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THE CARBON-NEUTRAL LNG MARKET: CREATING A FRAMEWORK FOR REAL EMISSIONS REDUCTIONS

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As governments and companies consider options to decarbonize their energy systems, addressing greenhouse gas emissions from natural gas and liquified natural gas (LNG) will inevitably become a greater concern. Natural gas is viewed by some as potentially providing a bridge in a broad energy transition from dependence on fossil fuels to lower-emission sources. Even with advancements in renewable energy, many forecasts show natural gas will remain core to meeting global energy demand for some time, including as a backup fuel source for renewables.[1] But as the emissions profile of the natural gas value chain has become clearer, estimates of its footprint have increased, raising questions about natural gas's transitory function. While gas will continue to have a prominent role in the energy mix,[2] without action to better account for, reduce, and offset natural gas and LNG emissions, the breadth and length of its use will increasingly come into question—including by countries with growing energy demand who see diminishing incentive to favor natural gas over high-emitting but fiscally cheap fuel sources, such as coal.

Amid these considerations, discussions of value chain carbon intensity and greenhouse gas (GHG) accounting are becoming an important component of LNG trade, giving rise to the concept of "carbon-neutral LNG." In the trade of carbon-neutral LNG, GHG emissions from supply and/or consumption are accounted for and offset by procuring and retiring carbon credits generated through GHG abatement projects, such as afforestation, farm/soil management, and methane collection.[3] Currently, carbon-neutral LNG makes up a slim portion of global LNG trade, with just 14 cargoes traded transparently since the first was sold in 2019, compared to over 5,000 cargoes of LNG being delivered globally in 2020 alone.[4] By examining the efficacy of the market at this early stage, as this commentary does, areas for improvement in the carbon-neutral LNG trade are highlighted.

Procurement of carbon credits does not negate the emissions from natural gas and LNG, and accordingly, adoption of offsets should be paired with a broader and deeper reduction in the emissions intensity of these fossil fuels to ensure they remain conducive to meeting growing energy demand without needlessly jeopardizing global, national, and corporate efforts to reduce emissions. When considering this alongside the important role LNG and natural gas are likely to continue to play in meeting energy demand in key parts of the world during the transition period, it becomes clear that efforts must be made to scale GHG emissions mitigation throughout the value chain, such as through leakage reduction and employment of less carbon-intensive liquefaction technology, as well as to offset remaining emissions through the procurement and retirement of high-quality carbon credits.

Serious questions remain about scaling the carbon-neutral LNG trade, including which emissions are accounted for, what methodology is employed in the emissions measurement and verification, and how the emissions are priced—either through a carbon credit or a carbon tax. If these questions are sufficiently addressed, natural gas and LNG may align better with global policy direction and emissions requirements. That is to say, GHG verification and mitigation will be critical to the sustainability of LNG in the decarbonizing global energy stack in the coming decade, with knock-on impacts on long-term LNG contract structure, trade flows, and market pricing.

While this commentary does not prescribe policy to meet carbon neutrality or Paris Agreement goals specifically, it does examine an existing and growing market trade behavior that has the potential to assist countries dependent on natural gas in meeting their climate targets during this transitory period for the global energy system. Section 1 outlines the current state of the carbon-neutral LNG trade, while section 2 suggests a structure for LNG GHG accounting based on existing accounting methodologies. Section 3 discusses the different forms through which emissions mitigation can be integrated into the LNG trade, including a discussion on the risks of greenwashing. Section 4 highlights the implications of the growing carbon-neutral LNG market and provides recommendations to market participants and policy makers.

Background

Of the 14 carbon-neutral LNG cargoes[5] that have been transparently traded, Shell supplied six from its global portfolio of LNG. Of the rest, Total and JERA each sold one, with the former from the Ichthys Field in Australia's Browse Basin and the latter sourced from gas across Abu Dhabi's onshore and offshore associated and nonassociated fields. The remaining six included a range of participants (see Table 1). All but two of the 14 cargoes were purchased by Asian buyers for delivery to China, India, Japan, Korea, and Taiwan, with two cargoes purchased by Shell for delivery to Europe, with one from Gazprom and the other from Cheniere Energy.

Table 1: Transparently completed carbon-neutral LNG deals

Date	Volume	Supplier	Buyer	Destination	Emissions covered	Carbon offset registry
06/18/19	1 cargo	Shell	Tokyo Gas	Japan	Full life cycle	VCS
06/18/19	1 cargo	Shell	GS Energy	Korea	Full life cycle	VCS
06/27/19	1 cargo	JERA	*unstated*	India	End-use only	CDM
03/04/20	1 cargo	Shell	CPC	Taiwan	Full life cycle	VCS
11/18/20	1 cargo	Shell	CPC	Taiwan	Full life cycle	VCS
06/22/20	2 cargoes	Shell	CNOOC	China	Full life cycle	VCS
09/29/20	1 cargo	Total	CNOOC	China	Full life cycle	VCS
03/01/20	1 cargo	Mitsui	Hokkaido Gas	China	Full life cycle	*unstated*
03/01/20	1 cargo	Gazprom	Shell	UK	Full life cycle	VCS
03/01/20	1 cargo	RWE	POSCO	Korea	WTT only	VCS
04/09/21	1 cargo	Mitsubishi/DGI	Toho Gas	Japan	*unstated*	*unstated*
04/16/21	1 cargo	*unstated*	Pavillion Energy	Singapore	WTT only	VCS and CCB
05/05/21	1 cargo	Cheniere	Shell	Europe	Full life cycle	*unstated*

Note: As of June 2021.

Source: See endnote 5.

The small proportion of European buyers could partially be explained by the fact that carbon emissions from direct fuel consumption in Europe's power and industrial sectors, of which some is sourced from LNG, are already covered by a carbon price via the EU's Emissions Trading System (EU ETS). Further emissions regulatory overlap arises due to numerous European countries subjecting sectors such as residential and commercial heating to carbon prices. This existing regulated coverage effectively reduces the incentivize for consumers to engage in additional voluntary carbon pricing or offsetting. The situation is markedly different in Asia though, where countries including Japan and South Korea, have yet to see their emissions reduction targets translate into mature carbon pricing mechanisms like those in Europe.[6] Further, while many Asian countries see natural gas and LNG as critical to displacing coal in the power sector, most have insufficient domestic natural gas production, few economically conducive options for further domestic production expansion, and limited alternative sources to import gas via pipeline. Collectively, these factors make carbon-neutral LNG supply attractive from the perspective of meeting emission reduction targets.

