RystadEnergy

WHITEPAPER

Well-to-tank emissions assessment 2025

GHG emissions study on the use of LNG as a marine fuel

Emissions Research – in partnership with SEA LNG

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Table of contents

GHG emissions study on the use of LNG as a marine fuel

Purpose

Rystad Energy's LNG well-to-tank emissions assessment studies the greenhouse gas emissions from the use of liquefied natural gas (LNG) as a marine fuel, in the year of 2024.

The study assesses the emissions originating from the five key lifecycle stages; upstream, transportation & processing, liquefaction, shipping and distribution & bunkering operations. Alongside the relative contribution of methane and carbon dioxide from each stage, the study summarises the well-to-tank emissions on both global and regional levels.

The importance of fully understanding lifecycle emissions becomes ever more important when taking a forward-looking view of the upcoming LNG-fuelled vessel orderbook, planned industry changes and the expected growth in the global LNG trade. By better understanding the well-to-tank (WtT) emissions of a given fuel source, Rystad Energy aims, in collaboration with SEA LNG, to provide insights for the shipping industry (and beyond) to better understand the potential impacts of fuel selection within the marine industry.

Methodology

The analysis presented in the report is based on Rystad Energy's GasEmissionsTracker database, which provides the emissions data associated with global gas and LNG trade from well-to-market. The GasEmissionsTracker is a bottom-up asset level database, grounded in granular, site-specific data which can be aggregated up from individual value chains/cargoes up to country, regional or global overviews.

The study is based upon the estimated individual value chain emissions intensity of each LNG cargo used for bunkering purposes. With each of these individual value chains volume/energy-weighted to calculate the aggregated views on the regional or global level.

Rystad Energy's methodology ties specific feed gas upstream assets to liquefaction facilities, rather than using regional or basin level-averages. This allows for greater accuracy when calculating the emissions intensity of feed gas, especially when utilising satellite detected methane plume analysis and reported asset level data.

Furthermore, Rystad's approach is very specific to LNG directly used for loading into the 'tank' of LNG fuelled vessel, rather than global averages for LNG as a whole.

The asset-by-asset emissions and production inventories for the global gas value chain, in addition to WtT intensities tied directly to bunkering volumes, allows Rystad Energy to provide a more representative view of LNG as a marine fuel, when compared to regional or industry averages.

The study assesses the relative impact of methane (CH_4) and carbon dioxide (CO_2). Nitrous oxide (N_2O) is not included in Rystad Energy's assessment of WtT emissions due to its estimated impact to be less than 1% of overall greenhouse gas emissions, smaller than the uncertainty in CO_2 or CH_4. Local pollutants such as nitrogen oxides (NOx), sulfur dioxides (SOx) and particulates have not been considered in this assessment, which is assessed in terms of the global warming potential of LNG as a marine fuel, rather than its impact on local environments.

Source: Rystad Energy GasEmissionsTracker

Background

In 2024, around 5% of the marine sector was powered by LNG, with the remainder powered by conventional marine fuels, such as heavy fuel oil and diesel. LNG's share of the market expected to grow further as the LNG carrier fleet expands, in addition to growth in LNG or LNG dual-fuelled vessels, which account for around 20% of the vessel orderbook.

The purpose of the Rystad Energy's well-to-tank greenhouse gas emissions assessment is to estimate value chain emissions intensity for LNG's use as a marine fuel, from initial extraction at the 'well' through to final loading into the 'tank' of the LNG-fuelled vessel.

Results

Key findings from the study highlight that for the year of 2024:

- The global well-to-tank emissions intensity for LNG used for bunkering fuel are estimated to be 13.9 g CO_2e/MJ lower heating value (LHV) in the calendar year 2024.
- The following global emissions intensities can be attributed to the five key lifecycle stages:
    - Upstream gas production was responsible for 4.2g CO_2e/MJ.
    - Transportation and processing was responsible for 1.3 g CO_2e/MJ.
    - Liquefaction was responsible for 5.9 g CO_2e/MJ.
    - Shipping was responsible for 1.8 g CO_2e/MJ.
    - Distribution & bunkering operations were responsible for 0.7 g CO_2e/MJ.
- Carbon dioxide dominates global well-to-tank emissions, responsible for 84% of emissions. Carbon dioxide emissions were most prevalent in the liquefaction stage, responsible for 99% of the stage's 5.9 g CO_2e/MJ.
- Methane emissions globally were responsible for 16% of total WtT emissions, equivalent to 2.2 g CO_2e/MJ. This methane release rate is equal to a methane intensity* of 0.34%.
- Global methane emissions were most prevalent in upstream gas production lifecycle stage, responsible for 38% of total emissions from that stage.
- There was significant variation in regional emissions intensities for bunkered LNG ranging from 9.3 to 15.9 g CO_2e/MJ in 2024.
- Europe, the region with the largest volumes of bunkered LNG in 2024, had a total WtT emissions intensity of 12.9 g CO_2e/MJ. Methane emissions were responsible for 2.4 g CO_2e/MJ of the regions total.
- Asia, North America and South America had regional WtT emissions intensities of 15.9, 12.8 and 14.4 g CO_2e/MJ respectively.
- The regions Russia, Oceania, Africa and the Middle East had minimal, or zero, volumes of LNG bunkering in 2024.

*Methane intensity defined as the ratio of methane emissions to that of gas sent to market.
Source: Rystad Energy GasEmissionsTracker

Conclusions

The Rystad Energy methodology, which utilises asset specific emissions inventories and direct connections between production sites and bunkered LNG volumes, provides a more representative and accurate WtT emissions estimates than industry/regional average approaches.

Well-to-tank emissions are dominated by liquefaction and upstream emissions, with these two stages combined contributing 73% of total emissions for bunkered LNG. Consequently, these two stages should be the focus for most future decarbonisation efforts. From the upstream perspective methane mitigation is best poised to deliver the greatest emissions reduction benefits, with methane contributing 38% of upstream emissions. Improvements in liquefaction emissions intensity has been observed over the past years, with the likes of newer technologically advanced plants and growth in electrification of liquefaction facilities.

The variation of WtT intensity from different exporting regions is significant, highlighting the impact that feed gas, liquefaction technology and shipping can all have on WtT emissions. Regional differences have been shown to be large as 6.6 g CO_2e/MJ, and the variation between individual cargoes is greater still. Thus, indicating that a single global average emissions overview of fuels is not always reflective of the industry and could potentially have negative consequences for the further decarbonisation of LNG as a marine fuel.

Another key characteristic observed was the impact of bunkering location. Globally LNG bunkering is most prevalent in Europe and in Asia, with these two regions dominating more than 80% of total volume. Volumes bunkered in other regions are marginal in comparison. Both Europe and Asia are significant importers of LNG with limited volumes of domestically produced LNG, consequently bunkered volumes incur additional emissions from shipping LNG from the traditional producing regions. LNG exporters like the US, Russia, Oceania and Africa have the potential to establish low emission LNG bunkering hubs that can be utilised for vessel fuel – as fuel can be used without long distance shipping.

WtT emissions intensity of regions such as Russia, Oceania, Africa and the Middle East, with minimal bunkering volumes, can show skewed results, that are not truly representative of the all LNG entering the given region. This is due to the volumetric dominance of a small number of cargoes used for specific LNG fuelling operations.

The number of stages in each of the value chains can vary significantly, depending on where, and at what point in the value chain, bunkering takes place. Loading fuel into an LNG fuelled vessel directly at the point of production, as is the case for LNG carriers, can significantly reduce overall well-to-tank emissions by around 2.5 g CO2e/MJ.

Source: Rystad Energy GasEmissionsTracker

Marine sector expected to undergo a transition

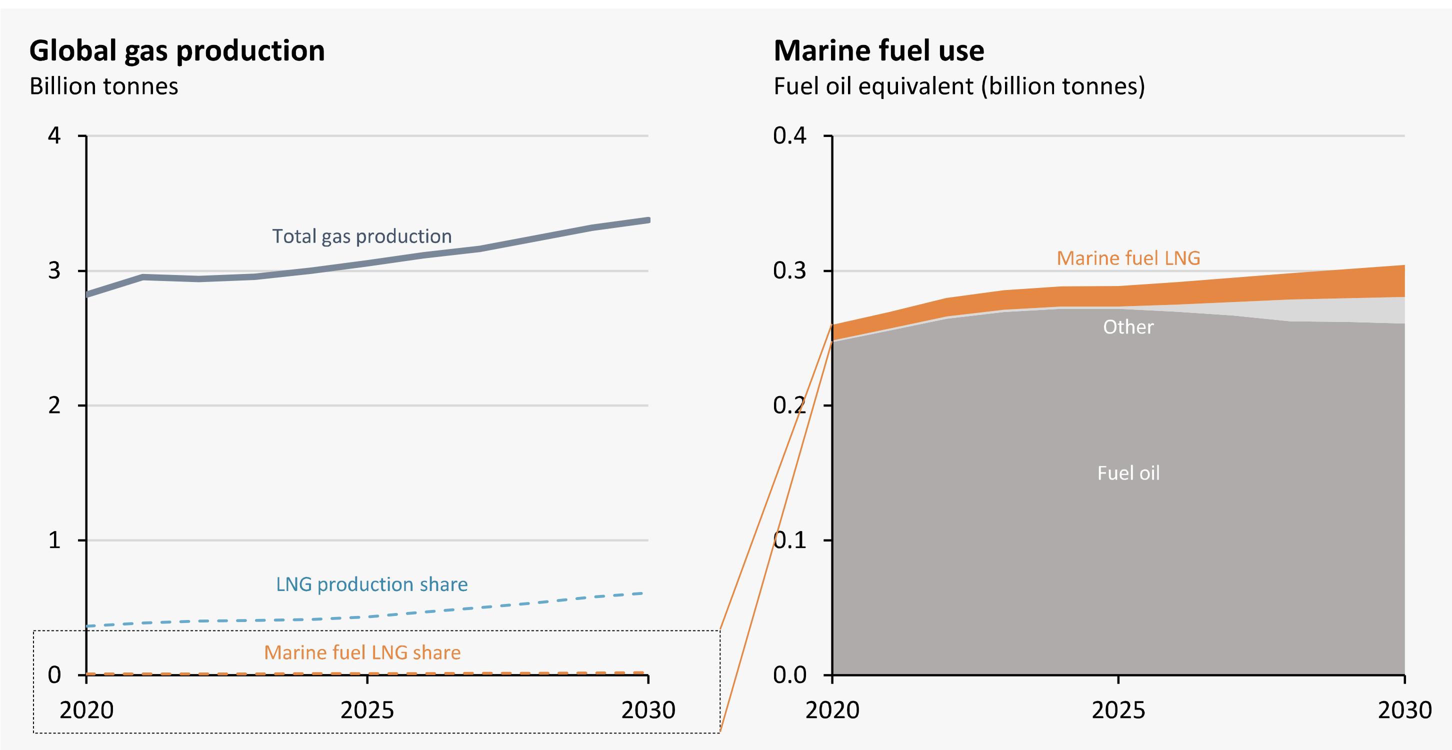
Background

Global natural gas production reached highs of 3 billion tonnes of gas in 2024, with growth expected to continue climbing in the coming years. Of 2024's produced volumes, more than 0.4 billion tonnes was transported as liquefied natural gas (LNG) representing around 14% of total gas production. This share is expected to rise to over the coming years as a tranche of upcoming global LNG projects come online.

The marine sector is expected to undergo a transition away from the use of conventional marine fuels, such as heavy fuel oils and diesel, to alternative lower carbon fuels that include fossil LNG. Around 95% of the marine sector in 2024 was powered by conventional marine fuels, with the remainder mostly fuelled by LNG. Rystad Energy analysis shows that vessel orderbook is sitting at over 1000 LNG or LNG dual-fuelled vessels, representing 20% of the total vessel orderbook.

LNG has emerged as the front-runner among alternative shipping fuels as the maritime industry seeks to cut emissions. With the growth in LNG, accurate estimation of emissions intensity for LNG's use as a marine fuel, from initial extraction at the 'well' through to final loading into the 'tank' of the LNG-fuelled vessel, becomes ever more significant.

Methane and carbon emissions can vary greatly between different stages in the value chain — and between different value chains globally — consequently, the WtT GHG emissions intensity default for LNG is a critical parameter of using LNG as a marine fuel.



Source: Rystad Energy GasEmissionsTracker; Rystad Energy Shipping Solution

Accurately estimating the entire WtT emissions of LNG, from the 'well' to the 'tank' of a marine vessel, is vital to understanding the decarbonisation potential of LNG compared to conventional marine fuels. To this end, Rystad Energy has laid out the following goals for the current assessment.

Goal of study

The goal of Rystad Energy's well-to-tank greenhouse gas emissions study, in collaboration with SEA LNG, is to estimate the value chain emissions intensity for LNG as a marine fuel, from initial extraction at the 'well' of an upstream asset through to final loading into the 'tank' of the LNG-fuelled vessel.

The study aims to quantify the following points:

1. The global average well-to-tank emissions intensity for bunkered LNG in the year 2024.
2. Regional variation in well-to-tank emissions intensity for LNG in the year 2024, covering:
    - I. North America
    - II. South America
    - III. Europe
    - IV. Middle East
    - V. Africa
    - VI. Russia
    - VII. Asia
3. Provide emissions intensity breakdowns into the following lifecycle stages:
    - I. Upstream
    - II. Transport and processing
    - III. Liquefaction
    - IV. Shipping
    - V. LNG terminal distribution and bunkering operations
4. For each of the above listed stages, provide overviews of the relative impact from carbon dioxide and methane emissions.

The study seeks to analyse the emissions intensity of fossil LNG specifically used for marine fuel bunkering purposes, rather than total volumes of LNG.

The estimates of WtT emissions are based on Rystad Energy's underlying asset-by-asset oil and gas databases, where facilities are tracked for both production/throughput and greenhouse gas emissions.

The aim of the study is not to provide a complete lifecycle assessment (LCA) of LNG as a marine fuel, instead is limited to providing a well-to-tank assessment.

Source: Rystad Energy GasEmissionsTracker

Well-to-tank scope and constraints

Lifecycle stages

The scope of this Rystad Energy study is an assessment of lifecycle emissions for LNG as a marine fuel from 'well-to-tank': from the 'well' of an upstream feed gas asset to entry into the 'tank' of the LNG fuelled vessel. Key lifecycle stages included within the analysis are upstream, transportation and processing, liquefaction, shipping, and the final LNG terminal distribution and bunkering operations.

The defined boundary of this study finishes after the final loading into the 'tank' of the LNG-fuelled vessel from the bunker barge. This analysis does not include the final use of the fuel for marine transportation, otherwise known as a 'tank-to-wake'. Nor does the analysis assess emissions from the 'well' through to final use for marine transportation, known as 'well-to-wake'. The study aims to align with the WtT system covered in the IMO's LCA guidelines and IPCC's AR5 GHG definitions.

Greenhouse gases

The following greenhouse gases have been included in the assessment; carbon dioxide (CO_2) and methane (CH_4). Methane emissions have been presented in the analysis as carbon dioxide equivalent (CO_2e), with a global warming potential (GWP) of 28 in line with IPCC's AR5, on a 100-year time horizon for methane of fossil origin.

This study has been written solely regarding the global warming potential of LNG as a marine fuel. Local pollutants such as nitrogen oxides (NOx), sulphur dioxides (SOx) and particulates have not been considered in this assessment. Nitrous oxide (N_2O) emissions are not included in the Rystad Energy databases and are omitted from the report. N_2O emissions are estimated to represent less than 1% of well-to-tank lifecycle emissions associated with LNG. This level of emissions is smaller than the error associated with data from CO_2 and CH_4, and consequently these are assumed to be immaterial.

Timeframe

Calendar year 2024 was used to assess lifecycle emissions because it provides the closest equivalence to current flow data and a reasonable level of emissions-reporting coverage.

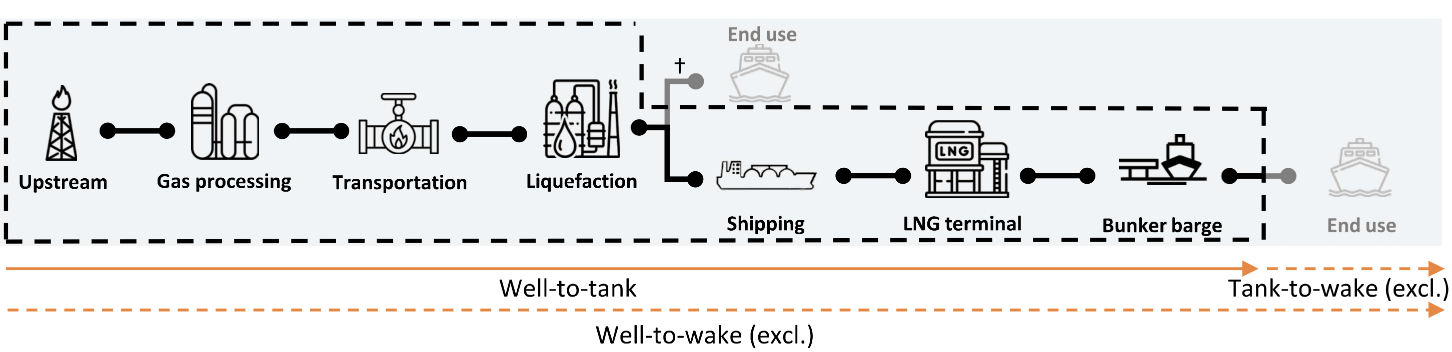
The study seeks to provides a snapshot of the year; however, Rystad recognises that the results is dynamic with constantly changing characteristics. Variations in LNG flow paths, project startups & shutdowns, changing upstream emissions profiles and other parameters all have the potential to affect WtT emissions intensity in future years.

Natural gas characteristics

Rystad Energy databases are constructed around the 'boe' measurement (barrel of oil equivalent), with all intensities listed as kilogram of CO_2 equivalent per boe (kg CO_2e/boe). For the purposes of this assessment, a conversion of the boe metric has been applied to convert the intensity of well-to-tank emissions to g CO_2e/MJ*.

Geographies

Data has been collated on a global - in addition to regional - level. The dataset has been built up from the underlying contributions of individual value chains and assets.



* LHV at 5508 MJ/boe (natural gas) equivalent to 0.04409 MJ/g. Note IMO LHV is 0.048 MJ/g.
† Well-to-tank boundary for LNG carriers
Source: Rystad Energy research and analysis; Rystad Energy GasEmissionsTracker

Volumes of bunkered LNG

The dataset provides well-to-tank emissions overviews for bunkered LNG loaded into the 'tank' of an LNG fuelled vessel, rather than total imported volumes of LNG. The impact between the two is quantified in the appendices.

Distribution of emissions

Rystad Energy has taken a physical/perimeter-based emissions origination approach to defining at which stage along the well-to-tank value chain emissions are assigned to. This approach assigns emissions to the specific location where they were released during a given process.

Examples of where this can have an impact include:

- LNG facilities where feed gas is supplied via subsea tiebacks, where gas is supplied to the liquefaction facility directly rather than through topside infrastructure above the gas field. In these examples, all power for upstream extraction, transportation and natural gas processing is assumed to occur at the liquefaction facility. Consequently, all emissions are assigned to the liquefaction facility itself and not to separate upstream/processing/transportation stages.
- LNG facilities where feed gas is solely processed at the liquefaction facility, rather than in a separate gas processing plant. Emissions associated with the processing activities will be directly assigned to the liquefaction plant, rather than to the processing stage.

Where co-products are produced at a given stage such as upstream assets (with crude, condensate, NGLs and gas co-production) and liquefaction plants (with LNG and LPG co-production). Rystad Energy tracks the relative energy related production of co-products (in barrel of energy equivalence). Facility emissions are then allocated to these co-products, based on the relative energy contribution.

Emissions coverage

The report does cover emissions from the operational phase of projects, and excludes emissions related to a project's fabrication, construction, installation or decommissioning phase. Or in the case of upstream, emissions from exploration activities such as seismic and exploration drilling are not included.

When compared with other emission categories, these emissions are typically marginal over the lifetime of an oil and gas asset.

Upstream

This study covers all emissions arising from the production of natural gas at upstream feed gas assets for liquefaction facilities. Rystad Energy defines upstream emissions as all on-site emissions originating from the extraction process of oil and natural gas.

This also includes emissions arising from upstream flaring, production drilling, on-site combustion from the extraction process (gas turbines and diesel engines), imported power (scope 2), fugitive methane, vented methane, methane from un-combusted flared volumes and gathering & boosting activities.

Transportation & processing

This study covers emissions from the transportation of natural gas that occur prior to the gas entering the liquefaction facility, including energy-related emissions (i.e. diesel/gas combustion at compressions stations, etc.), imported power (scope 2) and fugitive methane emissions.

The study also covers all processing-related emissions that occur prior to natural gas entering the liquefaction facility. This includes emissions related to phase separation, acid gas removal, water removal, fractionation, flaring, gas compression, imported power (scope 2), fugitive methane emissions and other gas treatments.

Source: Rystad Energy GasEmissionsTracker

Liquefaction

This study covers emissions relating to the liquefaction process. This includes gas reception, gas conditioning/fractionation, direct liquefaction emissions, venting and fugitive emissions, LNG storage and loading at export terminal, reservoir CO_2 removal, flaring, imported power and in certain instances, transportation and processing emissions.

Shipping

This study covers all emissions resulting from the transportation of LNG cargoes between the liquefaction facility and the LNG terminal. This includes emissions related to direct use of fuel during shipping, auxiliary power requirements and methane slippage. Shipping emissions cover a round trip, i.e. both the laden and ballast legs.

