Global Methane Tracker

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INTERNATIONAL ENERGY AGENCY

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Background

The IEA's estimates of methane emissions are produced within the framework of the World Energy Model (WEM). Since 1993, the International Energy Agency (IEA) has provided medium- to long-term energy projections using this large-scale simulation model designed to replicate how energy markets function and generate detailed sector-by-sector and region-by-region projections for the *World Energy Outlook* (*WEO*) scenarios. Updated every year, the model consists of three main modules: final energy consumption (covering residential, services, agriculture, industry, transport and non-energy use); energy transformation including power generation and heat, refinery and other transformation (such as hydrogen production); and energy supply (oil, natural gas and coal). Outputs from the model include energy flows by fuel, investment needs and costs, greenhouse gas emissions and end-user prices.

The WEM is a very data-intensive model covering the whole global energy system. Much of the data on energy supply, transformation and demand, as well as energy prices is obtained from the IEA's own databases of energy and economic statistics (http://www.iea.org/statistics) and through collaboration with other institutions. For example, for the *Net Zero by 2050: A Roadmap for the Global Energy Sector* publication, results from both the WEO and Energy Technology Perspectives (ETP) models have been combined with those from the International Institute for Applied Systems Analysis (IIASA) – in particular the Greenhouse Gas - Air Pollution Interactions and Synergies (GAINS) model – to evaluate air pollutant emissions and resultant health impacts. And, for the first time, results were combined with the IIASA's Global Biosphere Management Model (GLOBIOM) to provide data on land use and net emissions impacts of bioenergy demand. The WEM also draws data from a wide range of external sources which are indicated in the relevant sections of the WEM documentation.

The current version of WEM covers energy developments up to **2050** in 26 regions. Depending on the specific module of the WEM, individual countries are also modelled: 12 in demand; 102 in oil and natural gas supply; and 19 in coal supply (see Annex 1 of the WEM documentation).

Methane emission estimates

The Global Methane Tracker covers all sources of methane from human activity. For the energy sector, these are IEA estimates for methane emissions from the supply or use of fossil fuels (coal, oil and natural gas) and from the use of bioenergy (such as solid bioenergy, liquid biofuels and biogases). For non-energy sectors – waste, agriculture and other sources – reference values based on publicly available data sources are provided to enable a fuller picture of methane sources.

Upstream and downstream oil and gas

Our approach to estimating methane emissions from global oil and gas operations relies on generating country-specific and production type-specific emission intensities that are applied to production and consumption data on a country-by-country basis. Our starting point is to generate emission intensities for upstream and downstream oil and gas in the United States (Table 1). The 2021 US Greenhouse Gas Inventory (US EPA, 2021) is used along with a wide range of other publicly-reported, credible data sources. The hydrocarbon-, segment- and production-specific emission intensities are then further segregated into fugitive, vented and incomplete flaring emissions to give a total of 19 separate emission intensities.

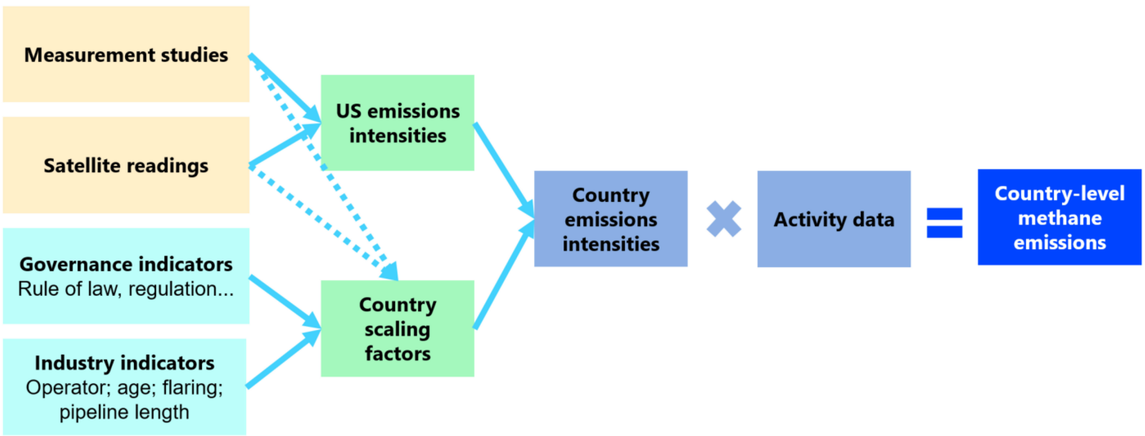
Table 1. Categories of emission sources and emissions intensities in the United States

Hydrocarbon	Segment	Production type	Emissions type	Intensity (mass methane/mass oil or gas)
Oil	Upstream	Onshore conventional	Vented	0.39%
Oil	Upstream	Onshore conventional	Fugitive	0.03%
Oil	Upstream	Offshore	Vented	0.39%
Oil	Upstream	Offshore	Fugitive	0.03%
Oil	Upstream	Unconventional oil	Vented	0.59%
Oil	Upstream	Unconventional oil	Fugitive	0.05%
Oil	Downstream		Vented	0.004%
Oil	Downstream		Fugitive	0.001%
Oil		Onshore conventional	Incomplete-flare	0.08%
Oil		Offshore	Incomplete-flare	0.02%
Oil		Unconventional	Incomplete-flare	0.09%
Natural gas	Upstream	Onshore conventional	Vented	0.40%

Hydrocarbon	Segment	Production type	Emissions type	Intensity (mass methane/mass oil or gas)
Natural gas	Upstream	Onshore conventional	Fugitive	0.18%
Natural gas	Upstream	Offshore	Vented	0.40%
Natural gas	Upstream	Offshore	Fugitive	0.18%
Natural gas	Upstream	Unconventional gas	Vented	0.67%
Natural gas	Upstream	Unconventional gas	Fugitive	0.31%
Natural gas	Downstream		Vented	0.14%
Natural gas	Downstream		Fugitive	0.26%

The US emissions intensities are scaled to provide emission intensities in all other countries. This scaling is based upon a range of auxiliary country-specific data. For the upstream emission intensities, the scaling is based on the age of infrastructure, types of operator within each country (namely international oil companies, independent companies or national oil companies) and average flaring intensity (flaring volumes divided by oil production volumes). For downstream emission intensities, country-specific scaling factors were based upon the extent of oil and gas pipeline networks and oil refining capacity and utilisation.