Although trades delivered into Asia so far have not gone toward meeting any specific emissions targets, buyers are setting the stage to do so in the future. This is best exhibited by statements made by the Carbon Neutral LNG Buyers Alliance, a group of 15 Japanese companies established in March 2021, with the objective of raising awareness of carbon-neutral LNG in order to establish its "position within the various systems in Japan with the aim of contributing towards Japan's achievement of a carbon-neutral society by 2050."[7] This awareness campaign is also a reflection of the fact that the incremental costs for carbon-neutral LNG will eventually be passed on to end users, in which case public awareness of why prices are increasing can help mitigate potential opposition.

There is currently no consensus on what qualifies an LNG cargo as carbon-neutral. While all the cargoes listed in Table 1 were designated "carbon-neutral LNG," the respective transaction details indicate there are significant differences in the range of value chain emissions covered in each trade. For example, carbon-neutral cargoes transacted by Shell, Total, Gazprom, and Mitsui covered emissions across the cargoes' entire value chain,[8] including emissions from upstream natural gas production, transportation, liquefaction operations, shipping, regasification, and final consumption.[9] However, JERA's trade only covered the direct emissions from final consumption, while the cargoes purchased by POSCO and Pavilion only covered emissions from production to delivery,[10] meaning the LNG was not fully carbon-neutral from a life cycle perspective. These differences not only have significant impact on the amount of emissions requiring mitigation but also on the environmental credentials of this emerging carbon-neutral LNG trade.

Calculating Life Cycle Emissions

GHG Emission Accounting

Confirming how environmentally beneficial this emerging trade structure is (i.e., how much emissions are reduced as a result of the carbon-neutral commodity trade) begins with what methodology is used to measure and verify emissions for the commodity itself. In the case of LNG, measurements encompass the entire value chain, from upstream natural gas production to downstream consumption. The majority of international companies calculate GHG emissions in line with the framework laid out by one of numerous GHG accounting methodologies,[11] which seek to define best practices and lay out a framework for reporting on a corporate level.

While different methodologies exist, the LNG industry could ensure aggregation and comparability of GHG emissions across companies and jurisdictions if calculations were in line with the International Organization for Standardization (ISO) framework.[12] The ISO offers comprehensive guidance for the industry from sourcing the natural gas to its final combustion.[13]

The ISO standards build on each other, starting with ISO 14040/ISO4044, which provides the framework for the life cycle assessment.[14] The methodology for measuring GHG footprint for products, such as natural gas, is given in ISO 14067,[15] which builds upon ISO 10404/44. Finally, the definitions for carbon-neutral claims and products are given in ISO 14021,[16] which refers to ISO 14067. These standards require that the full life cycle of the products is covered to make a carbon-neutral claim, which includes downstream combustion of LNG.

When a company is trying to measure GHG emissions from a particular source or trade, the accounting tool generally involves the use of "emissions factors" (i.e., the amount of GHG emitted by a source to a set amount of activity performed by that source). Because many sources lack the measurement tools to customize values, default or modeled values are often utilized for the emissions factors.[17]

Default emissions factors are averages based on extensive data sets from the Intergovernmental Panel on Climate Change (IPCC), which is considered the premier authority on default emissions factors.[18] When using default or modeled values, businesses need to input only their activity data, such as distance traveled for an LNG tanker, to calculate their emissions.

Emissions for a particular source are calculated as the product of the applicable emission factor (EF) and the activity factor (AF):

Emissions = EF * AF

Emissions for a particular LNG facility or operation are the sum of these individual products.

For example, during a warm ship cooldown (the process by which an LNG carrier's cargo tanks are pre-cooled to approximately –161.5°C in order to then load LNG), the marine flares on the ship have been assessed to have an EF of 12.20 CO_2e metric tons/hour.[19] Accordingly, during the cooldown process, which can take up to 12 hours on a membrane vessel, the emissions from the marine flare would be:

12.2 * 12 = 146.4 metric tons of CO_2e

Collectively these emissions are generally calculated in terms of carbon dioxide equivalent (CO_2e or CO_2-eq). CO_2e captures the combined effect of *all* anthropogenic GHG emissions in a single metric based on each gas's warming potential over a given period of time, a metric known as a substance's global warming potential (GWP). GHGs include, among others, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). An entity's greenhouse gas inventory should account for all GHGs, so the term "carbon-neutral LNG" should be interpreted henceforth as "CO_2e neutral LNG."

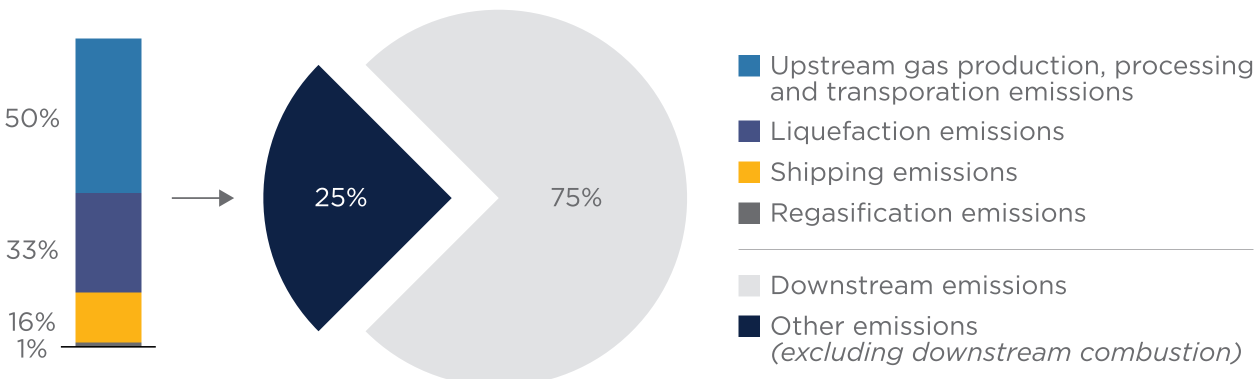
The CO_2e for each GHG gas is derived by multiplying the amount of the emitted gas by its associated GWP. For example, 1 kg of methane (CH_4) from fossil fuels causes 30 times more warming over a 100-year period compared to 1 kg of CO_2, and so fossil methane has a GWP of 30.[20] The 100-year time frame is the most commonly used factor for the calculation of CO_2e, including in the IPCC report, and will be the basis for figures used in this commentary. For example, if 1 kg of methane is emitted, this can be expressed as 30 kg of CO_2e (1 kg CH_4 * 30 = 30 kg CO_2e). That said, given the GWP of methane over a 20-year period is significantly higher, at 85 times that of CO_2e, discussion of GHG accounting for methane outside of this paper often warrantably employs this shorter time period.[21]