LNG terminal and bunker operations

This study covers all emissions arising from LNG terminal operations, distribution to the bunkering location, and final loading of fuel onto an LNG fuelled vessel. This includes energy-related (both imported and on-site produced emissions), in addition to fugitive methane emissions from storage, loading, delivery/transportation, and loading into the 'tank' of an LNG fuelled vessel*.

Well-to-tank emissions intensity methodology

Emissions are provided on an energy-weighted intensity basis. This approach analyses the relative impact of each individual well-to-tank route/cargo, and the energy transferred via that route (volume of LNG delivered) to provide its weighted impact at a regional or global level.

Global LNG trade flow consists of a series of individual LNG value chains that connect the production of natural gas at the upstream well all the way through to the end user. Rystad Energy's methodology of estimating global well-to-tank intensity is calculated by creating a digital twin of the world's LNG trade via the relevant assets and the physical flow volumes.

Regional and global LNG well-to-tank intensities are based on the following methodology:

1. Rystad Energy has connected the relevant feed gas assets and infrastructure to each individual liquefaction facility** for production volumes and emissions, allowing for emissions intensity assessments of LNG exiting each liquefaction facility globally.
2. Rystad Energy uses complete vessel-by-vessel tracking to monitor volumes of cargoes delivered between liquefaction facilities and LNG terminals globally, thus allowing each individual cargo delivered into each LNG terminal to have a unique value chain emissions assessment and volume. In addition to tracking vessel-by-vessel LNG deliveries into LNG terminals, Rystad Energy also tracks vessel LNG bunkering locations globally, which can be tagged to the LNG import terminals.
3. Each step means that for each vessel bunkered at each bunkering facility, Rystad Energy can estimate the individual value chains that have contributed to the LNG in a given location and their relative volumetric contribution. This allows for the relative impact of each value chain to be compiled and aggregated up from the value chain level to the bunkering location, and then aggregated further into country, regional or global scale.

* The 'tank' boundary is defined as the receiving flange of the end use LNG vessel.

** A different approach was taken for feed gas for US based liquefaction facilities to that other facilities. In the US, liquefaction plants are fed from the gas grid as opposed to direct connections between specific upstream assets and specific liquefaction plants. The feed gas for the US plants is therefore a mix of many producing basins and assets around the country, each with considerable variation in emissions intensity. Because of this, the impacts of upstream emissions intensity can be severe. To counteract this, Rystad Energy's approach takes a conservative view and assumes an average energy/volume weighted emissions intensity of the overall upstream gas emissions. The methodology used for the US is covered in more detailed in the Sensitivity Assessment section of the Appendices.

Source: Rystad Energy GasEmissionsTracker

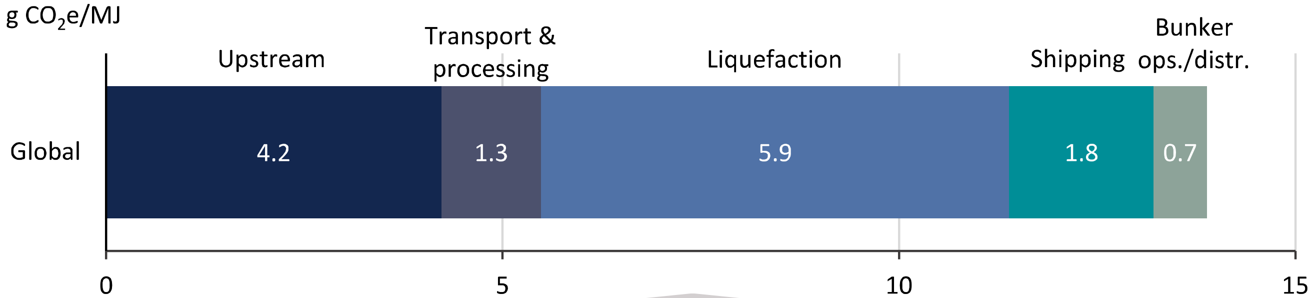
Well-to-tank results

Global results

The chart and table below display the estimated global well-to-tank average emissions intensity associated with bunkered LNG in 2024. The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to entry into the 'tank' of an LNG-fuelled vessel at the bunker barge location.

Overall emissions intensity for global LNG is estimated to be 13.9 g CO_2e/MJ (LHV) for bunkered LNG in the calendar year 2024.

Global well-to-tank emissions intensity of bunkered LNG



	Value chain stage	Emissions intensity (g CO_2e/MJ)	CH_4 impact* (% of stage total)
	Upstream	4.2	38%
	Transport & processing	1.3	7%
	Liquefaction	5.9	1%
	Shipping	1.8	8%
	Bunker operations/ distribution	0.7	37%
	Well-to-tank	**13.9**	**16%**

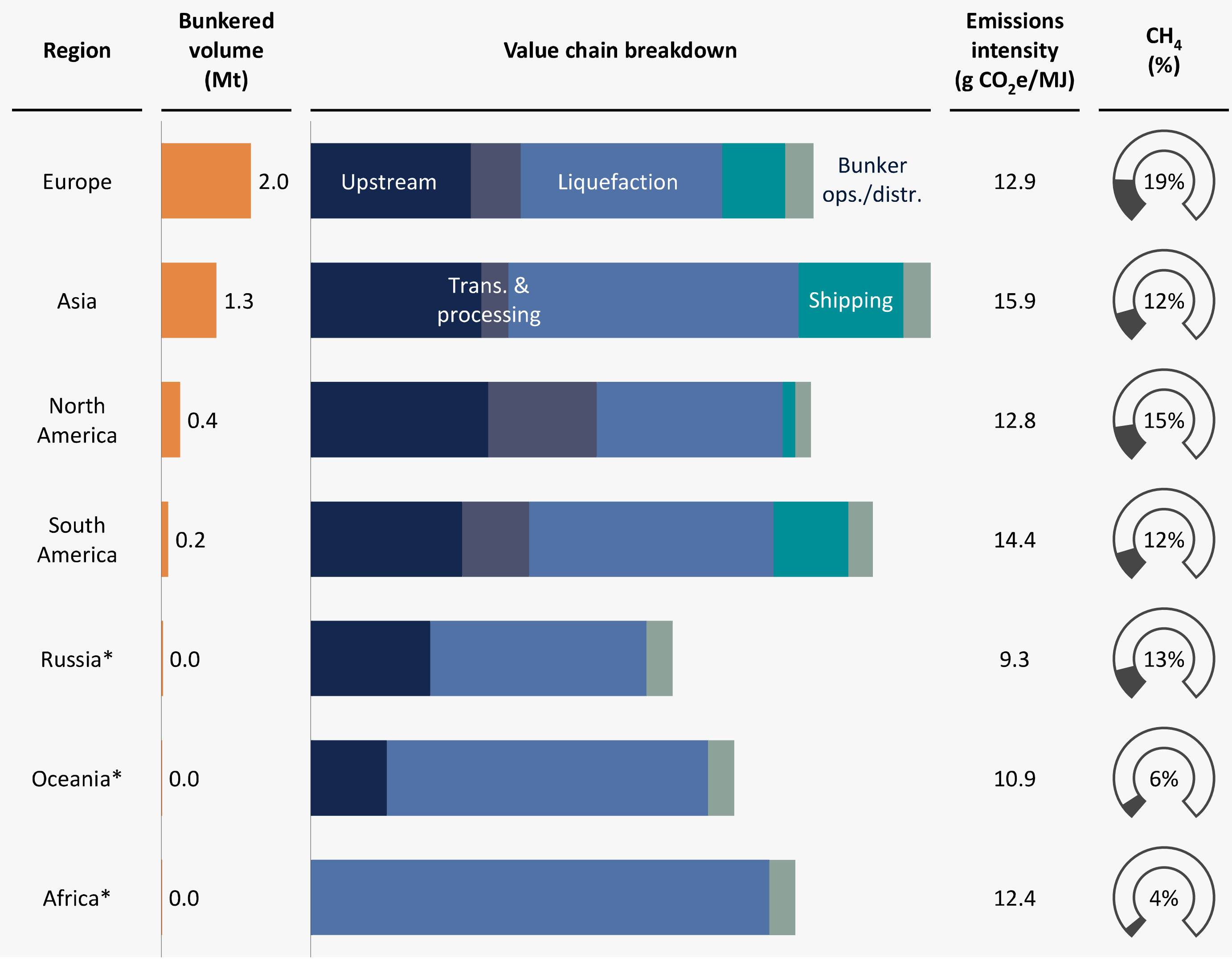
*CH_4 impact denotes the percentage that stages overall GHG emissions methane responsible for (i.e. a 10% value with an intensity of 10 g CO_2/MJ, denotes a methane contribution of 1 g CO_2e/MJ)
Source: Rystad Energy GasEmissionsTracker

Regional results

The chart and table below display the 2024 estimated well-to-tank average emissions intensity associated with bunkered LNG for each region, alongside the volume of bunkered LNG. The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to entry into the 'tank' of an LNG-fuelled vessel at the bunker barge location.

Overall emissions intensity for regional LNG well-to-tank emissions are estimated to range between 9.3 to 15.9 g CO_2e/MJ for bunkered LNG in 2024.

Well-to-tank emissions intensity of bunkered LNG per importing region



Regional emissions intensity is based upon the volume weighted emissions intensities of all LNG sources used for bunkering. There is large variation between regions, countries and facilities on emissions performance, and also in some instances large variation between different years analysed. Changes to production shares between assets, alternative feed gas assets being included or changes in operational practices/accidents can affect historic and future results.

*Minor adjacent bunkering, not fully representative of well-to-tank emissions due to limited bunker volumes.

Source: Rystad Energy GasEmissionsTracker

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Well-to-tank discussion

Global results

The global emissions average for LNG well-to-tank bunkering is 13.9 g CO_2e/MJ, with significant variations tied to each cargo's origination.

- Emissions arising within the liquefaction facility account for the largest proportion of GHG emissions from the bunkered LNG value chain, with around 5.9 g CO_2e/MJ, 43% of total value chain emissions.
- Upstream oil and gas production was responsible for an additional 4.2 g CO_2e/MJ, 31% of well-to-tank emissions.
- Shipping accounted for 1.8 g CO_2e/MJ (13%) of emissions, followed by transportation and processing (9%) and bunker operations and distribution (5%).
- Carbon dioxide emissions were responsible for 84% of overall lifecycle emissions, with methane accounting for the remainder.
- Methane emissions globally were responsible for 16% of total WtT emissions, equivalent to 2.2 g CO_2e/MJ. Methane emissions are most pronounced in the upstream stage, where it accounts for nearly 38% of the 4.2 g CO_2e/MJ total. Methane is responsible for 37% of bunker operations & distribution, however the magnitude of methane emissions is considerably lower than that of the upstream stage. The liquefaction stage had minimal methane emissions. Methane emissions, when compared to carbon dioxide have a higher level of uncertainty. This is due to its increased difficulties in accurate measurement of release rates.

Regional results

There were significant variation in emissions intensity by region ranging from 9.3 g to 15.9 g CO_2e per MJ in 2024.

- European bunkered LNG (with the greatest volume) had an overall intensity of 12.9 g CO_2e/MJ, which was lower than the global average. Domestically produced European LNG from Hammerfest LNG had a far lower emissions intensity of around 6.8 g CO_2e/MJ (depending on delivery location). The facility benefits from low ambient temperatures, in addition to direct connection to subsea fields supply feed gas. Furthermore, this facility, fed by gas fields with a reservoir CO_2 content of up to 8%, reinjects this stripped gas rather than venting, aiding the facility in producing the most competitive LNG from an emissions perspective. The European regional average was pulled up by imported volumes from higher-emitting regions.
- Volumes bunkered in Asia had an average well-to-tank emissions intensity of 15.9 g CO_2e/MJ, above the global average.
- Fuel loaded into the tanks LNG fuelled vessels in Russia have far lower intensities of only 9.3 g CO_2e/MJ, assisted by bunkering at locations close to the liquefaction facilities thus reducing shipping-related emissions, the lowest ambient yearly temperatures of all regions, modern/new facilities, and upstream gas production in close proximity to the LNG facilities. However, due to the limited bunker volumes not this does not fully representative of well-to-tank emissions of the region.
- Europe and Asia accounted for the vast majority of bunkered LNG in 2024, with small volumes in North America and very minor volumes in Russia, Oceania and Africa. Notably, the Middle East had no bunkered volumes in 2024, but the region was a significant exporter to LNG terminals where bunkering occurred.
- Liquefaction is the largest contributor of well-to-tank emissions for all regions, but significant variation exists among regions. Emissions range from slightly over 4.8 g CO_2e/MJ in North America up to 11.8 g CO_2e/MJ for Africa. Notably, European liquefaction emissions are substantially lower than Asia's, helped in some part from significant LNG volumes coming from the US, which employs some of the latest liquefaction technologies, and Russia, where low average temperature helping to reduce the energy required for liquefaction.

Source: Rystad Energy GasEmissionsTracker

- Methane emissions for the bunkering locations varied significantly among regions, with European well-to-tank methane emission representing the highest levels, of 19%. The reason for this is two-fold. Firstly, the fleet delivering LNG volumes into Europe is more modern than many vessels used elsewhere, reducing shipping emissions as a whole, but increasing the share of methane from slippage. Secondly, facilities fed predominantly with LNG from the US and Russia can have more methane emissions than those receiving more direct feed gas supplies from subsea tiebacks or offshore facilities.
- Of the very minor volumes bunkered in Russia, Oceania, and Africa, almost all were bunkered close or adjacent to a liquefaction plant, meaning shipping emissions were near zero for these regions. This picture was similar in North America, where bunkered volumes are often in close proximity to LNG production facilities, so shipping distances and emissions are significantly lower than regions that mostly import LNG such as Europe, Asia, and South America.
- The regional results show significant variation in methane's relative contribution to value chain emissions. However, this can be somewhat misleading if one considers the value chains in place for certain regions. Africa has one of the lowest methane intensities as a region, but bunkering in Africa occurred at only one location in 2024, Damietta LNG. Damietta LNG is fed directly by subsea tiebacks, with no onshore feed gas assets. This explains why Africa, or Damietta, has no upstream emissions, as the emissions occur and are accounted for within the liquefaction plant. Subsea oil and gas fields are assumed to have minimal methane emissions, and as LNG was bunkered in close proximity, there were no shipping-related emissions. The story is similar in Russia and Oceania, accounting for their low overall emissions, including methane.
- Current estimates of well-to-tank emissions from regions such as Russia, Africa and Oceania are based on very minor volumes of bunkered fuel. For example, bunkered LNG from these regions typically originates from a single facility and is not representative of all LNG produced in those regions. Which has the potential to skew the results, when compared to LNG produced over the entire region.
- LNG exporters like US, Russia and Africa – have the potential to establish low emission LNG bunkering – as they can utilise local LNG before long distance shipping. But if these regions were to grow more substantial, they would also need some "intra" regional transport, that would add additional shipping emissions.
- In addition to the variation in emissions from cargo to cargo, the lengths and number of stages in each of the value chains can vary significantly, depending on where, and at what point in the value chain, bunkering takes place. There are certain instances where bunkering occurs directly at the point of production, with the vessel filled at the exit gates of a liquefaction facility, rather than after the LNG has been shipped to an LNG terminal, offloaded, transported to a bunkering facility and then finally loaded into the 'tank' of a receiving vessel. These final two stages (shipping and bunker operations) are, on a global scale, responsible for 18% of total well-to-tank emissions. Consequently, bunkering directly at - or in close proximity to - the liquefaction facility can significantly reduce overall well-to-tank emissions by as much as around 2.5 g CO_2e/MJ, depending on the specific bunker location.
- Additional sensitivity analyses have been completed on the above results (see appendices), studying the effect of differing GWP factors and the impact that directly loading at liquefaction facilities can have on well-to-tank emissions for LNG carriers.

Source: Rystad Energy GasEmissionsTracker

Data quality assessment

Rystad Energy has leveraged the GasEmissionsTracker database to provide the assessment of overall emissions associated with the global LNG trade from well-to-tank. The GasEmissionsTracker is a bottom-up, asset-level database, grounded in granular, site-specific data, which can be aggregated from individual value chains for cargoes up to country or global overviews. The full global coverage of all LNG trade ensures completeness of the dataset, in addition to adequate coverage of all aspect of the value chain.

The traceability of the individual route-level approach provides more accurate assessment of LNG lifecycle emissions, rather than country/region-based averages, which can introduce significant errors. The use of 2024 as an assessment year ensures relevance of the dataset, without compromising on data quality.

The Rystad Energy database concatenates and compiles data points from an extensive selection of different sources, including asset-level reported information, company reported benchmarks, satellite data, and modelled numbers. Each of these data points can vary in:

- Reporting standards
- Levels of transparency
- Boundary definitions
- Global warming potential of GHGs
- Inclusions of GHGs
- Additional parameters

Where possible, Rystad Energy ensures all facilities and stages within a value chain are treated equally, adjusting these factors to ensure they are analysed and incorporated in a stable, consistent and transparent methodology. This involves mapping and adjustment of data sources to match reporting standards to Rystad Energy's own definitions and standards before entry into the databases. Data sources are also treated hierarchically, with the most granular asset-by-asset data being used before data in more aggregated format. These processes help to ensure the dataset is consistent and reliable across regions and timeframes. Each stage in the value chain undergoes thorough quality control. These data quality adjustments are explained in more detail in the methodology section of this report.

As a result of these data quality processes Rystad Energy's estimates provide a more representative and accurate view of LNG used for marine fuel, than broad regional or industry averages.

Source: Rystad Energy GasEmissionsTracker

Comparisons versus other studies

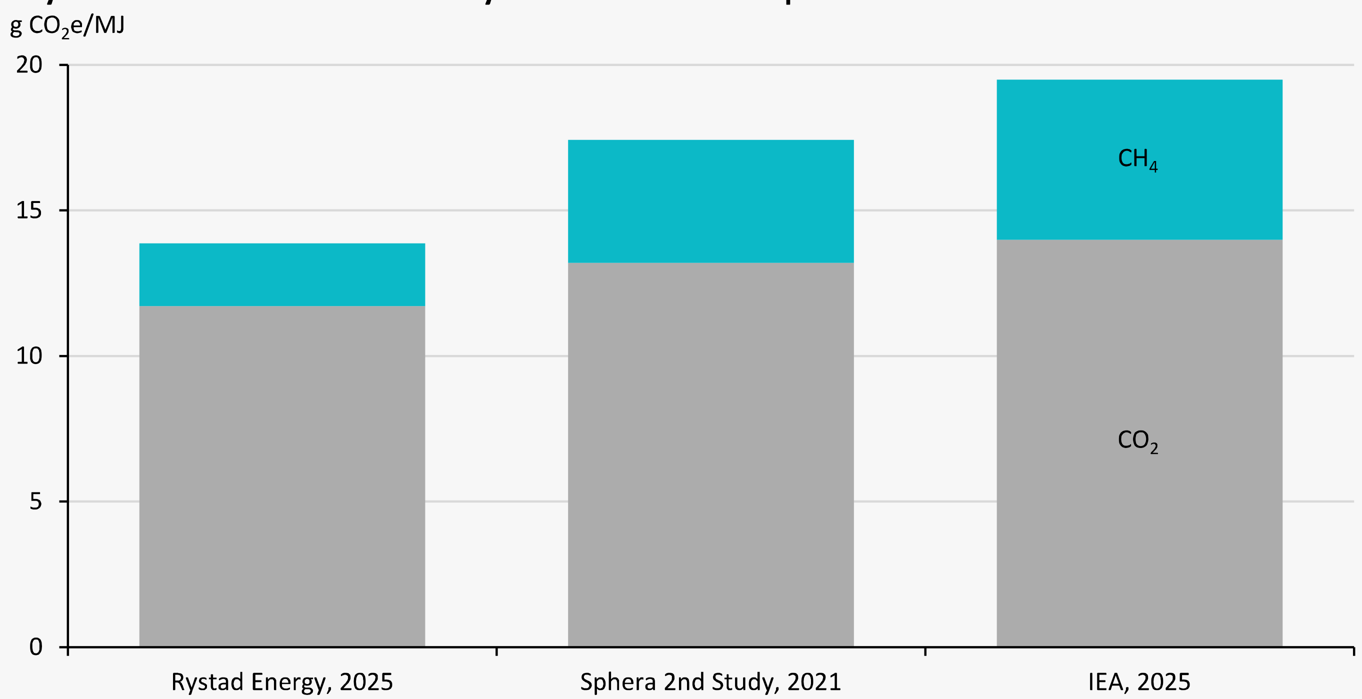
The below chart displays Rystad Energy's well-to-tank study against other selected studies that analyse well-to-tank emissions.

Although similar in overviews of well-to-tank or well-to-market emissions intensity, and listed together here, it should be noted that these studies can vary significantly and should be compared with care. No exhaustive comparison has been made between studies, and key areas of differences include:

- Boundary definitions
- GHG included
- Years included
- Data collection and validation standards
- Geographies covered in the analysis
- Emissions estimation methodology and assumptions
- Satellite data inclusion

Rystad Energy's approach can differ from other studies due to use of specific feed gas assets tagged to liquefaction facilities globally. This ensures asset specific emissions rates are used in the study, such as satellite detected methane plume analysis and reported asset level data. As opposed to regional or basin level averages which can introduce significant uncertainties into feed gas emissions rates. Rystad Energy seeks to provide the closest reflection of the current market, with 2024 data points and coverage of all liquefaction plants globally. And aims to align with the WtT system covered in the IMO's LCA guidelines and IPCC's AR5 GHG definitions. In addition, Rystad Energy's approach is very specific to LNG directly used for loading into the 'tank' of LNG fuelled vessel, rather than global averages for LNG as a whole, further improving the accuracy of the dataset.

