S&P Global
Energy

Emissions Guidebook

Center of Emissions Excellence

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Emissions Guidebook

Part 2: GHG fundamentals

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Center of Emissions Excellence

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About the Emissions Guidebook

Purpose

Greenhouse gas (GHG) emissions have emerged as a critical metric for governments and investors given an ever-growing focus on establishing transparent frameworks for measuring, reporting, quantifying and ultimately reducing GHG emissions globally. It is of utmost importance that methodologies used by different entities are transparent and clear so different studies and emission estimates can be compared on a like-for-like basis. Without this transparency, emissions estimates have limited utility in the marketplace. The Emissions Guidebook is an evergreen document that provides the market with unparalleled transparency into S&P Global Energy' approach, methodology and key assumptions behind our emissions work. We hope this document can contribute to advancing consistency in GHG emissions accounting.

Context

The Emissions Guidebook is a product of the S&P Global Energy Center of Emissions Excellence. The "Center" is a dedicated team of carbon accounting specialists focused on ensuring consistency, transparency and credibility of emissions data across any emissions offerings.

About S&P Global Energy

At S&P Global Energy, our complete view of global energy and commodity markets enables our customers to make decisions with conviction and create long-term, sustainable value.

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GHG estimation fundamentals

Why estimate emissions?

Emissions are not directly measurable in most cases; estimations can vary depending upon the quality of the underlying data available. Some emission sources are much easier to estimate than others, and varying levels of known data inputs are available in each circumstance. Combustion emissions estimation requires fewer assumptions than venting or fugitive emissions estimation. However, even for a combustion source, although the fuel amount is typically metered and known, assumptions must be made about how complete the combustion is, the amount of methane slip and the fuel composition to fully estimate the emissions from any source. Estimating venting emissions requires more assumptions, but some data inputs are not readily available. Compounding this, atmospheric conditions can greatly affect venting emissions and add to the complexity of estimating these sources. In every case, emissions quantification always requires some assumptions, as not all factors are fixed and known — this is the very reason that emissions are estimated.

Materiality

Some emission sources are larger, more significant and thus more “material” than other sources. With the possibility of hundreds or thousands of emission sources on a particular asset, it would take an inordinate amount of time to quantify even the most minute sources. S&P Global Energy typically assumes any source contributing less than 2% to an overall GHG intensity is immaterial.

Estimating emissions

Direct correlation emissions estimation

CO_2 combustion emissions can be estimated directly with some simple assumptions if fuel quantity and fuel composition are known. Assuming all carbon in the fuel is converted to CO_2 (complete combustion), one can correlate the volume of fuel to mass of carbon in the fuel to mass of CO_2, assuming stoichiometric and complete combustion.

Emission factor-based estimation

Emission factors are correlations of emissions to metrics, such as throughput through a device or fuel burned in a piece of equipment. Emission factors can be equipment specific and include various assumptions about fuel slippage amounts in combustion equipment, fuel composition or purity, typical operating parameters and conditions, and more. We use generic and equipment-specific emission factors in estimating emissions when direct emissions correlation is not possible.

Emission factors are commonly used to estimate GHG emissions for many reasons, including the following:

– Noncombustion sources of emissions, such as vented methane emissions from tanks or pneumatic devices, are difficult to quantify and measure.

– Nitrous oxide emissions are difficult to quantify, as they typically are a product of incomplete combustion and depend upon combustion temperatures and pressures.

– Fuel gas composition is not typically known for every fuel stream.

– Purchased fuels have a tight range of composition, so the use of combustion emission factors results in very close approximations of reality.

Table 1 contains the emission factors correlated to fuel quantities combusted, which we commonly use at S&P Global Energy.

