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1 **US Liquefied Natural Gas (LNG) Exports: Boom or Bust for the Global Climate?**

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5

6 **Abstract:** Due to surging natural gas production, the United States is now a growing exporter of
7 liquefied natural gas (LNG) to overseas destinations. However, the potential greenhouse gas
8 implications from increased US natural gas remain unclear. Through a hybrid lifecycle energy
9 strategy analysis, we investigate potential greenhouse gas scenarios of US LNG exports to Asia,
10 the largest source of global LNG demand. We find that the climate impacts of US exports to
11 China, Japan, India, and South Korea could vary tremendously. Annual global lifecycle
12 emissions range from -32 to +63 million metric tons CO₂e per billion cubic feet (Bcf) per day of
13 exports. Despite this range, emissions are not likely to decrease and may increase significantly
14 due to greater global energy consumption, higher emissions in the US, and methane leakage.
15 However, international climate obligations are a critical uncertainty underlying all emissions
16 estimates. Our results indicate the need for further research into quantifying the climate impacts
17 of LNG exports, and energy exports more generally.

18 **Keywords:** liquefied natural gas (LNG); energy exports; methane leakage; lifecycle analysis

19

1 1. Introduction

2 Natural gas production in the United States has increased significantly in the last decade due to
3 the shale revolution. [1] Originally faced with the prospect of having to import massive amounts
4 of liquefied natural gas, the US is now becoming a large net exporter. Dry natural gas production
5 increased by more than 35% since 2006 and is projected to grow further through 2020. [2]
6 Natural gas prices have fallen significantly, with major economic and emissions benefits
7 domestically. [3]

8 The shale revolution is now on the verge of rippling across the world. Rapidly increasing
9 domestic natural gas production in the United States is leading to mounting pressure from
10 industry and legislators to export domestic natural gas to other countries. The Department of
11 Energy (DOE) has received applications for projects with a cumulative natural gas export
12 capacity of more than 40 Bcf/day for permission to construct facilities to liquefy natural gas for
13 export to countries without Free Trade agreements. [4] Exports from the first of these terminals
14 recently began, with more under construction or under regulatory consideration.

15 Recently, many studies investigated the environmental implications of the domestic natural gas
16 boom in the US, which has largely replaced coal for electricity generation. Natural gas is
17 methane, which is itself a powerful greenhouse gas. Natural gas can leak out of its infrastructure
18 and into the atmosphere during normal production and transportation operations, leading to
19 greenhouse gas emissions greater than combusting the natural gas. Accordingly, despite having
20 lower combustion emissions than coal, Howarth argued that leakage of natural gas undermined
21 the lifecycle greenhouse gas advantages of natural gas. [5] Subsequent research found that while
22 methane leakage may be higher than official inventories, natural gas remains better than coal for
23 electricity generation for domestic uses. [6-9] This is due to the relative efficiency of the US
24 natural gas fleet, relative inefficiency of the coal fleet, coal mine leakage, and because natural
25 gas has replaced primarily coal instead of other fuel sources. [9]

26 However, relatively few studies have examined the global greenhouse gas implications of
27 expanded US LNG exports. To date, the DOE and the Federal Energy Regulation Commission
28 (FERC), the federal agencies responsible for approving LNG export projects, have not
29 comprehensively examined the impacts of export approvals on global greenhouse gas emissions.
30 The only study conducted by DOE thus far was limited to examining the replacement of coal
31 with natural gas for electricity generation, had key methodological shortcomings, and did not
32 account for several aggravating factors. [10]

33 A similar study by Abrahams et. al. was more comprehensive, including a first order
34 consequential lifecycle analysis, which is better able to capture replacement effects.
35 Nevertheless, this study also only examined, natural gas replacing coal, did not fully examine
36 domestic and international markets impacts, and did not analyze how energy strategies of
37 importing countries could affect emissions from LNG. [11]

38 This lack of inquiry into emissions and LNG is unfortunate, as the energy and carbon intensity of
39 its conversion could be significant. The liquefaction and transportation processes are very energy
40 intensive, as are the end uses (and displaced uses) of exported LNG.

1 Critically, the emissions impacts of expanded LNG exports can be difficult to determine because
2 they impact activities in two or more country's energy markets: the exporter and the importer.
3 Accordingly, analyses that look narrowly at only one replacement scenario (i.e. coal to LNG) are
4 incomplete looks of global market effects.

5 This study more accurately and comprehensively assesses the greenhouse gas emissions of US
6 LNG exports by developing a bounded hybrid lifecycle – energy strategy analysis. This new
7 approach combines lifecycle emissions uniquely normalized to an export metric with an analysis
8 of domestic and international energy markets. By investigating four of the largest LNG importers
9 in 2013 (China, Japan, India, and South Korea), we identify eleven potential uses of US LNG in
10 Asia, the most likely destination. Through developing individual lifecycle emissions for these
11 uses, we bound potential changes in greenhouse gas emissions per 1 Bcf/day of exports. Further,
12 this study measures how methane leakage, export-driven changes in domestic emissions, and
13 energy demand growth affect global greenhouse gas emissions from exports. Integrating analysis
14 of key energy concerns in each country with lifecycle profiles of individual technologies more
15 fully captures the dynamics at play in international fuel switching scenarios.

16 2. Identifying the Potential Uses of Exported LNG in Asian Countries

17 The countries that are likely to import LNG from the United States face energy challenges that
18 are somewhat distinct from those in the United States and Europe. The nuclear accidents at
19 Fukushima generally soured public opinion on nuclear power in Asia, leading to calls to
20 permanently close existing nuclear reactors and stop construction of new ones. [12-15] As such,
21 heavy dependence on imported fossil fuels in Japan and South Korea create significant energy
22 security concerns. In China and India, efforts to fight worsening air pollution conflict with ever
23 rising demand for energy. [15]

24 With diverse and complex energy dilemmas facing each country, the potential emissions
25 associated with each additional Bcf/day of US LNG exports could vary considerably. They
26 would depend on many factors, including: destination country, global markets, energy growth,
27 energy security issues, fuel choices, and environmental concerns. Examining the energy
28 challenges and strategies of importing countries is critical to fully assessing the potential
29 lifecycle emissions of US LNG exports. Highlights of a quantitative and qualitative country-by-
30 country analysis are presented in Figure 1, with detailed analysis following in the rest of this
31 section.