Figure 1 Methodological approach for estimating methane emissions from oil and gas operations



The strength of regulation and oversight, incorporating government effectiveness, regulatory quality and the rule of law as given by the Worldwide Governance Indicators compiled by the World Bank (2021), affects the scaling of all intensities. Some adjustments were made to the scaling factors in a limited number of countries to take into account other data that were made available (where this was considered to be sufficiently robust), such as comprehensive measurement studies. This includes data on satellite-detected large emitters and basin-level emissions, based on data processing by Kayrros, an earth observation firm (see Box 1.6). It also includes specific policy efforts to control methane emissions from the oil and gas sectors, as tracked in the IEA Policies Database.

Table 2 provides the resultant scaling factors in the top oil and gas producers (the countries listed cover 95% of global oil and gas production). These scaling factors are directly used to modify the emissions intensities in Table 1. For example, the vented emission intensity of onshore conventional gas production in Russia is taken as 0.40%×1.6 = 0.64%. These intensities are finally applied to the production (for upstream emissions) or consumption (for downstream emissions) of oil and gas within each country.

Table 2. Scaling factors applied to emission intensities in the United States

Country	Oil & gas production in 2021	Oil		Gas	
	mtoe	Upstream	Downstream	Upstream	Downstream
United States	1 516	1.0	1.0	1.0	1.0
Russia	1 170	2.1	1.4	1.6	1.2
Saudi Arabia	619	1.0	0.6	0.8	0.6
Canada	418	0.8	0.5	0.9	0.5
Iran	355	2.9	1.0	1.6	1.0
China	352	1.2	0.8	0.9	0.7
Iraq	222	1.8	0.8	1.1	0.8
United Arab Emirates	224	1.2	0.6	1.1	0.6
Qatar	221	1.0	0.6	1.0	0.6
Norway	195	0.0	0.0	0.0	0.0
Kuwait	147	1.1	0.7	0.8	0.7
Brazil	173	1.4	1.3	1.4	1.3
Algeria	143	4.2	1.3	1.7	1.3
Nigeria	120	3.8	1.8	2.0	1.7
Mexico	125	1.7	0.9	1.1	0.8
Kazakhstan	120	2.8	1.4	2.5	1.4
Australia	138	0.9	0.5	0.5	0.5
Indonesia	88	2.4	1.3	1.6	1.3
Malaysia	87	1.2	0.6	0.7	0.6
United Kingdom	69	0.5	0.3	0.4	0.3
Egypt	86	2.7	1.0	1.3	1.0
Oman	88	1.6	0.7	1.1	0.7
Venezuela	46	9.0	1.8	2.4	1.8
Turkmenistan	84	17.3	5.0	6.3	5.0
Angola	65	1.5	1.3	0.7	1.3

Box 1.1 Integrating emissions estimates from satellites

The Global Methane Tracker integrates results from all publicly-reported, credible sources where data has become available. This includes emissions detected by satellites. Changes in the atmospheric concentration of methane can be used to estimate the rate of emissions from a source that would have caused such a change. This is done based on data processing by Kayrros, an earth observation firm, to convert readings of concentrations to identify large sources of emissions from oil and gas operations. Reported emissions encompass individual methane sources above 5 tonnes per hour as well as clusters of smaller sources in dense areas (e.g. shale plays). Estimates are also provided using "basin-level inversions", which use satellite readings to assess methane emissions across a wider oil and gas production region; the same approach is also used to measure the methane footprint of coal basins.

Emissions detected by satellites are reported as a separate item within the Methane Tracker. These estimates are based on a conservative scaling up of emission events directly detected in order to take into account that considers the period within the year when observations could be made. This is carried out for all regions where observations were possible for at least 15 days in the year.

The increasing amount of data and information from satellites will continue to improve global understanding of methane emissions levels and the opportunities to reduce them. However, satellites do have some limitations:

- Existing satellites do not provide measurements over equatorial regions, northern areas or for offshore operations. This means that there are a large number of major production areas (e.g. in areas that are often covered with snow) where emissions cannot be directly detected by satellites.
- Existing satellites should be able to provide methane readings globally on a daily basis but this is not always possible because of cloud cover and other weather conditions. During 2021 there were around 70 countries where methane emissions from oil and gas operations could be detected for at least 15 days. Large emission events were observed in 15 of these countries in 2021. Coverage tends to be best in the Middle East, where a direct measurement could be made every 3-5 days. On the remaining days, cloud coverage or other interference prevented measurement operations.
- The satellite readings included in the Global Methane Tracker currently provide data only for large emitting sources. They may fail to capture small-scale emissions sources such as faulty components, which could add up to a large overall amount of emissions.

- The process of using changes in the atmospheric concentration of methane to estimate emissions from a particular source can rely on a large level of auxiliary data and be subject to a high degree of uncertainty.

Accounting for the level of satellite coverage, very large emitting events detected by satellite are estimated to have been responsible for around 3.5 Mt of emissions from oil and gas operations in 2021 (6% of our estimate of oil and gas emissions in the 15 countries where events were detected). This is, of course, subject to a high degree of uncertainty, but ensures that country-by-county estimates provide a comprehensive picture of all methane emissions sources. As additional data becomes available from measurement campaigns – whether recorded from ground or aerial processes or by satellites – these will be incorporated into the Global Methane Tracker and estimates adjusted accordingly.

Incomplete combustion of flares

Our approach to estimating methane emissions from flaring relies on generating country-specific and production type-specific combustion efficiencies that are applied to flaring data on a country-by-country basis. Global estimates of flared volumes of natural gas are based on reported data from the World Bank's Global Gas Flaring Reduction Partnership. These data are taken from the National Oceanic and Atmospheric Administration (NOAA) and the Payne Institute (World Bank, 2021).