For the integration of GHG emissions accounting and mitigation into LNG trade to have a sustained and meaningful environmental impact, it is critical that the industry adheres to a singular, comprehensive accounting methodology, of which the ISO framework outlined above is a strong example. Further, companies should not only be inclusive of all GHG emissions (i.e., utilize the CO_2e approach), but they should also be transparent about their calculations, making them publicly available as required by ISO. This transparency will not only act as a confidence-boosting measure to avoid greenwashing concerns in regard to overall emissions loads but also as a catalyst for more efficient market trade.

LNG-Specific Emissions Calculations

When looking at the LNG value chain specifically, emissions can be split up into two broad categories, with the first being everything from upstream production through regasification (see Figure 1). This segment can be thought of as DES (delivered ex-ship) emissions or "well-to-tank" (WTT) emissions.[22] The second category consists of downstream combustion of natural gas.[23] For this commentary, the life cycle emissions of an LNG cargo are broken up this way versus scope 1, 2, or 3 emissions.[24] This approach is taken in an effort to avoid undue confusion, given each carbon-neutral LNG trade has both a buyer and a seller, and thus scope 3 emissions for the seller of LNG (i.e., downstream combustion) equate to the scope 1 emissions for the buyer of the LNG cargo.[25]

Figure 1: Carbon intensity of the LNG supply chain



Source: Breakdown of "other emissions" (excluding downstream) from "GHG Intensity of Natural Gas Transport," Sphera, July 8, 2020, https://sphera.com/research/ghg-intensity-of-natural-gas-transport/; breakdown of downstream versus other emissions from "Greenhouse gas reporting: conversion factors 2020," UK Department for Environment, Food and Rural Affairs, updated July 17, 2020, https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020.

For downstream combustion of fossil fuels, emissions factors are calculated based on the carbon content of the fuel as a factor of the heat content (i.e., the amount of energy produced when a fuel is burned; measured in MMBtu).

The activity factor is the quantity of fuel used, which can be verified by a third-party meter of the fuel supplier.[26]

Therefore, calculating the emissions from downstream combustion of an LNG cargo in the power sector is relatively straightforward. For example, when combusted, natural gas has an emissions rate of 117 lb. of CO_2e/MMBtu.[27] Under the assumption of 52 MMBtu per metric ton of LNG,[28] one metric ton of LNG has direct emissions of 6,084 lb. of CO_2e or 2.76 metric tons of CO_2e. Accordingly, a typical LNG cargo of 70,000[29] metric tons has downstream emissions of approximately 190,000 metric tons or (0.19 million metric tons) of CO_2e. A more inefficient natural gas-fired plant or boiler will use more natural gas, but the volume of natural gas delivered by the LNG cargo will remain the same.

However, calculating the remaining LNG life cycle emissions (i.e., WTT emissions) is notably more complex. This derives from the fact that WTT emissions encompass several complex processes ranging from liquefaction to regasification terminals, huge variations in upstream production practices, and a diverse fleet of LNG tankers, each with their own characteristics. As a result, emissions along the WTT part of the value chain are far more challenging to simplify across the industry.

Emissions across the WTT value chain come from the following processes:[30]

- **Combustion-related emissions (different from downstream combustion):** Emissions resulting from fuel-fired equipment, including fuel use in engines or turbines that provide power to compress gases, pump liquids, and power generators, as well as fuel used for firing heaters and boilers in everything from liquefaction to loading to shipping to regasification.
- **Vented emissions:** Designed releases of methane (CH_4) and/or CO_2, including but not limited to process emissions where vented gas streams are not recovered or rerouted back to the fuel gas system. It also includes operations such as blowdown from compressors or other equipment for maintenance and direct venting of gas used to power equipment. Notably, this category also includes all gas flaring and emergency venting.
- **Fugitive emissions:** Emissions that occur unintentionally and could not reasonably pass through a flare or exhaust stack, chimney, vent, or other functionally equivalent opening. This would include leaks from piping components and other equipment and is often called methane leak or slip.
- **Transportation-related emissions:** Emissions associated with operations of transportation services, including ships, barges, and tank trucks, along with transfers into transmission or distribution pipelines.
- **Nonroutine emissions:** Nonroutine emissions associated with LNG operations are primarily a result of start-up, shutdown, or plant upset.

Each stage of the WTT value chain (upstream production, processing, liquefaction, storage, loading and unloading, shipping, and regasification) has to factor in the emissions from these processes as well as the indirect emissions from the use of imported electricity or heat in the value chain. For example, while loading and unloading LNG cargoes, emissions sources include combustion emissions from power generation facilities providing electricity to a ship's cargo pumps, venting when the ship loading connection is broken, venting when connections to barges or trucks are broken, and fugitive emissions from valves, piping flanges, and fittings.

Difficulties in Accurately Calculating LNG GHG

Given the wide variation in technologies and upstream activities across regions and time, WTT emissions of an LNG cargo can vary widely. Accordingly, custom or measured emissions values for each cargo or respective cargo's value chain (i.e., WTT configuration) would be the preferred reporting method as they would provide market participants and policy makers with more accurate data. This is especially the case when those values are certified by an independent third party, a distinction that will grow in importance due to concerns over greenwashing. In the case of a nascent market like the carbon-neutral LNG market, default or modelled emissions (especially when the higher "estimated emissions" values are used) provide a reasonable starting point, from which, as the trade matures, the market can become more differentiated based on verified, value chain–specific, measured emissions profiles.