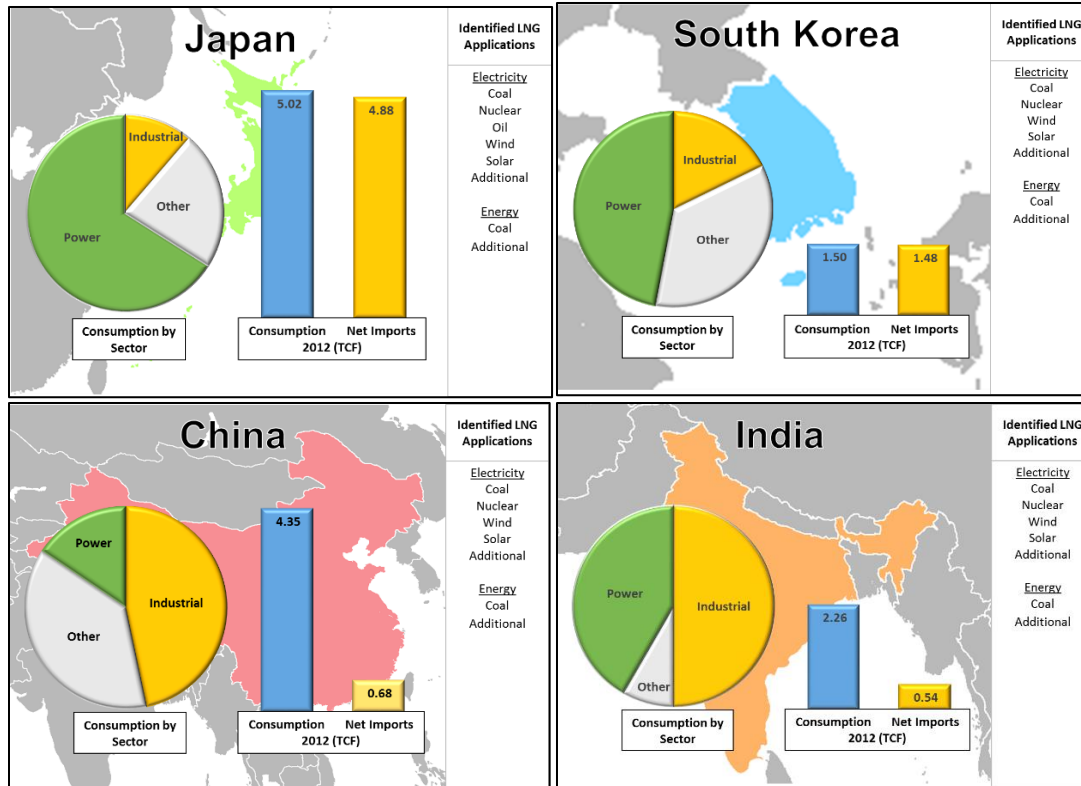


Figure 1. Natural Gas Consumption, Imports, and Identified LNG Applications by Country

Source: Natural Gas Statistics – [16]. Identified LNG Applications – this study. Note: Other refers to Commercial, Residential, and Transportation Sectors.

As the first and second largest respective importers of LNG globally, Japan and South Korea face two major challenges regarding their future LNG demand: near complete dependence on fossil fuel imports to meet energy demand and a diminished role for nuclear energy following Fukushima. [17, 18]

As advanced, developed economies, both countries have high energy and electricity demand. Japan, a series of islands, and South Korea, an isolated peninsula, have limited fossil fuel reserves and rely on large amounts of imports to meet domestic energy needs. [19, 20] Beyond LNG, both countries are among the largest importers of coal in the world. This heavy dependence has created stark and distinct energy security concerns due to volatility in global fossil fuel markets. With limited fossil fuel production, Japan and South Korea originally turned to nuclear power to diversify energy sources and reduce import dependency. [21]

The three-reactor nuclear meltdown at the Fukushima Daichi power station fundamentally altered the energy outlook for both countries. The effects were most immediate in Japan, which shut down its 48 nuclear reactors in the immediate aftermath of the accident. [17] Large increases in fossil imports, particularly LNG and fuel oil, were initially used to bridge the consequent energy gap. More recently, Japan has turned to coal to meet energy demand. With

1 lost nuclear output replaced by fossil fuels, Japan revised a targeted 25% reduction in greenhouse
2 gas emissions to only a 3.8% reduction, citing lost nuclear power as the main cause. [22] Japan's
3 heavy reliance on imported LNG makes coal an attractive energy source as it provides fuel
4 import diversity, limiting the ability of US LNG to replace Japanese coal consumption.

5 The nuclear industry was similarly hard hit in South Korea, which relied on nuclear power for
6 29% of its electricity in 2012. [18] Following the discovery of falsified certificates for
7 components at existing plants in 2012, four reactors were shut down temporarily. Driven by
8 public safety concerns, nuclear energy's planned role decreased greatly in a recent proposed
9 long-term energy plan. As in Japan, concerns about overreliance on LNG may limit the ability of
10 US LNG to displace coal in South Korea.

11 The energy situation in South Korea and Japan is further complicated by the recent international
12 agreement to limit carbon emissions in Paris. As part of this agreement, South Korea has pledged
13 to reduce its economy-wide emissions 37% below business-as-usual forecasts by 2030. [23]
14 Similarly, Japan pledged to reduce its emissions 26% below 2013 levels by 2030. [24] It is
15 unclear whether either country will be able to meet this pledges on this current trajectory. As
16 informed by our analysis below, importing U.S. LNG will not necessarily reduce emissions in
17 either country. It depends on what the LNG is replacing and what second order international
18 market effects are.

19 China's growing importance as an energy consumer cannot be understated, and at least three
20 pressing challenges relate to its demand for imported LNG: dramatic increases in economic
21 growth and energy consumption, growing dependence on foreign imports, and severe air
22 pollution resulting from heavy use of coal.

