Global gas market implications of methane emission reduction policies

Ruud Egging-Bratseth,
IØT, NTNU,
Trondheim, Norway
ruude@ntnu.no

Franziska Holz,
DIW Berlin,
Germany,
IØT, NTNU,
Trondheim, Norway

Kristina Mohlin,
Huong Nguyen,
Daniel Zavala-Araiza,
Environmental Defense
Fund, New York, USA

Carolyn Fischer
Resources for the
Future, Washington
D.C., USA

***Abstract*—Methane is the second-largest contributor to global warming due to anthropogenic greenhouse gas emissions. Reducing anthropogenic methane emissions quickly can significantly reduce global warming within just a few decades. The oil and gas sector is responsible for almost 20% of anthropogenic methane emissions. Yet, there are hardly any policies in place that address oil and gas sector methane emissions.**

We investigate two policy types: a) a global cap on methane emissions from the oil and gas sector; and b) a methane price implemented by a Clean Buyers Coalition. We extend a detailed global gas market model to allow investment in methane emission abatement measures. We find that the regional contribution to global reductions vary due to different mitigation potentials and associated abatement technology cost. Clean Buyers Coalitions can trigger major investment in methane abatement measures and much reduced emissions. However, a methane price must be balanced against available abatement potentials, as upstream suppliers lacking abatement options rather avoid abatement investments and, instead, re-direct their exports to non-Coalition importers.

***Index Terms*—global natural gas market, methane emission abatement, Greenhouse Gas mitigation policy**

INTRODUCTION

At the climate conference COP26 in Glasgow in the fall of 2021, more than 100 countries, representing half of anthropogenic methane emissions, committed to reducing global methane emissions by at least 30% between 2020 and 2030 [1]. Successful delivery on this *Global Methane Pledge* would help reduce global warming by at least 0.2°C by 2050. Methane (CH_4) is the second-largest contributor to global warming due to anthropogenic greenhouse gas (GHG) emissions, and, in contrast to CO_2, it is a so-called short-lived greenhouse gas with an atmospheric lifetime of about 12 years. However, it is more potent than CO_2 and will result in 84 times the warming caused by the same amount of carbon dioxide over a 20-year horizon [2]. Methane emissions have been responsible for approximately 20% of the increase in temperatures since preindustrial times [3]. The short lifetime of methane provides an opportunity. If anthropogenic methane emissions are reduced quickly, this can have a significant mitigation effect on global warming within just a couple of decades. However, there is great urgency in finding appropriate policies to reduce anthropogenic methane emissions because these emissions have been increasing much faster than CO_2 emissions in the last decades.

Sources of anthropogenic methane emissions include the energy sector, agriculture and cattle farming, wastewater treatment plants, and landfills [4]. Within the energy sector, methane-emitting processes like venting and incomplete flaring as well as leaky infrastructure in the oil and gas sector, and leakage from coal mines contribute to roughly one third of all anthropogenic methane emissions [5].

Abatement of fugitive methane emissions in the oil and gas sector can be achieved with relatively simple technical measures such as regular leak detection and repair (LDAR), increased maintenance frequency, modernizing equipment (such as replacing pumps or using electric motor equipment as well as replacing compressor seals or rods), and installing equipment to flare rather than vent the gas to the atmosphere [6]. It is estimated that more than 70% of the methane leakage from the oil and gas sector can be avoided (abated) using technologies available today and where about 40% is estimated to be avoidable at close to zero cost [5]. The net costs are estimated to be low because although oil and gas companies would incur the cost of plugging leaks, upgrading equipment and changing their operations, the captured gas can be brought to market and sold. However, despite the low abatement costs for a significant share of the potential abatable methane volumes, current emission levels suggest there are insufficient incentives for the oil and gas industry to invest in methane abatement. Policy instruments should provide these incentives.

Given the high impact of methane emissions – and the low abatement costs for a large share of these emissions, a global cap on methane emissions (*emission ceiling*) would seem an effective policy instrument. We argue that analyzing the costs and effects of a global ceiling as well as the distribution of contributions by the world regions can provide a benchmark for the analysis of any more complex policy instrument.

