POLICY BRIEF

The Climate Costs and Economic Benefits of LNG Export

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January 2024

Executive Summary

Gas provides nearly a quarter of the world's total energy supply.[1] As part of that supply chain, gas is shipped between continents in the form of liquefied natural gas (LNG).

The United States is now the world's largest LNG exporter following a surge in gas exports since 2016.[2] At the federal level, approval authority for LNG exports lies with the U.S. Department of Energy (DOE), which has broad permitting authority over most gas exports.[3] Since 2010, DOE has approved dozens of discretionary, long-term export applications.[4] These export approvals are valid for decades, with many extending through 2050.[5]

But these approvals have generated controversy due to their climate effects. Some environmental advocates[6] and elected representatives[7] have urged DOE to reform its approach to LNG permitting to focus more on the climate impacts of supplying other countries with gas for decades.[8] In response to these calls, the executive branch has issued a "temporary pause" on discretionary export approvals so that DOE can "update the underlying analyses for authorizations" to facilitate a proper balancing of environmental and economic impacts.[9]

This policy brief provides an analysis to support that effort to balance the full range of impacts from LNG export. Using DOE's own published studies, we compare the climate cost per unit of LNG export to the economic benefit (measured using consumer welfare). We find that climate costs likely exceed economic benefits. While the precise difference depends on several factors—including the share of gas production that merely displaces fossil-fuel production from other

[1] Int'l Energy Agency, World Total Energy Supply by Source, https://perma.cc/X6HG-VH2T (2021).
[2] Energy Info. Admin., *The United States Became the World's Largest LNG Exporter in the First Half of 2022* (July 25, 2022), https://perma.cc/FA4W-LZXC.
[3] 15 U.S.C. § 717b(a). Exports are "deemed to be consistent with the public interest" when directed to a country with which the United States has a gas-related free trade agreement. *Id.* However, such exports constitute only about 20% of the nation's total LNG exports. Dep't of Energy, LNG Monthly 4, https://perma.cc/638T-FVCM (Nov. 2023).
[4] *See* LAURA FIGUEROA & SARAH LADIN, INST. FOR POL'Y INTEGRITY, THE PUBLIC INTEREST REVIEW FOR LNG-RELATED AUTHORIZATIONS 56–62 (2022) (listing applications).
[5] *See* Extending Natural Gas Export Authorizations to Non-Free Trade Agreement Countries Through the Year 2050, 85 Fed. Reg. 52,237 (Aug. 25, 2020).
[6] *E.g.* Letter from Sierra Club et al. to Secretary Jennifer Granholm Re: April 8, 2013 Petition for Rulemaking Regarding Natural Gas Export Policy (Oct. 27, 2022)
[7] *E.g.* Letter from Sen. Jeffrey A. Merkley et al. to Secretary Jennifer Granholm (Nov. 14, 2023) ("DOE's case-by-case approach to approvals ignores the aggregate impact that the explosive growth in U.S. LNG exports is having on climate, communities, and our economy.").
[8] These calls have intensified following new research finding that greenhouse gas emissions from gas export are far higher than previously estimated and exceed emissions from coal. *See* Robert W. Howarth, *The Greenhouse Gas Footprint of Liquefied Natural Gas (LNG) Exported from the United States*, Working Paper (2023).
[9] White House, Fact Sheet: Biden-Harris Administration Announces Temporary Pause on Pending Approvals of Liquefied Natural Gas Exports (Jan. 26, 2024), https://perma.cc/UJV5-5H6C. In 2023, DOE reaffirmed its broad discretion to weigh the economic, environmental, and social impacts of LNG export and committed to continue evaluating the shifting landscape. Dep't of Energy, Order Denying Petition for Rulemaking on Exports of Liquefied Natural Gas (July 18, 2023) [hereinafter 2023 Order Denying Petition].

sources, the economic value assigned to climate damages, and the adoption of carbon-capture technology—gross climate damages greatly exceed economic benefits under all scenarios evaluated.

These findings provide useful insights as DOE prepares to re-evaluate the LNG export program. In particular, our findings provide a potential basis for DOE to rationally conclude that future export applications do not serve the public interest. At a minimum, our analysis supports DOE's efforts to more closely scrutinize export applications and provides important data points for the agency's consideration.

Background on DOE's Analyses and Study Design

DOE is responsible for reviewing applications to export gas, including liquefied natural gas.[10] Section 3 of the Natural Gas Act provides that DOE "shall" approve a proposed export application unless it concludes that the export "will not be consistent with the public interest."[11] As DOE has recognized, this broad standard allows the agency to consider "any . . . factors bearing on the public interest" including "economic, environmental, and international considerations."[12]

Although DOE evaluates each export application individually, it has commissioned several studies on the environmental and economic impacts of LNG export that it often relies upon in approving applications. DOE has published five different analyses of the macroeconomic effects of LNG export, most recently in 2018.[13] That 2018 analysis, prepared by NERA Economic Consulting, sought "to examine a wide range of scenarios for future [LNG] exports, to assess the likelihood of different levels of exports, and to analyze the outcomes of different export levels on gas markets and the U.S. economy."[14] The analysis concludes that U.S. economic output increases with greater LNG export[15] and estimates the increase in U.S. consumer welfare[16] and gross domestic product[17] associated with various increases in LNG export under different economic assumptions.