Key well-to-tank emissions intensity selected studies comparison



All GWP factors adjusted from study to AR5-100 year. The IEA study includes regasification of LNG.
Source: Rystad Energy GasEmissionTracker, Sphera (2021) 2nd Lifecycle GHG Emissions Study, IEA (2025) Emissions from LNG Supply and Abatement Options.

Appendices

Global and regional emissions intensity

The table below displays the estimated well-to-tank average emissions intensity associated with bunkered LNG in 2024. The results are shown for both the global overview, in addition to regional breakdowns.

The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to its bunker location. Zeroes in the table denote that no physical emissions were realised at that stage of the value chain.

Global and region-specific WtT emissions intensity overviews of bunkered

	Global overview		Europe		Asia		North America	
Bunkered volume	100%		52%		32%		11%	
Value chain stage	**Intensity (g CO_2e/MJ)**	**CH_4 impact**	**Intensity (g CO_2e/MJ)**	**CH_4 impact**	**Intensity (g CO_2e/MJ)**	**CH_4 impact**	**Intensity (g CO_2e/MJ)**	**CH_4 impact**
Upstream	4.2	38%	4.1	44%	4.4	31%	4.6	34%
Transport & processing	1.3	7%	1.3	7%	0.7	8%	2.8	7%
Liquefaction	5.9	1%	5.2	2%	7.4	2%	4.8	0%
Shipping	1.8	8%	1.6	10%	2.7	6%	0.3	7%
Bunker operations/ distribution	0.7	37%	0.7	36%	0.7	40%	0.4	26%
Well-to-tank	13.9	16%	12.9	19%	15.9	12%	12.8	15%

Source: Rystad Energy GasEmissionsTracker

RystadEnergy

The table below displays the estimated well-to-tank average emissions intensity associated with bunkered LNG in 2024 (cont.). The results are shown for both the global overview, in addition to regional breakdowns.

The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to its bunker location. Zeroes in the table denote that no physical emissions were realised at that stage of the value chain.

Global and region-specific WtT emissions intensity overviews of bunkered

	South America		Russia*		Oceania*		Africa*	
Bunkered volume	4%		1%		0%		0%	
Value chain stage	Intensity (g CO_2e/MJ)	CH_4 impact	Intensity (g CO_2e/MJ)	CH_4 impact	Intensity (g CO_2e/MJ)	CH_4 impact	Intensity (g CO_2e/MJ)	CH_4 impact
Upstream	3.9	29%	3.1	29%	2.0	11%		
Transport & processing	1.7	8%						
Liquefaction	6.3	1%	5.5	1%	8.2	3%	11.8	2%
Shipping	1.9	8%						
Bunker operations/ distribution	0.6	44%	0.7	37%	0.7	37%	0.7	37%
Well-to-tank	14.4	12%	9.3	13%	10.9	6%	12.4	4%

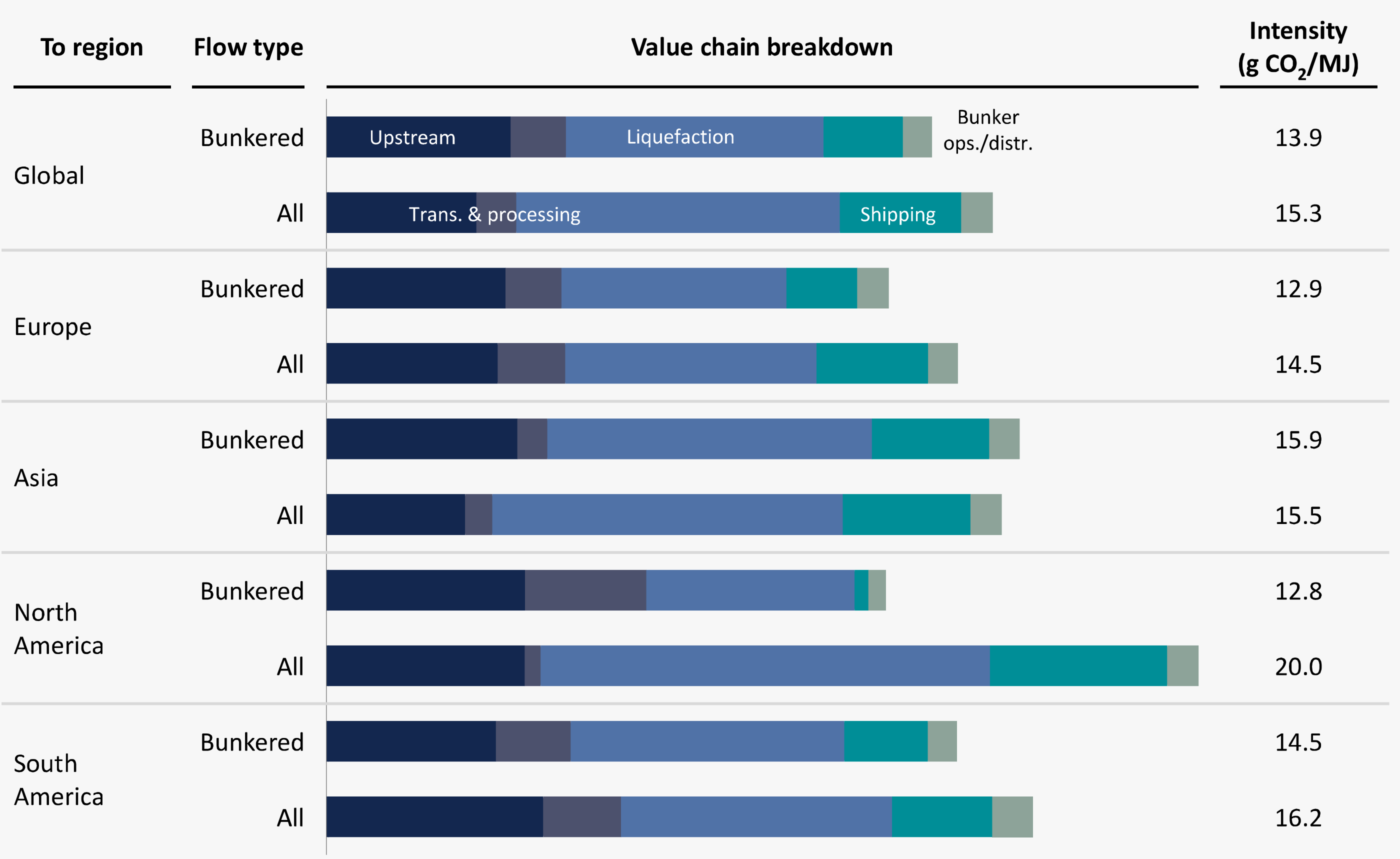
*Minor adjacent bunkering, not fully representative of well-to-tank emissions due to limit bunker volumes. Due to the marginal volumes bunkered within these regions, compared to other regions the effect on global bunkered volume is negligible on global overviews.
Source: Rystad Energy GasEmissionsTracker.

Bunkered versus total imported volumes

The table below compares the WtT emission intensities of bunkered volumes to all LNG volumes imported into a given region. The origination of LNG can have a significant impact on overall well-to-tank emissions, with emissions from LNG exiting a liquefaction plant varying from more than 4.6 g CO_2/MJ to as high as 14.6 g. Importing more from a particular region can significantly sway overall emissions.

- Analysing total LNG imported volumes on a global basis, well-to-tank emissions intensity rises by about 10%, from 13.9 g CO_2e/MJ to 15.3 g CO_2e/MJ.
- When examining emissions associated with all imported LNG versus purely bunkered volumes by region, most regions experience an uptick in emissions intensity.
- Europe's emissions intensity rises by 1.6 g CO_2e/MJ, up to 14.5 g CO_2e/MJ. North American imports jump by 36%, to 20.0 g CO_2e/MJ, pushed upwards by the increased volumes imported from South America. South America itself rises by 1.7 g CO_2e/MJ.
- One region that experiences a decrease in emissions intensity is Asia, with the intensity dropping from 15.9 g CO_2e/MJ to 15.5 g CO_2e/MJ. The decrease is helped in part by increased volumes from the Middle East, North America and reduced self-supply.

WtT intensity of bunkered LNG imports versus all LNG imported into a region (excluding minor adjacent regions)



Source: Rystad Energy GasEmissionsTracker

Minor adjacent bunkering regions

99% of the bunkered LNG fuel in 2024, occurred in four regions; Europe, Asia, North America and South America.

The remaining 1% was bunkered in Russia, Oceania and Africa, with no LNG bunkering occurring in Middle East. These four underrepresented regions have consequently been classified as 'minor adjacent' throughout the report. Russia, Oceania and Africa did have minor volumes bunkered and have a WtT intensities of 9.3, 10.9 and 12.4 g CO_2e/MJ respectively.

These WtT intensities can not be considered representative of their respective regions due to the limited volumes being bunkered. Rystad Energy's approach looks at the specific individual cargoes delivered into a region that are ultimately used for loading of LNG into the 'tank' of an LNG-fuelled vessel. These individual cargoes are then summarised using a volume/energy weighted approach to provide a regional average WtT emissions intensity.

In the case of Europe, Asia, North America and South America, the LNG used for bunkering has originated from multiple different liquefaction plants and then transported by various LNG carrier vessels. Therefore, the impact a single cargo can have on the regional bunkered WtT emissions intensity is minimised, when each individual cargo is only representative of a tiny fraction of the total volume used in LNG bunkering operations. Conversely, as the volume of bunkered LNG decreases the impact each individual cargo can have on the regional average becomes more pronounced.

For the regions Russia, Oceania and Africa bunkered volumes were very minimal and were linked to only a handful of bunkering operations and therefore often linked to single value chains. In these instances, results can easily be skewed towards single value chains/single cargoes and not provide a representative view of WtT intensities if bunker volumes were to expand in these regions. Due to the very limited volumes of LNG bunkered in these regions, there is no material effect on the global WtT emissions intensity.

In the case of Africa, all bunkering can be tied to one value chain fed by LNG from Damietta LNG. Damietta LNG is fed directly by subsea tiebacks, with no onshore feed gas assets. This explains why Africa, or Damietta, has no upstream emissions, as the emissions occur and are accounted for within the liquefaction plant. Subsea oil and gas fields have minimal methane emissions, and as LNG was bunkered in close proximity to the liquefaction plant there were no shipping-related emissions. In comparison with the LNG volumes used directly for bunkering in the region, the emissions intensity of all LNG imports into the region are 16 g CO_2e/MJ.

The story is similar in Russia and Oceania, where most volumes for LNG bunkering are estimated to have originated from Vysotsk & Portovaya LNG and North West Shelf and Pluto LNG respectively and are skewed towards these producing plants. Unlike Africa, the regions of Russia and Oceania are not importers of LNG.

Source: Rystad Energy GasEmissionsTracker

US feed gas variation

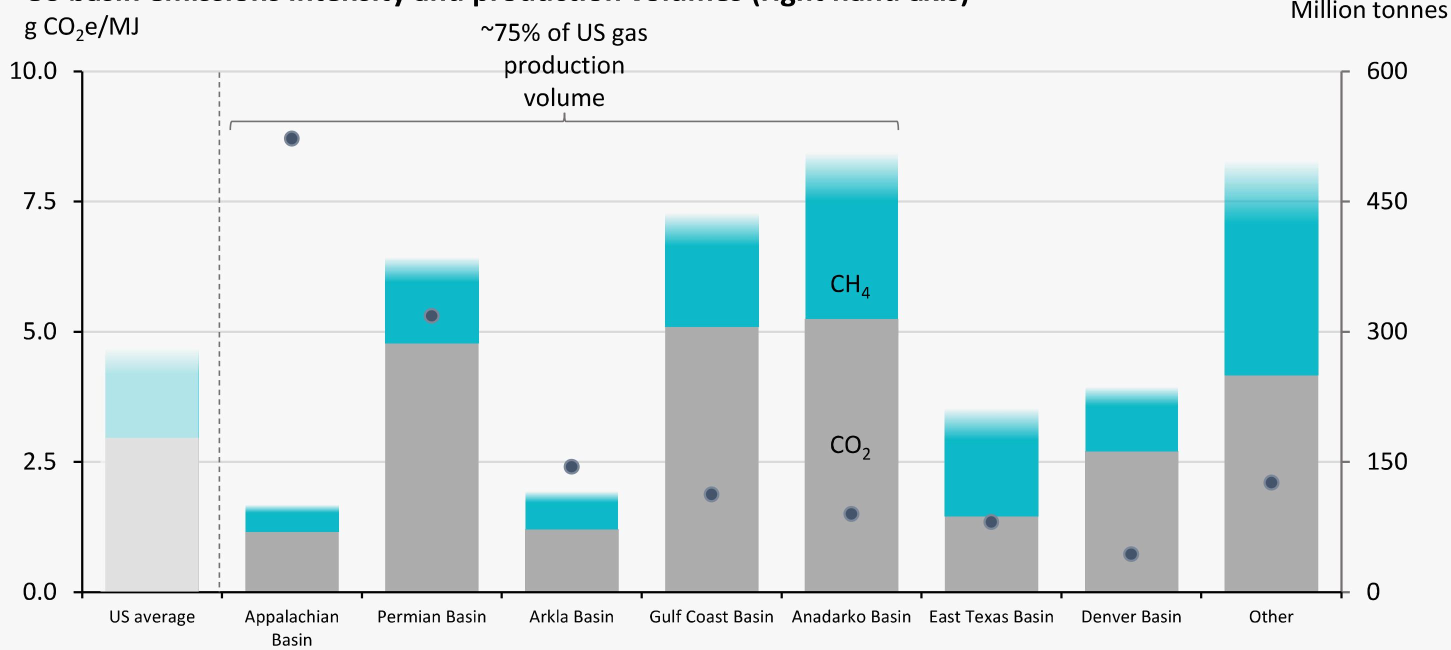
As discussed, the overwhelming number of liquefaction facilities are directly tied to their specific upstream feed gas assets. Calculation of upstream feed gas emissions intensity can then be estimated by volume-weighted analysis of the relative emission contributions of supplying assets. In the US, liquefaction plants are fed from the gas grid as opposed to direct connections between specific upstream assets and specific liquefaction plants. The feed gas for the US plants is therefore a mix of many producing basins and assets around the country, each with considerable variation in emissions intensity. Because of this, the impacts of upstream emissions intensity can be severe.

- Overall US gas production has an estimated emissions intensity of around 4.7 g CO_2e/MJ.
- The Appalachian basin, where around one-third of all US gas is produced, has an emissions intensity of less than 1.7 g CO_2e/MJ, with limited levels of methane leakage.
- The second-largest gas-producing basin, the Permian, which is predominantly centred around oil production, has a higher average intensity sitting above 6.4 g CO_2e/MJ. Methane emissions from the Permian are higher than in Appalachia, but lower than the US average.
- Intensities from basins responsible for 75% of US gas production vary between 1.7 g and 8.5 g CO_2e per MJ.

Many US liquefaction plants have offtake agreements with specific upstream gas producers. However, there are some difficulties in directly tying specific upstream assets from operators to LNG cargoes leaving a liquefaction facility. First, many of these offtake agreements are not publicly available, making it impossible to tie feed gas assets to liquefaction plants. Secondly, an offtake agreement is not a physical representation of where feed gas for liquefaction plants has physically come from. To counteract this, the Rystad Energy approach takes a conservative view and assumes an average emissions intensity of the overall gas grid.

Consequently, it is understood that how one defines upstream feed gas source in the US can cause the variation in upstream emissions.

US basin emissions intensity and production volumes (right hand axis)



Source: Rystad Energy EmissionsCube

Well-to-tank results (IPCC AR-6 100 year)

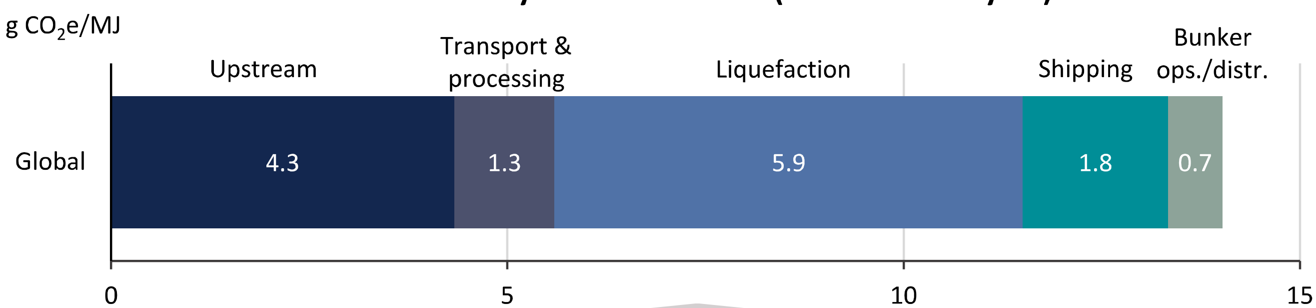
Global results

The chart and table below display the estimated well-to-tank average emissions intensity associated with bunkered LNG in 2024, updated to be inline with IPCC's AR6 assessment of global warming potential for green house gasses on a 100-year time horizon.

The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to its bunker location.

Overall emissions intensity for global LNG from an AR-6 assessment is estimated to be around 14.0 g CO_2e/MJ for bunkered LNG in the calendar year 2024.

Global well-to-tank emissions intensity of bunkered LNG (IPCC AR-6 100-year)



Value chain stage	Emissions intensity (g CO_2e/MJ)	CH_4 impact* (% of stage total)
Upstream	4.3	39%
Transport & processing	1.3	7%
Liquefaction	5.9	2%
Shipping	1.8	8%
Bunker operations/ distribution	0.7	38%
Well-to-tank	**14.0**	**16%**

*CH_4 impact denotes the percentage that stages overall GHG emissions methane responsible for (i.e. a 10% value with an intensity of 10 g CO_2/MJ, denotes a methane contribution of 1 g CO_2e/MJ)

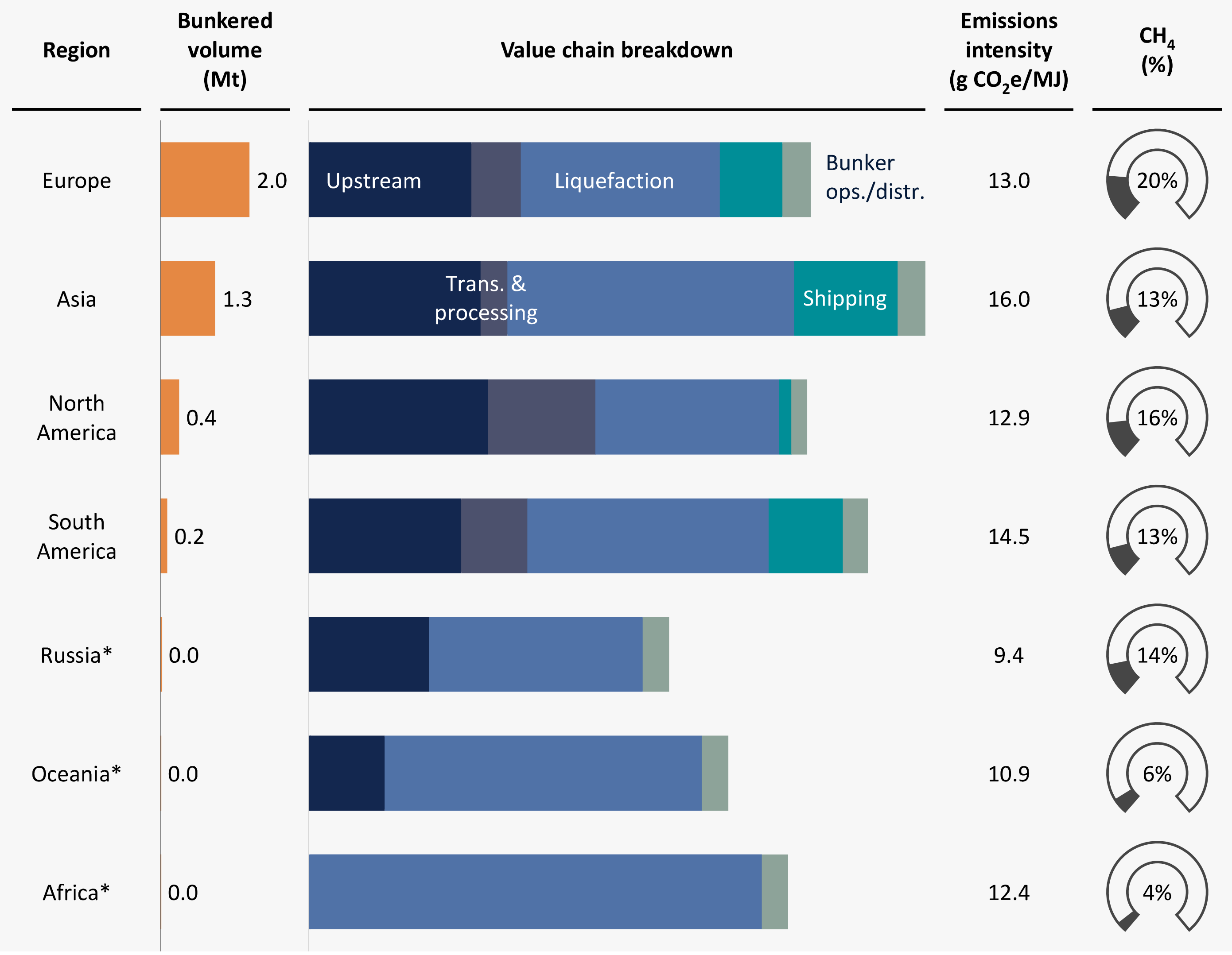
Source: Rystad Energy GasEmissionsTracker

Regional results

The chart and table below display the 2024 estimated well-to-tank average emissions intensity associated with bunkered LNG for each region, alongside the volume of bunkered LNG, updated to be inline with IPCC's AR6 assessment of global warming potential for green house gasses on a 100-year time horizon. The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to its bunker location.