Combustion efficiencies can reduce as a result of lower production rates, high and variable winds, and poor maintenance resulting from lack of regulatory policy, enforcement or company policy (Johnson, 2001; Kostiuk, 2004). We estimate combustion based upon a range of auxiliary country-specific data:

- Oil production type (unconventional onshore, conventional onshore and offshore), company type and production start-up year, based on Rystad Energy UCube data. Company type is grouped in Majors (ExxonMobil, Chevron, BP, Royal Dutch Shell, Eni SpA, TotalEnergies, and ConocoPhillips), National Oil Companies (NOCs) and Other (e.g. Independent, Private Equity). Maintenance levels to improve flaring combustion efficiencies were applied separately by company type assuming that more scrutiny from investors and the public is placed on the Majors as compared to NOCs or Other.
- Flaring design standards API 521 and API 537 were considered gauge flare stack sizes, assuming best-case design and optimal flare parameters during early production time (API, 2014; API, 2017).
- The impact of wind speed was incorporated using NASA's Prediction of Worldwide Energy Resources (POWER) Meteorology Data Access Viewer (NASA, 2021). Onshore wind speeds were assessed at 10m and offshore wind speeds at 50m to

reflect closest height of flare stacks in actual facility design. Wind speed variability and its impact on combustion efficiency was incorporated corresponding to the location of production.

- The World Bank's Worldwide Governance Indicators database (2021) was used as the basis to assess the general strength of regulatory oversight.

Adjustments are made to consider data on satellite-detected large emitters and specific policy efforts to control methane emissions from the oil and gas sectors, as tracked in the IEA Policies Database. Countries with stronger flaring regulation and strong regulatory oversight are calibrated assuming companies were mandated to quickly inspect and repair any malfunctioning or poor performing flare sites. Countries with weak flaring regulation and low levels of oversight are assumed to perform little to no additional maintenance.

Coal mine methane

Estimates for coal mine methane (CMM) emissions are derived from mine-specific emissions intensities for three major coal producing countries. The starting point is to generate emission intensities for coal mines in the United States using the US Environmental Protection Agency's Greenhouse Gas Reporting Program and US Greenhouse Gas Inventory (US EPA, 2021). This is supplemented by data sources that provided disaggregated CMM data for China (Wang et al., 2018; Zhu et al., 2017) and India (Singh A. K. and Sahu J. N., 2018) (India Ministry of Coal, 2018).

The mine-level CMM estimates generated in this way were then aggregated and verified against the country-level estimates taken from satellite based measurements (Deng et al., 2021; Miller et al., 2019). Based on these data, coal quality (e.g. the ash content or fixed carbon content of coal produced by individual mines), mine depth and regulatory oversight were used as key factors to estimate CMM emission intensities for mines in other countries for which there are no reliable direct estimates.

An important factor in estimating CMM emissions is the depth and age of the various mines in operation. Deeper coal seams tend to contain more methane than shallower seams, while older seams have higher methane content than younger seams. In the absence of any mitigation measures, methane emissions to the atmosphere will therefore tend to be higher for underground mines than for surface mines. Regulations can also affect emissions, limiting the amount of methane that can be vented or ensuring that these emissions are captured and put to use (e.g. mandating the application of drainage technologies and the development of capacity to support gas use, such as pipelines networks, gas-powered electricity generation).

Emissions from abandoned mines are not included in these estimates as related measurement studies cover a limited number of facilities and regions, and data on abandoned mines and wells is not available for most countries. Nevertheless, these sources can represent significant shares of emissions. For example, the United States Environmental Protection Agency indicates they are responsible for close to 5% of energy-related methane in the United States (US EPA, 2021).

Emissions from fuel combustion (end use)

Methane emissions are associated with fuel use, either due to incomplete combustion or as fugitive emissions. Methane can leak from storage vessels, pipelines or end use appliances (e.g. stovetops). It can also escape without combustion from mobile applications (e.g. natural gas fuelled vehicles) or stationary applications (e.g. power generators).

We estimate that around 9 Mt of methane emissions comes during the incomplete combustion of traditional use of biomass for cooking in emerging market and developing economies. With regards to fossil fuels, we estimate that about 4 Mt (3% of energy-related methane emissions) comes from the end use of coal, oil products and natural gas. This estimate is based on the emissions factors published by the Intergovernmental Panel on Climate Change (IPCC) for energy consumption in homes, industries and in the transport sector.

Estimates for methane emissions from the use of fuels in stationary and mobile applications are from the IEA Greenhouse Gas Emissions from Energy 2021, for the base year 2019. The Tier 1 methodology from the 2006 IPCC Guidelines for GHG inventories have been adopted for the purpose of estimating the non-CO2 emissions from fuel combustion. Unlike CO2, the non-CO2 greenhouse gas emissions from fuel combustion are strongly dependent on the technology used. Since the set of technologies, applied in each sector vary considerably, the guidelines do not provide default emission factors for these gases on the basis of fuels only. Sector-specific Tier 1 default emission factors can provide a reasonable estimate for these emissions.

Some measurement campaigns have suggested that these emissions factors could significantly underestimate actual emissions across different end-use environments, including in industries (Zhou et al., 2019), cities (Sargent et al., 2021) and households (Lebel et al., 2022). Emission levels might also have changed from 2019 to 2021, for example, the covid-19 pandemic might have led to an increase in the traditional use of biomass for cooking or heating. These are areas with very high levels of uncertainty and our estimates will continue to be updated as the evidence base grows.

For estimating the emissions corresponding to stationary combustion, the default Tier 1 non-CO2 emission factors provided in the 2006 IPCC guidelines assume effective combustion in high temperature. The emission factors provided for CH4 are based on the 1996 IPCC Guidelines and have been established by a large group of inventory experts. However, due to the absence of sufficient measurements and since the concept of conservation of carbon does not apply in the case of non-CO2 gases, the uncertainty range associated with these estimates are set at a factor of three.

Similarly and for mobile combustion, the non-CO2 emission factors are more difficult to estimate accurately than those for CO2, as they will depend on vehicle technology, fuel and operating characteristics, mainly the combustion and emission control system of the vehicles. As a result, default fuel-based emission factors are highly uncertain. However, the Tier 1 method does allow using fuel-based emission factors if it is not possible to estimate fuel consumption by vehicle type.

For more details on the underlying methodology and assumptions please refer to the IEA GHG emissions from energy documentation.

Waste and agriculture

The 2022 update of the Global Methane Tracker includes emissions estimates from non-energy sectors – waste, agriculture and other sources – based on publicly available data sources, to provide a fuller picture of methane sources from human activity. Reference estimates are taken as an average of estimates available for the most recent year from 2018 or 2019, based on the following sources.

United Nations Framework Convention on Climate Change (UNFCCC) – National greenhouse gas inventories submitted to the Climate Change secretariat. These submissions are made in accordance with pertaining reporting requirements, such as the UNFCCC reporting guidelines on annual greenhouse gas inventories. The inventory data are provided in the annual greenhouse gas inventory submissions by Annex I Parties and in the national communications and biennial update reports by non-Annex I Parties. Data available here.