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[10] 15 U.S.C. § 717b.
[11] *Id*. § 717b(a). DOE lacks discretion when the export is directed to a country with which the United States has a gas-related free trade agreement. *See supra* note 3.
[12] 2023 Order Denying Petition, *supra* note 9, at 12. *See also The Department of Energy's Strategy for Exporting Liquefied Natural Gas: Hearing Before the Subcomm. on Energy Policy, Health Care and Entitlements of the H. Comm. on Oversight and Government Reform*, 113th Cong. 45 (2013) (statement of Christopher Smith, Acting Assistant Sec'y for Fossil Energy, Office of Fossil Energy, Dep't of Energy), https://perma.cc/L3GC-DB9W (noting that DOE considers a "wide range of factors that Americans care about, everything from balance of trade, creation of jobs, GDP, impact of prices on consumers and American families, impact of prices on American industry, energy security and environmental issues").
[13] NERA ECONOMIC CONSULTING, MACROECONOMIC OUTCOMES OF MARKET DETERMINED LEVELS OF U.S. LNG EXPORTS (2018) [hereinafter 2018 MACROECONOMIC STUDY]; *see also id.* at 11 (discussing prior analyses); Study on Macroeconomic Outcomes of LNG Exports, 83 Fed. Reg. 27,314 (June 12, 2018) (announcing study and requesting comment).
[14] 2018 MACROECONOMIC STUDY, *supra* note 13, at 14.
[15] *Id.*
[16] *Id.* at 67 tbl.10.
[17] *Id.* at 69 tbl.11.

DOE has also published two analyses of the lifecycle greenhouse gas emissions associated with LNG export, most recently in 2019.[18] That 2019 study calculated the lifecycle greenhouse gas emissions of producing gas in the United States and shipping it from an LNG terminal located in the Gulf Coast to the Netherlands and China.[19] The 2019 study also calculated the lifecycle emissions of other potential fossil-fuel energy sources in those two destination countries (while notably omitting non-fossil-fuel energy sources such as wind, solar, or nuclear).[20] DOE found that the lifecycle emissions from U.S. export were comparable to or lower than those of other sources of global fossil-fuel energy supply, assuming full substitution of one fossil-fuel energy source for another.[21]

DOE supplemented this lifecycle analysis in 2023 in its review of an application to export LNG from Alaska (2023 Supplemental Analysis). There, it assessed the lifecycle emissions of producing gas and shipping it from Alaska to four countries: Japan, South Korea, China, and India.[22] For each destination country, DOE assessed the impacts depending on whether the downstream power-generating source used carbon sequestration.[23] DOE then compared the lifecycle results to those from two baseline scenarios. One baseline scenario assumed, like the 2019 study, that, without the Alaska export project, gas "would be produced from another global source and result in [greenhouse gas] emissions" (i.e., full substitution).[24] The other baseline scenario assumed that all of the exported gas represented additional supply that would not exist without the proposed export project (i.e. zero substitution).[25] DOE found a large emissions increase in the case of zero substitution and a relatively smaller emissions decrease with full substitution.[26]

We base our analysis on DOE's economic and climate studies. In particular, we use the 2023 Supplemental Analysis[27] and the 2018 Macroeconomic Study to compare the climate costs of LNG export to the consumer welfare benefits on an equivalent per-unit basis.

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[18] SELINA ROMAN-WHITE ET AL., NAT'L ENERGY TECH. LAB'Y, DOE/NETL-2019/2041, LIFE CYCLE GREENHOUSE GAS PERSPECTIVE ON EXPORTING LIQUEFIED NATURAL GAS FROM THE UNITED STATES: 2019 UPDATE (2019), https://perma.cc/Q7R9-YWE5 [hereinafter 2019 LIFE CYCLE REPORT]; *see also id.* at 1 (discussing prior 2014 lifecycle analysis); Life Cycle Greenhouse Gas Perspective on Exporting Liquefied Natural Gas from the United States: 2019 Update, 84 Fed. Reg. 49,278 (Sept. 19, 2019) (announcing study and requesting comment).
[19] 2019 LIFE CYCLE REPORT, *supra* note 18, at 2 (describing Scenario 1).
[20] *Id.* at 2–3 (describing Scenarios 2–4 involving, respectively, other sources of LNG, pipeline-delivered gas, and coal).
[21] *Id.* at 20 exh.6-1 (results for Europe); *id.* at 21 exh.6-2 (results for Asia). *See also* Jordan Cove Energy Project L.P., Order No. 3413-A, Docket No. 12-32-LNG, Final Opinion and Order Granting Long-Term Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Nations 109 (July 6, 2020) (explaining study's findings that "to the extent U.S. LNG exports are preferred over coal in LNG-importing nations, U.S. LNG exports are likely to reduce global [greenhouse gas] emissions").
[22] Dep't of Energy, Alaska LNG Project Final Supplemental Environmental Impact Statement 4.19-10 to -11 tbls.4.19-3 to -4 (Jan. 2023) [hereinafter 2023 Supplemental Analysis].
[23] *See id.*
[24] *Id.* at 4.19-6.
[25] *Id.*
[26] *Id.* at 4.19-10 to -11 tbls.4.19-3 to -4.
[27] Our analysis focuses on DOE's lifecycle emissions estimates from the 2023 Supplemental Analysis rather than the 2019 lifecycle analysis, as the 2023 estimates are more recent. Using both studies was infeasible because the two studies do not present estimates in comparable units.

Analysis Methodology

Our analysis compares the economic benefits per unit of LNG export to the per-unit climate costs, based on DOE's published analyses.