Overall emissions intensity for regional LNG well-to-tank emissions are estimated to range between 9.4 to 16 g CO_2e/MJ for bunkered LNG in 2024.

Well-to-tank emissions intensity of bunkered LNG per importing region (IPCC AR-6 100-year)



Regional emissions intensity is based upon the volume weighted emissions intensities of all LNG sources used for bunkering. There is large variation between regions, countries and facilities on emissions performance, and also in some instances large variation between different years analysed. Changes to production shares between assets, alternative feed gas assets being included or changes in operational practices/accidents can affect historic and future results

*Minor adjacent bunkering, not fully representative of well-to-tank emissions due to limited bunker volumes.

Source: Rystad Energy GasEmissionsTracker

Well-to-tank results (IPCC AR-5 20-year)

Global results

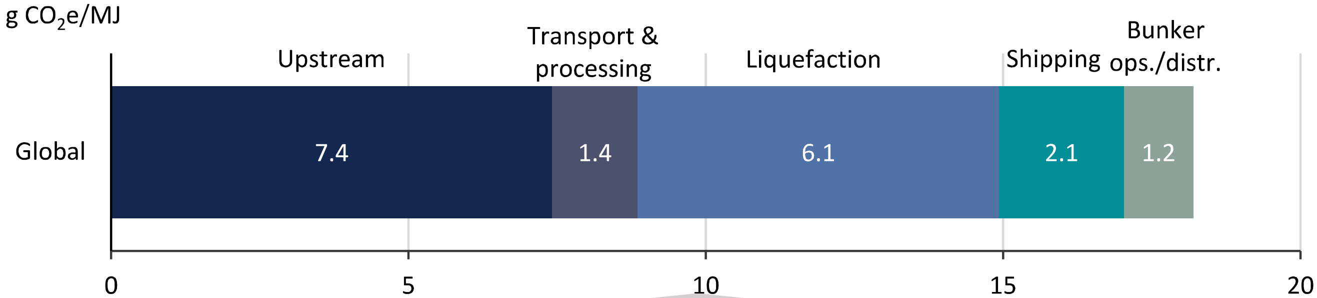
The chart and table below display the estimated well-to-tank average emissions intensity associated with bunkered LNG in 2024, updated to be inline with IPCC's AR5 assessment of global warming potential for green house gasses on a 20-year time horizon.

The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to its bunker location.

Overall emissions intensity for global LNG from an AR-5 20-year assessment is estimated to be around 18.2 g CO_2e/MJ for bunkered LNG in the calendar year 2024.

Global well-to-tank emissions intensity of bunkered LNG (IPCC AR-5 20-year)

g CO_2e/MJ



Value chain stage	Emissions intensity (g CO_2e/MJ)	CH_4 impact* (% of stage total)
Upstream	7.4	65%
Transport & processing	1.4	19%
Liquefaction	6.1	4%
Shipping	2.1	20%
Bunker operations/ distribution	1.2	64%
Well-to-tank	**18.2**	**36%**

*CH_4 impact denotes the percentage that stages overall GHG emissions methane responsible for (i.e. a 10% value with an intensity of 1 g CO_2/MJ, denotes a methane contribution of 1 g CO_2e/MJ)

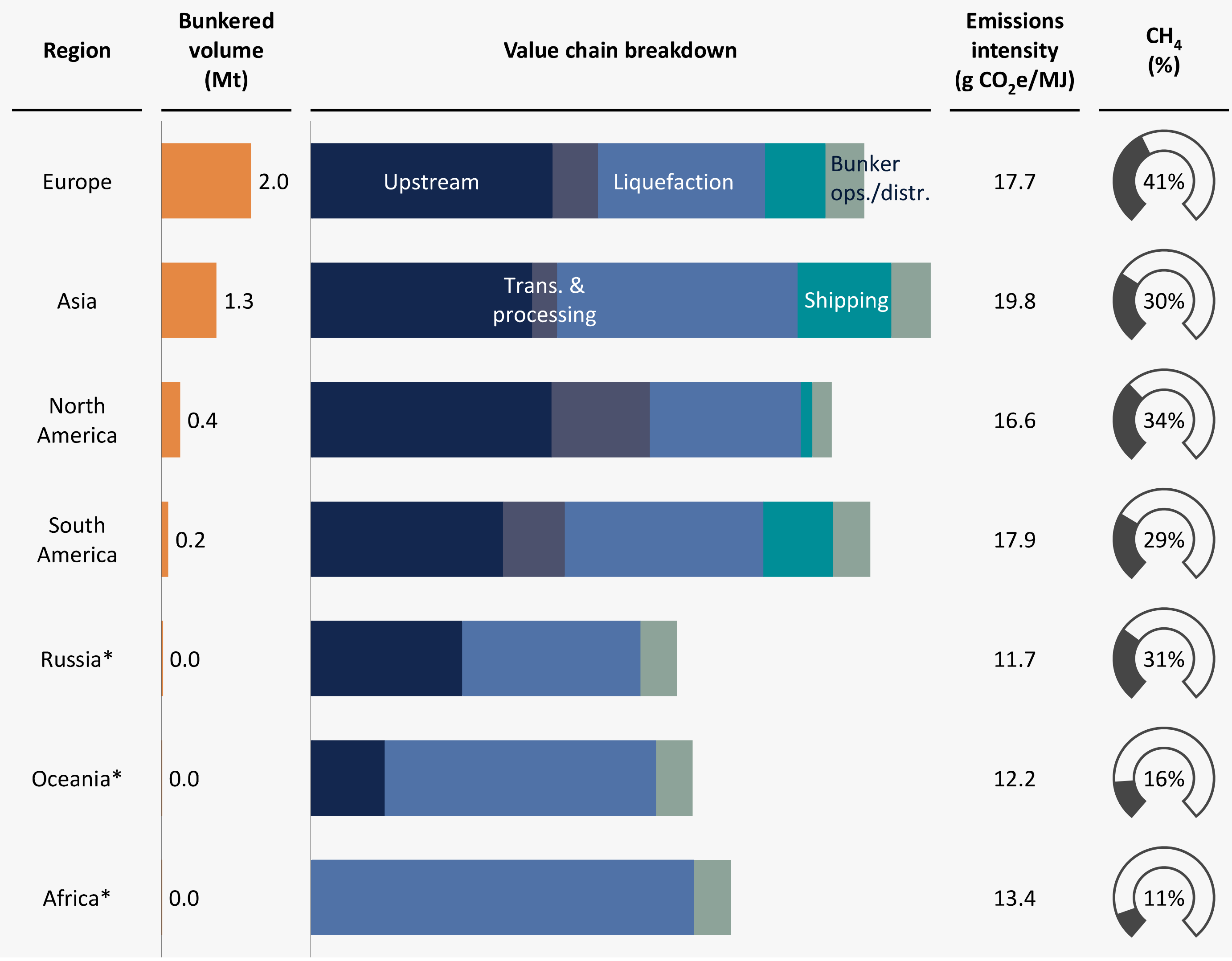
Source: Rystad Energy GasEmissionsTracker

Regional results

The chart and table below display the 2024 estimated well-to-tank average emissions intensity associated with bunkered LNG for each region, alongside the volume of bunkered LNG, updated to be inline with IPCC's AR5 assessment of global warming potential for green house gasses on a 20-year time horizon. The results displayed below are relative to the energy/volumetric contribution of LNG from each value chain to its bunker location.

Overall emissions intensity for regional LNG well-to-tank emissions are estimated to range between 12.2 to 19.8 g CO_2e/MJ for bunkered LNG in 2024.

Well-to-tank emissions intensity of bunkered LNG per importing region (IPCC AR-5 20-year)



Regional emissions intensity is based upon the volume weighted emissions intensities of all LNG sources used for bunkering. There is large variation between regions, countries and facilities on emissions performance, and also in some instances large variation between different years analysed. Changes to production shares between assets, alternative feed gas assets being included or changes in operational practices/accidents can affect historic and future results

*Minor adjacent bunkering, not fully representative of well-to-tank emissions due to limited bunker volumes.

Source: Rystad Energy GasEmissionsTracker

Rystad and Sphera 2nd study

Global results comparison

The table below displays the estimated Rystad Energy's well-to-tank average emissions intensity associated with bunkered LNG in 2024, alongside Sphera (2021) 2nd Lifecycle GHG Emissions Study.

- Rystad's global WtT emissions intensity is 13.9 g CO_2e/MJ, Sphera's is 17.4 g CO_2e/MJ, 25% higher.
- Globally Rystad Energy estimates that methane emissions are responsible for 16% of total well-to-tank emissions for bunkered LNG. Sphera estimates this to be 24%.
- Rystad Energy and Sphera have similar estimates for upstream, transportation & processing emissions and LNG bunker operations & distribution.
- The biggest variation stems from emissions associated with liquefaction and shipping emissions, where Rystad Energy estimates emissions to be 2.8 and 0.6 g CO_2e/MJ lower respectively.
- The largest drivers behind liquefaction emissions can be tied to methane emissions, where Sphera estimate this to be 1.4 g CO_2e/MJ higher, and Rystad Energy's bunker specific average representation of results.
- Rystad Energy's approach differs slightly to Sphera's with Rystad specifically tracking bunkered LNG volumes, rather than all volumes produced from LNG plants.

Global well-to-tank emissions intensity of bunkered LNG (Rystad Energy compared to Sphera 2nd study)

	Rystad Energy		Sphera 2nd study	
Value chain stage	Emissions intensity (g CO_2e/MJ)	CH_4 impact* (% of stage total)	Emissions intensity (g CO_2e/MJ)	CH_4 impact* (% of stage total)
Upstream, transport & processing	5.5	31%	5.7	40%
Liquefaction	5.9	1%	8.7	17%
Shipping	1.8	8%	2.4	9%
Bunker operations/ distribution	0.7	37%	0.7	31%
Well-to-tank	**13.9**	**16%**	**17.4**	**24%**

Sphera adapted to AR5 for comparison to Rystad Energy's results

*CH_4 impact denotes the percentage that stages overall GHG emissions methane responsible for (i.e. a 10% value with an intensity of 10 g CO_2/MJ, denotes a methane contribution of 1 g CO_2e/MJ)

Source: Rystad Energy GasEmissionsTracker; Sphera (2021) 2nd Lifecycle GHG Emissions Study

LNG carriers WtT emission intensity

The main WtT results presented in this report detail the intensity of LNG used for bunkering fuel. This involves analysing the origins of the LNG used to provide bunker fuel from a bunker barge. In addition to bunkered LNG, there is an additional pathway by which LNG is consumed as a marine fuel; LNG carriers using their cargo as fuel.

In the case of LNG carriers, direct loading at LNG export terminal of liquefaction plants eliminates shipping, LNG import terminal, distribution and bunker barge stages, and their subsequent emissions.

The below table compares the WtT emissions intensity between LNG directly loaded into an LNG carrier compared to the LNG used for bunkering fuel. WtT emissions intensity for LNG carrier fuel was 11.8 g CO_2e/MJ in 2024. The WtT emissions of bunkered LNG fuel sits around 18% higher than that used for carrier LNG, at 13.9 g CO_2e/MJ.

The emissions breakdown of LNG carrier emissions is different to that of LNG used for bunkering. With a higher liquefaction and a lower upstream emissions intensity. The swings in intensity are linked to increased relative volume proportions from the Middle East, Asia and Oceania and decreased volumes from North America for global produced volumes versus bunkered volumes. This has the effect of lowering upstream intensity, which sits higher in North America than in the Middle East, Asia and Oceania, which in turn have a higher liquefaction emissions intensity than North America.

Global average WtT intensity of LNG carriers compared to bunkered LNG vessels

Value chain stage	Emissions intensity (g CO_2e/MJ) LNG carrier	Emissions intensity (g CO_2e/MJ) Bunkered LNG
Upstream	3.4	4.2
Transport & processing	0.9	1.3
Liquefaction	7.4	5.9
Shipping	-	1.8
Bunker operations/ distribution	-	0.7
Well-to-tank	11.8	13.9

Source: Rystad Energy GasEmissionsTracker

Methane coverage constraints

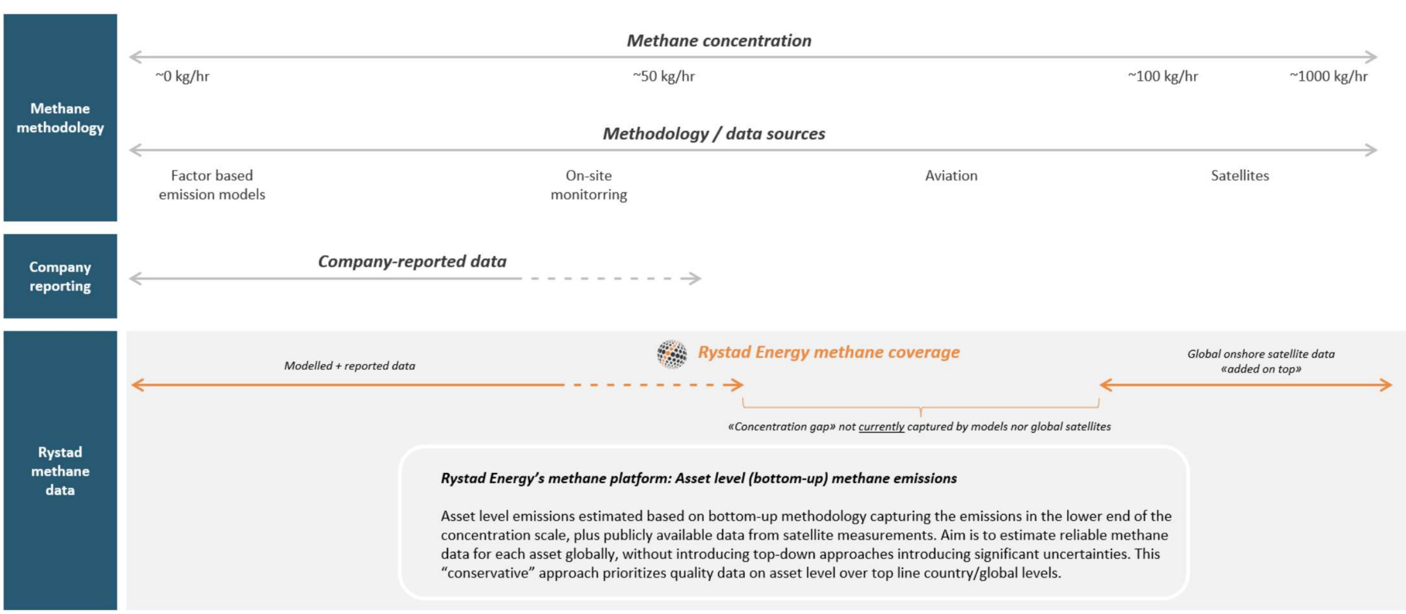
There are several unknowns to consider when tracking methane emissions. Rystad Energy's methane estimates use a combination of baseline methane profiles, asset-level estimates based on equipment inventories, and informed emission factors. The data is refined with reported data, both on asset and company/operator level where available.

Global satellite data is another key input in the process, covering the most significant upstream oil and gas methane emitters. Satellite-detected plumes are further contextualized with our facility overviews, which allocate all plumes to individual fields. This still leaves gaps, as smaller methane plumes are not registered continuously by satellites, and reported emissions are often based on assumptions rather than real-world data.

These uncertainties in methane monitoring are chiefly responsible for the numerous different outcomes and conclusions drawn from emissions studies. Discussions around leakage rates from upstream and midstream infrastructure and the potency of methane as a greenhouse gas can lead to different conclusions on the use of natural gas as a transition fuel. However, as the focus turns to methane emissions and the wealth of credible data grows from more granular satellites and increased on-site measurements, uncertainty surrounding methane data will diminish.

These technologies will also allow for methane analysis on a truly global scale, not just based on localised measurements from specific regions. This will in turn help reduce the emissions incurred in getting natural gas from well to market.

Rystad Energy's methane database versus company reported data



* Coverage capabilities can vary across different measurement technologies and platforms

Source: Rystad Energy EmissionsCube

Upstream feed gas emissions

The chart below details the LNG feed gas upstream emissions intensity for exporting regions globally. The data shown below has not been weighted to bunkered volumes, instead is representative of all LNG produced.

The global average for the combined upstream oil and gas production emissions intensity in 2024 was a little over 6 g CO_2e/MJ, with CO_2 emissions being responsible for just over half and methane responsible for the remainder. Significant volumes of feed gas for LNG is a byproduct of liquids production, and when analysed through the lens of liquids and gas production there is considerable variation as shown below, with liquids producing nearly 6.9 g CO_2e/MJ on average, versus gas at around 4.7 g CO_2e/MJ. Flaring rates and methane releases from liquids production drive intensity upward compared to gas production.

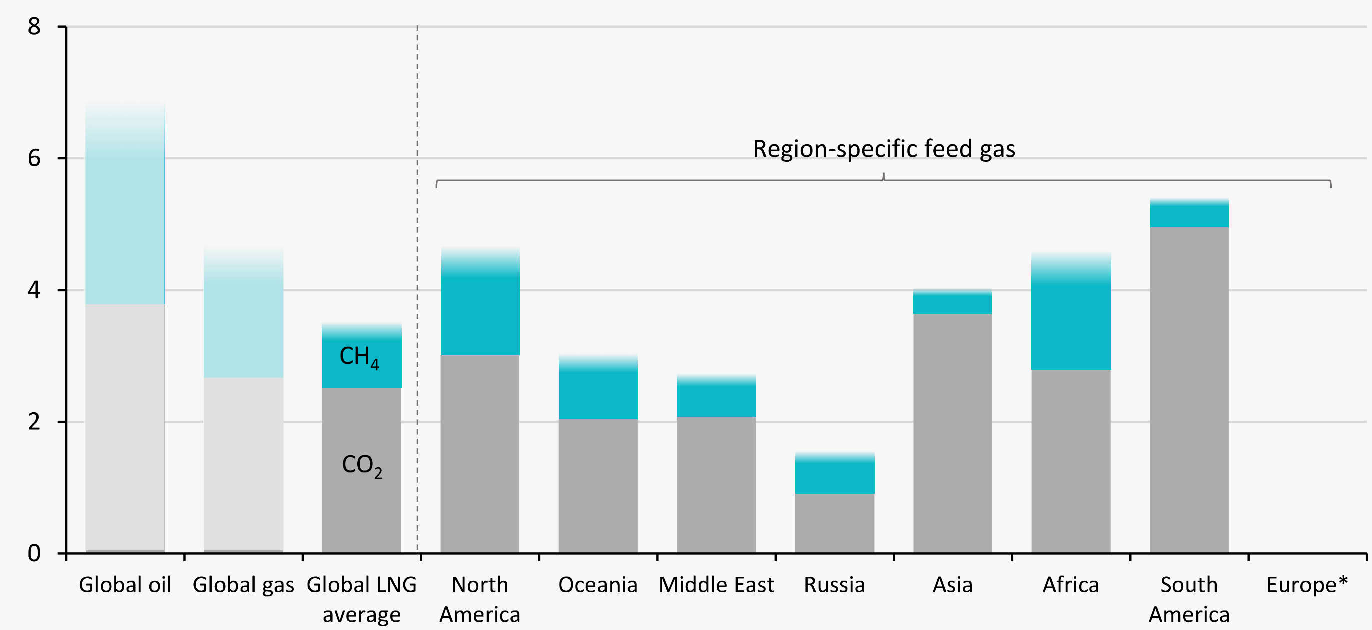
Assets producing feed gas for LNG plants typically have emissions intensities well below the global gas-producing average, with emissions rates of around 3.5 g CO_2e/MJ, of which methane accounts for around 30%. Methane rates are significantly lower for LNG feed gas than for natural gas production as whole. This is largely due to the greater proportion of feed gas for LNG that comes from offshore assets versus overall gas production. Both subsea tiebacks and conventional offshore platforms normally have lower methane emissions than conventional onshore gas fields.

Emission rates vary greatly between feed gas produced on different regions, and even more so between individual feed gas assets. Overall emissions intensity for regional feed gas varies from just under 1.6 g CO_2e/MJ for Russian volumes to around 5.4 g for South American feed gas. Feed gas for African LNG facilities has the highest rate of methane emissions, averaging around 1.8 g CO_2e/MJ, with North American volumes sitting slightly lower. Feed gas from South America are dominated by CO_2 emissions, driven mainly by mature production basins.

Upstream emission for feed gas can differ, substantially to all gas produced in a given region due to specific assets contributions.

Upstream emissions intensity of LNG exporting regions

g CO_2e/MJ



*European feed gas is fed by into liquefaction plants directly from subsea tieback. Power and emissions generation occur directly at the liquefaction plant, rather than the upstream asset itself.