Table 1

Default emission factors

	Fuel	CO_2 (gCO_2/MJ)	CH_4 (gCH_4/MJ)	N_2O (gN_2O/MJ)
Coal and coke	Anthracite coal	98.3	1.04E-02	1.52E-03
	Bituminous coal	88.4	1.04E-02	1.52E-03
	Sub-bituminous coal	92.1	1.04E-02	1.52E-03
	Lignite coal	92.6	1.04E-02	1.52E-03
	Mixed (commercial sector)	89.4	1.04E-02	1.52E-03
	Mixed (electric power sector)	90.5	1.04E-02	1.52E-03
	Mixed (industrial coking)	89.0	1.04E-02	1.52E-03
	Mixed (industrial sector)	89.7	1.04E-02	1.52E-03
	Coal coke	107.7	1.04E-02	1.52E-03
Other fuels — Solid	Municipal solid waste	86.0	3.03E-02	3.98E-03
	Petroleum coke (solid)	97.1	3.03E-02	3.98E-03
	Plastics	71.1	3.03E-02	3.98E-03
	Tires	81.5	3.03E-02	3.98E-03
Biomass fuels — Solid	Agricultural byproducts	112.0	3.03E-02	3.98E-03
	Peat	106.0	3.03E-02	3.98E-03
	Solid byproducts	100.0	3.03E-02	3.98E-03
	Wood and wood residuals	88.9	6.82E-03	3.41E-03
Natural gas	Natural gas	50.3	9.48E-04	9.48E-05
Other fuels — Gaseous	Blast furnace gas	260.0	2.09E-05	9.48E-05
	Coke oven gas	44.4	4.55E-04	9.48E-05
	Fuel gas	55.9	2.84E-03	5.69E-04
	Propane gas	58.3	2.84E-03	5.69E-04
Biomass fuels — Gaseous	Landfill gas	49.4	3.03E-03	5.97E-04
	Other biomass gases	49.4	3.03E-03	5.97E-04
Petroleum products	Asphalt and road oil	71.4	2.84E-03	5.69E-04
	Aviation gasoline	65.6	2.84E-03	5.69E-04
	Butane	61.4	2.84E-03	5.69E-04
	Butylene	65.1	2.84E-03	5.69E-04
	Crude oil	70.7	2.84E-03	5.69E-04
	Distillate fuel oil No. 1	69.4	2.84E-03	5.69E-04
	Distillate fuel oil No. 2	70.1	2.84E-03	5.69E-04
	Distillate fuel oil No. 4	71.1	2.84E-03	5.69E-04
	Ethane	56.5	2.84E-03	5.69E-04
	Ethylene	62.5	2.84E-03	5.69E-04
	Heavy gas oils	71.0	2.84E-03	5.69E-04
	Isobutane	61.6	2.84E-03	5.69E-04

Table 1

Default emission factors (continued)

	Fuel	CO_2 (gCO_2/MJ)	CH_4 (gCH_4/MJ)	N_2O (gN_2O/MJ)
Petroleum products	Isobutylene	65.3	2.84E-03	5.69E-04
	Kerosene	71.3	2.84E-03	5.69E-04
	Kerosene-type jet fuel	68.5	2.84E-03	5.69E-04
	Liquefied petroleum gases (LPGs)	58.5	2.84E-03	5.69E-04
	Lubricants	70.4	2.84E-03	5.69E-04
	Motor gasoline	66.6	2.84E-03	5.69E-04
	Naphtha (<401 degrees F)	64.5	2.84E-03	5.69E-04
	Natural gasoline	63.4	2.84E-03	5.69E-04
	Other oil (>401 degrees F)	72.2	2.84E-03	5.69E-04
	Pentanes plus	66.4	2.84E-03	5.69E-04
	Petrochemical feedstocks	67.3	2.84E-03	5.69E-04
	Propane	59.6	2.84E-03	5.69E-04
	Propylene	64.2	2.84E-03	5.69E-04
	Residual fuel oil No. 5	69.1	2.84E-03	5.69E-04
	Residual fuel oil No. 6	71.2	2.84E-03	5.69E-04
	Special naphtha	68.6	2.84E-03	5.69E-04
	Unfinished oils	70.7	2.84E-03	5.69E-04
	Used oil	70.1	2.84E-03	5.69E-04
Biomass fuels — Liquid	Biodiesel (100%)	70.0	1.04E-03	1.04E-04
	Ethanol (100%)	64.9	1.04E-03	1.04E-04
	Rendered animal fat	67.4	1.04E-03	1.04E-04
	Vegetable oil	77.3	1.04E-03	1.04E-04
Biomass fuels — Kraft pulping liquor, by wood furnish	North American softwood	89.5	1.80E-03	3.98E-04
	North American hardwood	88.8	1.80E-03	3.98E-04
	Bagasse	90.5	1.80E-03	3.98E-04
	Bamboo	88.8	1.80E-03	3.98E-04
	Straw	90.1	1.80E-03	3.98E-04

gCO_2/MJ = grams of CO_2 per megajoule; gCH_4/MJ = grams of methane per megajoule; gN_2O/MJ = grams of nitrous oxide per megajoule.
Based upon higher heating value of the fuel.
Source: Adapted from the US EPA GHG Emission Factors Hub 2023, https://www.epa.gov/climateleadership/ghg-emission-factors-hub.
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Data quality

Variability in quality of data and estimates

Reliability can be a source of inconsistency between GHG estimates. The rise in demand to understand GHG emissions has led to a proliferation of estimates. However, not all estimates are created equal. The level of information required and the complexity of some processes inevitably lead to assumptions and compromises. These challenges expand considerably when undertaking LCAs. As a result, uncertainty is unavoidable.