23 Between 1990 and 2010 China's economy grew almost fivefold, and its energy use more than
24 doubled, partially explaining why it now leads the world in total emissions of greenhouse gases.
25 [25] Today, China is the world's largest coal consumer and the second largest oil consumer. [26]
26 Responsible for almost half of global coal consumption, 69% of Chinese primary energy
27 consumption in 2011 came from coal, which dominates the power and industrial sectors. The
28 usage of natural gas is also growing in China, especially within the residential sector, and it now
29 represents 3% of China's total primary energy supply. Due to its expanding economy, China has
30 witnessed unprecedented growth in the demand for energy, led by the manufacturing sector and
31 followed by the residential sector. [27, 28]

32 This massive energy growth has led to increasing levels of fossil imports. In 1993, energy
33 imports emerged as a major concern to Chinese planners as net imports of oil ended "three
34 decades of self-sufficiency." [29] By 2009, soaring demand made China a net coal importer;
35 internal infrastructure constraints led to increasing seaborne deliveries. [26] Despite investments
36 in unconventional sources of gas, such as coal-bed methane and shale gas, Chinese demand for
37 natural gas already requires large and quickly growing levels of imports. [30] China is building
38 many LNG terminals to facilitate imports of LNG, along with a pipeline from Turkmenistan and
39 a recently signed gas deal with Russia.

1 Finally, heavy utilization of coal has led to the most severe and pressing air pollution issues in
2 the world, with deteriorating air quality in many Chinese cities. This severe air pollution brings
3 significant impacts on health and mortality to Chinese cities. [31] Natural gas, which burns much
4 cleaner than coal, could allow China to reduce its coal dependency and mitigate air pollution in
5 major cities. However, China's ambitious domestic shale goals are facing technology and
6 infrastructure constraints.

7 Although US LNG could be used to meet rising gas demand, it is likely that China will continue
8 its strategy of diversifying its international natural gas sources, limiting the portion of US LNG
9 that would flow to China. [32] It is unclear whether natural gas imports would displace existing
10 coal consumption or would just be used to meet rising energy demand. Further, pressing air
11 quality issues make replacing industrial or residential coal consumption more urgent, as the
12 power sector can utilize scrubbing technologies.

13 China's air pollution challenges are further intensified by its recent international pledge at the
14 Paris climate conference. China pledged to peak its carbon dioxide emissions by 2030 (at the
15 latest), decrease CO₂ GDP intensity by 60-65% from 2005 levels, and to increase non-fossil fuel
16 energy consumption to 20% of total energy. [33] The role that LNG could play in these activities
17 could be limited. In particular, U.S. LNG imports are likely to go to reducing industrial coal
18 consumption as opposed to electricity. From an air pollution perspective this makes sense – as
19 pollution control technologies can be applied to electricity generators, LNG is a top choice for
20 reducing air pollutants from industrial emissions. As described below, however, there are notable
21 carbon tradeoffs that would limit CO₂ reductions from replacing industrial coal.

22 With the world's second largest population, a growing economy, and pressing energy needs,
23 India faces very similar energy challenges to China: staggering increases in projected demand,
24 burgeoning dependence on imported energy, and severe infrastructure constraints.

25 India's growing economy and population are dramatically increasing demand for energy. With
26 an installed capacity of 189,000 MW in 2010, India already consumes the fifth largest amount of
27 electricity in the world. Coal-fired thermoelectric power plants produced about 71 percent of the
28 country's electricity in 2011-2012, with nuclear, hydropower, diesel and natural gas making up
29 the remainder. [34] India is both the third largest consumer and producer of coal in the world.
30 However, India's electricity sector relies on low quality coal, rendering coal-fired electricity
31 generation inefficient and necessitating the import of metallurgical coal. Energy demand, for
32 coal, natural gas, and oil is projected to continue to grow rapidly in coming years.

33 As in China, escalating energy demand is worsening the need for imports, which already supply
34 about one-third of India's energy consumption. The country imports its three major sources of
35 energy – coal, oil and natural gas, albeit in varying degrees. The IEA projects that by 2030, 91%
36 of India's oil will be imported. [35]

37 Soaring demand and rising imports underlie India's most pressing energy challenge: severe,
38 persistent infrastructure constraints. The pace of infrastructure build out, including power lines,
39 coal transportation capability, and generation capacity, has not kept up with demand. According
40 to the Government's economic survey, the gap in supply and demand of electricity was roughly 9

1 percent from 2007 to 2012. Despite adding 55,000 MW of new generation capacity the gap was
2 expected to remain unchanged for the fiscal year beginning in April 2012, with nearly 92,000
3 gigawatt hours (GWh) of demand going unmet. [36] In July 2012, this daunting shortfall for
4 energy was partially responsible for the largest blackout in human history, when 680 million
5 people lost power on two days. [37] Rolling blackouts continue to this day. India is thus looking
6 for LNG and other energy sources to fill the energy supply and infrastructure gap in virtually any
7 way possible.

8 More so than any other country in our analysis, US LNG exports to India are likely to serve
9 additional energy demand and are very unlikely to displace coal use. This is especially true in
10 light of India's pledge at the Paris climate conference: to install 175 GW of renewable capacity
11 by 2020, reduce CO2 GDP emissions intensity 33-35% below 2005 levels by 2030, and increase
12 non-fossil fuel share of power capacity to 40% by 2030. [38] None of these pledges are absolute:
13 as they are relative, they open the door for significant increases in overall energy demand even as
14 CO2 intensity decreases.

15 3. Methods

16 3.1. Normalizing Emissions and Selecting End-Uses

17 Two central tenants underlie the technology portion of our hybrid lifecycle – energy strategy
18 analysis: emissions normalization and the breadth of technologies examined.

19 First, normalization is necessary because the cumulative global climate impact of US LNG
20 exports will depend on the magnitude of exports and how LNG is used. However, decision
21 making for LNG exports is currently made on a project-by-project basis. This paper normalizes
22 the potential positive or negative lifecycle emissions from each potential use of exported LNG
23 into a commonly used industry and government metric, Bcf/day. By normalizing emissions
24 impacts into a 1 Bcf/day metric, the climate impacts from individual export projects can be
25 analyzed. Importantly, this normalization also allows a comparison between different uses of
26 natural gas, critical when examining emissions outside of the United States. Normal metrics for
27 electricity emissions, such as kg/MWh, and industry emissions, such as emissions/heat output,
28 can be readily converted into the Bcf/day metric.