Economic Benefits

We capture the per-unit economic benefits of LNG export using DOE's 2018 Macroeconomic Study. Specifically, Table 10 of that report estimates national consumer welfare in 2040 under different economic and export scenarios.[28] That report defines consumer welfare as the "present value measure of the standard of living of all households" in the United States.[29] Specifically, consumer welfare measures the net change in economic well-being within the United States.[30] The benefit in consumer welfare from LNG export primarily reflects the wealth transfer from foreign countries to the United States resulting from greater export.[31] Notably, consumer welfare does not capture non-economic impacts that may affect quality of life, such as environmental effects. Additionally, because it is an aggregate measure,[32] it does not capture the distribution of economic impacts across different groups, such as through increasing domestic natural gas prices or increasing the wealth of those who hold stock in natural gas producers.[33]

The Macroeconomic Report's analysis of consumer welfare reflects DOE's closest approximation of total economic benefit. Notably, this same metric is frequently used by other agencies to evaluate social costs and benefits associated with regulatory policy.[34] The Macroeconomic Report also estimates gross domestic product,[35] but this is distinct from social welfare and is not normally used by regulatory agencies as a measure of net economic impact.[36]

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[28] 2018 MACROECONOMIC STUDY, *supra* note 13, at 67 tbl.10.
[29] *Id.* at 20.
[30] *See id.* at 65 ("A positive change in welfare means that the policy improves overall economic well-being from the perspective of the average household.").
[31] *Id.* at 67 ("[A]s U.S. LNG exports increase, U.S. households receive additional income from two sources. First, the LNG exports provide additional export revenues, and second, households who hold shares in companies that own liquefaction plants receive additional income from take-or-pay tolling charges for LNG exports. These additional sources of income for U.S. consumers outweigh the income loss associated with higher energy prices.").
[32] *See supra* note 30.
[33] *Id.* at 64. ("If U.S. households, or their retirement funds, hold stock in natural gas producers, they will benefit from the increase in the value of their investment. . . . On the negative side, producing incremental natural gas volumes to support natural gas exports will increase the marginal cost of supplying natural gas and therefore raise domestic natural gas prices and increase the value of natural gas in general. . . . How increased LNG exports affect different U.S. households will depend on their income sources.").
[34] *E.g.* ENV'T PROT. AGENCY, SAGE MODEL DOCUMENTATION 81 (2021).
[35] 2018 MACROECONOMIC STUDY, *supra* note 13, at 69 tbl.11.
[36] *See* ENV'T PROT. AGENCY, GUIDELINES FOR PREPARING ECONOMIC ANALYSIS 3-2 (2010) ("[T]he social cost of a regulation is generally not the same as a change in gross domestic product (GDP), or another broad measure of economic activity, that may result from its imposition."); ENV'T PROTECTION AGENCY SCI. ADV. BD., SAB ADVICE ON THE USE OF ECONOMY-WIDE MODELS IN EVALUATING THE SOCIAL COSTS, BENEFITS, AND ECONOMIC IMPACTS OF AIR REGULATIONS 4 (Sept. 29, 2017) ("[General equilibrium] models are strongly grounded in economic theory, which allows social costs to be evaluated using equivalent variation or other economically-rigorous approaches. Simpler measures, such as changes in gross domestic product or in household consumption, do not measure welfare accurately and are inappropriate for evaluating social costs.").

Accordingly, we choose to focus on consumer welfare to measure the economic benefits of LNG export.

To capture this benefit on a per-unit basis, we use the three observations in Table 10 in each scenario (low, reference, and high U.S. natural gas supply that varies with resource costs and availability) to identify a fitted line using the ordinary least squares approximation.[37] Through this method, we find that adding one billion cubic feet of LNG export per day[38] increases consumer welfare in 2040 by $515 million, $450 million, and $405 million, respectively, in the low, reference, and high supply cases. (These values are in 2016$, which is the unit used in the 2018 Macroeconomic Study.) We use this estimate to infer the annual economic benefits of exporting an additional unit of LNG per day. See the Appendix for further details on our calculation of economic benefits.

Climate Costs

We capture the per-unit climate costs of LNG export using the 2023 Supplemental Analysis. Specifically, Table 4.19-6 reports the gross lifecycle climate costs (assuming no substitution) of exporting 27.8 trillion cubic feet of natural gas to four different countries, using climate-damage valuations from the Interagency Working Group on the Social Cost of Greenhouse Gases.[39] The table contains two scenarios: one assuming no carbon capture and sequestration (CCS) at end-use power plants, and the other assuming full CCS usage. For each scenario, we calculate the average climate cost of exporting one billion cubic feet of LNG per day over one year. In the case of full CCS usage, we also include the per-unit cost of using carbon capture technology from the U.S. Environmental Protection Agency (EPA). See the Appendix for further details on our calculation of climate and CCS cost.

In addition to the Interagency Working Group valuations that DOE applied, we also estimate climate costs using updated climate-damage valuations that EPA recently finalized.[40] (For consistency with economic benefits, we convert all climate-damage values to 2016$). EPA's valuations are more reliable because they incorporate updated scientific and economic

[37] The efficacy of this approach is somewhat compromised by the limited number of available observations in the 2018 Macroeconomic Study. Additionally, the estimates may be biased by assuming a linear relationship between LNG export levels and consumer welfare.
[38] For context, the United States exported 350.1 billion cubic feet of LNG in September 2023, which averages approximately 11.67 billion cubic feet per day. LNG Monthly, *supra* note 3, at 5.
[39] 2023 Supplemental Analysis, *supra* note 22, at 4.19-14 tbl.4.19-6.
[40] ENV'T PROT. AGENCY, EPA REPORT ON THE SOCIAL COST OF GREENHOUSE GASES: ESTIMATES INCORPORATING RECENT SCIENTIFIC ADVANCES (2023).

evidence,[41] as confirmed by expert peer reviewers.[42] These climate-damage estimates are likely underestimates due to omitted impacts.[43]

From this analysis, we can compare the consumer welfare benefits of LNG export to the equivalent gross climate costs. We present our results below.