It can be difficult to understand and thus consider the uncertainty when using these data to make decisions. For companies reporting their GHG emissions, it can be difficult to differentiate the level of effort or rigor that is put into their estimate. This is important because it can help justify investments to improve GHG accounting and estimation, such as deployment of sensors to increase the level of measurement. Improving the communication of the reliability of GHG estimates would support improvements in estimation, while allowing users to better understand any limitations in their use.

Principles of data quality

S&P Global values three key principles when it comes to evaluating data quality:

- **Reliability:** This is the degree to which an estimate can be depended on to be accurate (e.g., the comprehensiveness of underlying data). How dependable is the estimate? The answer in most cases will be informed by the underlying pedigree of the data, such as where it came from, how and who collected it, and where and how the data were published. Uncertainty about pedigree will obviously increase uncertainty about the quality and reliability of the data itself.
- **Representativeness:** This is the degree to which an estimate can be expected to reflect reality (e.g., to what degree the data represent the asset or assets in question). Even highly reliable information may still do a poor job of describing the process, the region being analyzed, or the time of the study. In GHG estimation, there can be significant data gaps, with assumptions needed. The purpose is not to determine definitively if data is “good” or “bad,” but rather to what degree does it fit the purpose for which it is being collected and used.
- **Utility:** This is the ease in assessing or assembling and interpreting the metric. Like the GHG estimates themselves, the underlying information is quantitatively rich and complex. That complexity is useful to analysts because it can point to very specific areas for improvement. But for stakeholders that need this data to inform decisions, complexity becomes a barrier. There is a balance between simplicity and utility, which includes legibility, complexity of information to be conveyed, and effort required to create metrics of reliability.

The data quality metric

GHG estimation is complex, and numerous factors can influence an estimate and the level of certainty or uncertainty. Communicating some of this complexity allows users of these data to better understand the estimate, its limitations and areas for potential improvement. S&P Global Energy, in collaboration with US National Energy Technology Labs, developed a Data Quality Metric (DQM) in response to these concerns as a means of reporting out the quality of our estimates.

The DQM leverages and builds upon existing literature. The principles of data and estimate quality are well documented throughout GHG estimation and life-cycle analysis literature. In 1996, Weidema et al. proposed the Data Quality Indicator (DQI) framework as a means of understanding and communicating data quality.[1] They proposed a "pedigree matrix" to assess quality across five dimensions, imposing a 1–5 value based on somewhat subjective evaluations of both the reliability and representativeness of the data behind an estimate. Although far from perfect, many practitioners have embraced the DQI framework. From its inception, the NETL Life-Cycle Analysis team adopted DQI as its quality evaluation framework.[2] The US Environmental Protection Agency's National Risk Management Laboratory modified the matrix and published a data quality guidance document in 2016.[3] DQI is further referenced within the GHG Protocol.[4] The Climate and Clean Air Coalition's Oil and Gas Methane Partnership (OGMP) 2.0 Framework does not directly reference the DQI, but it does include five reporting levels that describe the pedigree of methane emissions measurements in oil and gas systems in very similar terms to the more generic DQI framework.[5] In short, various entities recognize the importance of a DQI-like approach in assessing reliability. Since the DQM work was first published in 2019, similar metrics have been presented as part of the US DOE's MMRV framework[6] (in development) as well as adoption into the Open Hydrogen Initiative (OHI) model.[7]

The DQM builds upon the existing DQI framework. The existing, more generic DQI framework was modified to make it more oil and gas sector specific, less subjective, and the results easier to interpret and understand. Changes were made to the scoring to increase the differentiation in the resulting scores. Documentation was also created to reduce some of the subjectivity in the scoring. Guidance was also developed to support the aggregation of DQI through a life-cycle analysis and to support a consistent presentation of the resulting DQM.

The DQM matrix is presented in Table 2. Indicators are on the y-axis of the matrix, and the corresponding scores are along the x-axis. Within each cell, there is a brief description of the evaluation criteria associated with a particular score. Note that quality decreases as numbers increase from left to right so that "1" is the best score and "5" is the worst. Missing information about a piece of data must be scored with a "5" (the default) to indicate that understanding of the quality is impossible. The objective of any estimator or practitioner should be to continually improve the quality score and drive it toward a "1". Following the table, there is a brief description of each indicator.