Source: Rystad Energy EmissionsCube

Upstream flaring rates

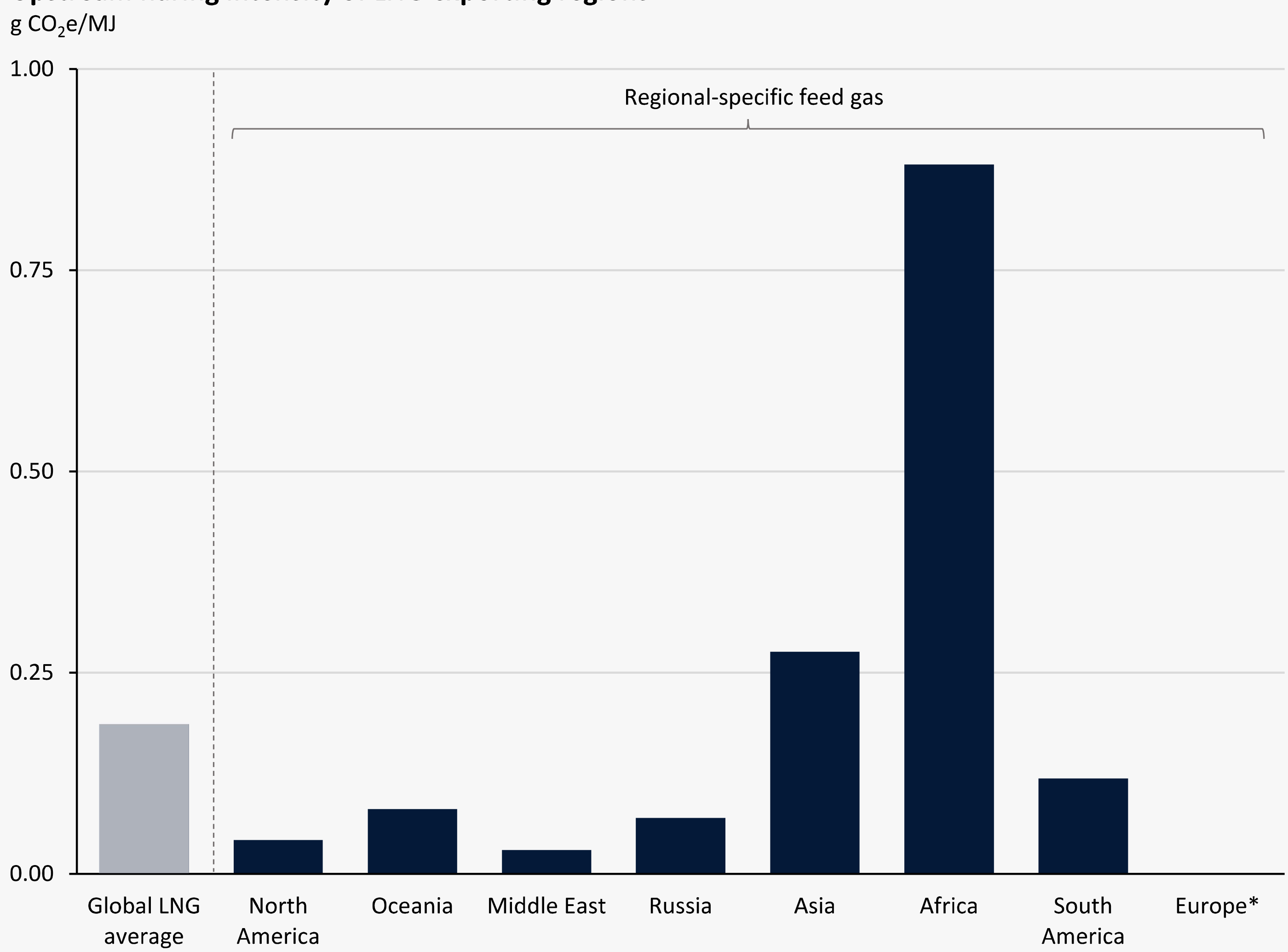
The chart below details the LNG feed gas upstream flaring emissions intensity for LNG exporting regions globally. The data shown below has not been weighted to bunkered volumes, instead is representative of all LNG produced.

The global average flaring emissions intensity for feed gas in 2024 was 0.2 g CO_2e/MJ. This rate is slightly below that of the global average for gas production, which was around 50% higher. These flaring rates are substantially lower than global flaring rates for oil production, which averaged around 1.5 g CO_2e/MJ in 2024.

African feed gas had an average upstream flaring intensity of just under 0.9 g CO_2e/MJ, far above the average for feed gas and and higher than the average for global gas production. Asia also had flaring intensity rates above the average for liquefaction plants.

Feed gas produced in the Middle East had the lowest flaring intensity from all LNG-producing regions, with exception of Europe (solely produced at Hammerfest LNG).

Upstream flaring intensity of LNG exporting regions



*European feed gas is fed by into liquefaction plants directly from subsea tiebacks.
Source: Rystad Energy GasEmissionsTracker

Transportation and processing

The chart below details the transport and processing emissions intensity for LNG exporting regions globally. The data shown below has not been weighted to bunkered volumes, instead is representative of all LNG produced.

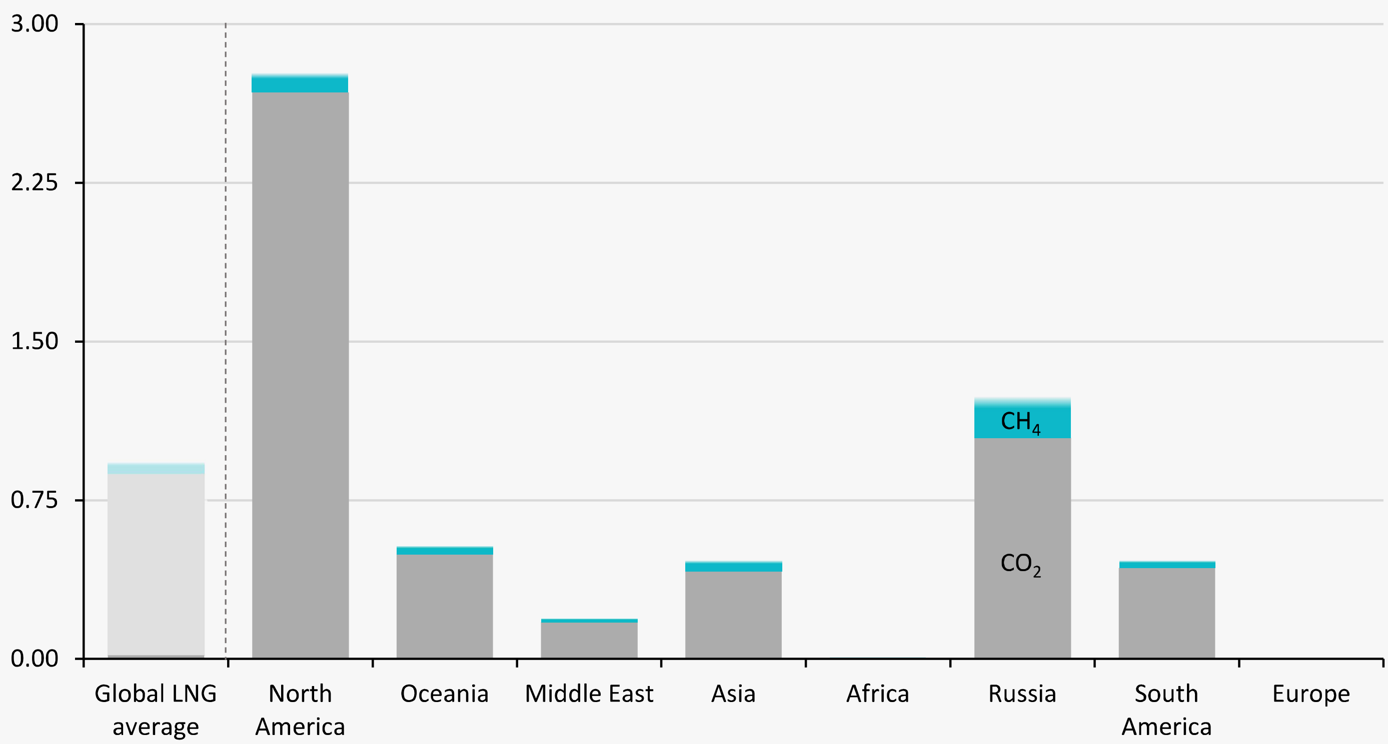
Liquefaction plant feed gas can vary significantly from asset-to-asset, both in terms of gas composition and the distance that must be covered. North America feed gas must, on average, travel more than 1,000 kilometers from production basins to the US Gulf and Atlantic Coasts. This distance leads to significantly higher transport emissions than those in other regions. Oceania and Africa feed gas covers significantly shorter distances, which is reflected in lower transport intensities. The associated emissions are further reduced by large volumes of feed gas in these regions stemming from offshore and subsea gas fields, with power for transport — and emissions — arising either at liquefaction plants or upstream facilities rather than compression stations along the pipeline.

The physical location of where gas processing occurs in the value chain can have a significant effect on emissions. Liquefaction plants located close to feed gas assets often perform all gas processing on site, rather than at a separate, dedicated gas processing facility. In these instances, plants will show zero emissions for processing, as this gas is processed either directly at the upstream asset or the liquefaction facility.

North America feed gas is pulled directly from the gas grid. Therefore, almost all gas is processed prior to entering the liquefaction facility (although this is further processed at the plant to reach the higher standards required for liquefaction).

Transportation and processing emissions intensity of LNG exporting regions

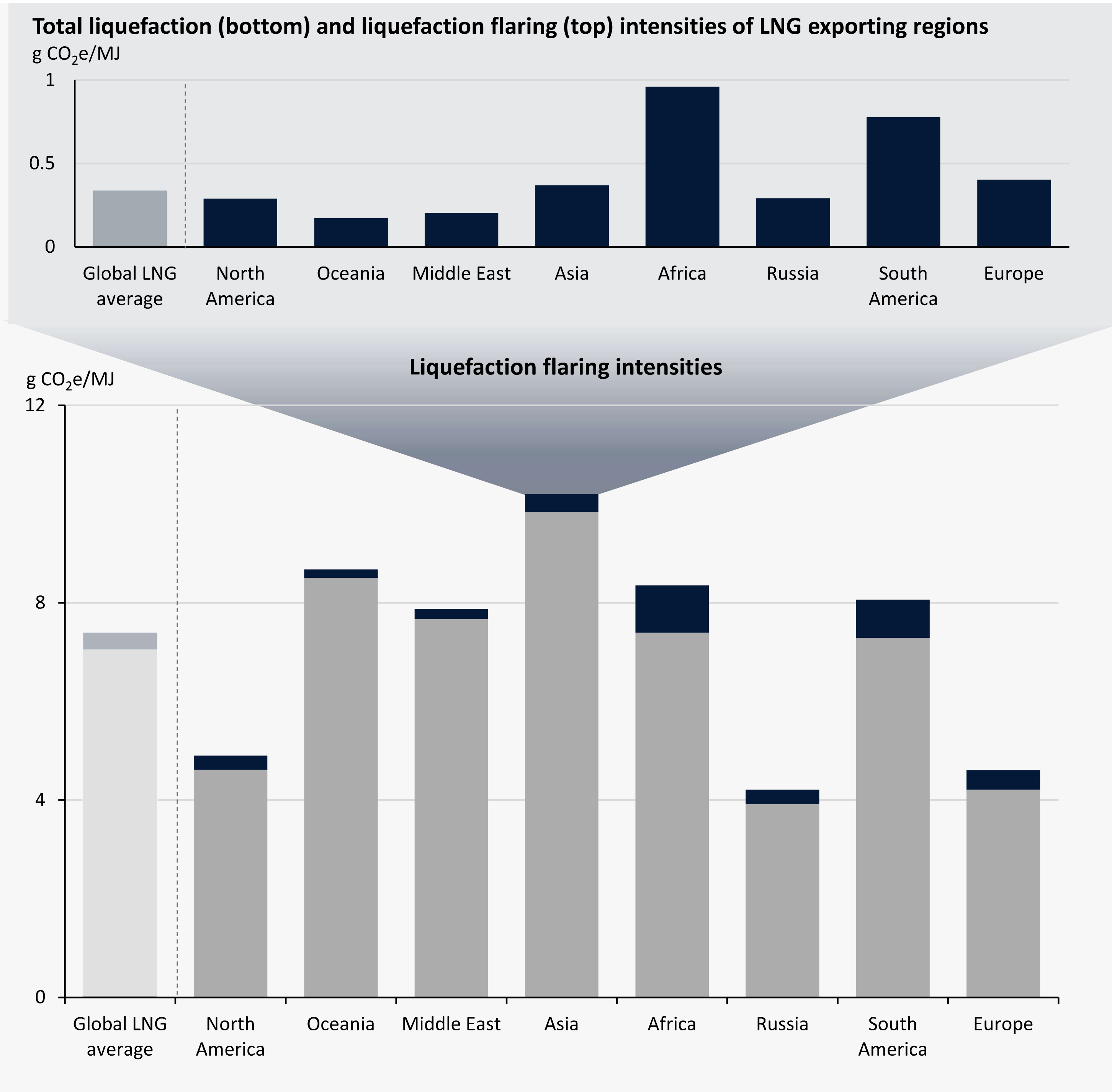
g CO_2e/MJ



Source: Rystad Energy GasEmissionsTracker

Liquefaction emissions

The chart below displays liquefaction emissions per exporting region, i.e. all emissions relating to the liquefaction process. This includes any emissions associated with power requirements for transporting and processing gas that occurs on site.



Source: Rystad Energy GasEmissionsTracker

Emissions intensity for LNG exporters

The chart on the previous page details the liquefaction emissions intensity for LNG exporting regions globally. The data shown has not been weighted to bunkered volumes, instead is representative of all LNG produced.

The global average for liquefaction emissions is just over 7.4 g CO_2e/MJ, with methane forming a small share of the total compared to carbon dioxide.

North American plants have the lowest average liquefaction intensities due to three main factors:

1. Having entered the LNG market in the late 2010s, the US has some of the world's most modern plants employing the latest technologies.
2. Coarse gas processing has already occurred prior to gas entering facilities, therefore minimal processing is required compared to liquefaction plants pulling gas directly from fields without intermediate processing.
3. The electrification of Elba Island and Freeport LNG reduces emissions due to power pulled from a partially decarbonised grid as opposed to gas turbines connected to the gas stream.

Russian LNG plants benefit hugely from the cooler ambient temperatures that average -2 degrees Celsius, compared to production in the rest of the world that takes place in mid-20s average temperatures. The cooler temperatures significantly reduce external energy input and subsequent emissions. Norway's Hammerfest LNG also benefits from low ambient temperatures in addition to direct connection to subsea fields for feed gas. Furthermore, this facility, fed by gas reservoirs with CO_2 content of up to 8%, reinjects the stripped gas rather than venting it, aiding the facility in producing the world's most competitive LNG from an emissions perspective.

Asian LNG facilities have higher-than-average liquefaction intensities due to high ambient temperatures coupled with high feed gas CO_2 content and no reinjection. These factors, combined with many ageing plants, push emission rates to near 10.2 g CO_2e/MJ.

African liquefaction facilities also face high ambient temperatures. However, a key factor in Africa's emissions intensity is much higher levels of flaring at liquefaction facilities versus elsewhere in the world. African liquefaction plants had the highest rates of observed flaring during 2024, with emissions averaging around 1 g CO_2e/MJ.

The global average for liquefaction plant flaring emissions is around 0.3 g CO_2e/MJ, representing around 4% of a liquefaction facility's overall emissions intensity. Oceania liquefaction plants had the lowest rates of observed flaring, with around 0.2 g CO_2e/MJ. European flaring rates were significant, due in large part to the connection of the feed gas subsea tiebacks directly into the liquefaction plant, which performs safety flaring that would ordinarily be completed at the upstream feed gas asset.

Source: Rystad Energy GasEmissionsTracker

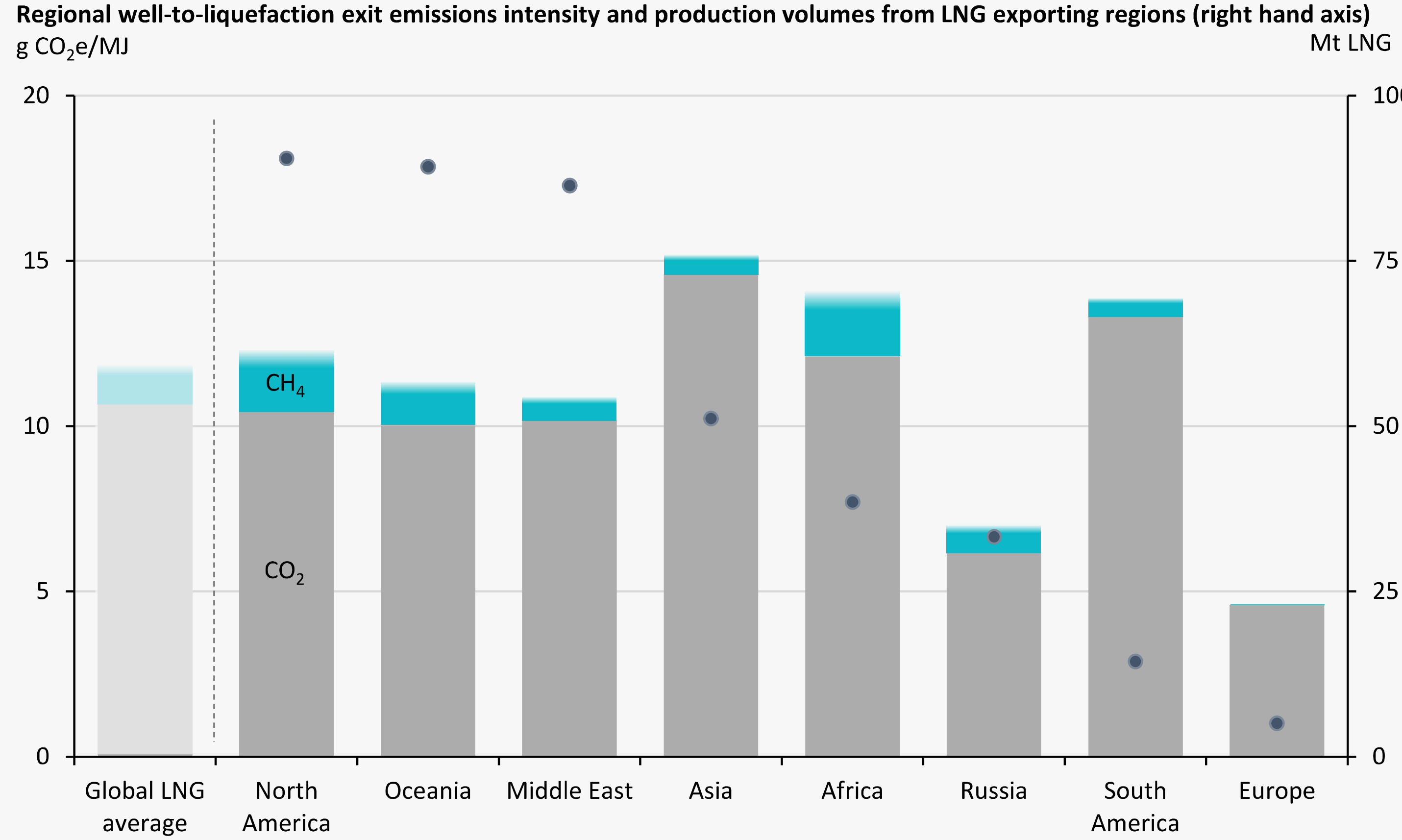
Well-to-LNG emissions – benchmarking

The chart below details the emissions intensity from production of gas at the 'well' to its exit at the liquefaction facility for LNG exporting regions. globally. The data shown below has not been weighted to bunkered volumes, instead is representative of all LNG produced.

This excludes the shipping and LNG terminal distribution & bunkering operations stages of the LNG value chain. 'Well-to-liquefaction exit' is a reasonable measure for comparison of liquefaction facility emissions performance, and eliminates stage variations, such as additional power requirements from the liquefaction facility. Summarisation of the below is based on produced volumes from each of the underlying liquefaction facilities and has not been scaled to that of the LNG being used for bunkering fuel.

- The global average of emissions intensity of LNG exiting liquefaction plants sits at 11.8 g CO_2e/MJ.
- There is significant variation in emissions intensity of LNG exiting liquefaction plants globally, with intensities ranging from 4.6 g CO_2e/MJ to near 15.2 g CO_2e/MJ.
- Methane emissions intensities vary significantly from region to region. On a global average of methane represents 10% of the total emissions. North American LNG, Russian LNG and African LNG, all have methane emissions responsible for roughly 12-15% of the total emissions of the LNG.
- European LNG is almost exclusively produced at Hammerfest LNG. The LNG exiting this facility has an emissions intensity far below that of other LNG sources, at around 4.6 g CO_2e/MJ.