Results and Analysis

As noted above, we quantify the gross, lifecycle climate costs of exporting one billion cubic feet of LNG per day over one year. Consistent with DOE's analysis, we quantify these costs under two scenarios: 1) assuming no downstream CCS adoption (Table 1), and 2) assuming full downstream CCS adoption (Table 2).

In each scenario, we assess climate damages using six different federal estimates of the social cost of greenhouse gases. We use three valuations last updated in 2016 by the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG): at a 3% discount rate, 2.5% discount rate, and 3% discount with 95th percentile damages.[44] (We omit a fourth IWG damage estimate using a 5% discount rate because it is regarded as a particularly conservative underestimate.) We also use the three valuations published by EPA in December 2023: at a 2.5% discount rate, 2% discount rate, and 1.5% discount rate.[45] As noted above, EPA's valuations are more robust and reliable than the IWG estimates.[46]

Table 1: Gross Lifecycle Climate Costs, No CCS (2016$ Billion, Exporting One Billion Cubic Feet of LNG per Day for One Year)

	IWG 3%	**IWG 2.5%**	**IWG High Damage**	**EPA 2.5%**	**EPA 2%**	**EPA 1.5%**
Climate Cost ($B)	0.99	1.52	2.99	2.56	4.33	7.63

[41] *See id*. at 46 fig.2.3.1 (comparing publication year of studies underlying EPA's estimates to those underlying Interagency Working Group estimates).
[42] FINAL COMMENTS SUMMARY REPORT, EXTERNAL LETTER PEER REVIEW OF TECHNICAL SUPPORT DOCUMENT: SOCIAL COST OF GREENHOUSE GAS 7-15 (2023) (praising EPA's numbers as a "huge advance," a "significant step," and a "much-needed improvement" over the Interagency Working Group's estimates that "advanc[es] our state of knowledge" and "represents well the emerging consensus in the literature").
[43] ENV'T PROT. AGENCY, *supra* note 40, at 1("The[se] estimates are . . . a partial accounting of climate change impacts and likely underestimate the marginal benefits of [emissions] abatement"); *id.* at 87 tbl.3.2.1 (highlighting omitted impacts and damages).
[44] INTERAGENCY WORKING GRP. ON THE SOCIAL COST OF GREENHOUSE GASES, TECHNICAL SUPPORT DOCUMENT: SOCIAL COST OF CARBON, METHANE, AND NITROUS OXIDE INTERIM ESTIMATES UNDER EXECUTIVE ORDER 13990 at 5 tbl.ES-1 (2021) (presenting values). The values were identical to the 2016 values from the Interagency Working Group, except adjusted for inflation. *Id.* at 5 n.3.
[45] ENV'T PROT. AGENCY, *supra* note 40, at 4 tbl.ES.1 (presenting values).
[46] *See* nn.41–42 and accompanying text.

Table 2: Gross Lifecycle Climate and Carbon-Capture Technology Costs, Full CCS (2016$ Billion, Exporting One Billion Cubic Feet of LNG per Day for One Year)

	IWG 3%	IWG 2.5%	IWG High Damage	EPA 2.5%	EPA 2%	EPA 1.5%
Climate Cost ($B)	0.93	1.09	1.57	1.40	1.96	3.00

Table 1 shows that gross climate costs assuming no CCS range from $0.99 billion using the IWG's conservative, central climate-damage valuation to $7.63 billion using the EPA's highest climate-damage valuation. Table 2 shows that gross climate and CCS-technology costs assuming full CCS range from $0.93 billion using the IWG's conservative, central climate-damage valuation to $3 billion using the EPA's highest climate-damage valuation. As noted above, the climate-damage estimates toward the higher end of these ranges are based on more recent and extensive data and thus are considered more accurate.

Using the climate-damage estimates from Tables 1 and 2, we next compare climate costs to the equivalent unit of economic benefits. As detailed above, DOE's 2018 Macroeconomic Study enables us to derive estimates of the national annual consumer welfare benefits from exporting an additional one billion cubic feet of LNG per day. We compare climate costs to our three derived benefit estimates of $515 million, $450 million, and $405 million (representing the low, reference, and high supply cases, respectively).