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[1] Weidema, Bo Pedersen and Marianne Suhr Wesnæs. "Data Quality Management for Life Cycle Inventories — an Example of Using Data Quality Indicators." Journal of Cleaner Production 4, no. 3–4 (1996): 167–74. https://doi.org/10.1016/S0959-6526(96)00043-1.

[2] NETL. "NETL Life Cycle Inventory Data – Unit Process: Coal Railcar, 244000 Lbs Net Capacity, Construction - Version 01," 2009. https://netl.doe.gov/LCA, retrieved Dec. 21, 2021.

[3] Edelen, Ashley and Wesley Ingwersen, "Guidance on Data Quality Assessment for Life Cycle Inventory Data," EPA/600/R-16/096, 2016.

[4] "Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard," World Resources Institute/World Business Council on Sustainable Development, 2011.

[5] Mineral Methane Initiative OGMP2.0 Framework, UNEP, 2020. https://www.ccacoalition.org/en/resources/oil-and-gas-methane-partnership-ogmp-20-framework.

[6] DOE MMRV: https://www.energy.gov/fecm/greenhouse-gas-supply-chain-emissions-measurement-monitoring-reporting-verification-framework

[7] Open Hydrogen Initiative: https://www.gti.energy/ohi/

Table 2

Scoring criteria matrix for the data quality metric

Indicator		1	2	3	4	5 (default)
Data reliability		Verified data based on measurements; Reported similarly to Level 2, but with addition of site-level measurements (which characterize site-level emissions distribution for a representative population).	Verified data based on a calculation or non-verified data based on measurements; Emissions reported by detailed source type and using specific EFs and activity factors (AFs).	Non-verified data based on a calculation; Emissions reported by detailed source type and using generic emission factors (EFs).	Documented estimate; Emissions reported in consolidated, simplified sources categories, using a variety of quantification methodologies, progressively up to the asset level, when available.	Undocumented estimate; Emissions reported for a venture at asset or country level (i.e., one methane emissions value for all operations in an asset or all assets within a region or country).
Data representativeness	**Temporal correlation**	Less than 1 year of difference.	Data is greater than 1 year of difference but less than 2.	Data is greater than 2 years of difference but less than 3.	Data is greater than 3 years of difference but less than 5.	Greater than 5 years of difference or unknown.
	Geographic correlation	Data from same resolution and same area of study.	Data is from a known and related but larger area of resolution than the study. Within one level of resolution.	Data is from a known and related but larger area of resolution than the study. Within 2 levels of resolution.	Data is from a known and related but larger area of resolution than the study. Greater than 2 levels of resolution.	From a different or unknown area of study.
	Technology correlation	Data is from technology being modeled.	Data is from a mix of technologies.			Data is from a different technology than being modeled.
	Completeness	Data from >80% of the relevant activity, over a sufficiently representative period.	Data from 60%-79% of the relevant activity, over a sufficiently representative period or from >80% of the relevant market, over a shorter period.	Data from 40%-59% of the relevant activity, over a sufficiently representative period or from 60%-79% of the relevant market, over a shorter period.	Representative data from <40% of the relevant activity, over a sufficiently representative period or from 40%-59% of the relevant market, over a shorter period.	Unknown or data from a small number of sites and from shorter periods.

Source: Modified by S&P Global Energy from EPA 216, based on Weidema et al., 1996 and OGMP 2.0.
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Data reliability is about the dependability of the data. The answer in most cases will be informed by the data pedigree or how much is known about the data and its credibility (i.e., who or how was it collected and/or where and how was it published). Uncertainty about data pedigree will obviously increase uncertainty about the quality of the estimate itself. For instance, a "1" might be data from your own device and facility level measurements, and a "5" could be a public summary of emissions across an entire business sector. This indicator has been modified with input from the OGMP framework.

Data representativeness is about how well the data collected meet the study purpose and fits with the emissions being modeled. Highly reliable information can still be unrepresentative of a particular process technology, or an activity in a particular region, or a specific time period.

There are four data representativeness indicators in the DQI framework. The first three relate to data correlation. These address questions around the degree to which the data being used represent what is being estimated. These data can vary in terms of time, location and technology. Note that the technology correlation indicator values (2-4) have been collapsed to a single indicator value of "3." This has the effect of accentuating the differences in scoring when data is of a different technology.