In the European Union (EU), the European Commission came out with a proposal for regulation of methane emissions in the energy sector in December 2021 [7]. The proposal includes mandated regular leak detection and repair, restrictions on venting and flaring and measurement-based Monitoring, Reporting and Verification. In August 2022, the US adopted the Methane Emission Reduction Program as part of the Inflation Reduction Act, introducing a fee of \$900/ton of methane in 2024, \$1200 in 2025, and \$1500 in 2026 respectively on owners and operators of facilities. The fee applies to methane emissions at production facilities above 0.20% of the natural gas delivered from the facility, emissions above 0.11% in transmission, and emissions above 0.05% for other, non-production facilities.

Pricing methane emissions, for example through a methane emission fee (tax) or inclusion in a cap and trade program, could provide a strong incentive to reduce methane emissions in the oil and gas industry. The US methane fee proposal entails proportionally penalizing producers that emit a higher amount of methane per produced unit of energy than a threshold (target) emission intensity. Such a producer side approach would typically be the most effective as it taxes emissions directly at the source.

At present, many oil and gas producing countries – with some notable exceptions such as Norway – are still to tackle their methane emissions. At the same time, gas importing countries and regions like the EU are concerned about the footprint emissions associated with their gas imports. The European Commission – well-aware of the substantial footprint methane emissions of the EU's fossil fuel imports – in its proposal, therefore, introduced a set of transparency tools for methane emissions occurring outside the EU. These measures include an obligation by importers to provide information on measurement, reporting and mitigation of methane emissions undertaken by exporters and a transparency database of companies and countries exporting fossil energy to the EU. The proposal also includes a review clause that preserves the option to amend legislation to impose more stringent measures on importers once better global methane emission data are available [7]. Such more stringent measures could include putting restrictions on the methane emission intensity of imported fossil fuels with associated penalties. Relatedly, ideas around a Clean Gas Buyers Coalition of countries expanding beyond the EU wherein all members would put methane emission restrictions on their imports have sprung up.

A Clean Gas Buyers Coalition can mitigate the well-known leakage effect of unilateral import policies, which here would be the effect of trade diversion to countries without methane emission restrictions on their imports. In the context of natural gas markets, trade diversion may, however, be somewhat limited because of long term contracts and, more importantly, limited physical transport capacities, e.g., of pipelines which is the dominant import mode in Europe [8].

In this paper, we explore these ideas further and investigate the impacts of two types of policies: a) a global cap on methane emissions; and b) a methane emissions price on all gas consumed (imported as well as domestically produced) in the EU or a larger group of countries. We assume that this price would be implemented by a Clean Buyers Coalition and we explore the impacts of two different coalition groups. We use an updated and extended version of the Global Gas Model (GGM) for our numerical analysis. We aim to get an insight in the opportunities for "dirty" gas exporters to divert exports to non-coalition countries, the impact on total supply to coalition countries, and the resulting global emission reductions.

Our study expands on an earlier non-peer reviewed consultancy analysis with an optimization model of European gas supply to investigate the trade effects of two moderate methane prices [9]. We expand the analysis in several directions, in particular by a) endogenizing abatement investments b) using a global model and policy approach, c) presenting the benchmark results for various emissions ceiling assumptions, d) comparing various buyers coalition sizes.

In the following, we present our methods before discussing our results and concluding in the remaining sections.

Methodological Approach

A. *The Global Gas Model*

The Global Gas Model [10] is a mathematical programming formulation reflecting different agents in the global natural gas market. It is implemented in GAMS and available open-source. The model considers the entire natural gas value chain (excluding storage). We assume that all actors have perfect information. Suppliers and service providers (liquefiers, regasifiers, and transmission system operators) maximize their profits, while consumers maximize their consumer surplus. The model allows for market power exertion by suppliers on consumer markets by strategically withholding part of the supply according to pre-specified market power parameter values (*conjectural variation*). Although the model is a partial equilibrium problem in nature, the resulting equilibrium is computed exactly via optimization wherein the conjectural variation terms appear in a set of market power adjustment terms in the objective function [11].

We have expanded the model to include upstream methane emission intensities, methane prices, minimum bounds for globally captured methane, and investment in abatement options. Abatement captures methane that would otherwise have been emitted to the atmosphere. Additionally, captured methane contributes positively to the supply balance in a country as it becomes available as natural gas supply.

Methane emission intensities are endogenously computed for each country by adjusting a baseline emission intensity with volumes captured due to investment in abatement options. The intensity is multiplied by an emission price, and the emissions price is subtracted from the sales price for volumes sold.