To date, though, publicly available emissions data across the entire WTT portion of the LNG value chain, from upstream production to liquefaction, storage, shipping, and regasification, are largely unverified and therefore remain best estimates.

For many countries that supply LNG (e.g., Algeria, Russia, and Nigeria), there is limited verified emissions data available, a dynamic complicated by vast disparities in regional and company practices around key processes that impact emissions, such as flaring, venting, permitted valves, and types of storage tanks or compressors used. A similar issue exists within the United States where practices across natural gas producing basins and producers vary widely. This is further complicated by the fact that it is difficult for natural gas physically delivered at a specific downstream hub, such as Henry Hub or Houston Ship Channel, to be differentiated by upstream value chain and thus emissions profile, though the emergence of instruments such as the MIQ protocol (which aims to improve methane emissions monitoring and abatement by certifying facilities that meet certain performance standards) will be helpful tools in addressing this problem.[31]

Further, while most non-combustion estimates are based off engineering estimates using equipment type and expected leakage rates, those estimates are based on equipment that is expected to be functioning properly. Recent studies have shown that most leaks, particularly of methane, occur when equipment is malfunctioning and therefore result in actual emissions factors being significantly higher than the estimated emission factors,[32] a dynamic that once again highlights the importance of movement toward actual measured emissions factors.

Methane's Magnitude Requires Focus on Total CO_2e

Actual emissions measurements are particularly important because of the GWP of methane, so that even small methane leaks across the value chain have outsized impacts on LNG's final warming potential.[33] Recent upstream studies have shown that there is a wide differential for methane leaked across equipment—e.g., 19 percent of the pneumatic controllers in the US account for 95 percent of emissions from controllers.[34] But while much progress has been made in methane measurement from upstream supply chains in the last eight years, the LNG value chain has been less studied, especially when it comes to the liquefaction plants themselves and LNG shipping.

Although methane detectors may have been installed on a number of liquefaction plants, the data around those emissions has not been disclosed publicly.

For LNG shipping, there are more than 564 ships that vary in age, engine type, size, storage/boil off management, and operator, with each configuration requiring different emissions factors.[35] Further, methane slip during a respective ship's operations can be a significant source of emissions as it can vent stacks and flares. To date, however, specific measurements have not been performed to determine the real extent of methane leaks across the LNG shipping fleet. A pilot study led by Queen Mary University London was completed in May, but the results have not yet been released.[36] In fact, without verifiable data available, the International Council on Clean Transportation has taken the position that there is no climate benefit from using LNG as a bunker fuel due to methane slip.[37]

Given these realities, if the full extent of greenhouse gas emissions produced by an LNG cargo is to be addressed, it is essential that the LNG industry focuses on CO_2e neutrality (versus just carbon dioxide neutrality), especially as the oil and gas industry faces increased scrutiny over methane emissions, which recent reports show to be significantly higher than reported in many parts of the world.[38]

As the International Energy Agency, along with numerous satellite and ground-based and aerial projects, begin providing more up-to-date and accurate data on just what methane leakage rates are along the natural gas value chain, it is likely that estimates of CO_2e emissions for an LNG cargo will increase.[39] However, better monitoring and repair practices along with targeted policies for methane reduction, such as those under consideration in the EU[40] and expected from the Biden administration, should lead to further industry action to systematically address and reduce methane emissions.[41]

Approximating LNG Emission with BEIS

In the absence of a standard for LNG WTT emissions, numerous industry groups and marketers are using guidance from the UK Department of Business, Energy, and Industrial Strategy (BEIS); these are used interchangeably with the standards released by the UK Department for Environment, Food, and Rural Affairs and from here on out will be referred to as BEIS.[42] They include separate WTT estimates for all fuels, defined as the "emissions associated with extraction, refining, and transportation of the raw fuel sources to an organization's site (or asset), prior to combustion." BEIS estimates, which are based on a study that follows the ISO 15050 protocol,[43] find that WTT emissions for LNG amount to 0.88 metric tons of CO_2e per metric ton of LNG on average, compared to an estimated 0.33 metric tons of CO_2e per metric ton of natural gas sourced via pipeline into the United Kingdom.[44]

Along with standard assumptions around downstream combustion (2.76 metric tons of CO_2e per metric ton of LNG), BEIS estimates imply that one metric ton of LNG has life cycle emissions of around 3.64 metric tons of CO_2e (0.88 WTT emissions plus 2.76 downstream combustion). As such, a standard-sized 70,000 metric ton cargo of LNG would have life cycle emissions of approximately 250,000 metric tons (0.25 million metric tons[45]) of CO_2e. Accordingly, these BEIS estimates imply that the emissions from liquefaction to regasification or WTT emissions (thus excluding those from final combustion) are on average around a quarter of total LNG life cycle emissions.

Without a generally accepted industry-wide assumption around LNG emissions, the UK BEIS WTT emissions estimates can act as a transparent and potentially useful reference point in the development of carbon-neutral LNG trade. This has been recognized by the LNG industry, with corporate statements indicating both Shell and Total use UK BEIS life cycle emissions estimates when calculating the GHG load requiring mitigation in their respective carbon-neutral LNG trades.[46] That said, the UK BEIS number is a general estimate and not value chain specific. That is a critical distinction due to the extreme differences in value chain specific emissions figures. For example, a study by CSIRO Energy concludes that WTT emissions from Origin Energy's coal seam gas-fed LNG export project in Queensland, Australia, are roughly 0.73 metric tons of CO_2e per metric ton of LNG, roughly 16 percent lower than the BEIS WTT estimates.[47]

These kinds of emissions estimate disparities underline the importance of specific, verifiable value chain emissions measurements. In a scenario where estimates are provided that are below other recognized industry values, verification becomes essential to mitigate risk of greenwashing. Further, by injecting transparency into what is currently an opaque part of the LNG industry, publicly verified, value chain-specific measurements would also catalyze efforts to reduce value chain GHG intensity—a metric that, in time, will become an integral part of a respective LNG supply chain's competitiveness.