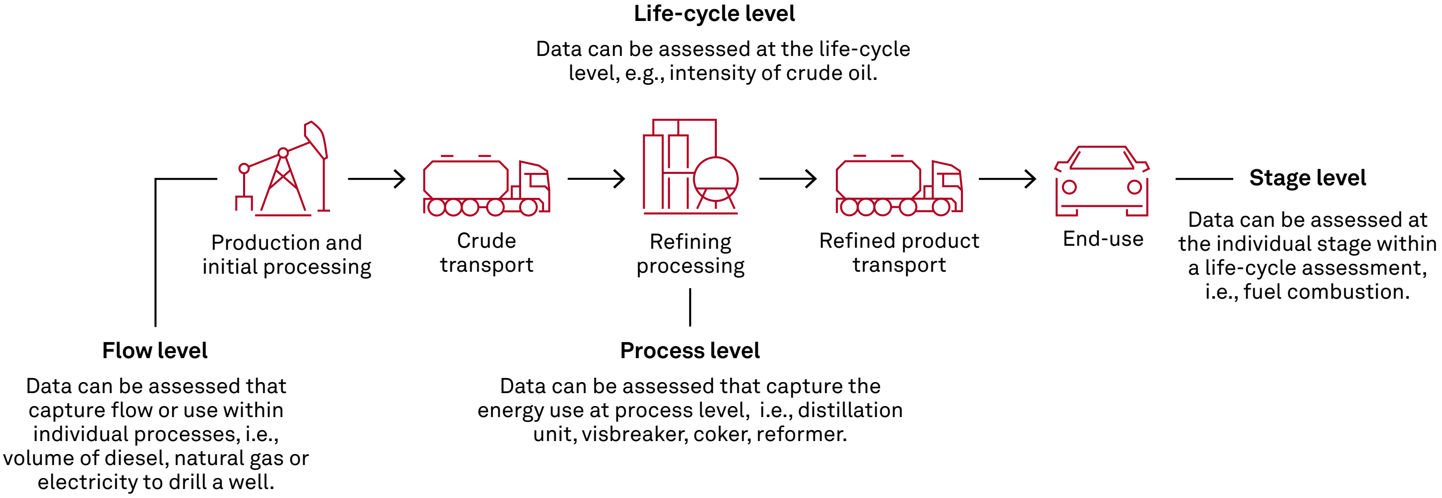
- **Temporal:** To what extent does the data used correspond to the period of assessment? A "1" would be emissions and activity data from the year 2020 for estimates of 2020. A "5" would be data from five or more years earlier, specifically 2016 or earlier in this example.
- **Geographic:** To what extent does the data match the area of the study? A "1" would be data that comes from inside the boundary of interest. A "5" would be data from assets from a different geography. For upstream extraction, geographic correlation would also include geologic correlation. Data from a different region but of similar geology may still obtain a score of "3," but a "1" would be unreasonable.
- **Technology:** To what extent does the data represent the technology being assessed? A "1" would be data for the technology being characterized. A "5" would be data for an unknown or significantly different technology (e.g., emissions from conventional oil extraction used to represent unconventional extraction).
- **Completeness:** How well does the data reflect the population, or what share of the actual study population does the data represent? A "1" would be assigned if data from over 80% of the wells in the basin/play were included, whereas a "5" would be data from an unknown source or small percentage of or an archetypical representation of activity.

Assessment boundaries

The construction of a GHG emission estimate, whether it be of upstream or downstream processes, involves various levels of data gathering, estimation and aggregation. Theoretically, quality could be assessed for every source of information. However, this would be incredibly laborious and unwieldy because there can be numerous data points to consider in assessing even one stage of a life-cycle estimate, to say nothing over an entire life cycle. Conversely, assessments that are conducted at only the highest level, such as a complete life-cycle estimate, would likely be too subjective and provide little insight on the quality of the underlying data. Some level of compromise is required. Figure 1 shows the various levels at which data can be assessed.

Figure 1

Illustration and description of various levels which data quality can be assessed



Source: S&P Global Energy.
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– Flow level: Flows can be of feedstock product, or emissions, and are themselves the result of underlying flow rates, performance parameters in engineering calculations, and emission factors.

– Process level: A process is the description of the transformation of one set of flows to another set of flows and the emissions created.

– Stage level: Logical but figurative groupings of processes are called stages. A stage might represent all the processes involved in the extraction of raw materials for the product of interest, for instance.