Figure 1. Ratio of Gross Lifecycle Climate Costs (No CCS) to Consumer Welfare Benefit

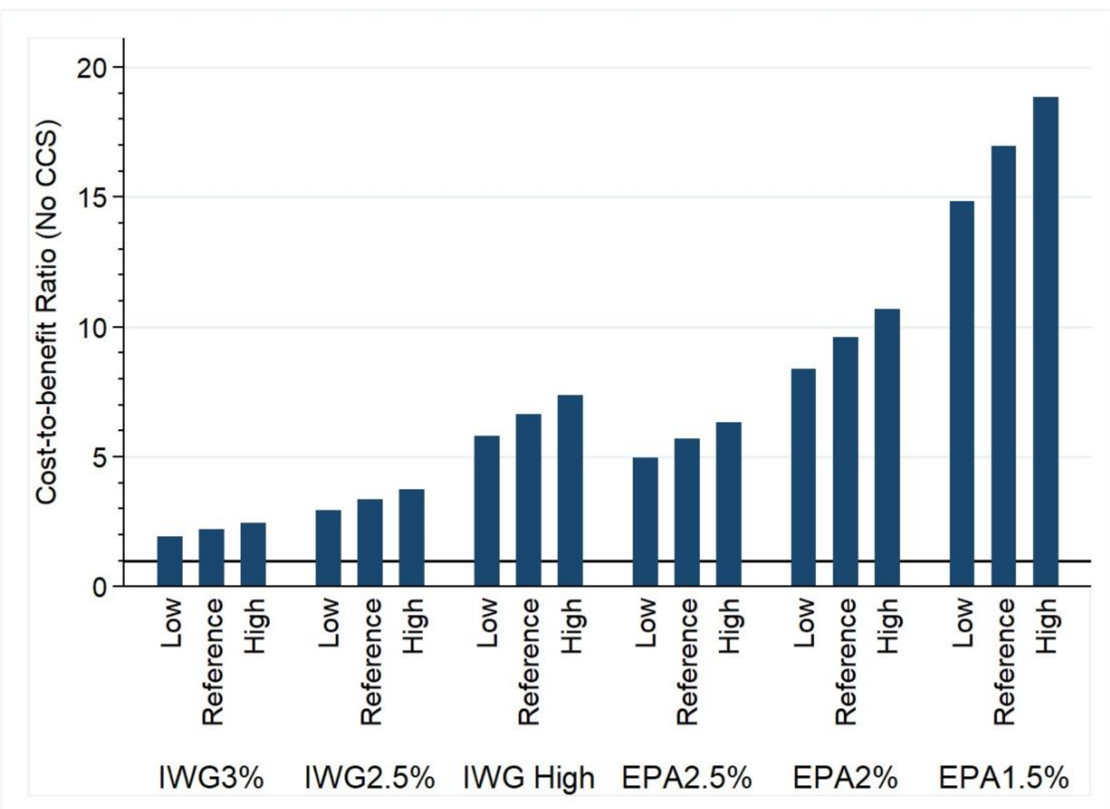


Table 3: Ratio of Gross Lifecycle Climate Costs (No CCS) to Consumer Welfare Benefits

	IWG 3% ($0.99 B)	**IWG 2.5%** ($1.52 B)	**IWG High Damage** ($2.99 B)	**EPA 2.5%** ($2.56 B)	**EPA 2%** ($4.33 B)	**EPA 1.5%** ($7.63 B)
Low Supply ($0.515 B)	1.93	2.95	5.80	4.97	8.40	14.82
Reference ($0.45 B)	2.21	3.37	6.63	5.69	9.61	16.97
High Supply ($0.405 B)	2.45	3.75	7.37	6.32	10.68	18.85

Table 3 shows that gross lifecycle climate costs, assuming no CCS, range from 1.93 to 18.85 times the consumer welfare benefit, depending on the climate-damage valuation and supply scenario. As both the IWG and EPA climate-damage values are likely underestimates, the true ratio of climate costs to economic benefits is potentially higher than even the highest estimates in this table.

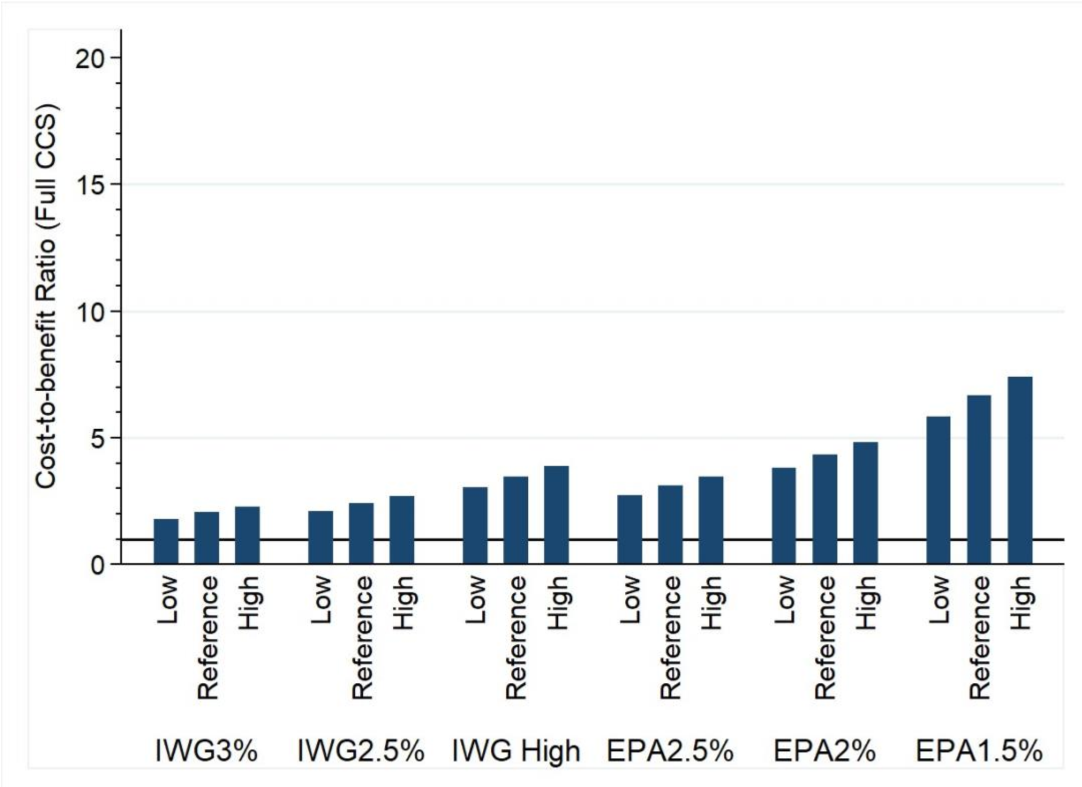
Still, these valuations are somewhat limited in that they represent *gross* climate costs, without considering energy substitution. In reality, gas export likely displaces a range of substitute energy sources including both other sources of gas and renewables. This "leakage" effect[47] means that the *net* climate costs of LNG export—that is, the gross lifecycle climate costs attributable to LNG export minus the gross lifecycle climate costs from energy sources that the LNG export displaces—are lower than the *gross* costs. Although the *net* climate costs of LNG exports are likely substantial,[48] calculating the leakage rate presents a substantial challenge that is beyond the scope of this analysis.[49]