Emissions Database for Global Atmospheric Research (EDGAR v6.0) – EDGAR is a global database of anthropogenic emissions of greenhouse gases and air pollution. EDGAR provides independent emission estimates compared to what is reported by Parties under the UNFCCC, using international statistics and a consistent IPCC methodology. Additional information can be found in Crippa et al. (2021). Data available here.

Community Emissions Data System (CEDS v_2021_04_21) – CEDS produces consistent estimates of global air emissions species over the industrial era (1750 - present). It uses a variety of data to do so, from population and energy statistics to emissions inventories and a variety of auxiliary data. Note that EDGAR is among the sources used to establish emissions factors for non-combustion sources, further information on CEDS methodology and sources can be found in Hoesly et al. (2018) and here. Data available here.

Climate Watch (CAIT) – CAIT draws on climate-relevant data from research centres, government agencies, and international bodies, including the U.N. Food and Agriculture Organization (FAO, 2021) and the U.S. Environmental Protection Agency. The CAIT Historical GHG Emissions data contains sector-level greenhouse gas emissions data for 194 countries for the period 1990-2018, including emissions of the six major greenhouse gases from most major sources and sinks. Further information can be found here. Data available here.

These datasets were aligned with the categories and regions shown in the Global Methane Tracker by considering individually all major emitters and anthropogenic emissions sources included in each database.

Marginal abatement cost curves for oil and gas

To construct the marginal abatement cost curves presented in the Methane Tracker Database, the 19 emissions sources listed in Table 1 were further separated into 91 equipment-specific emissions sources (Table 3).[1] The allocation of emissions from each of the 19 emissions sources to these 91 equipment-specific sources was generally based on proportions from the United States. However a number of modifications were made for countries based on other data sources and discussions with relevant stakeholders. Some of the largest changes made were for the proportion of emissions from: pneumatic controllers (which are less prevalent in many countries outside North America), LNG liquefaction (which were assumed to be larger in LNG exporting countries), and associated gas venting.

Table 3. Equipment-specific emissions sources in the marginal abatement cost curves

Equipment source	Hydrocarbon	Segment
Large Tanks w/Flares	Oil	Upstream
Large Tanks w/VRU	Oil	Upstream

[1] To aid visualisation of the marginal abetment cost curves, the costs and savings from multiple technologies are generally aggregated together. Within each country, the abatement options that could be applied to each of the 19 emission sources are aggregated into three cost steps. These steps roughly represent the cheapest 50% of reductions, the next 30% of reductions and the final of 20% reductions.

Equipment source	Hydrocarbon	Segment
Large Tanks w/o Control	Oil	Upstream
Small Tanks w/Flares	Oil	Upstream
Small Tanks w/o Flares	Oil	Upstream
Heaters	Oil	Upstream
Boilers	Oil	Upstream
Malfunctioning Separator Dump Valves	Oil	Upstream
Pneumatic Devices, High Bleed	Oil	Upstream
Pneumatic Devices, Low Bleed	Oil	Upstream
Pneumatic Devices, Int Bleed	Oil	Upstream
Chemical Injection Pumps	Oil	Upstream
Vessel Blowdowns	Oil	Upstream
Compressor Blowdowns	Oil	Upstream
Compressor Starts	Oil	Upstream
Associated Gas Venting	Oil	Upstream
Associated Gas Flaring	Oil	Upstream
Well Completion Venting (less HF Completions)	Oil	Upstream
Well Workovers	Oil	Upstream
HF Well Completions, Uncontrolled	Oil	Upstream
HF Well Completions, Controlled	Oil	Upstream
Pipeline Pigging	Oil	Upstream
Tanks	Oil	Downstream
Truck Loading	Oil	Downstream
Marine Loading	Oil	Downstream
Rail Loading	Oil	Downstream
Pump Station Maintenance	Oil	Downstream
Pipeling Pigging	Oil	Downstream
Uncontrolled Blowdowns	Oil	Downstream
Asphalt Blowing	Oil	Downstream
Process Vents	Oil	Downstream
CEMS	Oil	Downstream
Glycol Dehydrator	Gas	Upstream
Production Compressor Vented	Gas	Upstream
Gas Well Completions without Hydraulic Fracturing	Gas	Upstream
Gas Well Workovers without Hydraulic Fracturing	Gas	Upstream
Hydraulic Fracturing Completions and Workovers that vent	Gas	Upstream
Hydraulic Fracturing Completions and Workovers with RECs	Gas	Upstream
Well Drilling	Gas	Upstream
Pneumatic Device Vents (Low Bleed)	Gas	Upstream
Pneumatic Device Vents (High Bleed)	Gas	Upstream
Pneumatic Device Vents (Intermittent Bleed)	Gas	Upstream
Chemical Injection Pumps	Gas	Upstream
Kimray Pumps	Gas	Upstream
Dehydrator Vents	Gas	Upstream
Large Tanks w/VRU	Gas	Upstream
Large Tanks w/o Control	Gas	Upstream
Small Tanks w/o Flares	Gas	Upstream
Malfunctioning Separator Dump Valves	Gas	Upstream
Gas Engines	Gas	Upstream
Well Clean Ups (LP Gas Wells) - Vent Using Plungers	Gas	Upstream