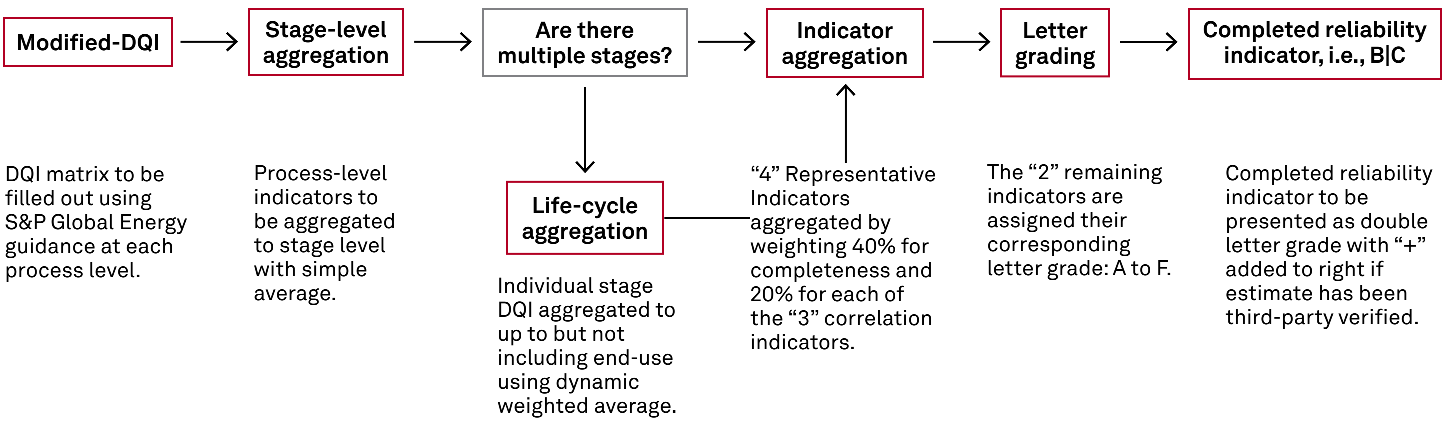
Selection of the DQM application involved finding a balance between simplicity (both for practitioners who need to apply the DQM, as well as stakeholders who must interpret it) and usefulness, with the assumption that more information is more useful. For a life-cycle analysis, data quality assessment would likely be most relevant beginning at the stage level through to the full life-cycle level.

Aggregating and grading

Converting individual DQM assessments from the process level through to stage and ultimately to the full life cycle reduces the number of indicators from 5 to 2 (a reliability score and a representativeness score) and final results are converted into letter grades. The resulting two-letter score represents the final DQM assessment. Figure 2 describes the process.

Figure 2

Flow diagram of reliability indicator process



Source: S&P Global Energy.
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To illustrate how the final letter grading is done, an example of how a letter grade is added for Reliability and Representativeness is provided in Table 3. Let's assume the following scores were assigned to a crude oil grade quantification:

Table 3

Example of grading

Data quality indicator	Subindicator	Proportion assigned to overall category (%)	Score	Score aggregating	Final DQI score
Reliability		100	2	2	2
Representativeness	Temporal correlation	20	3	3x20%=0.6	3.4
	Geographic correlation	20	4	4x20%=0.8	
	Technology correlation	20	2	2x20%=0.4	
	Completeness	40	4	4x40%=1.6	

Source: S&P Global Energy.
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The final DQI scores for Reliability and Representativeness are then translated to a letter grade according to the categorization in Table 4:

Table 4

Equivalent number scores to letter grades

DQI score	Letter grade
1-1.5	A
1.5-2.5	B
2.5-3.5	C
3.5-4.5	D
4.5-5	F

Source: S&P Global Energy.
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In the example above, the letter grades would be assigned **B l C**.