Integrating Emissions into LNG Trade

Once established, either through custom measurement or standard adoption, GHG emissions can broadly be integrated into LNG trade through two approaches: the "offset approach" and the "attribute approach." So far, trades in this space have generally focused on the offset approach, given the relative ease with which offsets are procured and retired, versus the time required to implement carbon intensity reductions across the value chain in the attribute approach (described below). In the offset approach, emissions associated with various scopes of the LNG value chain have been offset through procurement and retirement of voluntary carbon offsets or credits.[48]

In comparison to the offset approach, in the attribute approach the focus shifts to the carbon intensity of a specific LNG value chain; that is, the GHG emissions associated with an LNG cargo's upstream, midstream, and consumption configuration. In this approach, the carbon, or more accurately GHG, intensity, can then act as an attribute of a specific cargo, akin to how attributes such as sulfur content and API gravity in a specific crude oil can impact the value of that crude.[49] In the context of the attribute approach to carbon-neutral commodity trade, producers with a lower carbon intensity will find themselves advantaged on a price basis, which can incentivize suppliers to reduce the carbon footprint of their entire value chain. Similarly, buyers would seek out supply with the lowest carbon intensity to reduce both potential cost as well as the GHG footprint of their own energy supply. While the specific costs of carbon intensity reduction measures along the LNG chain are outside the scope of this commentary, they will be the subject of further research by the authors.

In practice these two approaches are not mutually exclusive. Many LNG project developers and operators are already engaged in efforts to reduce GHG intensity across their respective value chains (some of these efforts are discussed further below). These efforts have the potential to increase the competitiveness of a specific LNG value chain from the attribute perspective through the reduction of the value chain's carbon, or GHG, intensity. From the perspective of the offset approach, these efforts will also reduce the amount of emissions requiring mitigation through procurement of carbon credits, in turn providing another potential boost to the competitiveness of that supply.[50] This is especially important, given carbon credits themselves do not make a specific LNG cargo "clean" on their own; instead, they look to mitigate the overall GHG load in the atmosphere. Therefore, the offset approach should be viewed as a bridge to ensure carbon neutrality as GHG emissions reductions are implemented along the value chain (i.e., upstream flaring mitigation measures, methane slip reduction, carbon capture, and sequestration at liquefaction plants and at the site of combustion, such as power plants).

Carbon Credits in LNG Trade

The function of a carbon credit is to represent a verified reduction in GHG emissions in one location. This credit then acts as an exchangeable instrument that can be used to offset emissions in another location on behalf of the credit's purchaser.[51] In effect, these credits, or offsets, represent an accounting mechanism through which a business, a government, or an individual pays someone else to cut or remove a given quantity of GHGs from the atmosphere. These reductions represent avoided or sequestered emissions that are additional to business-as-usual operations. Thus, in effect, an LNG marketer or consumer considers an LNG cargo to be carbon-free or carbon-neutral when those credits, and their respective emissions reductions, are taken into account and subsequently permanently retired, meaning their transaction has been recorded in publicly accessible emission registries and they cannot be used again.

There are considerable and warranted concerns that the use of carbon offsets can result in greenwashing, meaning claims around environmental credentials, upon inspection, are not verifiable. This is especially relevant if the carbon credits utilized to offset GHG emissions are generated from low-quality projects—i.e., a project wherein the generated emission reductions are in question.[52] In a scenario where low-quality credits are employed, a commodity claiming to be carbon-neutral, such as carbon-neutral LNG, may not fully, if at all, neutralize its emissions load. While ISO 14021 outlines the necessary steps to denote a commodity or product carbon-neutral, the issue of carbon credit quality is one that the industry must address if the offsets are to be taken seriously. Due to these concerns, it is critical that only high-quality offsets are utilized to ensure the carbon-neutral credentials remain intact. High-quality offsets are generally those that adhere to principles around measurement, permanence, additionality, independent verification, and uniqueness (not claimed by another entity).[53] While there is currently no single internationally recognized body who regulates, oversees, or standardizes offset issuance or verification, there are generally accepted principles that the most credible carbon-crediting entities follow.[54]

There are numerous well-established programs which issue carbon credits across both the government and nonprofit sectors. The most notable public sector entities include the United

Nations Clean Development Mechanism (UN CDM) as well as several national and local government-run offset programs across China, Japan, and Korea; the provinces of Alberta and British Columbia in Canada; and California. Across the private, nonprofit space, well-known programs, or registries, include but are not limited to Gold Standard, Verra (formally Verified Carbon Standard), and the American Carbon Registry (ACR).[55]

Most of these programs follow a similar process for generating offsets, which starts with a specific project applying to generate offsets in compliance with a respective program's methodology. Projects vary significantly, but generally can include things like afforestation, renewable energy development, methane capture, and energy efficiency initiatives, such as cookstove deployment.[56] Each project will have its own specific methodology to adhere to that outlines the necessary rules in calculating what emissions are avoided. For example, in cookstove deployment, abated emissions would need to be estimated for the replacement of traditional cooking methods such as burning wood or charcoal with more efficient technology like low-smoke stoves, which reduce the need to burn firewood, protecting local forests and reducing carbon emissions.

When these requirements are met and the project enters operation, mitigated emissions are regularly tracked and independently verified by a specialized third-party contractor. It is only after the mitigated emissions are tracked and verified that the program will issue offsets equal to the avoided GHG emissions.[57]

These offsets are then sold to buyers who have a range of incentives, including compliance with regulated emissions reduction programs such as the California/Western Climate Initiative or the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) program, managed by the International Civil Aviation Organization. Along with procurement of credits for compliance reasons, entities may buy carbon offsets to meet their own internal emissions reduction or environmental targets. This second tranche of offset procurement is considered voluntary. The use of carbon credits in carbon-neutral LNG thus far has fallen into this second category, as the offsets are not intended for use in any regulatory requirement.[58]

Projects loosely fall into three categories:

1. Emission reduction projects include those focused on methane collection, energy efficiency, and destruction of potent industrial gases (like HFCs/PFCs).
2. Emission avoidance projects include renewable energy as well as farming/soil management.
3. Emission removal projects include land use and forestry projects (afforestation and reforestation) as well as carbon capture.