29 Second, the examination of multiple applications and technologies is necessary because natural
30 gas is a versatile fuel and can be used for electricity, heating, transportation, or as an industrial
31 feedstock. In assessing lifecycle impacts from US exports, many existing government and
32 industry analyses assume that liquefied natural gas will replace coal for electric generation. This
33 represents the dominant paradigm in the United States, where coal is used almost exclusively for
34 electricity and where increased natural gas production frequently offsets coal for electricity
35 generation. However, this paradigm is not dominant in most of the countries that would use US
36 LNG exports. A complete analysis of the lifecycle emissions of LNG needs to address all
37 potential uses, of which this study examines eleven.

1 3.2. Justification for leakage scenarios

2 The three leakage scenarios developed in this study, 1.45%, 2.93%, and 5.87%, are based on data
3 from EPA and Brandt et. al. [6] The 1.45% leakage rate is based on EPA’s greenhouse gas
4 inventory, with distribution emissions removed. The 2.93% and 5.87% leakage cases are based on
5 worst case leakage scenarios from Brandt et. al., similarly modified to remove a representative
6 proportion for distribution. [6] These leakage scenarios are applied to international LNG cases as
7 well as the domestic coal to gas fuel switching case. As such, the greenhouse gas benefits of
8 replacing domestic coal in each scenario compared to international consumption are likely higher
9 than indicated in the main body of the study. International applications would likely have some
10 leakage between the regasification and consumption processes. This would lower the breakeven
11 additionality rate for LNG applications and increase the emissions benefits of using gas
12 domestically to replace coal.

13 3.3. Lifecycle Emissions Profiles of Likely LNG Uses

14 The identified uses of LNG in Asia range widely, covering applications in the electricity,
15 industrial, commercial, and residential sectors. Accordingly, the greenhouse gas emissions of
16 different uses have wide ranges. In order to understand the climate impacts of US exports,
17 emissions profiles must be developed for each potential application. Lifecycle analysis (LCA) is
18 a widely used tool to assess the complete environmental impacts of certain activities. By looking
19 at the upstream and downstream environmental impacts associated with an activity, LCA
20 provides the best methodology to identify the full climate ramifications of specific applications
21 of LNG exports.

22 Country-specific lifecycle emission factors are often overlooked when examining lifecycle
23 impacts of switching from coal to gas. For example, DOE’s report on the lifecycle emissions of
24 replacing Chinese coal with LNG is misleading as it uses the emissions profile of an American
25 coal plant. [10] Chinese coal plants were built recently, resulting in greater efficiency and less
26 emissions during combustion. To accurately compare the emissions of cross border uses of LNG,
27 lifecycle profiles for coal generation in each importing country are needed.

28 This study combines data from multiple studies to create emissions profiles for eight types of
29 electricity generation, of which five are country specific: Chinese coal, Indian coal, Japanese
30 coal, South Korean coal, Japanese oil, nuclear, wind, and solar. Fossil emissions are based on
31 three upstream processes (energy used for extraction, methane leakage, and transportation) and
32 one downstream process (combustion). Emissions from the three non-fossil electricity
33 technologies include different processes, including cultivation, fabrication, construction,
34 operation, and decommissioning.

LNG Application	Location	KG CO2e Emissions/MWh	Source
Coal Generation	United States	1,050	This study
	China	894	S. Yu et. al.
	India	1,129	Agrawal et. al.
	South Korea	1,001	K.M. Lee et. al.
	Japan	1,005	H. Hondo
Oil Generation	Japan	740	H. Hondo
Coal (heating)	Global	107*	Composite
Nuclear	Global	66	Sovacool
Solar	Global	50	Nugent and Sovacool
Wind	Global	34	Nugent and Sovacool

[39-46]

Table 1. Lifecycle Emissions Factors for Different Technologies for LNG

Compared to the United States and Europe, there are considerably fewer LCA studies examining domestic energy consumption in the countries profiled in this study. While the authors were able to determine lifecycle emissions for each identified use in CO₂ equivalents, they were unable to gather molecule specific emissions factors (i.e. CO₂ emissions, CH₄ emissions, N₂O emissions) for each use. For a complete picture of lifecycle emissions, this information is necessary as different studies used different GWP values for methane and nitrous dioxide emissions. To overcome this limitation, the authors disaggregated emissions from CO₂e into molecule emissions when possible. When the CO₂e constituents were unclear, the authors used CO₂e emissions. This introduces some uncertainty due to changing GWP values for different greenhouse gas pollutants. In particular, the emissions benefits of replacing some types of coal with LNG may be higher, especially in the short term. However, as CO₂ is the primary source of CO₂e emissions for all sources examined, this uncertainty does not affect this paper's conclusions. Using unnormalized CO₂e values from different studies is a widely practiced method in energy studies, despite the decreased accuracy. [45-47] Due to changes in GWP values over time, future LCA studies should clearly delineate constituent molecules.

To understand emissions from displacement by LNG in the electricity sector, sources are compared to a new natural gas combined cycle plant, which includes transportation emissions from liquefaction, tanker transport to each country, and regasification. This means we likely underestimate, rather than overestimate emissions from natural gas generation, since the average combustion emissions of existing natural gas plants in each country examined is higher than that of a new plant. If utilization of existing plants is increased instead of building a new plant, the emissions change associated switching to LNG would be lower than indicated in this study. The emissions associated with a natural gas plant displacing construction of a new coal plant would be lower due to the high efficiency of new coal plants compared to existing plants.

