work (Merrill et al. 2018). The USGS report was meant to establish a methodology for subsequent analysis; however, that annually updated database for federal lands and waters did not materialize. Our research fills this gap by extending historic emissions analysis through 2019 and provides a forward-looking emissions projection to 2030. Our work also helps inform the Biden Administration, who ordered a short-term pause in 2021 on new oil and gas leases on federal lands and waters pending a review of whether management of public resources is in line with national climate goals (Exec. Order No. 14008 2021). Our strategy also provides a replicable methodology that is easily updated when future, publicly available data is released.

2 Methods

This research begins by extending the USGS’s estimates (Merrill et al. 2018) through 2019 using the same general emissions accounting methods and emission factors used by USGS (US Environmental Protection Agency (EPA) 2020a) (Fig. 1a and b). We then impute federal production to 2030 and again estimate associated life cycle CO\textsubscript{2}e emissions.

To estimate historic federal fossil fuel emissions we first aggregate publicly available data on historic coal, oil and gas production from 2005 to 2019 for federal lands and waters, not including American Indian and Tribal lands, from the Office of Natural Resources Revenue (ONRR) (US Office of Natural Resources Revenue (ONRR) 2020). To be consistent with USGS we use 2005 as our start year. We calculate associated life cycle emissions of greenhouse gases (carbon dioxide, methane, and nitrous oxide) from the federal mineral estate (coal, onshore natural gas, offshore natural gas, onshore oil, and offshore oil) using calculation methods and assumptions employed by the EPA Inventory (US Environmental Protection Agency (EPA) 2020a).

To calculate upstream and midstream emissions, we scale down EPA’s national-level, fuel- and segment-specific emissions data (US Environmental Protection Agency (EPA) 2020a) using a ratio of federal production (US Office of Natural Resources Revenue (ONRR) 2020) to the Energy Information Administration’s (EIA) national production (US Energy Information Administration (EIA) 2020a). To calculate downstream emissions we multiply production volumes (minus the natural gas volume emitted as fugitive methane or...
burned in the upstream and midstream segments) by annual fuel-specific consumption by end-use sector from EIA’s Monthly Energy Review (US Energy Information Administration (EIA) 2020f), and apply sector specific emission factors. Sector specific emissions factors are derived by multiplying average annual heat content by fuel type and consuming sector from the EIA (US Energy Information Administration (EIA) 2020f, h) by EPA’s emission factors by gas or annual carbon content coefficient by fuel type (US Environmental Protection Agency (EPA) 2018, 2020b). In order to mirror our analysis to USGS for overlapping years 2005–2014, we also employ the EPA Inventory methods that at the time of this writing use IPCC Fourth Assessment Report (AR4) 100-year global warming potentials (GWP) to convert total emission estimates into a common carbon dioxide equivalent unit. We use a GWP value of 25 for methane and 298 for nitrous oxide (Solomon et al. 2007), which differ from the GWP values recommended in the IPCC’s Sixth Assessment Report published in 2021 (Supp Fig. 1). These estimates may underestimate methane leakage. The EPA revised its methane emissions inventory methodology in 2019 to show a 1.1% leakage rate for the natural gas system, which is below top-down estimates of 2.36% (Alvarez et al. 2018).

We employ the same overarching emissions accounting methods used by USGS (based on the methods and emission factors from the EPA Inventory energy chapter). Our accounting differs due to data availability differences. ONRR continues to adjust historic annual federal production data for up to seven years. This means that in addition to including 5 years of additional historic production data (2015–2019), we also used updated historic volumes for the overlapping years covered by USGS (2005–2014). We use the annual emission factors from the 2020 EPA Inventory whereas USGS used the factors employed by the 2016 EPA Inventory.

To estimate future emissions we collect additional data from the EIA. Specifically, the EIA’s Annual Energy Outlook (AEO) provides projections for oil and gas production for offshore federal waters, but not onshore federal lands. To predict future onshore federal production we assemble panel data for variables of interest by harmonizing available historic data from EIA and ONRR with projected data from the AEO to create panel data across 2005–2030. This approach includes matching regional categorization discrepancies between historic and projected data sets. The panel includes consumption, export, import, and regional production data from the Energy Information Administration’s historic data sets (US Energy Information Administration (EIA) 2020b, c, d, e, f) and the 2020 AEO Reference Case Scenario, which runs from 2020 to 2050 (US Energy Information Administration (EIA) 2020g). In total, we use 31 control variables (Supp Fig. 2) to predict three output variables, total federal lands and waters coal, oil and gas production.