Offsets from the first two categories tend to have somewhat lower costs (though energy efficiency projects are a notable exception). Indeed, there are some concerns as to whether renewable energy projects in a number of regions still even qualify as additional, given the improved cost competitiveness of these technologies.[59] This has led to stringent definitions for what projects do qualify for crediting mechanisms. For example, Gold Standard now only recognizes large scale renewable projects in "least developed countries" or where the penetration of the proposed renewable technology is less than 5 percent of the grid.[60]

Forestry-based credits have become increasingly popular, with the World Bank estimating forestry-based credits made up 42 percent of credits issued between 2015 and 2019.[61] The World Bank postulates that this is driven by co-benefits and cost effectiveness of nature-based carbon emissions credit generation, given the ability for a single project to generate credits over a prolonged period of time.[62] Co-benefits are terms attached to carbon credits providing evidence of meeting some of the 17 Sustainable Development Goals defined by the United Nations General Assembly in 2015, which include gender equality, clean water, and biodiversity.

It is these nature-based credits that have been the most widely used in the transparently completed carbon-neutral LNG trades thus far, with Shell's transactions coming from the company's portfolio of nature-based offsets from the Verra registry and other credible standards.[63]

Carbon Credit Cost versus Carbon Intensity

Carbon credits are priced in an extremely broad range, depending on crediting project, credit quality, and crediting mechanism (voluntary versus compliance-based). For example, certified emissions reductions from the UN CDM were priced as low as $0.20/metric ton over the last two years,[64] while carbon credits compliant with California's Western Climate Initiative recently cleared around $18/metric ton of CO_2e,[65] and carbon credits in the EU ETS recently breached the $45/metric ton level.[66]

When it comes to voluntary carbon offsets, the price of the offset will be impacted by a number of factors including the quality of the offset, whether the offset came from a party's inventory or is newly purchased, and other transaction costs, including verification and registry fees. The first of these factors is the most important, with carbon offset quality a key determiner of price and dependent on the project type, the crediting mechanism, and any co-benefits the project generated.

The price for voluntary carbon credits was estimated between $1 and $13/metric ton of CO_2e in 2019; the latest period transparent public data is available.[67] Credits generated from renewable projects sit on the lower end of this range while credits from forestry projects sit on the higher end. The average price of forestry-based credits, which have been frequently used in LNG trade, was $4.30/metric ton of CO_2e in 2019, while credits based on afforestation and reforestation projects, which are a subset of forestry credits, went for a premium, averaging $7.69/metric ton of CO_2e.[68]

Real-time pricing for secondary trade in voluntary carbon credits has been relatively opaque, but efforts to bring transparency to the market are gaining momentum, with S&P Global Platts recently launching a price assessment for voluntary carbon credits, the Carbon Emissions Credit, or CEC, that meets the specific eligibility requirements for use in the CORSIA program.[69] Since the launch in December 2020, these credits have been assessed around $1.70/metric ton of CO_2e.[70]

Considering a forestry-based carbon credit range of \$4 to \$7/metric ton of CO_2e, a standard 70,000–metric ton cargo of LNG would incur a "green premium" associated with offsetting its 0.25 million metric tons of CO_2e of up to \$1.75 million per cargo, or around \$0.40–0.55/MMBtu, based on aforementioned assumptions for final combustion emissions and BEIS estimates for WTT emissions. For context, the Japan Korea Marker, the benchmark for spot traded LNG delivered into Northeast Asia, has settled at an average of \$6.42/MMBtu over the last five years, implying that the "green premium" associated with a carbon-neutral LNG cargo would add roughly 6 to 9 percent to the overall LNG price.[71]

While pricing around completed carbon-neutral LNG trades has remained confidential, market indications suggest the "green premium" associated with these trades was somewhere in the range of \$0.50/MMBtu, implying a carbon price of somewhere in the range of \$6 to \$7/metric ton of CO_2e, largely in line with the aforementioned scenario.[72] It is important to remember that final costs may deviate from this price for a number of reasons, including the administrative costs associated with registering or retiring the offsets, which may be incremental to the cost of the offset itself, or due to the fact that the offsets already existed in a marketer's portfolio of carbon offsets, thus implying an underlying value not directly related to freely traded credits.

Although this range may currently represent relatively minimal costs compared to the underlying value of the commodity, with large swaths of the commodity industry looking to lean on voluntary carbon credits to sustain production, voluntary carbon prices could face significant upward pressure in the coming decade. This would put upward pressure on the "green premium" associated with carbon-neutral LNG. For example, if one were to utilize a carbon price of \$50 to \$100/metric ton of CO_2e, in line with what the High-Level Commission on Carbon Prices estimates is the 2030 carbon price required to cost-effectively reduce emissions, in line with the temperature goals of the Paris Agreement, the "green premium" rises to around \$3.50 to \$7/MMBtu.[73]

A ramp-up in the cost of voluntary carbon credits to this range would represent a significant headwind to the adoption of carbon-neutral LNG by challenging the affordability that LNG offers during this transition period. In this scenario, core markets in Asia, which until now have acted as the bedrock for LNG demand growth, would find it difficult to economically rationalize further natural gas penetration. More specifically, in a world where the cost of carbon neutrality becomes a core component of the fuels mix, LNG could find itself relatively disadvantaged.

For example, while an influential report by the US Department of Energy's National Energy Technology Laboratory finds that LNG imported into China and used for power generation has a lower life cycle emissions rate than using locally produced coal, the latter's emissions are overwhelmingly concentrated (98 percent) at the point of combustion.[74] The implication here is, if emissions in China were to become regulated at prices higher than the cost of retrofitting a coal plant with carbon capture technology, theoretically a domestic power producer could find more economic incentives to generate using coal with carbon capture and storage (CCS) than offset the life cycle emissions of an LNG cargo. This scenario is critical for consideration in Japanese and Korean markets, where LNG demand is driven by gas use in the power sector. While there are many variables here, the underlying principle highlights the importance of reducing the carbon intensity across LNG value chains, with these reductions in turn minimizing the amount of GHG emissions requiring offset and thus reducing the overall cost of utilizing natural gas in an emissions-regulated environment.