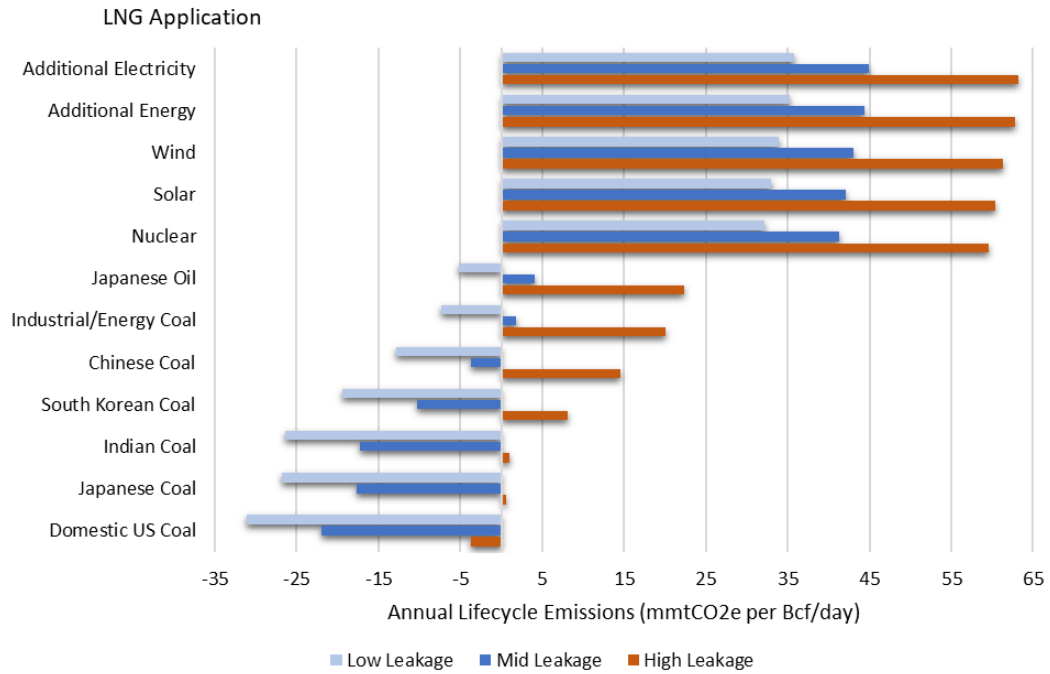
For the purpose of understanding emissions put to industrial and household uses, we analyzed upstream and combustion emissions for industrial, commercial, and residential applications normalized to Higher Heating Values (HHVs) for each fuel. Unlike the United States, coal consumption in studied countries is not dominated by the power sector, and is widely used for

1 industrial applications and for space heating. Similarly, natural gas is used for multiple uses.
2 HHVs are not appropriate when comparing electricity uses as natural gas can be more efficient
3 than coal for electricity generation due to combined cycle technology; however, no such
4 advantage exists for heating applications. [48] Normalizing coal used for heating and its potential
5 replacement LNG to HHVs creates a useful proxy of emissions from industrial, commercial, and
6 residential applications. Further normalizing these emissions into Bcf/day allows a comparison
7 of the emissions changes from using LNG for heating use with other applications, such as
8 electricity generation. In calculating the upstream emissions associated with coal use for heating,
9 we averaged upstream emissions from Japan, South Korea, China, and India coal for electricity
10 use divided by a heat rate of 10,000 btu/MWh. Individual heat rates for each country were not
11 available, so this value was used as an indicative measure. As most emissions for HHVs come
12 from combustion (~90%), the error introduced by this measure is minimal.

13 4. Calculating Normalized Lifecycle Emissions Changes from LNG

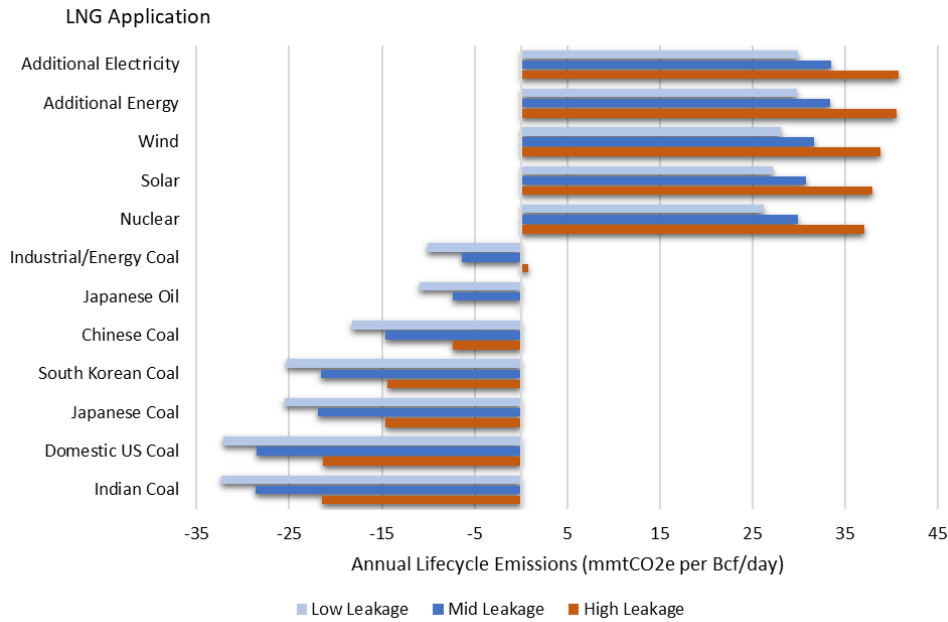
14 In the United States, recent studies have found that natural gas infrastructure leaks more methane
15 than previously estimated by the US Environmental Protection Agency (EPA). [5, 6] As methane
16 is a more potent greenhouse gas than carbon dioxide, methane leakage potentially undermines
17 the climate benefits of coal to natural gas fuel switching domestically and abroad. Despite
18 increased scrutiny, substantial uncertainty remains as to the amount of methane that is leaking.
19 To test the impacts of different leakage levels on the LCA emissions of LNG exports, this study
20 considers three leakage values: 1.45%, 2.93%, and 5.87%. This study does not explicitly account
21 for methane leakage between LNG import terminals and final use, so these leakage scenarios are
22 representative of both domestic and international lifecycle leakage rates for all scenarios.