With our panel of control variables, we predict future federal coal, oil, and gas production to 2030 via a regularized regression technique, synthetic controls with elastic net (SC-EN) introduced by Doudchenko and Imbens (2016). SC-EN uses an elastic net penalty term (a combination of LASSO and ridge penalties) to limit overfitting. This machine learning approach combines the original synthetic controls method, introduced by Abadie et al. (2010), with regularized regression. SC-EN provides a more flexible regression technique than traditional synthetic controls or ordinary least squares. Formally, SC-EN estimates values via:

\[
\hat{Y}_j,T(0) = \hat{\mu}^{en}(j; \alpha, \lambda) + \sum \hat{\omega}_i^{en}(j; \alpha, \lambda) \ast Y_{i,T}^{obs}.
\]

\(\hat{Y}\) is the unit being predicted. \(\alpha\) is how much weight to put on the LASSO or ridge components of the elastic net estimator, which is fixed at .5 in our model. \(\lambda\) is a penalty term and defined by cross validation (Doudchenko and Imbens 2016). \(\omega\) is a weight for each control observation, \(Y_{i,T}^{obs}\). \(\hat{\mu}\) is the intercept.
Effectively, each pre-period predicted variable is regressed separately on pre-period control variables and penalized by an elastic net operator, thereby providing coefficients for each control variable. These coefficients are applied to the post-period control variables to estimate the post-period predicted variable in each future year.

We use cross validation to test our predictive accuracy. Here, we randomly select control variables with replacement and re-estimate held-out variables in each bootstrap run. We focus our performance test on three similar control variables supplied in the EIA data — total US coal, oil and gas production, and re-predict their AEO projected values from 2020 to 2030. In 100 bootstrap samples per fuel type, we find an absolute mean difference between observed and imputed values of 0.86%, 1.55%, and 1.23% for coal, oil and gas respectively.

Applying this same randomly selected bootstrap approach we impute our three variables of interest - federal coal, federal oil and federal gas - and record the mean of 100 model runs as our reference case. We then subtract EIA’s federal offshore oil and gas projections from our predicted total federal oil and gas production estimates to obtain projected onshore by-fuel estimates from 2020 to 2030 (Fig. 1). We report low and high cases by averaging the second and third lowest and second and third highest bootstrap outputs per year and per fuel type. Finally, we calculate CO₂e emissions from our production figures to obtain a future profile of CO₂e produced on federal lands and waters.

We calculate the social cost of emissions for years 2005–2019 using the average annual per ton dollar value of CO₂e emissions established by the Interagency Working Group (IWG) on Social Cost of Greenhouse Gases under Executive Order 12866 (Interagency Working Group on the Social Cost of Greenhouse Gases 2016). For 2020–2030 we calculate the social cost of carbon, social cost of methane, and social cost of nitrous oxide using the annual values reported in the interim IWG 2021 Technical Support Document (Interagency Working Group on the Social Cost of Greenhouse Gases 2021b), (Interagency

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**Fig. 1** Future emissions associated with the extraction and combustion of fossil fuels produced on US federal lands and waters are projected to decrease minimally from 2020 to 2030 based on EIA data. Panel A shows historic (2005–2019) and projected (2020–2030) federal production by fuel source. Decreases in some fuels, like coal, are offset by increases in other fuels, like oil, resulting in a modest net reduction through 2030. Panel B depicts historic and projected life cycle MMTCO₂e emissions by fuel type, with dotted lines illustrating high and low emissions estimates. Emissions decline by 27% from a 2005 baseline, with the majority of those reductions having already occurred.
Working Group on the Social Cost of Greenhouse Gases 2021a), Supp Fig. 3. We use the IWG annual global values and a central 3% average discount rate to account for the cost of climate impacts to future generations. The 2005–2019 values are adjusted for inflation to 2020 dollars.

3 Results and discussion

Historic emissions (2005–2019) averaged over 1,400 MMTCO$_2$e annually (Fig. 1a and b), equivalent to roughly 23% of total US emissions (US Environmental Protection Agency (EPA) 2021). Over this 15-year period, total federal lands emissions declined by 22%. Emissions associated with federal coal led the decline, falling by 38%, and natural gas emissions dropped by 37%. Federal oil emissions, however, rose by 60% due to onshore and offshore production growth, offsetting some of the declines in the coal and gas sectors.

The estimated costs to society from these historic emissions averaged $57 billion per year in 2020 dollars, more than 5 times the average federal mineral revenue collected per year (US Office of Natural Resources Revenue (ONRR) 2021). Altogether, federal emissions for years 2005 through 2019 carry a cumulative cost of more than $850 billion.

Looking forward, our model finds modest changes to total future federal energy production by 2030 (Fig. 1a), decreasing by just 5% between 2019 and 2030. Coal continues its decline, losing 23% of federal production by 2030. Declines in onshore gas production are partially offset by increases in offshore gas, −22% and +15% respectively. Both onshore and offshore oil are expected to continue growing at 8% and 24% respectively, contributing an additional 190 million barrels per year by 2030.