Structure of Trade

Financial responsibility for the incremental "green premium" associated with carbon-neutral LNG supply remains a critical unanswered question, with the potential for the premium to be split up among the trade's participants in numerous ways, ranging from the buyer paying to offset the entire life cycle emissions to the buyer's just covering those from final consumption. That said, key fundamentals and market developments indicate a potential financial responsibility matrix. Publicly available estimates indicate that somewhere between 60 percent and 80 percent of total life cycle GHG emissions associated with LNG utilized for power generation are emitted at the point of combustion, with the remainder released during WTT operations.[75] Given this dispersion, from the point of LNG supplier (seller), it would make sense to take responsibility for WTT emissions, given this is the portion they have direct control over (upstream production through delivery). This portion of the emissions aligns with the respective suppliers' scope 1 and scope 2 emissions.[76] It is thus not surprising that major LNG suppliers globally, including Shell and Total, have committed to reaching net-zero emissions for all their scope 1 and 2 across their respective global operations by 2050 at the latest.[77]

If markets were to develop along these lines, it is critical to ensure that, when denoting a cargo as carbon-neutral, coverage of emissions across the value chain are fully accounted and mitigated, albeit by different parties. In a scenario wherein WTT emissions are covered by the supplier at the point of transaction but end use remains unmitigated, the bulk of the LNG's life cycle's emissions (up to 80 percent) would remain additive to the global GHG concentration. This, in turn, threatens to undermine the legitimacy of denoting the transaction as carbon-neutral and could prove counterproductive to LNG's role in the energy transition.

The focus on WTT emissions has manifested in two long-term LNG procurement contracts signed by Pavilion for supply from Qatar Petroleum Trading and Chevron, respectively, with both contracts dictating that each cargo delivered under the agreement would come with a statement quantifying WTT GHG emissions.[78] Similarly, Cheniere Energy, the largest LNG exporter in the United States, recently committed to providing all its customers with WTT emissions data for each LNG cargo it produces.[79] While there is no current obligation to offset these emissions, these developments highlight the potential for buyers to request an emissions reporting, verification, and mitigation component alongside traditional contractual terms as part of future LNG medium- and long-term sales and purchase agreements. In this scenario, merchant players, which mostly do not own upstream assets, could face difficulty if they do not procure supplies with reported and verified emissions. Conversely, fully integrated players that can measure and control emissions across their entire value chain may find themselves relatively advantaged.

Collectively, these factors point to a structure wherein suppliers are taking responsibility for WTT emissions, while purchasers are financially responsible for emissions associated with the final use of the commodity. In this scenario, it is conceivable that the supplier (i.e., seller) would offset their emissions, thus covering their own scope 1 and 2 emissions, while the buyer (i.e., importer) could conduct a similar mitigation measure, be it through a national-level carbon tax or procuring carbon credits. In this trade structure, the seller would in essence be delivering a cargo that has had all its associated emissions through the point of delivery already mitigated through the retirement of offsets. The buyers/importer would be in a position where they could then procure offsets for the final use of that LNG. Those offsets could be procured directly from the seller, from another market participant or from a carbon registry. In many cases, this cost of mitigating the emissions associated with final consumption will then be passed on to the end user through higher energy prices.

If it were to evolve into a market standard that the seller of the LNG cargo also assisted in the procurement of offsets for final consumption on behalf of the importer, it would provide greater competitive advantage to LNG marketers (sellers) with in-house carbon trading divisions. It would be these marketers that would be able to lean on their existing carbon trading expertise and competitively priced offsets to provide incremental services to, and thus revenue streams from, LNG buyers.

For suppliers to remain competitive in this environment, carbon intensity reductions will take center stage. Reducing GHG emissions across the LNG value chain can take many forms, including methane slip monitoring and mitigation, reducing forced methane venting and flaring, implementation of renewable power generation to feed power-intensive liquefaction processes, and use of carbon capture and sequestration or utilization across upstream operations.[80] When considering these technological changes, there exists an economic trade-off, wherein these emission-reducing enhancements will impact the development costs of an LNG project but could simultaneously increase the competitiveness of that respective project's production. Accordingly, in the development of new carbon-neutral LNG projects, or upgrading of existing projects, the key question producers must consider is whether the GHG intensity reductions can be accomplished at a price lower than that paid for a commensurate amount of carbon credits.[81]

Efforts to reduce the carbon intensity of LNG production are already gaining significant momentum. For example, in its efforts to reach a final investment decision, LNG project developer NextDecade has stated it is exploring options to make LNG exports from its proposed Brownsville, Texas, Rio Grande export facility carbon-neutral, mainly through the use of carbon capture utilization and storage.[82] Shell's LNG Canada will use natural gas that's produced and compressed using renewable electricity from the BC Hydro grid; energy-efficient gas turbines and the latest methane mitigation technologies will help reach the low-emissions standards.[83] In the Middle East, Qatar Petroleum is including 2.1 million metric tons per annum of CO_2 capture capacity into its ongoing 33 million metric ton per annum LNG North Field East expansion, with stated aims of expanding this to 7 million metric tons per annum in the coming decade, larger than Qatar Petroleum's reported scope 1 and 2 emissions in 2018 (4.8 million metric tons of CO_2e).[84] These projects signal a trend wherein projects start to actively incorporate emissions reductions components into project planning, with the consequential reduction in emissions intensity becoming a key marketable attribute of their LNG. While the specific costs of carbon intensity reduction measures along the LNG chain are outside the scope of this paper, they will be the subject of further research by the authors.

Conclusions and Recommendations

Carbon-neutral LNG may constitute a tiny share of the LNG market now, but the trade holds the potential to take up a larger, and more critical, role in the commodity's trade over the next decade. Many of the largest LNG importers (i.e., Japan, South Korea, Spain, France, and the UK) have pledged to become carbon-neutral by 2050, and by 2060 in China's case,[85] with India being a notable exception. It is conceivable that governments will start imposing stricter limits on imports of GHG intensive goods, such as energy products. In this scenario, sellers may find that carbon-neutral LNG becomes not just a premium product but a required offering for participating in key markets.