23 Lifecycle emissions across electricity and heating uses were pulled from scientific literature and
24 normalized into the amount of that activity that would occur using 1 Bcf/day of LNG imports.
25 The results of this normalization are presented in Figure 2, which compares the direct emissions
26 change that would occur with each identified application of LNG, with variations based on
27 leakage rate scenarios. Here and elsewhere, we consider 20-Yr and 100-Yr global warming
28 potentials (GWPs) to evaluate both short and long term climate impacts.



1

2 **Figure 2. Net Emissions Resulting from Identified Applications of LNG**



3

4 **a. 100-Yr GWP**

5 Note: Domestic US Coal is included for reference and refers to emissions saved from replacing coal for electric
 6 generation in the US with a new domestic natural gas combined cycle plant.

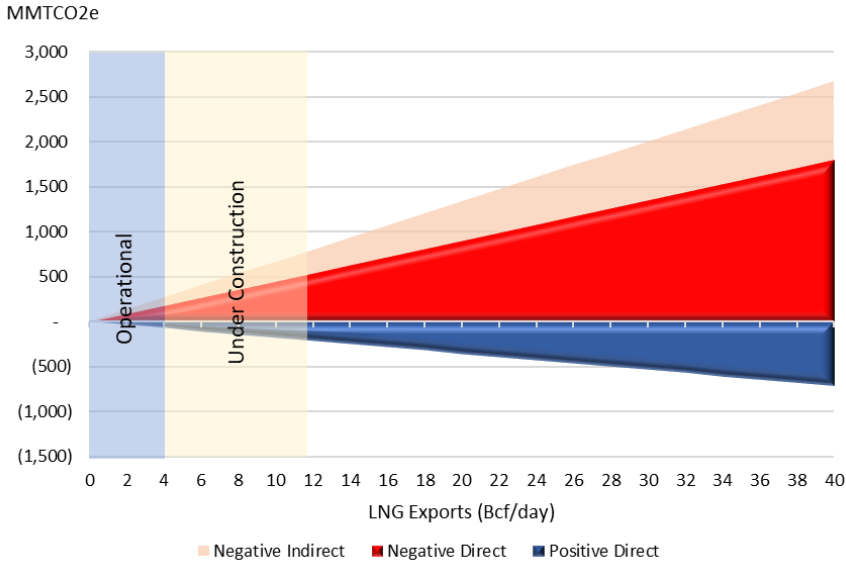
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1 The potential net changes in emissions from 1 Bcf/day of LNG exports ranges from -32-63
2 MMTCO₂e, across leakage scenarios and timeframes. There are considerable variations in the
3 benefits of replacing coal for electricity generation in each individual country. Replacing
4 electricity from US coal with domestic natural gas brings higher climatic benefits than almost all
5 LNG applications. Conversely, meeting additional electricity or energy demand using imported
6 LNG has the greatest negative climate effect across all leakage scenarios and timeframes. This is
7 due to no GHG emissions being offset in importing countries, leading to net emissions
8 increasing.

9 Leakage rates and GWP time frame choice greatly influence the estimated net climate impacts of
10 exported LNG. Generally, the emissions benefits of replacing coal-fired electricity generation
11 with LNG decrease significantly at higher leakage rates and when using a shorter GWP. Notably,
12 our estimates indicate that the three uses of exported LNG with the largest potential to decrease
13 net global emissions are replacing Indian, Japanese, or South Korean coal for electricity.
14 However, replacement of these energy sources with LNG is not likely to happen at large levels
15 because of each country's energy security goals, as explained earlier. Finally, using LNG to
16 replace heating uses of coal (i.e. non-electricity industrial, commercial, or residential use) brings
17 lower net emissions benefits than replacing coal for electricity generation.

18 Figure 3 bounds the potential upside and downside emissions from US LNG exports. The figure
19 is scaled to 40 Bcf/day, the approximate amount of applications before DOE, with the current
20 state of regulatory approval indicated. Note, as many applications are unlikely to be approved, 40
21 Bcf/day is likely much higher than maximum US LNG exports in the short or medium term.
22 Positive Direct indicates decreases in emissions from use of LNG, bounded by replacement of
23 Japanese Coal. Negative Direct indicates increases in emissions from use of LNG, bounded by
24 meeting additional electricity demand. Negative Indirect are the emissions that could be reduced
25 by using natural gas domestically to replace coal instead of exporting it. The actual emissions
26 associated with LNG will most likely be somewhere between the ranges.

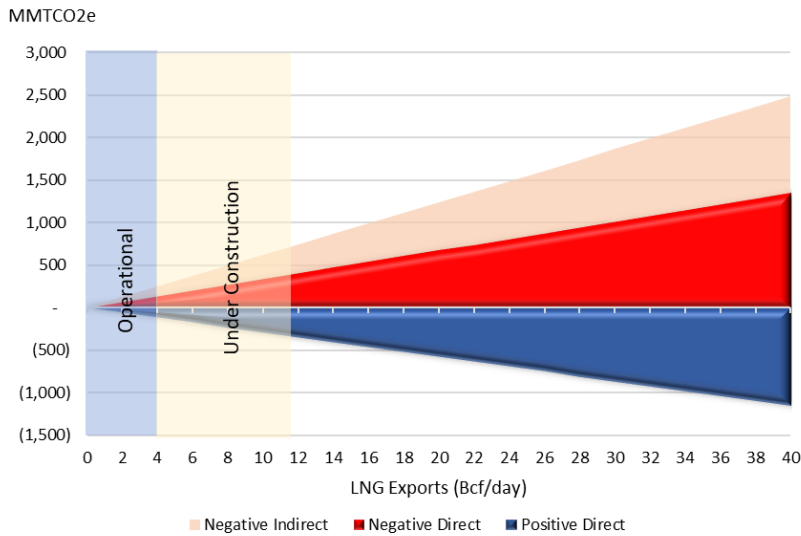
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1 Projects with some level of

2 **Figure 3. Bounded Direct and Indirect Emissions of Proposed LNG Projects**

3 **a. 20-Yr GWP**



4

5 **b. 100-Yr GWP**

6 **c.** Note: Mid Leakage Scenario. Replacing Indian coal for electricity generation was excluded from this

7 bounding as it is highly unlikely to occur at significant levels.