Regional well-to-liquefaction exit emissions intensity and production volumes from LNG exporting regions (right hand axis)

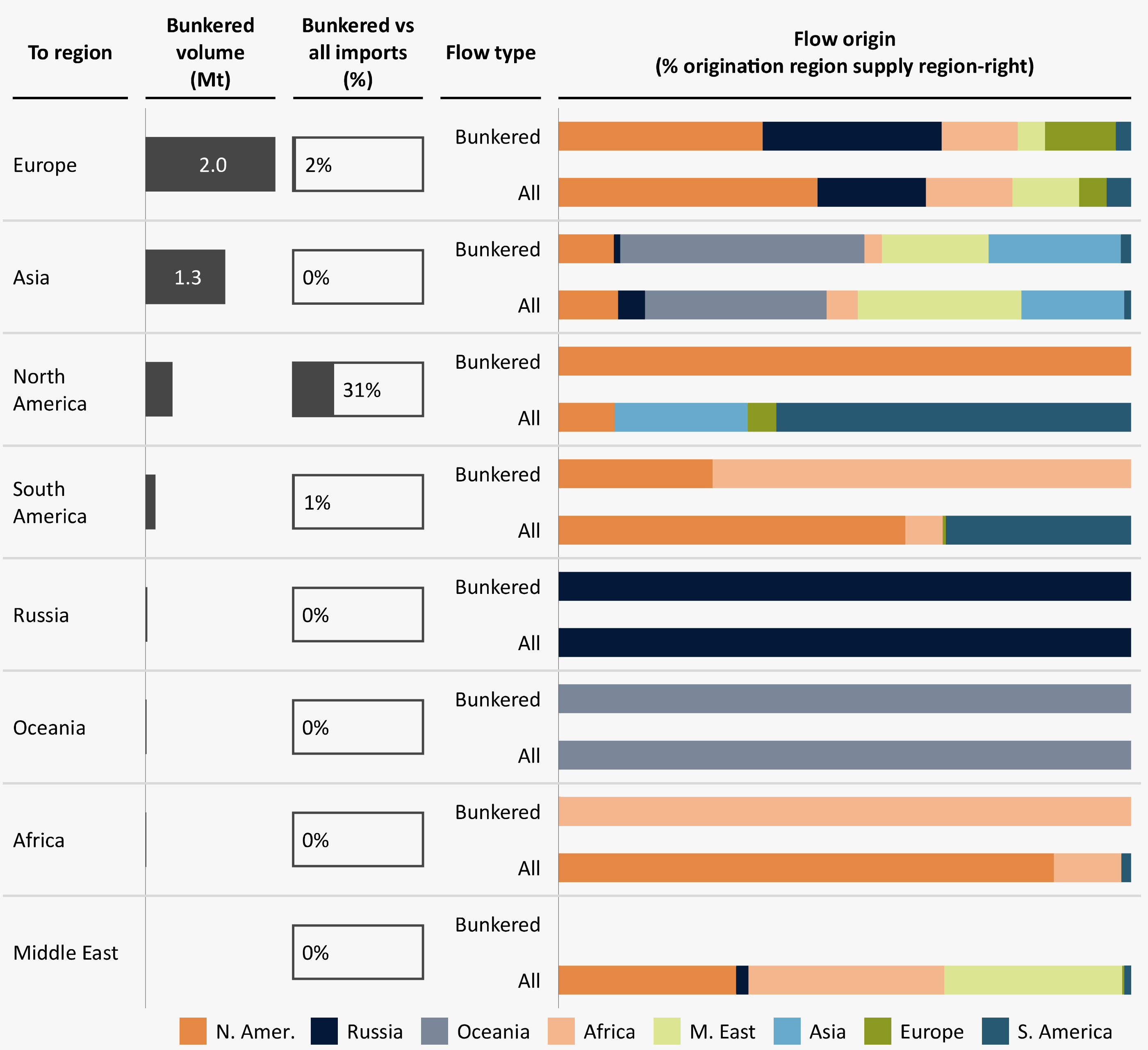


Source: Rystad Energy GasEmissionsTracker

LNG bunkered volumes

The table below displays bunkered LNG volumes by region, the volume of that bunkered volume versus total imported volumes of LNG into that region, and splits of volume origination for each of the regions for both the bunkered volume and all LNG imported into that region.

Regional volume LNG imports by origin location (bunkered and all imports)



Example, in the first row of the table it can be seen that Europe has been supplied by LNG originating from North America, Russia, Africa, Middle East, Europe (self flow) and South America.
Source: Rystad Energy GasEmissionsTracker

Global bunkered LNG volumes

The composition of LNG origination, and therefore the emissions contribution from each value chain, can vary significantly between all LNG entering a region and the LNG that is specifically loaded into the 'tank' of an LNG fuelled vessel. Rystad Energy's approach for this assessment is to look into the relative contributions of value chains that are specifically bunkered. However, the origin of LNG that is bunkered can vary significantly when compared to all LNG imported into a given region. To account for this, a sensitivity analysis has also been constructed to look into the overall difference between these two, as seen in the sensitivity analysis.

- Global bunkered LNG volumes totalled just over 3.9 million tonnes in 2024. Total produced LNG was around 400 million tonnes in 2024, meaning just under 1% went into bunker activities to ultimately to be loaded into the 'tank' of an LNG fuelled vessels.
- Singapore and the Netherlands delivered the greatest volumes of bunkered LNG in 2024, with around 0.46 million tonnes each. China and Sweden bunkered around 0.43 million tonnes, and Malaysia, France, Germany and the US all bunkered volumes over 0.22 million tonnes. The remaining 1.25 million tonnes was bunkered around the rest of the world.
- Even though the Middle East is one of the world's most significant LNG producers prior to early 2025, no LNG volumes had been bunkered in the region. Therefore, no results can be presented for this region.
- European LNG directly used in bunkering had a significantly smaller proportion of LNG from North America compared to the volumes Europe's total LNG imports (36% vs 45%) and that of the Middle East (5% vs 12%). Conversely, imports of Russian LNG made up a higher proportion of bunkered LNG volumes than total LNG volumes.
- In the Pacific, Asian volumes used directly for bunkering purposes had a saw greater volumes of LNG originating from Oceania, than the share of Oceania when looking at total imported volumes. In addition, Asian bunkered volumes had a smaller contribution of coming from the Middle East, than compared to the regions impact for total imported volumes.
- North American bunkered volumes almost entirely consisted of North American LNG. However, volumetric analysis shows that there were significant volumes imported from South America and Asia. Mexico, for example, received LNG from Indonesia.

Source: Rystad Energy GasEmissionsTracker

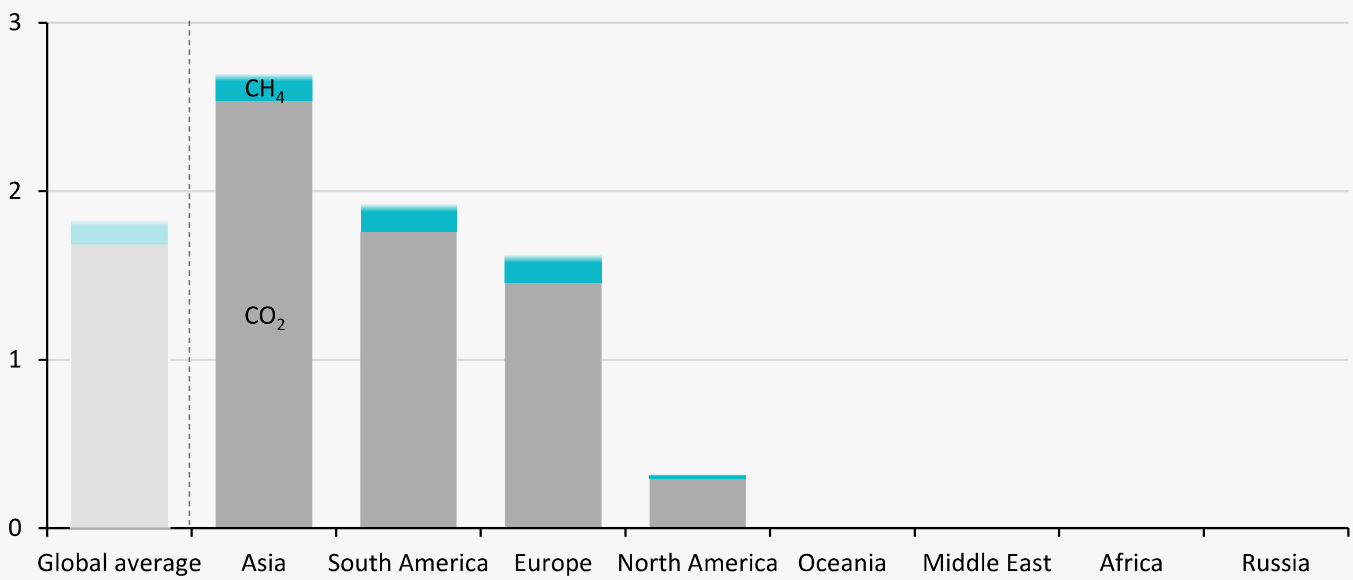
Shipping – emissions

The chart below details the emissions intensity from shipping of LNG. The data shown below has been weighted to bunkered volumes shown in the two previous page. Shipping emissions are modelled using several factors, including distance travelled, average speed, vessel engine type, fuel type, and vessel size. The chart below displays the relative volume-weighted shipping intensities of LNG bunkered in regions around the globe.

- Of the LNG bunkered in 2024, average shipping emissions intensity was 1.8 g CO_2e/MJ for a round-trip journey (both laden and ballast legs), with the average round-trip distance travelled around 15,000 kilometers (8100 nm).
- Shipping emissions arising from methane slippage accounted for around 8% of total shipping emissions. However, there was significant variation between methane emissions in each region, ranging from 6% in Asia to 10% in Europe. This highlights the trade-off involved in more efficient engines, which come with increased methane slippage compared to steam turbines. Some 55% of the Asia fleet delivering bunkered LNG in 2024 was powered by steam turbines, whereas in Europe the number was around 15%.
- The LNG cargoes delivered into Asia and used for bunkering had emissions intensities around 48% higher than the global average, mainly due to increased shipping distances and partly to regional technology differences.
- When emissions intensities are normalised for distance travelled, Asia fleets had shipping intensities 28% higher than their European counterparts, indicating that, although steam-based technologies have lower methane slippage, their overall lack of efficiency leads to detrimental emissions performance.
- The point along a value chain that bunkering occurs can have significant impacts on emissions intensity. Bunkering direct at or in close proximity to a liquefaction facility significantly reduces or completely eliminates the emissions associated with LNG shipping. Examples of this include North American, Oceanian, African and Russian shipping emissions which were far below the global average, partly due to very local supplies of bunkered LNG with minimal shipping required.

Regional shipping emissions intensity from importing bunkering region (weighted for bunkering region)

g CO_2e/MJ



Source: Rystad Energy GasEmissionsTracker

Report overview

Years

This report is based on 2024 data. This is to provide the best trade-off between the most up-to-date vessel tracking data and bunkering analysis, versus the greatest amount of reported emissions data being available.

Natural gas and LNG

Natural gas is a naturally occurring hydrocarbon gas which consists predominantly of methane (CH_4), in addition to some shorter-length alkanes and other gases such as carbon dioxide, nitrogen, hydrogen sulphide and helium.

The extraction process of natural gas can vary significantly according to whether the deposit is of conventional nature or unconventional, such as tight/shale gas or coal bed methane. Conventional gas production accounts for the largest proportion, roughly two-thirds of production by volume, with shale-related production accounting for a further 25%.

Liquefied natural gas (LNG) is natural gas that has been converted into a liquid form, through a process which involves cooling to a temperature of approximately –162 °C. This process, while energy-intensive, allows LNG to take up approximately 1/600th of its original volume, allowing for greater flexibility during storage and transportation. With this process, LNG can be transported with LNG carriers to a LNG import terminal, where it is restored to its gaseous state and transported to end users.

Allowable levels of impurities are far lower in LNG than in natural gas. Differing freezing temperatures of impurities can lead to damage to liquefaction plant equipment if not carefully controlled.

Conversion factors

Rystad Energy has leveraged the GasEmissionsTracker and EmissionsCube databases to provide emissions insights into the use of LNG as a marine fuel. Data housed within Rystad Energy databases are constructed on a barrel of oil equivalent (boe) production rates as is typical for the oil and gas industry. Consequently, all emissions intensities in our database are presented in the unit of kg CO_2e/boe.

For the purposes of this assessment, a conversion of the boe metric has been applied to convert the intensity of well-to-tank emissions to g CO_2e/MJ*.

*Equivalent to 0.0441 MJ/g LNG

Source: Rystad Energy research and analysis; Rystad Energy GasEmissionsTracker; API Compendium (2021) Table 3-8

Greenhouse gasses

The following greenhouse gases have been included in the assessment: carbon dioxide (CO_2) and methane (CH_4). Methane emissions have been presented in the report analysis in terms of carbon dioxide equivalence (CO_2e), with the global warming potential factor taken from IPCC's AR5 on a 100-year time horizon for methane with fossil origin.

This study has been written with respect to the global warming potential of LNG for use as a marine fuel, rather than its impact on local environments. Local pollutants, such as SO_x, N_2O NOx and particulate matter, have not been considered in this assessment.

Although high in terms of GWP when compared to CO_2, these pollutants have an insignificant global warming impact in this study when compared to CO_2 and CH_4, and are estimated to beless than 1% of lifecycle emissions associated with LNG from well-to-tank. This level of emissions is smaller than the error associated with data from CO_2 and CH_4, and consequently these are deemed to be immaterial.

Rystad Energy covers the global LNG trade on an asset-by-asset basis. The well-to-tank study presented is based upon the individual contribution of numerous feed gas assets, liquefaction facilities, and regasification and bunkering terminals, and leverages LNG vessel trade analysis to precisely estimate the global flow of LNG.

Emissions distribution/allocation

Rystad Energy uses a physical/perimeter-based methodology to emissions distribution along the well-to-tank value chain. The process involves assigning emissions to the stage where they were physically released or where power was directly imported from a grid. This distinction is important to avoid double counting emissions in a WtT calculation. This methodologies greatest impacts are most pronounced in the upstream, transportation & processing and liquefaction stages of the WtT value chain. For these stages the liquefaction facility itself can often be responsible for the processes onsite and can provide the power to other nearby facilities. Consequently, in these instances these the emissions are directly attributed to the liquefaction stage rather than upstream or transport & processing. Key examples can include:

- **Subsea tiebacks:** Liquefaction facilities can often be fed by subsea tiebacks, where gas is supplied to the liquefaction facility directly rather than through topside infrastructure. In these instances all power (and emissions) for upstream extraction, transportation and natural gas processing occurs at the liquefaction facility. Consequently, all emissions are assigned to the liquefaction facility itself and not to separate stages.
- **Gas processing and transportation:** Where upstream facilities are located in close proximity to feed gas upstream assets, gas processing will typically occur within the liquefaction facility, and hence processing emissions are assigned to the liquefaction stage. Similarly close proximity between feed gas assets and liquefaction plants implies that power to transport gas (and hence emissions) are included within the upstream or liquefaction stage, as there will be no specific boosting stations between the two assets from which transport emissions can occur.

GWP factors used for CO_2 and CH_4 emissions

Greenhouse gas	GWP factor
CO2	1
CH4	28

Source: Rystad Energy research and analysis; Rystad Energy GasEmissionsTracker; IPCC Global Warming Potential Values – AR5, (2014)

Liquefaction plants

Rystad Energy's GasEmissionsTracker benchmarks the emissions performance of over all major operating LNG facilities, allowing for analysis emissions performance from well-to-tank or well-to-market for each facility.

LNG plant coverage, 2024

Oceania	Asia	Middle East	Africa
Australia Pacific LNG	Bontang LNG	QatarGas LNG	Damietta LNG
Darwin LNG	Donggi-Senoro LNG	Adgas LNG	Egyptian LNG (Idku)
GLNG	Tangguh LNG	Oman LNG	Coral South FLNG
Gorgon LNG	MLNG	Yemen LNG	Angola LNG
Ichthys LNG	Petronas FLNG 1 Satu		Congo Marine XII FLNG
North West Shelf LNG	Petronas FLNG 2 Rotan		Cameroon FLNG
Pluto LNG	Brunei LNG		NLNG
Prelude FLNG			EG LNG
Queensland Curtis LNG			Arzew GL1Z
Wheatstone LNG			Arzew GL2Z
PNG LNG			Arzew GL3Z (Gassi Touil)
			Skikda GL1K

South America	North America	Europe	Russia
Peru LNG	Altamira LNG	Hammerfest LNG	Portovaya LNG
Atlantic LNG	Calcasieu Pass LNG		Sakhalin 2
	Cameron LNG		Vysotsk LNG
	Corpus Christi LNG		Yamal LNG
	Cove Point LNG		
	Elba Island LNG		
	Freeport LNG		
	Maxville LNG		
	Plaquemines LNG		
	Sabine Pass LNG		
	Tilbury LNG		

Source: Rystad Energy GasEmissionsTracker

Upstream methodology – feed gas composition of liquefaction plants

Understanding the feed gas composition of LNG is crucial to accurately estimating the upstream greenhouse gas footprint of LNG for use as a marine fuel. Large variations exist in the upstream emissions intensity of differing sources of gas production. Accurately understanding the location of feed gas is thus vital.

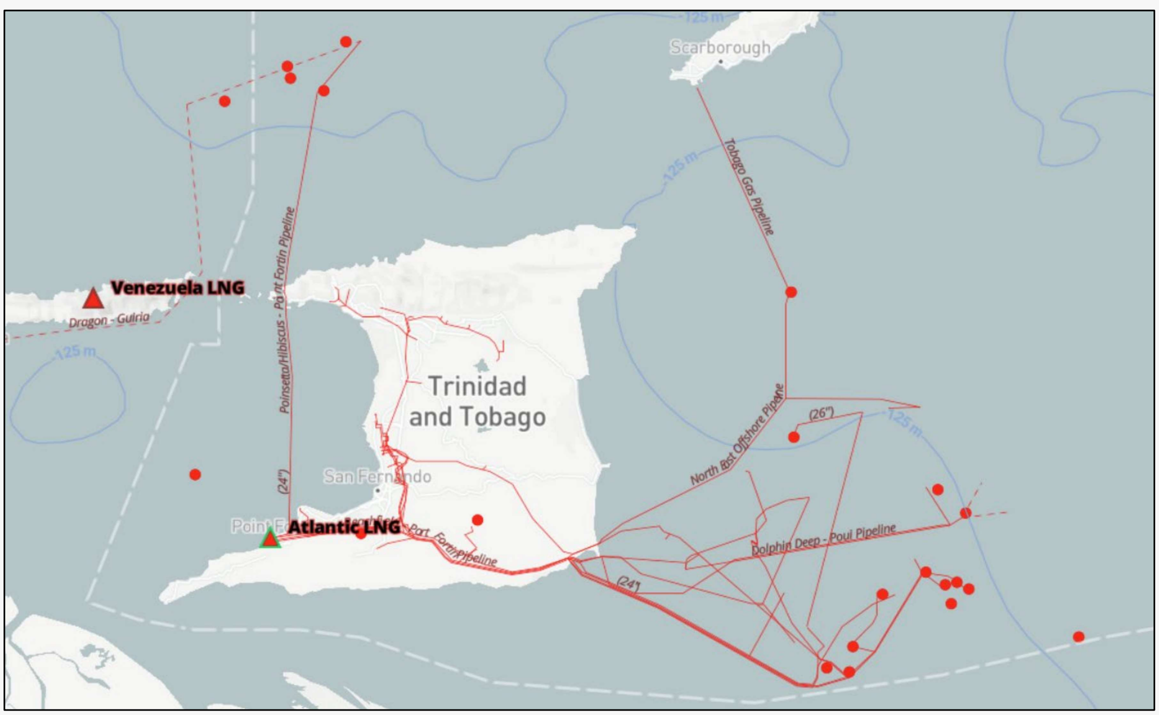
To this end, the study leverages Rystad Energy's bottom-up upstream oil and gas database 'UCube', which covers global production from more than 85,000 fields and licenses. Each asset has a wide range of different data types, both dynamic data (production profiles, economics, ownership, etc.) and static data (location, development solution, infrastructure information, etc). This data is available on a year-by-year basis, with the database stretching from 1900 through to 2100.

The individual upstream assets that supply feed gas have been assigned to a given liquefaction facility. An example can be seen below for Atlantic LNG, where individual red dots represent upstream assets that are tied to the facility.

As discussed, the UCube database provides yearly oil and gas productions rates for each upstream asset, including the upstream assets supplying feed gas for LNG. With this information. Rystad Energy can estimate the relative proportions of feed gas each individual asset supplies to any given liquefaction facility (i.e. feed gas asset 1 supplies X%, asset 2 Y% and asset 3 Z%).

In addition to global oil and gas production volumes, Rystad Energy is tracking associated emissions and making the data available in our EmissionsCube database. The relative proportion of feed gas to a given liquefaction facility can therefore be used to distribute the relative impact of the upstream emissions of each of the oil and gas feed gas assets to provide a volume-weighted overview of upstream emissions intensity for each liquefaction facility.

Upstream asset tagging to liquefaction facilities (example: Atlantic LNG)



Source: Rystad Energy GasEmissionsTracker; Rystad Energy EmissionsCube

Upstream methodology – GHG overview

Rystad Energy's EmissionsCube is a complete global field-level upstream emissions database that includes emissions originating on-site from the extraction process of oil and natural gas. The database is powered by Rystad Energy's upstream database UCube. EmissionsCube includes both carbon dioxide (CO_2) and methane (CH_4) emissions from fugitive emissions and venting activities.

Rystad Energy defines upstream emissions as all on-site emissions originating from the extraction process of oil and natural gas. This also includes emissions from upstream flaring and imported power. Emissions from exploration activities such as seismic and exploration drilling are not included, and neither are emissions related to the fabrication, construction and installation phase. Compared with the other emission categories, these emissions are marginal (typically less than 1% of upstream emissions). On-site emissions include emissions from production drilling, on-site combustion from the extraction process (gas turbines and diesel engines), fugitive methane, vented methane and flaring. Emissions related to gathering and boosting (G&B) of natural gas are also included in the upstream definition in this report. This is especially relevant for onshore US shale developments.