Equipment source	Hydrocarbon	Segment
Well Clean Ups (LP Gas Wells) - Vent Without Using Plungers	Gas	Upstream
Vessel BD	Gas	Upstream
Pipeline BD	Gas	Upstream
Compressor BD	Gas	Upstream
Compressor Starts	Gas	Upstream
Gathering and Boosting Stations	Gas	Upstream
Pressure Relief Valves	Gas	Upstream
Mishaps	Gas	Upstream
Recip. Compressors	Gas	Upstream
Centrifugal Compressors (wet seals)	Gas	Upstream
Centrifugal Compressors (dry seals)	Gas	Upstream
Dehydrators	Gas	Upstream
AGR Vents	Gas	Upstream
Pneumatic Devices	Gas	Upstream
Blowdowns/Venting	Gas	Upstream
Produced water from Coal Bed Methane Wells	Gas	Upstream
Reciprocating Compressor	Gas	Downstream
Centrifugal Compressor (wet seals)	Gas	Downstream
Centrifugal Compressor (dry seals)	Gas	Downstream
Reciprocating Compressor	Gas	Downstream
Dehydrator vents (Transmission)	Gas	Downstream
Dehydrator vents (Storage)	Gas	Downstream
Pneumatic Devices (High Bleed)	Gas	Downstream
Pneumatic Devices (Intermittent Bleed)	Gas	Downstream
Pneumatic Devices (Low Bleed)	Gas	Downstream
Pneumatic Devices (High Bleed)	Gas	Downstream
Pneumatic Devices (Intermittent Bleed)	Gas	Downstream
Pneumatic Devices (Low Bleed)	Gas	Downstream
Pipeline venting	Gas	Downstream
Station Venting Transmission	Gas	Downstream
Station Venting Storage	Gas	Downstream
LNG Reciprocating Compressors Vented	Gas	Downstream
LNG Centrifugal Compressors Vented	Gas	Downstream
LNG Station venting	Gas	Downstream
LNG Reciprocating Compressors Vented	Gas	Downstream
LNG Centrifugal Compressors Vented	Gas	Downstream
LNG Station venting	Gas	Downstream
Pressure Relief Valve Releases	Gas	Downstream
Pipeline Blowdown	Gas	Downstream
Mishaps (Dig-ins)	Gas	Downstream

The abatement options included in the marginal abatement cost curves to reduce emissions from these sources are listed in Table 4. We are unable to provide the specific costs and applicability factors for these as it is based on proprietary information gathered by ICF (although see (ICF, 2016a) and (ICF, 2016b) for data that has made available publically). Every abatement option has a specific capital cost, which is annualised based on the number of years it is expected to last. These are added to yearly operational costs, which entail wages, maintenance and related expenditures. Costs were again based upon information from the United States. However labour costs, whether the equipment is imported or manufactured domestically (which impacts the capital costs and whether or not import taxes are levied), and capital costs were modified based on country-specific or region-specific information. Similarly the applicability factors are modified based on other data that is available publically (for example that solar-powered electric pumps cannot be deployed as widely in high-latitude countries).

Leak detection and repair (LDAR) programmes are the key mechanism to mitigate fugitive emissions from the production, transmission or distribution segments of the value chain. The costs of inspection differ depending on the segment in question since it takes longer to inspect a compressor on a transmission pipeline than in a production facility. It is assumed that inspections can be carried out annually, twice a year, quarterly or monthly, with each option included as a separate mitigation option in the marginal abatement cost curves. We also consider the option of a continuous monitoring system, either based on remote or facility-based sensors (Daily LDAR), which abates emissions from large leaks that occur sporadically such as those detected by satellites. Annual inspections are assumed to mitigate 40% of fugitive emissions, biannual inspections mitigate an additional 20%, quarterly inspections mitigate an additional 10%, and monthly inspections mitigate an additional 5%. Implementing a monthly LDAR programme therefore reduces fugitive emissions by 85%; the remaining 15% cannot be avoided. As the frequency of implementing each programme increases, so does the cost per unit of methane saved. For example, while the incremental cost of a biannual inspection programme is the same as that of an annual inspection, the incremental volume of methane saved is lower (20% rather than 40%). Nevertheless, LDAR programmes remain some of the most cost-effective mitigation options available, i.e. they tend to comprise a large proportion of the positive net present value options in countries.

Table 4. Abatement options for methane emissions from oil and gas operations

Abatement option
Blowdown Capture and Route to Fuel System (per Compressor)
Blowdown Capture and Route to Fuel System (per Plant)
Early replacement of high-bleed devices with low-bleed devices
Early replacement of intermittent-bleed devices with low-bleed devices
Install Flares-Completion
Install Flares-Portable
Install Flares-Portable Completions Workovers WO HF
Install Flares-Portable WO Plunger Lifts
Install Flares-Stranded Gas Venting
Install Flares-Venting
Install New Methane Reducing Catalyst in Engine

Abatement option
Install Non Mechanical Vapor Recovery Unit
Install Plunger Lift Systems in Gas Wells
Install small flare
Install Vapor Recovery Units
LDAR Gathering
LDAR LDC - Large
LDAR LDC - MRR
LDAR Processing
LDAR Reciprocating Compressor Non-seal
LDAR Transmission
LDAR Wells
Mechanical Pumping for Liquids Unloading
Pipeline Pump-Down Before Maintenance
Redesign Blowdown Systems and Alter ESD Practices
Reduced Emission Completion
Replace Kimray Pumps with Electric Pumps
Replace Pneumatic Chemical Injection Pumps with Electric Pumps
Replace Pneumatic Chemical Injection Pumps with Solar Electric Pumps
Replace with Instrument Air Systems
Replace with Electric Motor
Replace with Servo Motors
Replace with Solenoid Controls
Replacement of Reciprocating Compressor Rod Packing Systems
Route to existing flare - Large Dehydrators
Route to existing flare - Large Tanks
Route to flare - Small Dehydrators
Route to existing flare - Small Tanks
Route Vent Vapors to tank
Wet Seal Degassing Recovery System for Centrifugal Compressors
Wet Seal Retrofit to Dry Seal Compressor
Microturbine
Mini-LNG
Mini-GTL
Mini-CNG

In our marginal abatement cost curve, we have grouped these abatement options into several categories. We have also associated each abatement option with policy measures that target those actions. The abatement and policy options that appear in the marginal abatement cost curves are described in further detail in the glossary below.

Box 1.2 Policies Database and Policy Explorer

The Global Methane Tracker incorporates information from the IEA's Policies Database. This cross-agency database brings together information on past, existing or planned government policies and measures covering many topics across the energy sector, including energy efficiency, renewables, technology innovation and methane abatement.

The entries in the Policies Database related to methane abatement are categorised by policy type and by sector. For each entry, we have included a brief description, links to original source material and other information about the measure. This information is based on a broad review of policy and regulatory measures in place across the world. We have identified different measures through desktop research and through discussions with governments. As of the release of the Global Methane Tracker 2022, this database has over 350 entries including in-depth information on policies in place in 25 countries plus the European Union and more limited information on many more. We welcome feedback regarding any updates to existing policies or on additional policies that are missing from the database.

The Global Methane Tracker includes a new policy explorer tool that provides a snapshot of the different policies and regulations in already in place in 25 countries. The policy explorer shows 16 different types of policies, which are categorised by the primary regulatory approach: prescriptive, performance-based, economic, or information-based. Detailed definitions for these categories and policy types can be found in the glossary.