8

9 federal approval could have the eventual potential to decrease emissions by 302 MMTCO_{2e} or

10 increase emissions by 353 MMTCO_{2e} annually in the mid leakage and 100-Yr indicative

11 scenario. The scale of net global emissions impacts from LNG exports depend on the magnitude

12 of total LNG exports. Critically, using exported LNG domestically to replace coal instead of

13 exporting it could reduce U.S. emissions by up to 300 MMTCO_{2e}.

1 5. The Aggravating Factors: Lost Displacement and Additionality

2 On a bounded technological LCA basis, our results indicate a spectrum of potential global net
3 emissions outcomes of exporting LNG. However, the actual impacts are going to depend on
4 natural gas impacts domestic and international energy markets. In domestic markets, LNG
5 exports could lead to higher natural gas prices decreasing total natural gas consumption in the
6 United States. In international markets, primarily the countries in this study, LNG exports could
7 lower LNG prices and lead to greater LNG consumption. This could then lead to LNG displacing
8 domestic energy sources or leading to higher overall energy demand.

9 In 2012, the Energy Information Administration (EIA) analyzed how different levels of LNG
10 exports would impact domestic fuel prices and energy use. [39] EIA's report indicated that LNG
11 exports would indeed lead to higher domestic prices and less domestic natural gas consumption
12 in all export cases. In the four scenarios examined EIA found that, between 2015 and 2035, an
13 average of 65% of exported natural gas would be met by new domestic natural gas production.
14 Meanwhile, 24% would come from reduced natural gas consumption by power plants and the
15 rest would come from decreased consumption in other domestic sectors.

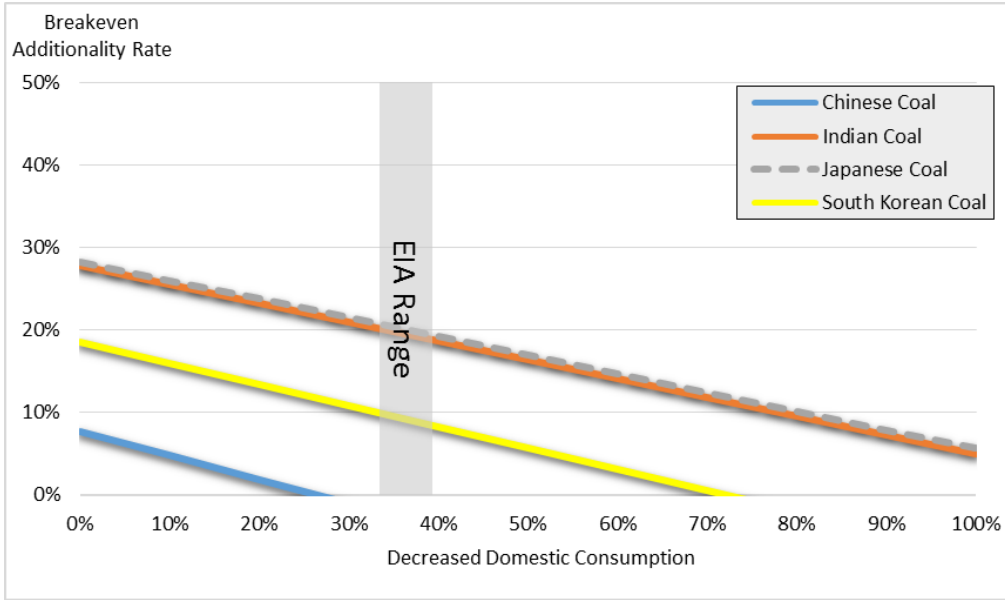
16 With natural gas and coal currently in competition for market share in the United States, EIA
17 found that reduced natural gas generation from these exports would be met by higher coal
18 generation.

19 Reducing domestic natural gas consumption impacts the net global emissions associated with
20 LNG in three ways. First, liquefaction, transportation, and regasification lead to higher upstream
21 emissions for the use of exported LNG compared to domestic consumption. Second, decreased
22 domestic coal to gas fuel switching increases emissions. Third, emissions in the US would
23 somewhat fall due to decreased natural gas consumption, although this effect is much smaller
24 than the first two factors. On balance, based on EIA's study and likely behavior of energy
25 markets, domestic lifecycle emissions would increase due to greater upstream emissions and
26 higher coal use.

27 Just as LNG exports leads to reduced domestic natural gas consumption in several end-use
28 sectors, new LNG supplies will lead to higher natural gas consumption in importing countries in
29 multiple sectors. Natural gas demand could increase in electricity, industrial, residential, and
30 commercial uses. If natural gas consumption rises, total energy consumption rises. This is
31 additionality: exported US natural gas provides heating or electricity in importing countries but
32 does not displace or replace other energy end uses. To the degree this energy consumption would
33 otherwise not occur, the additional energy usage causes increased greenhouse gas emissions.

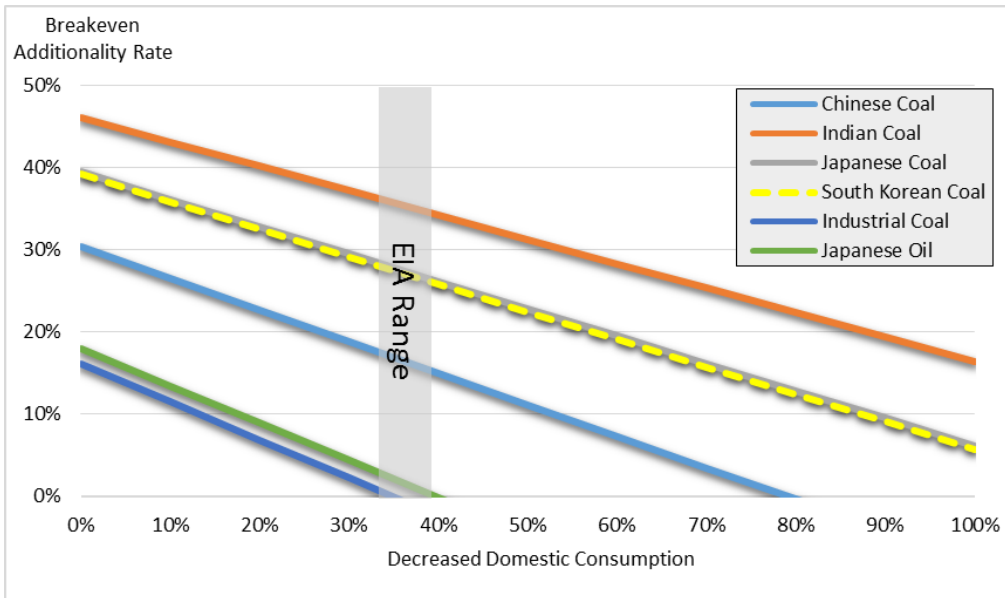
34 Decreased domestic gas consumption and additional international energy consumption combine
35 to limit the range of potential climate outcomes from US LNG exports. Figure 4 indicates the
36 breakeven additionality rate for lost domestic gas consumption for different LNG applications
37 (i.e. the amount of LNG that would need to supply additional energy use at a domestic
38 displacement rate for the climate benefits of LNG to be zero). Note: EIA's studies found that
39 approximately 34-37% of exported LNG came from projected reductions in domestic natural gas