Product life-cycle fundamentals

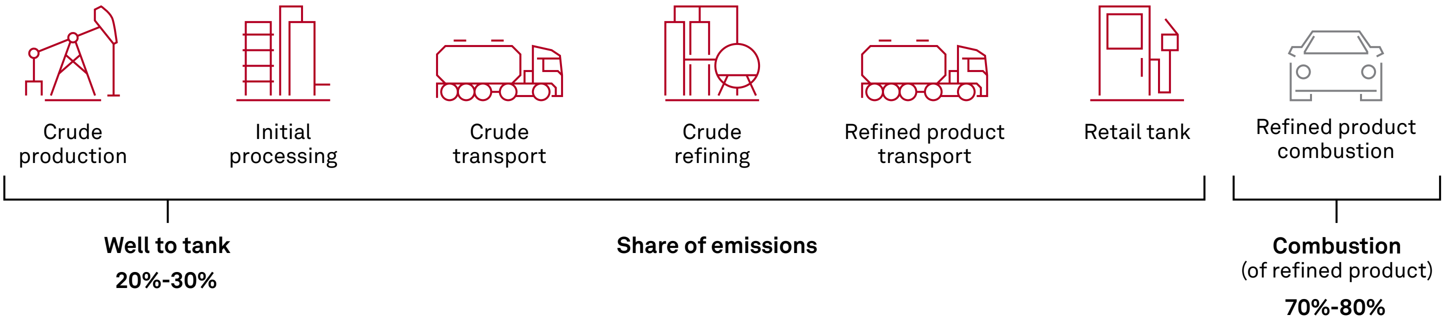
System boundaries

System boundaries define which emissions are included or counted. It is infeasible to include every source of GHG emissions over the life cycle of a product. Some simplifications are required. When undertaking any GHG estimate, the system boundaries should be clearly stipulated.

An example of a life-cycle system boundary of crude oil is shown below. In this example, the segments of the supply chain include emissions associated with crude production, initial processing (such as separation from coproducts like natural gas liquids and natural gas), crude transport to refinery gate, refining, refined product transport (in this example, gasoline) to the fueling station, and then end-use combustion of the gasoline in the car engine. While a full life cycle is typically quoted including end-use combustion, it is also quite common to look at the various production pathways a product can take to the point where an end user consumes it. In that case, the product life cycle could be quoted as a partial life cycle, such as well-to-tank in the example of gasoline in Figure 3.

Figure 3

Life-cycle of petroleum fuels



Source: S&P Global Energy.
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Units

Functional unit

A functional unit must be chosen before an assessment is undertaken and it must be kept consistent throughout the evaluation of each segment of a supply chain. This functional unit is the denominator basis for a GHG intensity calculation. Options can include emissions per unit mass or energy. A volumetric basis is not acceptable due to scientific principles that must be upheld across a value chain: namely, conservation of energy and conservation of mass. For energy supply chains, units of emission per unit of energy are the most common. An energy basis can also support comparison of one energy type versus another (e.g., electric vehicle efficiency versus combustion engine). For example, grams of CO_2 per megajoule (gCO_2e/MJ) is the unit of choice in both the California Low Carbon Fuel Standard (LCFS) and the Canadian Clean Fuel Standard (CFS) so that an energy supply may be compared to another for crediting or payment purposes. The gCO_2e/MJ units are the measurement of choice for evaluating life-cycle emissions of an energy supply chain.

The basis for the energy must also be specified to be on a lower heating value (net calorific value) or higher heating value (gross calorific value) basis. This basis must be specified and kept consistent for each segment of a supply chain. S&P Global Energy prefers to use the lower heating value (LHV) basis. For commodities other than energy, the functional unit is less clear and may need to be examined on a case-by-case basis.

Reporting unit

While the functional unit of quantifying an energy related life cycle for S&P Global Energy is emission per unit of energy (gCO_2e/MJ), after completing the supply chain quantification and aggregation processes, units may be converted to a unit that is commonly understood in the marketplace. Across estimates, studies and disclosures, different units are being used, and it is not always the case that estimates can be readily converted. Reporting units should be fit for purpose and relevant to the intended application. For example, in crude oil markets, it is most common to talk in barrels ($kgCO_2e/b$ oil). In natural gas markets, millions of cubic feet of gas are commonly accepted ($tCO_2e/MMcf$ gas). For global liquified natural gas (LNG), metric tons have become a common unit ($tCO_2e/tLNG$).

Treatment of coproducts

Some processes can result in an array of coproducts. This issue is like that of system boundaries in that there can be differences between studies and estimates about which coproducts are included, how they are treated, and how GHG emissions are allocated. It is important to define how emissions should be allocated between products and when emissions should be allocated.