Well-head prices used in net present value calculation

Since natural gas is a valuable product, the methane that is recovered can often be sold. This means that deploying certain abatement technologies can result in overall savings if the net value received for the methane sold is greater than the cost of the technology. Well-head prices are used in each country to determine the value of the methane captured. As described in *WEO-2019,* the marginal abatement cost curves examine this issue from a global, societal perspective. The credit obtained for selling the gas is therefore applied regardless of the contractual arrangements necessary and the prices assume that there are no domestic consumption subsidies (as the gas could be sold on the international market at a greater price). The well-head gas prices used could therefore be substantially different from subsidised domestic gas prices.

Representative average natural gas import prices seen from 2017 to 2021 are the starting point for the well-head prices within each country. To estimate well-head prices over time, each country is assigned to be either an importer or an exporter based on the trends seen in the Stated Policies Scenario. For importing countries, any gas that would be saved from avoiding leaks would displace imports. The well-head price is therefore taken as the import price minus the cost of local transport and various taxes that may be levied (assumed to be around 15% of the import price). For exporting countries, the relevant well-head price is taken as the import price in their largest export market net-backed to the emissions source. For the net-back, allowance is made for transport costs (including liquefaction and shipping or pipeline transport), fees and taxes. For example, in Russia the export price is taken as the import price in Europe ($7.4/MBtu based on average 2017-2021 prices). Export taxes are then subtracted along with a further $0.5/MBtu to cover the cost of transport by pipeline. This gives a well-head gas price in Russia of about $4.7/MBtu. In the United States and Canada, the well-head price is taken as the Henry Hub price minus 15% (to cover the cost of local transportation and fees).

The costs and revenue for each technology or abatement measure are converted into net present value using a discount rate of 10% and divided by the volume of emissions saved to give the cost in dollars per million British thermal units (MBtu).

Projections of energy-related methane emissions and assessed temperature rises

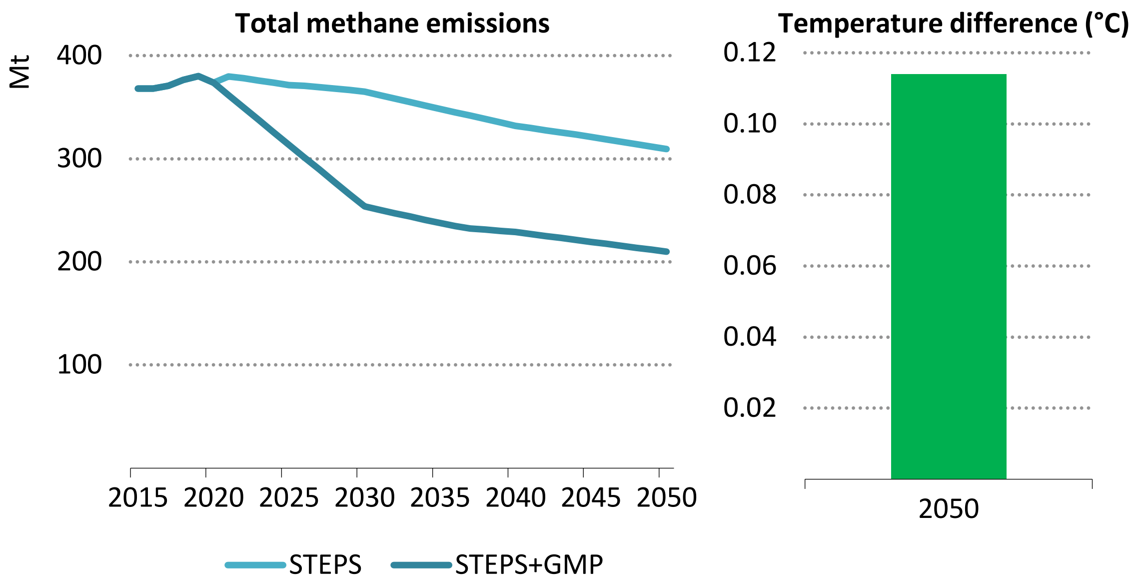
We have carried out analysis using the Model for the Assessment of Greenhouse Gas Induced Climate Change ("MAGICC") to assess the impacts of different emissions trajectories on the average global surface temperature rise. MAGICC climate models have been used extensively in assessment reports written by the Intergovernmental Panel on Climate Change. MAGICC 7, the version used in this analysis, is one of the models used for scenario classification in the IPCC's 6th Assessment Report (IPCC, 2021). Emissions of all energy-related GHG from the WEO-2021 scenarios are supplemented with commensurate changes in non-energy-related emissions based on the scenario database published as part of the IPCC Special Report on Global Warming of 1.5 °C (IPCC, 2018). All changes in temperatures are relative to 1850-1900 and match the IPCC 6th Assessment Report definition of warming of 0.85 °C between 1995-2014.

An important consideration in assessing temperature rises is the date to examine. If the aim of climate policy is to limit peak warming, then the key factor is the time when the global temperature rise will reach a peak (Allen et al., 2016). In the IEA's Net Zero Emissions by 2050 Scenario, global CO_2 emissions drop to zero in 2050 and this is approximately the date when the global temperature rise peaks. We therefore choose to focus our analysis on the temperature rise in 2050.

The Stated Policies and Net-Zero Emissions by 2050 scenarios project methane emissions from fossil fuel operations to 2050. Changes in other non-energy sources of methane are introduced via a process of "infilling" based on the most relevant Shared Socioeconomic Pathway-Representative Concentration Pathway (SSP-RCP) and a quantile rolling windows method from Silicone (Lamboll et al. 2020). For the Stated Policies Scenario, non-energy sources of methane are initially based on SSP 2-4.5.

Differences are then examined in the temperature rise in 2050 between the Stated Policies Scenario and the Stated Policies Scenario with the full achievement of the Global Methane Pledge (a 30% reduction in all human sources of methane by 2030). After 2030, the difference in methane emissions between these two cases is assumed to close slightly. All other variables, including the other greenhouse gases (such as CO_2, N_2O, HFCs etc.), are kept constant to isolate the impact of the methane abatement policies on the median temperature rise in 2050. Full implementation of the Global Methane Pledge reduces the temperature rise in the Stated Policies Scenario by around 0.12 °C in 2050.

Figure 2 Total methane emissions with and without implementation of the Global Methane Pledge in the Stated Policies Scenario and difference in temperature in 2050



Source: IEA analysis based on outputs of MAGICC 7.5.3.