A clearer picture of the emissions profile of LNG will also emerge over the next few years as more data from independent sources becomes available along the value chain. This is particularly important when it comes to methane leaks as well as currently understudied areas such as liquefaction and shipping. The result will likely be an upward revision of the WTT emissions from current estimates, and that, in turn, will put more emphasis on carbon intensity reductions across the LNG value chain by producers.

Industry standards around what emissions, emissions ratios, and accounting methodologies are being used to determine the overall GHG load of LNG is a necessary component in the development of a verifiable and trusted carbon-neutral LNG market. Most importantly, if done transparently and uniformly, it will help alleviate fears of greenwashing—that cargoes are being marketed as environmentally friendly when they are not, either due to poor carbon credit quality or erroneous GHG measurement and accounting.

The following developments would help foster a robust and trusted carbon-neutral LNG market:

- **An independent third-party organization given a mandate to create the necessary global standards for accounting and reporting of LNG emissions and offsets.** The International Group of Liquified Natural Gas Importers (GIIGNL) is currently working on such a framework for reporting and verification to be released ahead of COP 26 meeting in October with the hope that it will be adopted industry-wide.[86]

- **Buyers and sellers must disclose the cost (or green) premium associated with these trades.** Keeping such data confidential may be beneficial to the parties involved, but it prevents the market from evaluating necessary data points, which could help spur future deals. This includes the cost of offsetting emissions from LNG cargoes or information on who bears what portion of the associated costs.

- **Not having a full picture of the WTT emissions of LNG should not preclude the growth of the carbon-neutral LNG market.** It is important for both participants and policy makers to note that measurements of downstream emissions from the combustion of natural gas have been robust, and thus there is relative certainty when it comes to the end use estimate of 2.76 metric tons of CO_2e per metric ton of LNG, which accounts for 60–80 percent of the total life cycle emissions of the LNG cargo. WTT emissions will also become more accurate as more customized data and measurements become available in the coming years.

- **The UK Department of Business, Energy, and Industrial Strategy (BEIS) standard values have been used in many carbon-neutral LNG trades to date and offer a good option as a starting point.**[87] The industry can lay a solid foundation by coalescing around specific standards with the understanding that inputs will be adjusted as better measurements become available. BEIS standard values are updated yearly and thus while WTT emissions for LNG are currently calculated to average 0.88 metric tons of CO_2e per ton of LNG, should that number be revised higher, the industry should update calculations to reflect the most recent BEIS standard value available in the same way industry emissions factors should come from the latest IPCC assessment report.[88]

- **As the market evolves over the next few years, an ISO-based framework for LNG value chain GHG accounting could be utilized as a standard, with a preference for measured, over modeled/default, emissions factors where possible.** Basing GHG measurement to a verifiable, internationally recognized accounting standard will alleviate concerns around greenwashing, or undercounting, GHG emissions across the LNG value chain. Further, transparent accounting will give credit to elements along the value chain with lower carbon intensity (i.e., if an LNG vessel has a low methane slip engine) and also provide an incentive for players to lower their carbon intensity.

- **A natural division of cost burden would be for sellers to bear responsibility for the costs of offsetting or reducing WTT emissions while buyers are responsible for the downstream combustion emissions.** This would enable the LNG market to maintain a critical characteristic—destination flexibility—versus having to make each carbon-neutral LNG deal a point-to-point trade based on the specific emissions profile of the end user. Downstream combustion emissions must still be mitigated either through the purchase of offsets by the buyer or through mitigation of the emissions of the final combustion component such as with CCS on a power plant. This is critical because, in a scenario wherein WTT emissions are covered by the supplier at the point of delivery, but end use remains unmitigated, the vast majority of the LNG's life cycle's emissions would not be covered. This would undermine the legitimacy of denoting the transaction as carbon-neutral.

- **Third-party verification is required to ensure that offsets meet the standard of additionality and that emissions reductions are appropriately estimated, permanent, and not double-counted. Audits by this third party should occur on a yearly basis.** The offset approach can be expected to remain a critical mechanism for achieving carbon-neutral LNG, although its use should decrease as companies increase focus on emissions reductions and the costs of direct mitigation become economic compared to offsets. The creation of a carbon offset index based on a voluntary carbon market could provide a helpful benchmark for long-term contract pricing, especially if sellers provide the service of offsetting buyers' direct emissions. In time, this carbon offset index could be included in long-term LNG contracting.

Should voluntary offset prices rise to a range of $50–100/metric ton by 2030, it will provide an even greater incentive for both buyers and sellers to adopt the attribute approach of reducing carbon intensity along the value chain (e.g., venting and flaring reductions for producers and natural gas combustion with CCS for buyers). This practice will allow for GHG mitigation at a lower dollar per ton of CO_2e, in turn reducing the cost of mitigating the overall GHG load of a given supply chain and thus relatively reducing dependency on the carbon offset market.

Policy makers both in LNG producing and consuming countries can have an active role in the development of a carbon-neutral LNG market by:

- **Supporting research and development of emissions monitoring along the LNG value chain and by pushing for disclosure of emissions calculations and offsets**
- **Creating tax incentives such as production tax credits or investment tax credits for sellers producing carbon-neutral LNG**
- **Offering tax incentives to buyers of low carbon LNG or setting low carbon fuel standards within their countries**
- **Applying carbon intensity requirements on energy imports to catalyze a focus on reducing carbon intensity by suppliers**

The carbon-neutral LNG market is in its infancy, and its success will likely require a foundation for globally understood and adopted standards using the best practices available for emissions estimates and offsets. As long as the industry is willing to be adaptive to benchmarks as they are updated and are held to a high level of transparency, the market should improve in both accuracy and efficiency over time.

Such a trajectory could benefit from companies communicating openly with both investors and policy makers about how carbon-neutral LNG will fit into their overall net-zero plans, inclusive of how they address the offset or attribute approaches to carbon-neutral commodity trading.

Notes

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