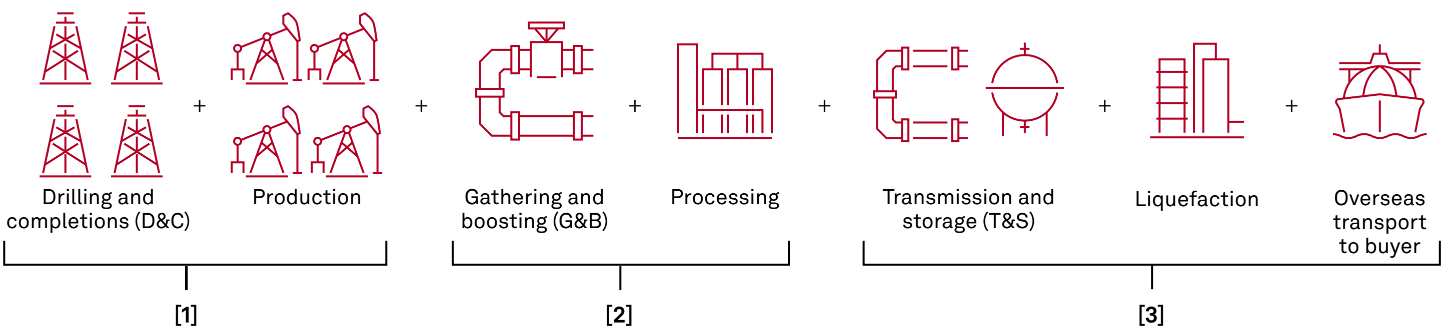
To illustrate, consider oil and gas extraction. Depending upon the system boundaries of the study, the resulting products could include crude oil, natural gas and natural gas liquids (NGLs). Crude oil is further refined into an array of products such as end-use fuels, petrochemicals and other products. NGLs are processed into products such as propane, butane and ethane, and some may be processed further into the suite of petrochemical products. For energy-based supply chains, S&P Global Energy allocates emissions to coproducts based upon energy.

Aggregating emissions across a product life cycle

As discussed in previous sections, care must be taken to ensure correct treatment of coproducts, consistent functional unit and well-defined system boundaries when attributing emissions to a product on a life-cycle basis. Given that this is not that easy to do, an example is provided below for an LNG product life-cycle intensity. Figure 4 shows a typical LNG supply chain.[8] First, natural gas and oil are drilled for and coproduced. The natural gas and oil are separated at the wellhead. The natural gas, which often contains NGLs (which is often called rich gas), must be "gathered" into larger volumes by smaller pipelines and have the pressure "boosted" to be transported a short distance by pipeline to a gas processing plant. The processing plant separates the liquids from gas and purifies the gas-to-pipeline quality by removing impurities, namely, H_2S and CO_2 entrained within the produced gas. Typically, long-distance transmission pipelines bring the natural gas to a liquefaction plant where is it compressed and cooled to produce LNG. Finally, it is shipped overseas to the buyer of the product.

Figure 4

LNG product life-cycle example



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To arrive at an estimate of the delivered LNG product GHG intensity/carbon intensity (CI), each segment of the life cycle must be considered separately and accurately accounting for changes in product flows through each segment. The total CI may be added up using the following equation

[8] Partial LCA, as it does not include emissions associated with construction and land-use change or end-use combustion of natural gas.

$$CI_{LNG} = \frac{gCO_{2e\,D\&C+Prod}}{MJ_{NG}} + \frac{gCO_{2e\,G\&B}}{MJ_{NG}} + \frac{gCO_{2e\,Processing}}{MJ_{NG}} + \frac{gCO_{2e\,T\&S}}{MJ_{NG}} + \frac{gCO_{2e\,Liquification}}{MJ_{NG}} + \frac{gCO_{2e\,Shipping}}{MJ_{NG}}$$

Where emissions per segment should be allocated to natural gas according to the energy ratio (ER):

$$ER = \frac{MJ_{NG}}{MJ_{NG} + MJ_{Oil+NGLs+Condensates}}$$

Oil and gas are typically coproduced at the well head. Additionally, there is variability in the liquids content of all gas streams produced. Some have a large amount of NGLs (ethane, propane, butane) and higher carbon content liquids often characterized as condensates. When we are accounting for a final dry marketable natural gas carbon intensity, we want to apportion to just the natural gas supply chain. This is done by applying an energy ratio (ER) to the emissions at each segment of the supply chain. The ER changes throughout the value chain. In the beginning (part 1 in Figure 4), coproducts of natural gas, NGLs and oil are produced so all of the products must be accounted for in the energy content of the stream. After production, oil is separated from the rich gas and the rich gas is gathered and subsequently processed (part 2 in Figure 4). After processing, dry gas is collected, stored and transported to liquefaction facilities and LNG transported further overseas. For the T&S segments and beyond, no emissions allocation to coproducts is needed as all emissions are associated with marketable natural gas or LNG (part 3 in Figure 4).

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