Glossary

Abatement technologies

A wide variety of technologies and measures are available to reduce methane emissions from oil and gas operations. The options deployed vary by country, depending on the prevailing emissions sources, gas prices and capital and labour costs. For the purposes of the marginal abatement cost curve, we have grouped the different abatement technologies into the following categories:

Replace existing devices

Many pieces of equipment in the oil and natural gas value chains emit natural gas in their regular course of operation, including valves, and gas-driven pneumatic controllers and pumps. Retrofitting these devices or replacing them with lower-emitting versions can reduce emissions.

Early replacement of devices. Pneumatic devices are used throughout production sites and compression facilities to control and operate valves and pumps with changes in pressure. Gas-driven automatic pneumatics release a small amount of natural gas as part of their control functions. Devices can be categorised as low-, intermittent- or high-bleed, based on the rate of gas that escapes. Intermittent-bleed devices release gas only when actuating. Replacing higher-bleed devices with lower-bleed devices reduces emissions. The earlier devices are swapped out, the more emissions will be avoided.

Replace pumps. Pneumatic pumps that use pressurised natural gas as a power source also vent natural gas in the ordinary course of their operation: these emissions can be eliminated through replacement with electrical pumps powered by solar or other generators, or connected to the grid.

Replace with electric motor. Gas-driven pneumatic devices continuously release small amounts of gas, even when specified as "low-bleed." These devices can be replaced with "zero-bleed" technologies that use electrical power to operate, instead of pressurised natural gas. An electric motor can also replace a diesel or gas engine used onsite during drilling and well completion.

Replace compressor seal or rod. Different kinds of compressors are used across the oil and natural gas supply chains to move product through the system, and the methane abatement cost curve include several activities that reduce the possibilities for gas to escape.

Replace with instrument air systems. Pumps and controllers that vent natural gas by design can be replaced by instrument air systems, which pressurise ambient air to perform the same functions without emitting methane.

Installing new devices

There are a number of opportunities across the supply chain to install new devices that can reduce or avoid large sources of vented emissions.

Vapour Recovery Units (VRUs). VRUs are small compressors designed to capture emissions that build up in pieces of equipment across the oil and natural gas supply chains. For instance, VRUs can capture gases that accumulate in oil storage tanks and that are otherwise periodically vented to the atmosphere to prevent explosion.

Blowdown capture. Gas blowdowns are conducted at wellheads or elsewhere along the supply chain when equipment (e.g. vessels, compressors) must be depressurised. Blowdowns can be triggered by emergency signals or routine start up or shut down procedures. When this happens, operators open up the well to remove the liquids and gas. Emissions are mitigated when excess gas is recovered and used onsite or sent to the sales line, instead of being vented or flared.

Install flares. While still a source of CO2 and methane emissions, flaring is preferable to direct release of the methane gas to the atmosphere. Flares can be installed at oil and gas production sites where gas production exceeds onsite demand or nearby pipeline capacity, to combust methane emissions. Portable flares can expand a facility's flare capacity and provide an outlet for gas captured during well workovers or completions.

Install plunger. Periodically over the life of a producing well, downhole liquids need to be removed to facilitate continued flow of product (often called "liquid unloading"). Traditionally, a well operator opens the well and vents methane, relieving pressure and drawing liquids up through the wellbore. Plunger lifts may be installed to extract liquids more efficiently, while limiting the escape of methane. As pressure from accumulating fluids builds up, it pushes on the plunger. The plunger draws up gas and liquids in its wake. If a certain threshold of reservoir pressure is achieved through withdrawal of the plunger, gas can go directly to the sales line with no venting.

Leak detection and repair (LDAR)

Leak detection and repair (LDAR) refers to the process of locating and repairing fugitive leaks. LDAR encompasses several techniques and equipment types. One common approach is the use of infrared cameras, which make methane leaks visible. LDAR can be applied across the supply chain—to upstream activities (including well development, gathering, processing) and/or downstream activities (such as transmission or distribution lines).

In the cost curve, we include varying frequencies of these programmes, from monthly to yearly—the more frequent LDAR programmes are, the less the amount of gas that tends to be saved as a result of each programme, while the costs remain stable. This is what one would expect from effective programmes. We also consider the option of a continuous monitoring system, either based on remote or facility-based sensors (Daily LDAR), which abates emissions from large leaks that occur sporadically such as those detected by satellites.

The cost of inspection differs depending on the value chain segment in question—LDAR programmes tend to be more cost effective for upstream operations since it takes longer to inspect compressors on transmission pipelines, relative to those concentrated in a production facility.

Other

IEA analysis includes alternative and innovative technologies and techniques in addition to the categories above. The “Other” label includes approaches such as: installing methane-reducing catalysts; deploying microturbines or other technologies that allow for local productive use of associated gas in remote locations: conducting a pipeline pump-down before maintenance; and reduced-emission or "green" completions.

Policy options

Different types of regulatory measures can be applied to methane. For each abatement technology described above, we have assigned a specific policy measure that targets this technology. Thus, for the purposes of our estimates of mitigation potential in the marginal abatement cost curve, we have grouped the different abatement actions into the following policy options:

Tried and tested policies

Certain policies have well-established precedents, as they have already been applied in multiple settings. These measures have proven to be both effective and relatively straightforward to administer. Policies in this category have the added benefit of not requiring very advanced tools to verify compliance, although some basic quantification and reporting mechanism is generally necessary. The measures in this category also tend to fall on the lower end of the abatement cost curve – and tend therefore to be the most cost-effective overall.

Leak detection and repair (LDAR). This refers to policies that require companies to establish programs for locating and repairing fugitive leaks. These policies often specify the method and equipment required for leak detection, the frequency of detection campaigns, which facilities must undertake the inspections, and a requirement to fix leaks within a certain timeframe. Within the IEA methane emissions model, this corresponds to both upstream and downstream abatement options. The model assumes that leak detection and repair will apply to all facilities and may be applied at different frequencies. In the policy marginal abatement cost curve, this includes inspection requirements that are at least quarterly, as this frequency is common among current requirements.

Technology standards. This refers to policies that set specific guidelines for equipment, technologies or procedures. Generally, such requirements mandate that certain equipment be replaced by a lower-emitting alternative. Within the methane model, this corresponds to the following abatement options: replace compressor seal or rod; early replacement of devices; replace with instrument air systems; and replace pumps.