All 85,000 assets in UCube are assigned an annual GHG emissions profile from start-up to shutdown, including producing fields (historical emissions and future projections), fields under development (sanctioned fields), discoveries (non-sanctioned fields), and exploration licenses (risked volumes where emissions are modelled based on the supply segment, empirical data, and regional trends).

The mechanisms by which field-level emissions profiles are estimated vary depending on the greenhouse gas in question (see later pages). However, an overarching methodology is applied based on a hierarchy of data sources from reported field-level data, reported aggregated data (e.g. by operator), satellite data (flaring and methane) and Rystad Energy's proprietary upstream emissions models.

Upstream CO_2 and CH_4 profiles are determined by a hierarchy of data sources used for data collection and calibration. The highest of these data sources is reported field-level data, with this given priority, followed by field-specific satellite flaring, then aggregated benchmarks (such as company or regional-level reporting) which can be used to calibrate modelled numbers and, finally, purely modelled emissions.

Rystad Energy's UCube database assigns annual production profiles to each upstream asset, for all co-products, such as crude oil, condensate, NGLs and gas. Production for these co-products is tracked in terms of energy equivalence of production, using a barrel of oil equivalent (BOE) as the basis. The energy split between co-products is combined with annual GHG emissions profiles of the assets, to distribute emissions between the product categories. The assessment presented in this report focuses on the relative contribution of only gas produced at feed gas assets.

Source: Rystad Energy GasEmissionsTracker; Rystad Energy EmissionsCube

Upstream methodology – CO_2

Field-level emissions

Reported emissions, where the information is of high-enough quality, is linked directly to Rystad Energy's emissions sources and to the UCube asset structure. These data points are classified as 'fixed' and are not calibrated, regardless of any aggregated benchmarks.

For flaring emissions, where these are not explicitly reported, Rystad Energy uses satellite flaring data from Earth Observation Group (VIIRS Nightfire). Rystad has developed a GIS methodology for assigning satellite upstream emissions to oil and gas assets, using actual field shapes (reservoir boundaries) and latitude/longitude coordinates. By tagging upstream flare sites (and hence flaring volumes measured in cubic meters) to oil and gas-producing fields, flaring CO_2 emissions and intensities can be calculated. Upstream flare sites located outside known field boundaries are also assigned to producing oil and gas assets by using distribution functions based on distances, production volumes, supply segments, and field types (oil fields vs. gas/gas-condensate fields). Similarly, reported data-matched satellite flaring volumes are 'fixed' and cannot be calibrated.

Asset modelling

Where no asset-level is reported, or if the data is impossible to disaggregate in a meaningful way, Rystad Energy's proprietary asset-level extraction emissions models are used to estimate emissions rates from oil and gas fields. These modelled emissions rates are calibrated if a valid calibration datapoint exists for these assets, or if not, are used as the determinate for a given oil or gas field

Rystad Energy has over several years developed extraction models based on our analysis of emission drivers, which use empirical field-level data, scientific reports, and industry interviews. Drivers vary between different field types: for example, conventional fields are by nature different from shale, and so, too, are the drivers for emissions. Another example is crude quality. Heavy oil fields require more energy in the extraction and pre-processing phase. Where reliable reported data exists, the models are overwritten or calibrated.

For a given asset, all years that are not reported at asset level are modelled from field start-up to shutdown. Powered by UCube and other commercial and internal databases, Rystad Energy can estimate annual emissions from 1900 to 2100 by using identified drivers for each emission source. For example, future upstream flaring emissions are estimated by calculating historical intensities based on either reported figures or satellite data, which are further multiplied by liquids production (a key driver). Another example is drilling emissions, where the number of wells is the key driver. Here we use our global WellCube database, with both historical and future well data on the asset level. Maturity of an oil and gas field has a key impact on emissions intensities with rates progressing upwards as an asset matures.

For assets with historical reported data, information from the corresponding calibration is taken into account in the emission forecasts. Future projections on the operator and company level assume that no asset/portfolio/company transactions which have not been agreed upon and communicated to the market will take place, and that new field startups and mature field shut-downs will occur at Rystad Energy's estimation.

Source: Rystad Energy EmissionsCube

Aggregated benchmarks

The second priority is reported aggregated benchmarks. This can be both top-line upstream emissions for a country, region, basin, or operator, or a combination thereof. However, countries, operators and companies have vastly different reporting methods, with different assumptions, emissions boundaries, and coverage. Therefore, reported data from one operator cannot be compared directly with another operator without a thorough analysis of their reporting schemes.

While a few companies report on the asset level, most report emissions on an aggregated level. Some report different branches of the company separately (e.g. upstream), while others report on the corporate level. Some report Scope 1, while some report Scope 1, 2 and 3 combined. Some report CO_2, while others report total GHG emissions including CO_2. Some report operated emissions, while some report owned emissions (equity-based, i.e. on all assets with ownership interest). The system boundary for what the company defines as "upstream" also varies and can contain several elements which Rystad Energy's upstream definition may or may not include. Rystad Energy therefore analyses reported benchmarks and makes the necessary adjustments to obtain a set of consistent and comparable data. All suitable benchmarks are incorporated in the emissions database, and field-level emissions are calibrated to reach reported top-line benchmarks.

Calibration inputs

As mentioned previously, every upstream oil and gas asset is assigned to both static and dynamic data, such as the basin the asset is situated in, the operating company running an asset in a given year or current ownership.

Therefore, for a given aggregated benchmark, whether for an operator or a basin, Rystad energy has an understanding of the exact assets that are operated by a given company, or the assets that are situated in a given basin, respectively.

When a benchmark is applied, Rystad Energy models ensure that the summation for asset level emissions for each of operator/basin/region adds up to the topline of the input.

For each asset globally there are a number of fixed emissions associated to each asset, these stem from scouted data points or matched satellite data, minimum levels of emissions from different emissions sources. These fixed data points cannot be adjusted by the calibration process.

On the flip side, for a given asset there are often a series of non-fixed emissions, such as modelled emissions, that can be calibrated to ensure that asset emissions, when combined, will sum up to the given benchmark for an operator. Calibration takes into account the same factors used by modelling, in addition to relative contributions of emissions, maximum caps for certain emissions categories and the relative contributions of each asset relative to each other to scale non-fixed data points to ensure matching of the benchmarks topline.

Source: Rystad Energy EmissionsCube

Upstream methodology – CH_4

Similarly to CO_2 profiles, CH_4 profiles are determined by a hierarchy of data sources used for data collection and calibration. Methane emissions are generally more challenging to estimate compared to carbon dioxide as the latter is directly linked to the energy demand on site. Methane emissions, on the other hand, are linked to fugitives/leakage and venting, which inherently means that monitoring and measurements are required to obtain more reliable estimates. Rystad Energy has therefore developed a flexible methane platform that is designed to include current and future available measured and reported data.

Currently, the upstream methane database includes asset-level reported data (in regions where available), quality aggregated reported data (e.g. company and regional level), methane satellite data, and aggregated/derived flaring data (based on VIIRS Nightfire, Colorado School of Mines).

Due to the nature of methane emissions, the methane hierarchy of data follows a similar, yet slightly different hierarchy to that of CO_2. More focus is therefore placed upon empirical data measurements, such as satellite-detected plume, rather than purely reported data.

Field level emissions

Reported emissions, where this information is of high-enough quality, are linked directly to Rystad Energy's emissions sources and to the UCube asset structure. These data points are classified as 'fixed' and are not calibrated, regardless of any aggregated benchmarks. Similarly, flaring volumes can be used to assign a proportion of unburnt hydrocarbon (methane emissions) to individual assets (see above methodology on flaring assignment).

On-site methane measurement data is very limited on a global scale and is rarely made public. Satellite data is therefore currently the most important technology for global methane tracking, even with its limitations such as detection thresholds, frequencies, and geographical coverage. Rystad Energy uses global facility inventory overviews for targeted processing of upstream locations globally and then allocates plumes to assets based on reservoir boundaries, facility locations, and production levels, among other factors.

Satellite plume analysis

Rystad Energy's upstream facility dataset (UCube) location information is used for targeted satellite data (Sentinel 2/5) processing. This enables global coverage of all relevant upstream facilities. The satellite coverage includes all onshore upstream facilities consistent with Rystad's boundary definition. As is the case for all satellite imaging/processing, offshore is not covered due to factors such as background noise and the generally limited methane emissions.

CH4 plumes and concentrations (kgCH4/hr) are allocated to Rystad Energy's assets based on well locations, reservoir boundaries and other facility location information, in addition to other relevant data such as oil and gas production mix and field type. Rystad Energy is utilising a risking approach when plumes are located outside field shapes (upstream facility locations) and could potentially also be related to other nearby infrastructure.

After each methane plume (which has a corresponding time stamp) has been assigned an asset, accumulated concentrations (kg/hr) are calculated per day (per asset) and assumed to be lasting for 24 hours (the entire day). Then, the day gaps are estimated, which is based on Rystad's proprietary methodology. Input data includes satellite observations (where no plumes have been qualified for different reasons), in addition to satellite overpasses with no plumes detected. Based on this data, in addition to historical detected plumes and methane activity level, Rystad Energy estimates methane emissions in between the snapshots.

Source: Rystad Energy EmissionsCube

The final step is to estimate and accumulate each asset level methane emission profile to annual levels. This is done for all onshore assets globally with satellite data allocated. This dataset is furthermore used as input in the broader methane platform.

Asset-level emissions are estimated based on bottom-up methodology capturing the emissions in the lower end of the concentration scale, plus publicly available data from satellite measurements. The aim is to estimate reliable methane data for each asset without introducing top-down approaches with significant uncertainties. This conservative approach prioritizes quality data at the asset level over top-line country/global levels.

The latter issue highlights the fundamental challenge in methane emission calculations: estimates and assumptions are needed to calculate absolute emissions, which introduces uncertainties. This also speaks to the need for more accurate and high-quality reported measurement data in the industry. As more data is made available, the Rystad Energy methane platform will evolve and provide increasingly more accurate figures.

Asset modelling

Once again, bottom-up methane models are in place to model underlying methane fugitive emissions. The starting point and foundation of this data is our global facility inventory overviews, including asset-level information such as geographical location, development solution, ownership/operatorship, hydrocarbon production, infrastructure information (e.g. number of well completions) field types, well sizes, production volumes and on-site energy demand. Based on facility inventory and relevant activity data, Rystad Energy establishes a baseline methane emission profile for each oil and gas asset, using empirical information and measurement-informed factors.

Calibration inputs

Baseline modelled fugitive, combusted, and vented CH_4 emissions are also calibrated for a given aggregated benchmark, whether for an operator or a basin, allowing for the summation of asset-level emissions for each operator/basin/region to 'add up' to the topline of the input. This is similar to the methodology applied for CO_2 emissions, however there is a divergence when it comes to satellite methane data.

As mentioned, satellite methane plume analysis is an important addition to Rystad Energy's methane database. Satellite methane plumes are typically not included* in the calibration process for operators or regional/basin level emissions estimates. Typical methods for estimating upstream oil and gas methane emissions by the majority of operators/overseers globally rely heavily on factor/engineering-based approaches, rather than empirical measurements. This approach assigns an expected methane release factor to each component on site and builds those up to provide asset-level and then company-level emissions rates. This methodology has been shown to severely underestimate upstream emission rates as it fails to capture any large-scale methane releases.

The bottom-up, facility-level approach is different compared to top-down. While the latter focuses on obtaining a complete aggregated estimate of methane emissions in a specific sector or region/country (or globally), the bottom-up approach uses activity drivers and measurements to obtain a fundamental view of methane emissions on the asset level.

*In the instances where satellite analysis is included for operator-reported methane emissions, calibration methodology is altered accordingly.
Source: Rystad Energy EmissionsCube

Transportation and processing methodology

Feed gas transportation

Rystad Energy defines transportation emissions as all on-site emissions originating from the transportation of natural gas from production at the upstream asset through to the liquefaction facility. This includes all energy-related emissions (i.e. diesel/gas combustion at compressions stations, etc.), imported power (scope 2) and fugitive methane emissions.

Many factors affect transportation emissions, the most significant of which is distance travelled between upstream feed gas assets and the liquefaction facility. As mentioned, individual upstream assets have been tagged directly to their relative liquefaction facility. In addition to this tagging, Rystad Energy has a global database of oil and gas infrastructure. Most importantly, this application includes gas pipelines — in addition to tagging to relevant liquefaction plants, upstream assets are tagged to their linked gas pipeline. This allows asset-by-asset estimation of distances that feed gas travels to reach its destination.

Once the relative distances from the liquefaction facilities is understood for all feed gas assets, a volume weighed supply distance can be calculated based on the relative volumes weighted distance of supply each liquefaction plants feed gas has undergone. These distances are combined with CO_2 and CH_4 emissions factors, which take into account electrification status of the relevant pipeline network, expected leak rates and geographical emissions factors.

Another factor impacting the transportation emissions is the type of facilities that supply feed gas to liquefaction facilities. A large number of facilities globally are supplied by subsea tiebacks involving no topside infrastructure. Subsea tie-backs instead receive power and directly flow via subsea pipelines to an existing piece of infrastructure kilometres away, and tie directly into a liquefaction facility. This can have significant impact on the overarching emissions for transportation because the power to drive a subsea tieback originates from the liquefaction facility itself rather than power along the pipeline at compression stations. These transportation emissions are therefore captured at the liquefaction facility, and any additional pure transportation emissions would be double-counting. Norway's Hammerfest LNG, for example, is fed by subsea tiebacks that receive power from the LNG plant; consequently, transportation emissions are near zero.

Regional average gas transport distance

Region	Average transport distance (km)
North America*	1,200
Oceania	300
M. East	107
Russia	196
Asia	120
Africa	315
South America	197
Europe	130

*North American liquefaction plants fed from an interconnected gas grid, average distance and feed gas reservoir content based on average weighting from relative contribution from producing assets.
Source: Rystad Energy GasEmissionsTracker

Gas Processing

Rystad Energy defines gas processing emissions as natural gas processing that occurs after production at the upstream asset and prior to entry into the liquefaction facility (processing emissions at the liquefaction facility are not included in this stage).

The majority of natural gas must undergo some level of gas processing before it can enter gas networks. The purpose of gas processing is to remove impurities from the gas which can be toxic and or damaging to infrastructure if not removed. Typical impurities include sulphides, carbon dioxide, water, heavy metals, and heavier hydrocarbons. Because of the risks to transporting unprocessed gas and the increased cost of constructing infrastructure able to cope with unprocessed gas, gas processing typically occurs in close proximity to upstream production sites.

Typically, most gas has undergone some form of processing prior to entering a liquefaction facility, but not always. Therefore, similarly to transportation emissions, ensuring that the emissions from gas processing are assigned to the correct location is vital to ensuring lifecycle emissions are accurate and accounted for, and avoids double-counting.

Rystad Energy is tracking gas-processing plants globally and has used this information in combination with the feed gas supply asset data to estimate whether gas processing has occurred before feed gas enters an LNG facility or first occurs at the liquefaction facility.

Rystad Energy's gas processing module estimates emissions from around the globe, including emissions related to phase separation, acid gas removal, water removal, fractionation, flaring, gas compression, imported power (scope 2), fugitive methane emissions and other gas treatments.

Regional average feed gas reservoir CO_2 content

Continent	Feed gas reservoir CO_2 content (%)
North America*	4%
Oceania	7%
Middle East	5%
Russia	5%
Asia	8%
Africa	5%
South America	5%
Europe	8%

Reported facility-level gas processing is used to calibrate and improve the accuracy of emission models. Depth of electrification and typical technology installed in different geographies, alongside the properties of the gas, all feed into the module to provide estimations of processing emissions. In addition to all processing-related emissions that occur prior to natural gas entering the liquefaction facility. This includes

The level of reservoir CO_2 content in the feed gas supplying the liquefaction facilities is also key to assessments. Again, Rystad Energy's EmissionsCube has estimations of reservoir CO_2 content for every upstream oil and gas asset globally. Combined with the respective proportion of feed gas supply from each assets, this can be used to estimate the volume of stripped CO_2 during processing.

Compared to piped natural gas, the allowable CO_2 content of LNG is far lower due to limitations involved in the liquefaction process. Even if gas processing has occurred prior to gas entering an LNG facility, further processing must be performed.

*North American liquefaction plants fed from an interconnected gas grid, average distance and feed gas reservoir content based on average weighting from relative contribution from producing assets.
Source: Rystad Energy GasEmissionsTracker

Liquefaction methodology

Similar to upstream oil and gas assets, Rystad Energy is tracking liquefaction plants globally. This includes all emissions originating from the liquefaction process, including both CO_2 and CH_4 emissions from combustion and power-dependent activities, in addition to methane emissions from fugitive & venting emissions and associated emissions from imported power. The database is fed with data points on liquefaction plant production and infrastructure from Rystad Energy's GasMarketCube.

Similarly to the upstream co-product based emissions distribution, liquefaction plants are assigned emissions profiles based on the relative contribution of products. i.e. total plant emissions are distributed between LNG and LPG production rates based on an energy related distribution.

Rystad Energy defines liquefaction emissions as all emissions tied to the liquefaction process of natural gas. This includes gas reception, gas conditioning/fractionation, direct liquefaction emissions, venting and fugitives, LNG storage and loading, reservoir CO_2 removal, flaring and in certain instances (below) transportation and processing emissions. Emissions from construction or installation are not included as these emissions are marginal when compared to direct emission activities.

All 100+ global liquefaction plants are assigned an annual GHG profile from 2010 through to 2030, including producing plants, plants under development and historical plants. The mechanism by which plant-level emission profiles are estimated vary depending on the plant itself and the greenhouse gas in question, based on a hierarchy of data sources from reported field-level data, reported aggregated data (e.g. by operator), satellite data (flaring and methane) and Rystad Energy's proprietary upstream emissions models.

Data collection for liquefaction facilities follows a hierarchical structure. The highest level of data for liquefaction facilities is reported asset-level data, which is given priority, followed by field-specific satellite flaring and then modelled emissions rates.

Asset-level reporting

Reported emissions data, where this information is of high-enough quality, is linked directly to Rystad Energy's emissions sources and to the liquefaction plant asset structure.

Matched satellite data

Rystad Energy has processed methane satellite data around multiple LNG facilities globally but has not detected a plume. Indicating the low levels of methane emissions from liquefaction facilities.

For flaring emissions, where these are not explicitly reported, Rystad Energy uses satellite flaring data from Earth Observation Group (VIIRS Nightfire). Rystad has developed a GIS methodology for assigning liquefaction-related flare sites to liquefaction plants, using physical plant boundary shapes and latitude/longitude coordinates. By tagging liquefaction flare sites (and hence flaring volumes measured in cubic meters) to plants, absolute flaring volumes and emissions intensities can be calculated.

Flare volume tagging (example: Hammerfest LNG)

Source: Rystad Energy GasEmissionsTracker

Understanding facility processes

Accurately estimating emission rates requires understanding the processes taking place plant by plant. As discussed in the transportation and processing section, there are many plants where power for transportation of feed gas, and therefore emissions, originate at the plant itself. To accurately estimate the impact of this, additional energy requirements related to transportation emissions need to be allocated to the facility consequently increasing the emission rates at the plant. Similarly, if initial processing of gas does not occur before the feed gas enters the plant, additional energy (and its related emissions) is required to process this gas versus a plant where feed gas has already been processed prior to entering the facility. Furthermore, electrification status of the plant can have a significant effect on the associated imported emissions.

Train level modelling

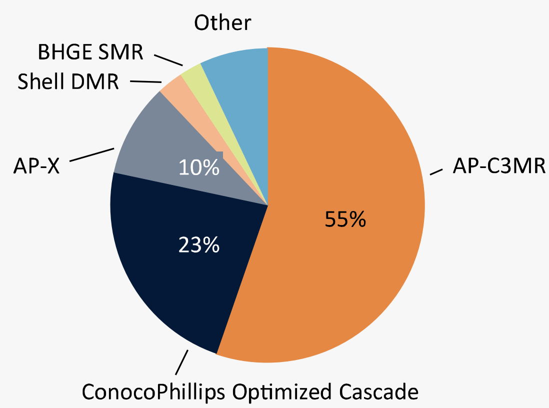
Liquefaction facilities are built on trains, defined as complete and independent process lines that are able to produce LNG from natural gas.

A liquefaction plant can include a single train or multiple independent trains. For example, Calcasieu Pass LNG currently operates 18 independent trains, whereas a smaller facility such as Angola LNG only has a single operating train.

Understanding the individual trains of each facility is crucial to establish a solid foundation for emissions modelling for liquefaction plants. For this reason, all Rystad Energy modelling is initially based on train-level data, which is then aggregated up to an overall facility intensity based on production-weighted relative capacity of each of the trains.

Modelling on the trains is based around the installed technologies, feed gas, capacities, utilisation rates, average yearly temperatures and other variables. The most common technology installed on liquefaction plant trains globally is Air Product's AP-C3MR, which has roughly 55% of the market and is particularly dominant in Asia and Africa, followed by ConocoPhillips' Optimised Cascade design.

Global installed technology breakdown



Regional installed technology breakdown

Region	AP-C3MR	ConocoPhillips Optimized Cascade	AP-X	Shell DMR	BHGE SMR	Other
Africa	70%	21%	0%	0%	0%	9%
Asia	90%	0%	0%	0%	0%	10%
Europe	0%	0%	0%	0%	0%	100%
Middle East	53%	0%	47%	0%	0%	0%
North America	35%	45%	0%	0%	12%	4%
Oceania	51%	40%	0%	4%	0%	0%
Russia	57%	0%	0%	33%	0%	10%
South America	23%	77%	0%	0%	0%	0%

Source: Rystad Energy GasEmissionsTracker

Train level modelling (cont.)