Nonetheless, the figures above are helpful as they allow consideration of how much substitution would be required for consumer welfare benefits to exceed net climate costs. For instance, Table 3 shows that gross lifecycle climate costs (without CCS) are 9.61 times that of consumer welfare benefits when using the EPA's central climate-damage estimate and the reference supply scenario. When considering leakage, this means that climate costs exceed consumer welfare benefits if the *net* climate costs constitute more than roughly 10% (1/9.61) of the *gross* climate costs.[50] In other words, leakage would need to be 90% or higher for economic benefits to exceed

[47] As used in this report, "leakage" refers to the degree to which the greenhouse gas emissions from the production, transport, and combustion of exported gas displaces greenhouse gas emissions that would otherwise come from the production, transport, and combustion of other sources.
[48] *See generally infra* note 51.
[49] For relevant literature, see, e.g., Shuting Yang et al., *Global Liquefied Natural Gas Expansion Exceeds Demand for Coal-to-Gas Switching in Paris Compliant Pathways*, 17 ENV'T RSCH. LTRS. 64,048 (2022); Alexander Q. Gilbert & Benjamin K. Sovacool, *Carbon Pathways in the Global Gas Market: An Attributional Lifecycle Assessment of the Climate Impacts of Liquefied Natural Gas Exports from the United States to Asia*, 120 ENERGY POL'Y 635 (2018).
[50] Assuming that $\frac{net\ costs}{gross\ costs} = s$. Whenever $s > \frac{1}{9.61}$, net costs > $\frac{gross\ costs}{9.61}$, i.e., net costs > $\frac{9.61 * benefits}{9.61} = benefits$, given that $\frac{gross\ costs}{benefits} = 9.61$.

climate costs. In other contexts involving domestic gas supply, the federal government has estimated far lower leakage rates.[51]

Figure 2. Ratio of Gross Lifecycle Climate and Carbon Capture-Technology Costs (Full CCS) to Consumer Welfare Benefits



[51] The Bureau of Ocean Energy Management's (BOEM) latest five-year offshore leasing plan estimates a total leakage rate of approximately 75% for proposed oil and gas lease sales from 2024 to 2029. It finds, in other words, that the net lifecycle climate costs from oil and gas extraction will be roughly 25% of the gross lifecycle climate costs. *See* BOEM, Final Programmatic Environmental Impact Statement: 2024–2029 National Outer Continental Shelf Oil and Gas Leasing Program 30–33 (2023). We derived this percentage by starting with emissions in each leasing scenario (*id.* C-11 tbl.C-8), subtracting emissions from substitute sources (*id.*), and then adding emissions from induced foreign consumption (*id.* at C-13 tbl.C-10). We then divided the sum of that equation by gross emissions to generate the percentage. Percentages varied slightly by scenario but were all close to 25%, implying a leakage rate of about 75%.

That 75% figure is likely an overestimate for our purposes here for two key reasons. First, BOEM finds that its analysis likely overstates leakage and thus understates net climate costs. BOEM, 2024–2029 NATIONAL OUTER CONTINENTAL SHELF OIL AND GAS PROPOSED FINAL PROGRAM 6 (2023) ("BOEM's analysis shows that, in a future where the U.S. makes significant progress towards its net-zero emissions goals, a reduction in reliance on [offshore] oil and gas production would occur. This reduction will result in greater energy substitution from renewable sources and a greater reduction in consumption than is currently projected."); *see also* BOEM, ECONOMIC ANALYSIS METHODOLOGY FOR THE 2024–2029 NATIONAL OUTER CONTINENTAL SHELF OIL AND GAS LEASING PROGRAM 4.15–4.19 (2023) (performing sensitivity analysis around other assumptions and finding lower leakage). Second, the 25% estimate includes both oil and gas. When disaggregated, however, BOEM finds lower leakage for gas than oil. According to our analysis, BOEM finds that 93% of offshore oil—but just 66.2% of offshore gas—would displace alternative fossil-fuel sources.