1 demand. As most reduced natural gas consumption would otherwise replace coal, the emissions
 2 penalties from additionality effects for each LNG applications can be significant.



3
 4 **Figure 4. Breakeven Additionality Rate versus Domestic Consumption**

5 **a. 20-Yr GWP**



6
 7 **b. 100-Yr GWP**

8 c. Note: Mid Leakage Scenario. Only some LNG uses are plotted in Figure 4, as the remaining uses
 9 would lead to greater emissions regardless of the additionality or domestic displacement rates.

1 For example, if a LNG terminal exported 0.5 Bcf/day of natural gas, 34% of which came from
2 reduced domestic coal to natural gas fuel switching, then all the exported natural gas would need
3 to displace only industrial coal or Japanese oil to keep net global emissions to zero (100-yr
4 GWP). If any of that LNG were to go to additional energy demand instead, emissions would
5 increase.

6 This displacement versus additionality analysis reveals that exporting US LNG to Asia will only
7 yield long-term climate benefits if exported LNG was used almost entirely to replace coal for
8 electricity generation. However, the three uses of LNG that we identify have the greatest
9 potential emissions benefits are the least likely to happen due to the energy strategies of
10 importing countries. These uses are replacing Indian, South Korean, and Japanese coal for
11 electricity generation – coal for industrial use in these countries does not yield the same potential
12 emission benefits. While replacing coal with LNG for electricity generation in China could lead
13 to emissions benefits, LNG is not likely to replace exclusively coal for electricity generation. If
14 LNG replaces marginal amounts of zero carbon resources, moderate amounts of industrial coal,
15 or leads to modest increases in energy demand, net global greenhouse emissions resulting from
16 exporting LNG to China would be negative.

17 Our displacement-additionality analysis thus suggests that the most likely uses of US LNG
18 exports would result in increases in global greenhouse gas emissions. Critically, this analysis
19 indicates that the market impacts of LNG exports, both domestically and internationally, have
20 very large impacts on total emissions changes. Considering the multi-decade lifetimes of LNG
21 infrastructure, and the need to reduce emissions greatly by 2050, even favorable assumptions for
22 LNG exports indicate they may not a climate solution based on current technologies.

23 6. Conclusion and Policy Implications

24 Our hybrid lifecycle-energy strategy analysis, based on both emissions estimates and likely
25 market effects, indicates that exporting LNG is likely to increase global greenhouse gas
26 emissions. While uncertainty remains, methane leakage, additional energy demand, and
27 decreased domestic coal displacement have the very real potential to undermine any prospective
28 climate benefit in the long term. LNG exports lead to increased short-term climate emissions in
29 most scenarios. Only with favorable assumptions which conflict with the energy strategies and
30 needs of importing countries are there net climate benefits from LNG exports. With this in mind,
31 we offer two conclusions.

32 First, policymakers, including regulators and legislators, must consider the complete climate
33 ramifications of LNG exports. To date, FERC has refused to look at emissions beyond the
34 facility fence-line. DOE, responsible for determining whether exports are in the public interest,
35 has not comprehensively examined the full suite of factors impacting lifecycle emissions of
36 exports. The factors it has examined are methodologically misleading. The sheer scale of
37 potential LNG exports, corresponding increases in global emissions under the most probable
38 scenarios, and lifetimes of LNG infrastructure make enhanced regulatory scrutiny not only
39 necessary but imperative. Future LNG export facilities could become today's coal plants, where

1 entrenched interests fight meaningful action to reduce climate emissions, with significant
2 negative impacts on the global public.

3 Second, both technological and market changes could make LNG exports into a better climate
4 mitigation technique. Aggressive actions to address emissions across the entire lifecycle can
5 lessen or even reverse likely emissions increases. Methane leakage from natural gas
6 infrastructure can be better monitored and controlled. Utilization of carbon capture and storage
7 could reduce emissions from combustion and liquefaction processes. Most importantly, more
8 detailed emissions profiles of importing countries could create policy roadmaps which ensure
9 that natural gas replaces the highest emitting resources. If the US wants to export its natural gas
10 to other countries in a climate friendly manner, it should ensure those countries have the
11 technical capabilities and international obligations to reduce their emissions.

12 Third, the implementation of countries' Paris climate pledges could greatly impact emissions
13 outcomes from U.S. LNG exports. While all importing countries in this study pledged to reduce
14 their emissions or emissions intensity, it is unclear to what extent they will do so and what role
15 U.S. LNG could play in helping them do so. South Korea and Japan's struggles with nuclear
16 energy, as well as the critical role coal plays in their electric mix, could make it very hard for
17 U.S. LNG to reduce emissions in either country. U.S. LNG may similarly have uncertain policy
18 implications in both India and China as energy demand continues to grow in these countries and
19 the relative nature of their Paris pledges could limit overall absolute emissions reductions. The
20 US' recent decision to leave the Paris agreement and emergence as an international climate
21 pariah could present significant challenges to increased US LNG exports. The relationship
22 between U.S. LNG exports and the Paris pledges in all four countries is thus a critical area for
23 further research.

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