Total emissions associated with the extraction and combustion of these fuels drop from 1,550 to 1,130 MMTCO$_2$e between 2005 and 2030, 27%. However, the majority of these emissions reductions occurred between 2005 and 2019. We find that emissions are projected to fall only 6.4% between 2019 and 2030, from 1,208 to 1,130 MMTCO$_2$e.

Continuing their historic declines, coal emissions are predicted to decrease by another 21% below 2019 by 2030, an additional 114 MMTCO$_2$e. Future emissions from offshore gas increase by nearly 9 MMTCO$_2$e, while onshore gas emissions decrease by 47 MMTCO$_2$e in our projections. Federal oil emissions increase by a combined 75 MMTCO$_2$e in our model, nearly canceling out the bulk of the reductions from the coal sector’s projected decline. Dropping federal coal and onshore gas production are not surprising given the continuing declines in coal demand and a presumed decline in onshore federal gas production, as new US gas production will likely come more from non-federal lands.

The annual cost to society of future federal fuel emissions are substantial. We compute the annual cost ranges from $55 to $76 billion per year between 2020 and 2030, for an aggregate cost of $602 to $830 billion. Added to the historic costs, we find the social cost of emissions from fuels produced on federal lands and waters between 2005 and 2030 could be over $1.6 trillion.

When looking at the 2005 to 2030 trend lines we note that the majority of emissions reductions were made between 2010 and 2016, when natural gas began rapidly replacing coal in the electricity sector, due in part to the falling costs of natural gas (Marsters et al. 2017), and before unconventional oil development had begun to grow on federal lands. Based on the EIA’s projected data, and without new policies or market shifts, our modeling predicts minimal additional emissions reductions stemming from fuels produced on federal lands and waters. This thesis is reinforced in the federal fuels case because some of the cheapest fuels in the US lie under federal lands, they are effectively subsidized with leasing
and production fees that have not been updated in decades, and many already-leased parcels have ample future supply (US Government Accountability Office 2019).

4 Conclusion

Together, our historic and projected emissions estimates provide a comprehensive assessment of near-term emissions stemming from fossil fuels extracted from US federal lands and waters. The results indicate that absent a change in policy or substantial market shift, production and associated emissions will likely remain largely unchanged through 2030 (Fig. 2). We find the average social cost of these emissions to be near $60b annually, totalling $1.6t between 2005 and 2030. To put the magnitude of these costs in perspective, $60b represents about 2% of total federal revenue in 2019.

Furthermore, federal fuel production could be persistent beyond 2030 given that federal surface coal is some of the cheapest coal to produce, that many federal energy resources are effectively subsidized by outdated leasing and revenue policies, and that many already leased parcels have substantial untapped production. As a result, federal fossil fuel production could remain a significant part of the US emissions profile to 2040 and beyond.

While the US government has enacted and continues to pursue a series of policies to limit GHG emissions, the federal government also has the unique ability to implement new policies that target federal lands and waters.

![Fig. 2](image_url) Emissions associated with the extraction and combustion of fossil fuels from US federal lands and waters will continue to comprise nearly 20% of total US emissions through 2030. Total historic US emissions are shown in light gray. The solid red line illustrates historic US energy emissions, and the dotted red lines show the Energy Information Administration’s projections through 2050. Gold squares depict benchmarks of the US 2021 Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change. The US NDC is designed to bring US emissions to 50–52% below 2005 levels by 2030 and to achieve the Biden Administration’s stated target of net zero emissions, economy wide, before 2050. The EIA’s energy emissions projections, as well as our federal lands projections, illustrate the challenge of reducing emissions in the near-term.
policies that directly interface with fuels produced on federal lands and waters. For example, the Department of the Interior has legal authority to employ a wide range of options - from adding a carbon fee on new coal, oil and gas leases to reducing methane waste and requiring mitigation measures at the drilling approval stage (Pleune et al. 2020; Leshy 2019; Krupnick et al. 2016). Research indicates that a number of policies targeting fossil fuels from the federal mineral estate would result in meaningful emissions reductions even after accounting for partial shifts in production to non-federal lands (Prest 2021, Prest and Stock 2021; Gerarden et al. 2020). As such, the US government should consider how policies directed at federal lands and waters fit into their broader climate strategy, particularly given the aggressiveness of the Biden Administration’s Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change, which calls for a 50–52% reduction in economy wide emissions by 2030.

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Author Contributions Nathan Ratledge and Laura Zachary contributed equally. Chase Huntley contributed to policy analysis and edited the paper.

Declarations

Competing interests Chase Huntley works for The Wilderness Society, an organization that advocates for public land protection; and The Wilderness Society funded an earlier iteration of this work.

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