Zero non-emergency flaring and venting. This refers to policies that either prohibit all non-emergency flaring and venting or those that mandate specific processes and procedures which result in less flaring and venting. Within the methane model, this corresponds to the following abatement options: install plunger; install flares; blowdown capture; and vapour recovery units.

Additional measures

Robust measurement-based monitoring regimes combined with additional regulations can encourage additional abatement. Within the IEA methane emissions model, additional measures correspond to the following abatement options: replace with electric motor; monthly leak detection and repair; daily leak detection and repair; other. These actions can be driven by a combination of different policies, including enhanced technology standards, performance standards, emissions pricing, financing instruments, and monitoring, reporting and verification regimes. More information about these additional measures can be found in Curtailing Methane Emissions from Fossil Fuel Operations.

Policy explorer

The Global Methane Tracker now includes a detailed country-by-country breakdown of policies in place for certain countries. This tool is based on the IEA's Policies Database. The explorer tool categorises policies by type of policy (prescriptive, performance-based, economic, or information-based). Specific definitions used in the policy explorer tool are found below. Further details can be find in Driving Down Methane Leaks from the Oil and Gas Industry: A Regulatory Roadmap and Toolkit.

Prescriptive

Regulations that direct regulated entities to undertake or not to undertake specific actions or procedures. This command-and-control approach focuses on setting procedural, equipment or technological requirements such as the installation or replacement of specific devices.

Leak detection and repair. Requirements to implement fugitive emissions management plans that include the process of locating and repairing fugitive leaks. Policies may address the type of equipment used, frequency of inspection, the leak threshold that triggers repair requirements and the length of time allowed to conduct the repairs.

Flaring or venting restrictions. Regulations that limit the amount of flaring or venting allowed or that prescribe the equipment or process for flaring or venting. This includes limitations on total volume, banning of such activities in routine proceedings (allowed only for safety reasons or special conditions), the need to request authorisations beforehand, or specifications of equipment or procedures.

Technology standards. Requirements that outline the equipment, technology or procedure that must be employed in a regulated activity (e.g. requires the use of no-bleed pneumatic devices; both high- and low-pressure gas-liquid separation stages must be used to minimise vapour released from produced hydrocarbon liquid; vented natural gas from liquids unloading must be collected). This includes best available technology requirements, which refer to a benchmark technology or procedure for reducing emissions that is considered reasonably practicable and evolves according to technological development.

Permitting requirements. Permits are a means of granting authorisation for specific operations or procedures (e.g. pollution permits, drilling permits). Permits also include conditions that limit their validity, which may be temporal, technological or spatial.

Performance

Regulations that establish a performance standard for regulated entities, but do not dictate how the target must be achieved. An absolute or relative performance target can be applied at the national level, through economy- or sector-wide targets; at the company level; at the level of each facility; or even to individual types of equipment.

Reduction targets. These refer to reduction goals, including the definition of baselines, intermediate goals and means of assessing progress, reviewing objectives and achieving established targets. At national level or sectoral level (e.g. 50% methane reductions in the oil and gas industry in 2030 from the 2010 baseline), these generally serve as a strategic instrument and do not impose specific requirements on companies.

Flaring or venting standards. Regulations that limit the amount of flaring or venting for the purpose of disposal allowed through a performance metric (e.g. minimum gas utilisation rates, admissible volume as a percentage of output) or establish other performance requirements (e.g. flaring must be designed for 98% efficiency). Regulations aimed primarily at fugitive emissions are not included in this category.

Process or equipment emissions standards. Regulations that limit emissions through a performance metric set at the process- or equipment-level (e.g. glycol dehydration units must control emissions by 95%). They generally cover different aspects related to atmospheric emissions, such as leak rates, discharge characteristics (e.g. temperature) or means (e.g. minimum height of discharge).

Facility or company emissions standards. Regulations that limit emissions through a performance metric set at the facility or company-level (e.g. each company must reduce emissions by 20% on a per unit basis). They generally cover different aspects related to atmospheric emissions, such as quantity (e.g. volume) or characteristics (e.g. concentration). This includes company or facility specific limits and associated reduction plans.

Economic

Regulations that use economic provisions to induce action by applying financial penalties or incentives. This may include taxes, subsidies or market-based instruments, such as tradeable emissions permits or credits, that allow firms to choose among different strategies to address emissions (e.g. directly reduce emissions or pay for offsets), effectively changing the cost curve of abatement.

Taxes or charges on emissions. Taxes, fees or other charges that are levied on emissions, including nationwide carbon taxes applied to methane or royalties and other charges imposed on fugitive emissions and methane emitted as result of operation of equipment or certain processes (e.g. emissions from high- or intermittent-bleed pneumatic devices).

Taxes or charges on gas disposal (flaring or venting). This refers to taxes, fees and charges that are levied when operators dispose of excess gas by flaring or venting.

Grants or other financial incentives. This includes all types of positive financial incentives that governments provide to reduce emissions. This could include direct provision of loans or grants to invest in reduction measures or other incentives such as allowing cost recovery for abatement costs via reductions in royalties, taxes or fees.

Emissions trading schemes and certified reduction credits. Emissions trading schemes typically define an emissions limit and allocate emissions allowances among the regulated community. These allowances can then be traded among companies according to their needs and capabilities. Certified reduction credits allow entities that go beyond established requirements to be accredited as voluntary methane reductions, which may be traded. This item also includes any requirement that allow companies to achieve emissions reduction requirements by buying tradable credits.

Information

Regulations that are designed to improve the state of information about emissions, and may include requirements that regulated entities estimate, measure and report their emissions to public bodies.

Measurement requirements. Mandatory data collection for activities, equipment or production flows (e.g. volume of gas flared or vented, fugitive emissions leak rates from compressors), requiring operators to record, process and submit requested information. They support the definition of activity or emission factors that are specific to measured devices, facilities and settings.

Reporting requirements. Regulated entities must record and report required information. This can include reporting emissions monitoring data, key events (e.g. accidents, flaring), state of facilities or operational data. Regulations can indicate if information must be disclosed to the public or sent to regulatory authorities.

Emissions estimates and quantification. Requirements to estimate methane emissions through the use of activity factors and emission factors.

Public disclosure. Requirements for regulated entities to share specified information related to methane emissions with the public (e.g. requirements to publish methane emission reports online, to undertake public information campaigns, or to disclose information upon public request). This also includes instruments that require public bodies to make specified information received from regulated entities available to the public.

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