Table 4: Ratio of Gross Lifecycle Climate and Carbon Capture-Technology Costs (Full CCS) to Consumer Welfare Benefits

	IWG 3% ($0.93 B)	**IWG 2.5%** ($1.09 B)	**IWG High Damage** ($1.57 B)	**EPA 2.5%** ($1.40 B)	**EPA 2%** ($1.96 B)	**EPA 1.5%** ($3.00 B)
Low Supply ($0.515 B)	1.80	2.12	3.04	2.72	3.80	5.83
Reference ($0.45 B)	2.06	2.43	3.48	3.12	4.35	6.67
High Supply ($0.405 B)	2.29	2.70	3.87	3.46	4.84	7.41

With full CCS, the cost-to-benefit ratios are lower but remain positive. For instance, Table 4 shows that gross lifecycle climate and CCS-technology costs with full CCS are 4.35 times higher than consumer welfare benefits when using EPA's central climate-damage estimate and the reference supply scenario. When considering leakage, this means that climate costs exceed consumer welfare benefits (assuming full CCS) if the *net* climate costs constitute more than roughly 23% (1/4.35) of the *gross* climate costs. In other words, leakage would need to exceed 77% for economic benefits to exceed climate and CCS costs assuming full CCS use.[52] Because CCS use is currently limited,[53] however, Table 4 reflects a lower bound of climate costs.

Conclusion

This policy brief provides an analysis that can inform DOE's balancing of factors to assess whether LNG exports are in the public interest. We use DOE's prior studies to compare consumer welfare benefits to climate costs on an equivalent per-unit basis. This analysis finds that climate costs likely exceed consumer welfare benefits. While the cost-to-benefit ratio depends on several factors including the level of substitution, the climate-damage value, and the level of CCS adoption, gross costs substantially exceed benefits under all scenarios evaluated.

Although this analysis provides useful and immediately applicable information, further study on key uncertainties would be informative. Most significantly, further analysis of the substitution effects related to LNG exports would enable a more holistic assessment of net climate costs. In that context, analysis of substitution under future decarbonization pathways would be particularly useful.[54] Further analysis around future CCS adoption would also enable a single,

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[52] This 77% leakage rate is nearly identical to BOEM's estimates in the offshore extraction context. *See supra* note 51. To the extent that BOEM overestimates the leakage rate, *see id.*, this means that even assuming full CCS adoption, the net climate costs of LNG export may exceed the consumer welfare benefits. The leakage rate in the full CCS leakage case assumes full CCS usage at substitute sources.

[53] As of December 2023, there were only 40 commercial CCS facilities completed and/or operational, of which 17 are located in the United States. *See* Global CCS Inst., Facilities Database, https://co2re.co/FacilityData (last visited Dec. 11, 2023) (search for "Commercial CCS Facility" as Facility Category and both "Completed" and "Operational" under Facility Status).

[54] *See* PETER HOWARD & MAX SARINSKY, INST. FOR POL'Y INTEGRITY, BEST PRACTICES FOR ENERGY SUBSTITUTION ANALYSIS 5–7 (2022), https://perma.cc/MJ6T-BLKD (explaining that substitution analysis must "consider long-term changes to the energy mix and not reflexively assume long-term reliance on fossil fuels").

integrated analysis rather than two analyses based on extreme scenarios (full CCS and no CCS). An additional limitation of this analysis is that it does not consider non-climate costs and non-economic benefits that factor into DOE's assessment.

Though it does not represent a complete public-interest analysis, our finding that climate costs likely exceed economic benefits offers a useful data point for DOE's re-evaluation of the LNG export program. We urge DOE to incorporate this finding into its ongoing reassessment of LNG export.

Technical Appendix

Economic Benefits

Table 10 from the DOE's 2018 Macroeconomic Study reports consumer welfare in 2040 based on various levels of LNG exports in different scenarios. For example, the scenario labeled *Low_High_Low_Low* represents a situation with low U.S. gas supply (attributed to high resource costs and low availability), high U.S. gas demand, low rest of world gas supply (constrained by factors like production limits, war, unfavorable geology, etc.), and low rest of world demand. DOE's analysis shows that the key variable affecting consumer welfare is the U.S. gas supply. Thus, within each U.S. supply scenario, we identify a fitted line through available observations using the least square approximation approach. The analysis shows that, in cases of low, reference, and high U.S. supply, one additional BCF of LNG export per day increases consumer welfare in 2040 by **0.52, 0.45,** and **0.41** billion in 2016 dollars, respectively.

Table 10: Consumer Welfare for the More Likely Scenarios in 2040

	LNG Exports (Bcf/day)	Consumer Welfare (2016$ Billion)
Low_Ref_Ref_Ref	0.1	$30,006
Low_Ref_Low_Ref	9.9	$30,011
Low_Ref_Low_High	23.4	$30,018
Ref_Ref_Ref_Ref	12.9	$30,252
Ref_Ref_Ref_High	24.0	$30,255
Ref_Ref_Low_Ref	29.6	$30,260
High_Ref_Ref_Ref	23.3	$31,320
High_Ref_Ref_High	30.7	$31,323

Climate Costs

We estimate the per-unit climate costs of LNG export using Table 4.19-6 of DOE's Final Supplemental Environmental Impact Statement for the Alaska LNG Project.[55] That table provides the gross, lifecycle climate damage from exporting 27.8 trillion cubic feet of LNG between 2029 and 2061.[56] It provides sub-analyses for four different destination countries—Japan, South Korea, China, and India—and two different downstream cases: one with full CCS adoption and one without any CCS adoption.[57]

Our analysis focuses on Scenario 3, which assumes the use and storage of byproduct carbon dioxide.[58] For reference, we reproduce a truncated version of Table 4.19-6 below.