A key characteristic driving energy requirements for a given liquefaction facility are average yearly ambient temperatures. Lower ambient temperature can significantly reduce the energy required for cooling by considerable levels – a 30-degree swing in ambient yearly temperature can increase the energy required for cooling by around 20%.

Ambient air temperatures can vary significantly between different facilities within the same country or region. Consequently, accurate estimations of facility level ambient temperature is a key input Rystad Energy tracks.

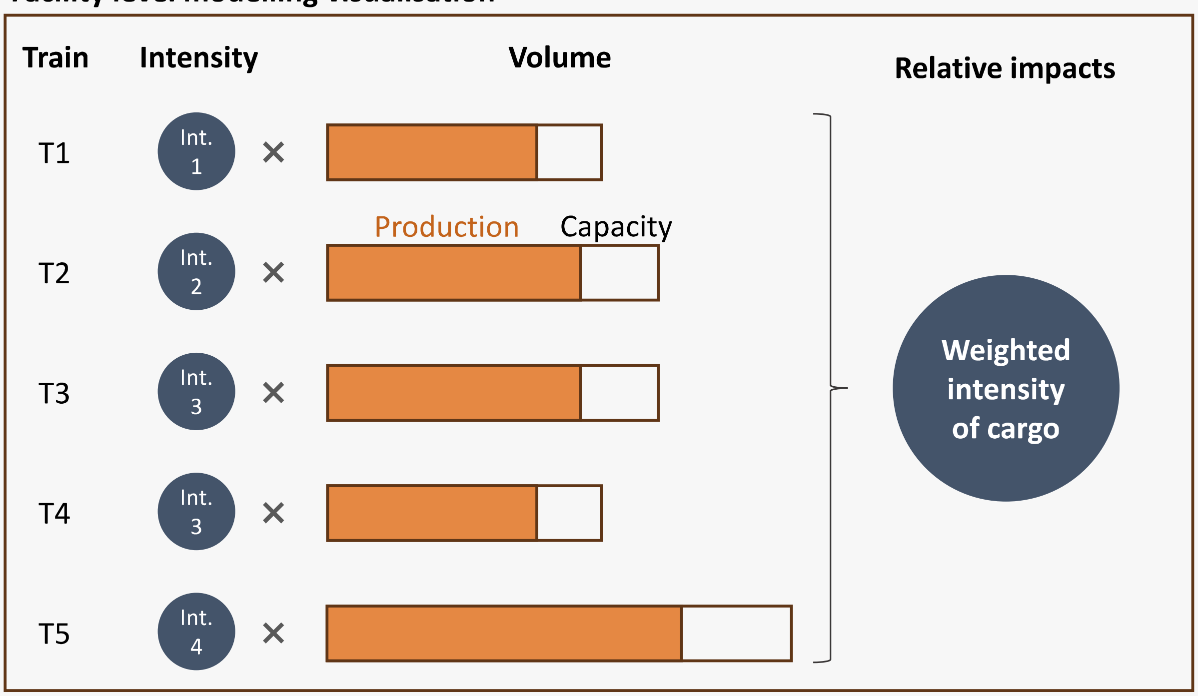
Regional average yearly plant temperature

Region	Average temperature (°C)
Oceania	25
Asia	26
Middle East	28
Africa	24
South America	25
North America	21
Europe	2
Russia	-1

Facility modelling

Each individual train within a facility will have a yearly estimated emissions intensity, centered around multiple parameters including feed gas, train technologies, nameplate capacity, utilisations, train age, average yearly temperatures, etc. The relative contribution each train will have on the emissions intensity of LNG from that facility are summarised and normalized to provide the average intensity of a cargo from the given liquefaction facility. A train with higher production capacity will have more effect on the overall facility intensity than a smaller-capacity train at the same facility.

Facility level modelling visualisation



Source: Rystad Energy GasEmissionsTracker

Shipping/bunkering volume methodology

The backbone of accurately estimating well-to-tank emissions for LNG as a marine fuel is understanding the origin of the LNG bunker fuel itself.

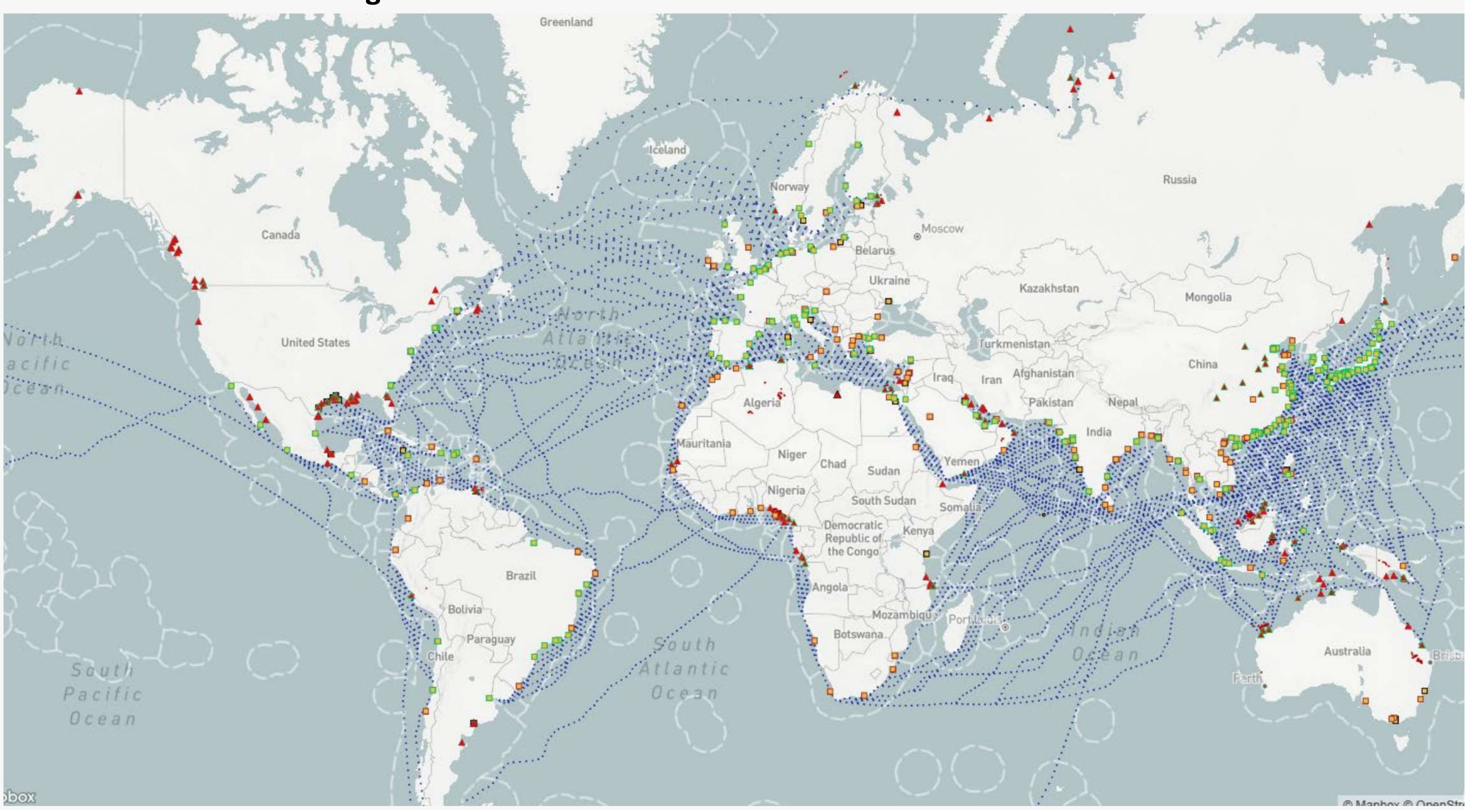
Rystad Energy is tracking the global LNG trade using Automatic Identification System (AIS) data. The system follows every LNG carrier and its position and movement on an 8-hour basis. This vessel-by-vessel information is then tied to our in-house vessel and facility databases, allowing connections to be made between the LNG carrier, loading at a liquefaction plant, and discharge at an LNG terminal.

In addition, Rystad Energy is tracking all LNG bunkering on an individual bunker activity basis. The system utilises both AIS vessel tracking, vessel specific information data and reported bunkering data to calibrate global bunkered volumes from each bunkering location to receiving vessel. Rystad has tagged LNG bunkering locations to either an importing LNG terminal or directly to a producing liquefaction plant.

These connections between liquefaction facilities, LNG terminals and bunkering locations allow Rystad Energy to directly connect supplying value chains to their origination liquefaction plant. The value chain emissions intensities can be combined with volumetric data to energy-weight the relative contribution of each value chain to a given bunkering location.

This volumetric approach/individual value chain approach allows emissions data to be aggregated up from the individual vessel cargo level, to bunkering facility level, to country, to region and eventually to a global view.

Visualisation of global LNG flow routes



Source: Rystad Energy GasEmissionsTracker

Shipping methodology

The same AIS data that tracks volumetric deliveries of LNG to regasification and bunkering facilities can also be leveraged to estimate emissions associated with each LNG delivery. This vessel-by-vessel information is then tied to our in-house vessel database, which contains key information on each vessel that impacts overall shipping intensities.

Emissions coverage includes all emissions related to direct use of fuel during shipping, auxiliary power requirements and methane slippage. Emissions profiles are estimated per vessel and per voyage based on the following key factors:

- **Distance travelled.** Shipping emissions are directly proportional to distance travelled by an LNG vessel. These have each been estimated using AIS tracking to provide accurate representations of distances.
- **Ballast leg inclusions.** Both the laden leg and ballast leg of a journey are included in the dataset. Although not directly linked to the delivery of LNG, ballast leg returns are a significant contributor to LNG lifecycle emissions and are therefore are included in the analysis. Rystad Energy made the decision to estimate the ballast leg emissions, assuming the same route back from the unloading location to the liquefaction plant, although this may not technically be where the vessel's route terminates. The reason for this was to not indirectly punish a cargo where the ballast leg is a multiple of distance greater than the laden leg, or vice versa, assigning the ballast leg a fraction of the emissions as the next journey is shorter.
- **Fuel and engine type.** Engine technologies and fuel types can significantly impact shipping emissions intensity. Older propulsion types such as steam or steam reheat can have emission intensities far greater than modern technologies, such as XDF, MEGI or Dual fuelled propulsion.

There typically are significant differences between fleet numbers/propulsion types and real-world delivered cargoes and volumes. This difference becomes even more pronounced when looking into specific delivery routes. Accurately understanding LNG lifecycle emissions requires accurate real-world understanding of the specific vessels delivering LNG. Of the global LNG cargo deliveries in 2024, around 33% were delivered by older steam turbine powered vessels, this is greater than the fleets capacity at 28%, indicating they are utilised more frequently. Similarly, tri-fuelled diesel electric (TFDE) and slow-speed diesel (SSD) vessels delivered more volumes than their nameplate capacity in 2024, with XDF slightly below its volume characteristics.

LNG carrier by capacity and total delivered volume, 2024

Propulsion type	Methane slip rates*	Fleet by capacity (%)	2024 delivered cargo volume (%)
Steam	0%	26%	30%
XDF	0.8%	20%	17%
Tri-fuelled diesel electric (TFDE)	3.1%	12%	15%
Duel-fuel diesel electric (DFDE)	3.4%	13%	12%
MEGI	Near 0%	11%	11%
Slow-speed diesel (SSD)	0%	9%	10%
Steam reheat	0%	2%	3%
Other	Near 0%	7%	2%

*Large variations in methane slip rates exist between engines types and are linked to a number of different factors, consequently there are large variations in estimated slip rates from different sources. To account for this variation, Rystad Energy conducted a sensitivity analysis looking into the effect of increasing slip rate by 1% for XDF, TFDE, DFDE, MEGI and Other (i.e. DFDE increases from 3.4 to 4.4%). The effect of this on global WtT emissions is marginal and would lead to an estimated emissions increase of ~0.2 g CO_2e/MJ for bunkered LNG WtT emissions.
Source: Rystad Energy GasEmissionsTracker, Rystad Energy Shipping Solution

LNG terminal and bunkering emissions

Rystad Energy's GasEmissionsTracker follows the emissions associated with all LNG terminals. At these terminals, the vast majority of LNG imported is regasified from its liquid form before it is sent out to the importing nation's gas grid.

The emissions associated with these LNG terminals in the GasEmissionsTracker are based on multiple parameters. As is typical of Rystad Energy's methodologies, reported facility-level information, where it is available, is incorporated into Rystad databases.

For flaring emissions, where these are not explicitly reported, Rystad Energy uses satellite flaring data from Earth Observation Group (VIIRS Nightfire). We have developed a GIS methodology for assigning LNG terminal-related flare sites to individual LNG terminals, using physical plant boundary shapes and latitude/longitude coordinates. By tagging liquefaction flare sites (and hence flaring volumes measured in cubic meters) to plants, absolute flaring volumes and emissions intensities can be calculated.

Where no reported emissions information exists, regasification emissions including direct combustion emissions, imported emissions and fugitive methane emission rates are modelled. The emissions models are based on multiple factors, including facility parameters (including electrification status), ambient temperatures, capacities, utilisation rates, facility age etc. This provides asset-by-asset overviews.

Rystad Energy has defined 'LNG terminal and bunker operations' emissions as all emissions arising from LNG terminal operations, distribution to the bunkering location, and final loading of fuel onto an LNG fuelled vessel. This includes energy-related (both imported and on-site produced emissions), in addition to fugitive methane emissions from storage, loading, delivery/transportation, and loading into the 'tank' of an LNG fuelled vessel.

However, the existing LNG terminal emissions database coves regasification emissions which are not part of bunkering operations. And does not cover the additional distribution emissions if LNG is not bunkered directly at the liquefaction facility.

The database was adapted to account for these differences by removing the contribution of regasification and including the effects of additional distribution and loading onto the LNG fuelled vessel.

To account for these changes a the following approach was taken:

- LNG terminal methane fugitive/venting/boiloff gas emissions were fixed and not adjusted, neither were detected satellite flaring volumes and remain consistent with terminal operations, nor was imported emissions.
- Additional fugitive methane emissions from the distribution of LNG to the bunker location and final loading onto the LNG fuelled vessel were included.
- Regasification emissions typically contribute the majority of the emissions from an LNG importing terminal (60-80%) due to the process of heating LNG from around -162 to 10°C. However, combustion-related CO_2 emissions were reduced by around 40%, rather than the more conservative 60-80% reduction, as LNG bunkering and distribution does incur some increased distribution emissions because LNG is not always bunkered direct at the LNG facility.

These alterations to the existing database, although conservative, provide an asset-by-asset view of LNG terminal distribution and bunkering operations.

Rystad Energy recognises that this approach is conservative and there is a chance that emission intensities for LNG terminal import and bunkering are slightly lower than those in practice. However, our asset-by-asset approach was viewed as a priority for than using a single factor applied to all terminal operations globally, ignoring the facility-by-facility (and by extension, regional) differences we currently see.

Source: Rystad Energy research and analysis; Rystad Energy GasEmissionsTracker

Aggregation of data

All emissions data is provided on an energy/volumetric-weighted intensity basis. This approach analyses the relative impact of each individual well-to-tank route/cargo, and the energy transferred via that particular route (volume of LNG delivered). The intensities of the cargo alongside the delivered volume is then used to provide its weighted impact at a regional or global level.

The global LNG trade flow is made of a series of individual LNG value chains that connect the production of natural gas at the upstream well all the way through to the end user. Rystad Energy's methodology of estimating the global well-to-tank intensity is calculated by created a digital twin of the world's LNG trade, via the underlying assets and the physical flow volumes.

Regional and global LNG well-to-tank intensities are based on the following methodology:

1. Rystad Energy has connected the relevant feed gas assets and infrastructure to each individual liquefaction facility for production volumes and emissions, allowing emissions intensity assessments of LNG exiting each liquefaction facility globally, from well to liquefied natural gas.
2. Rystad Energy uses complete vessel-by-vessel tracking to monitor volumes of cargoes delivered between produced liquefaction facilities and LNG terminals globally, thus allowing each individual cargo delivered into each LNG terminal to have a unique value chain emissions intensity (WtT_{int}) and volume (V_i).
3. In addition to tracking vessel-by-vessel LNG deliveries into LNG terminals, Rystad Energy also tracks vessel LNG bunkering locations globally, which can be tagged to the nearest LNG import terminals.
4. Each of these steps allows Rystad Energy to estimate the relative volumes and emissions intensities of the individual value chains that have contributed into the LNG fuel being loaded into the 'tank' of an LNG fuelled vessel.
5. The relative impact of each of the individual value chains can be aggregated, using the below formula, to provide an aggregated WtT emissions intensity (WtT_{agr}) up from the individual cargo to the intensity for a bunkering location or country, regional or global scale.

The approach taken for weighting makes the following assumptions:

- All LNG globally has the same characteristics and chemical properties (i.e. the same purity and ratios of various hydrocarbon lengths).
- LNG bunkering locations are fed with LNG from the closest LNG import terminal.
- The origins of contributing LNG at the import terminal is reflected and identical to the LNG of nearby bunkering locations.

Aggregated WtT emissions intensity calculation formula

$$WtT_{agr} = \frac{\sum_{i=1}^{n} V_i \cdot WtT_{int,i}}{\sum_{i=1}^{n} V_i}$$

Where:

V_i = Volume of LNG delivered for cargo

WtT_{int} = Well-to-tank emissions intensity for each individual cargo

n = Total number of cargoes

WtT_{agr} = Aggregated well-to-tank emissions intensity (volume/energy-weighted)

Source: Rystad Energy research and analysis

Availability of data

LNG Trade flow data availability

Rystad Energy tracks both LNG carrier journeys and bunkering activities using Automatic Identification System (AIS) data. The system follows all LNG carrier/bunkering vessels and their positions and movements on an 8-hour basis, allowing for near real-time analysis of LNG trade. From this perspective, it is possible to provide LNG trade and emissions-related data for any period up to the present day. However, the closer the cutoff is set to the present day, a trade-off is created to the amount of real-world emissions data encapsulated in the data set.

Emissions data availability

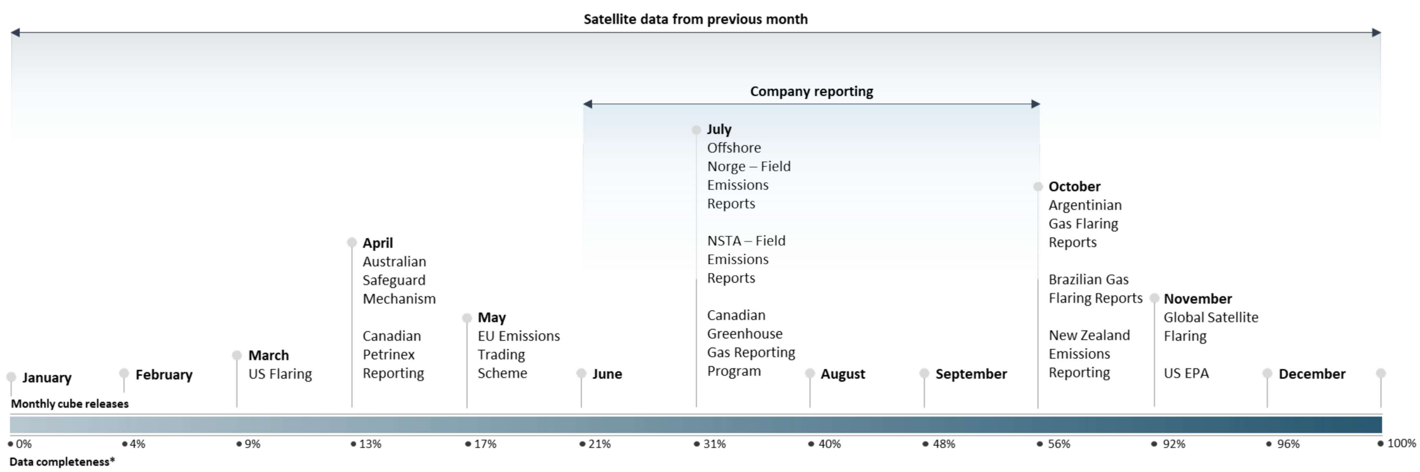
Rystad Energy is covering emissions from the entirety of the oil and gas sector, including the global LNG trade, from upstream through to final entry into the market via an LNG terminal. Emissions data from reported sources, granular or aggregated, is reported yearly.

Data processed and pulled into the emissions databases comes from a variety of sources, including operators, governments, and satellite data. All these different sources release information at various times throughout the year.

Reported emissions data by nature contains a latency period between the close of the calendar year and when the raw data is processed, submitted and released by operators and government agencies. Once released, Rystad Energy processes and pulls reported data into our databases as the year progresses. Data for 2024 will be complete at the end of 2025, when all reporting for the previous calendar year has been released. However, at a point in 2025, a proportion of 2024 data will be available and inside Rystad Energy databases. Where missing, historic data from the previous calendar years is used to estimate 2024 levels.

By comparison, satellite data for both methane and flaring is available almost in real time. With data updates occurring monthly, with a latency period of around one month.

Example of data availability in a given month*



*Timelines stated above are indicative and can change year to year
Source: Rystad Energy research and analysis

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RystadEnergy

Navigating the future of energy

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