[55] 2023 Supplemental Analysis, *supra* note 22, at 4.19-14 tbl.4.19-6 (2023).
[56] *Id.* (volume); *id.* at 4.18-7 (timeframe).
[57] *Id.* at 4.19-14 tbl.4.19-6.
[58] *Id.*; *see also id.* Appx. C at 5. Scenario 3 and the No Action Scenario propose similar amounts of oil production in Alaska such that the difference in greenhouse gas emissions across the two scenarios can be attributed to the proposed LNG export. Scenario 2 assumes the same amount of total oil production as Scenario 3 but differs in the

Destination Country	Cumulative Social Cost of CO2, CH4, N2O without CCS on End Use NGCC Power Plant, Billion 2020$				Cumulative Social Cost of CO2, CH4, N2O with CCS on End Use NGCC Power Plant, Billion 2020$			
	5%	3%	2.50%	3%, 95th	5%	3%	2.50%	3%, 95th
No Action Alternative 2, SEIS Non-equivalent Energy Baseline (0 TCF Natural Gas, 1,356 MMbbl Oil)								
Japan	9.5	37.6	57.5	114	9.5	37.6	57.5	114
South Korea	9.5	37.6	57.5	114	9.5	37.6	57.5	114
China	9.5	37.6	57.5	114	9.5	37.6	57.5	114
India	9.5	37.6	57.5	114	9.5	37.6	57.5	114
Proposed Action, Scenario 3: Use and Storage of By-Product CO_2 (27.8 TCF Natural Gas, 1,360 MMbbl Oil)								
Japan	30	118.2	180.7	356.2	16.7	63.7	96.5	190.4
South Korea	30.1	118.6	181.2	357.3	16.8	64.1	97.2	191.8
China	30.1	118.6	181.2	357.4	16.8	64.1	97.2	191.8
India	30.5	120.4	184.2	363	17.5	66.9	101.4	200.1
Results Comparison: Scenario 3 *minus* No Action								
Japan	20.5	80.6	123.2	242.2	7.2	26.1	39	76.4
South Korea	20.6	81	123.7	243.3	7.3	26.6	39.7	77.8
China	20.6	81	123.8	243.4	7.3	26.6	39.7	77.8
India	21	82.9	126.7	249	8	29.4	44	86.1

Using this information, we identify the average cost of exporting one billion cubic feet of LNG export per day for one year (in $2016, for consistency with the estimates of consumer welfare benefits). First, for each climate-damage valuation and CCS case, we take the average cost of the four destination countries. (For instance, using the 3% discount rate and no CCS, the average is 80.6+81+81+82.9 ($ billion) divided by 4, which equals $81.38 billion in 2020 dollars, or $75.68 billion in 2016 dollars). Second, we convert this average climate cost to an annualized figure assuming one billion cubic feet of daily export. 27.8 trillion cubic feet over 33 years (2029–2061) equates to 2.31 billion cubic feet per day on average. Thus, this required dividing the average climate cost ($75.68 billion in the scenario described above) by 2.31 and then dividing it again by 33.

Table 4.19-6 provides cost estimates using the four climate-damage valuations from the Interagency Working Group on the Social Cost of Greenhouse Gases. We conduct additional analysis using the three climate-damage valuations that the Environmental Protection Agency published in December 2023. We also cut the Interagency Working Group's lowest climate-damage estimates (using a 5% discount rate) from our final presentation because it is regarded as a conservative underestimate.

In the case of full CCS usage, we added the cost of CCS technology to the climate costs. First, we calculate the total reduced cumulative lifecycle greenhouse gas emissions attributed to CCS. Specifically, for each of the two scenarios that assume no and full downstream CCS adoption, we take the average lifecycle emissions associated with LNG exports of the four destination countries in each scenario using the figures in Tables 4.19-3 and 4.19-4. (For instance, in the scenario of no CCS, the average is 1,861+1,871+1,871+1,922 divided by 4, which equals 1,881

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allocation of oil production between Alaska and the global market. It was thus not a suitable candidate for this analysis.

million metric tons of CO_2-equivalent (MMT CO_2 eq)). We then take the difference in the average emissions between the two scenarios, which equals 1,289 MMT CO_2 eq. Next, we take the cost of CCS per metric ton of CO_2 as $45 in 2023 dollars estimated by EPA.[59] Next, we multiply the amount of reduced emissions attributed to CCS by the per-unit cost of CCS and convert the value into 2016 billion dollars for consistency ($45.44 billion in 2016 dollars). Finally, we convert the total CCS cost into the average CCS cost of exporting one billion cubic feet of LNG export per day for one year following the same procedure for the climate costs as aforementioned.

[59] ENV'T PROT. AGENCY, GREENHOUSE GAS MITIGATION MEASURES CARBON CAPTURE AND STORAGE FOR COMBUSTION TURBINES TECHNICAL SUPPORT DOCUMENT 11 fig.7 (2023). EPA's estimate of $41 per ton of CO_2 (or $45 per metric ton of CO_2) is based on the assumptions of new combustion turbines, 90% capture rates, 12-year amortization, 7 percent interest rate, $3.69/MMBtu natural gas, $85/metric ton tax credit, 75 percent capacity factor, and $10/metric ton TS&M costs. *Id.* In 2005, the IPCC also provided a wide range of estimates between $15 and $75 in 2002 dollars (or $26–128 in 2023 dollars) based on a literature review. IPCC SPECIAL REPORT CARBON DIOXIDE CAPTURE AND STORAGE TECHNICAL SUMMARY 42 tbl.TS.9 (2005).

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