Captured methane increases the natural gas supply at the node where the abatement investment is made. Assuming a 90% methane content in natural gas and considering a weight of 0.671 kg per cubic meter (cm), we multiply captured tons of methane by 1.65 to compute kcm (1 kcm =1000 m^3).

Although the model does not represent an oil market, it can allow for abatement investment in options listed by the IEA GMT [15] as oil sector abatement options. We use this feature in the analysis of a global emission ceiling.

The model is run for the years 2015, 2020, 2025, with the methane price being applied in 2025 only. We do counterfactual analysis where we compare model outcomes for different methane prices and methane emission ceilings compared to a baseline without a methane policy.

B. *Input Data Set*

We have updated the data compared to the GGM version published in [10]. In contrast to many other global models, we use mostly publicly available sources. For past years we use production and consumption data from IEA. Liquefaction and regasification data originate from GIIGNL [12], and the pipeline data set is largely based on EIA [13] and ENTSO-G [14]. Many other sources provide data for costs, loss rates, etc. (refer to [10], or contact the authors for additional details.) For the year 2025, we consider a combination of projections from a recent EU project (SET-Nav) and the IEA World Energy Outlook, adjusted for a near-complete boycott of Russian gas by the EU.

Recently, the IEA introduced the annual report *Global Methane Tracker* (GMT) [15], a very detailed database with estimates of country level methane emissions from various sources, methane abatement potentials, and (annualized) methane abatement net costs. Unfortunately, not all countries are covered individually and, despite several clarifying descriptions on assumptions in the newly available data documentation document, the data cannot be used "as is" in our analysis. Instead, we compute gross annualized abatement costs for the USA which is the best documented region (based on data sources provided in the IEA documentation) and that we apply to all global regions. We abstain from any country-level adjustments. For countries for which GMT does not provide individual level emissions, we assume the same emission intensity as in a neighboring country. As countries that are not individually reported by the IEA GMT have rather low emissions, this will hardly affect global results.

In the absence of transparent documentation of the GMT, we believe that there is a large arbitrary component in the allocation of country-level (upstream) emissions to either oil or gas subcategories. To reflect the uncertainty in the data, we analyze several methane emission allocation variants. We use the following reported methane emissions alternatives by the GMT to obtain methane intensity variants. Of the five alternatives in our data set, this paper considers three variants.

1. Methane emissions reported for upstream gas (production) by the GMT;

4. Methane emissions reported for upstream oil and gas (production) by the GMT;

5. All oil and gas related emissions reported by the GMT.

Naturally, variant 1 provides the lowest upstream natural gas methane intensities, and variant 4 the highest.

Emissions are reported in kton of methane at the country level. In GGM, the country-level methane emissions are applied to the 2020 natural gas production levels to compute a methane intensity (leak rate) in $\left(\frac{\text{ton}}{\text{Mcm}}\right)$, which is then also used as the base line methane intensity in 2025, before any abatement options are invested. Table I. presents the reference projections for 2025 for natural gas production and consumption, as well as methane emissions (according to variant 5., i.e., allocate all oil and gas related emissions reported by GMT to upstream natural gas).

Global regions in the model are North America (NAM), South America (SAM), European Union (EU), Rest of Europe (ROE), Africa (AFR), Russia (RUS), Caspian Region (CAS), Middle East (MEA), and Asia Pacific (ASP).

TABLE I. Reference projections for gas production and consumption (bcm) and methane emissions "var 5" for the year 2025

	NAM	SAM	EU	ROE	AFR	RUS	CAS	MEA	ASP	World
Prod (bcm)	1158	183	82	156	274	645	219	704	691	4112
Cons (bcm)	999	173	421	144	159	490	130	563	932	4010
Net Trade	159	10	-339	12	115	156	90	142	-241	
CH_4 Emissions (Mton)	19.7	6.1	0.8	0.4	10.7	13.6	8.3	17.6	9.1	86.4
CH_4 Abatement potential	13.3	4.2	0.5	0.3	7.7	10.6	5.7	11.3	5.6	59.2
Potential as % of emissions	67%	69%	54%	65%	72%	78%	68%	64%	61%	68%

C. *Case Study Set Up*

Firstly, we consider imposing a global emission ceiling (cap). We implement this across the oil and gas sectors. We choose different cap sizes corresponding to various attainability levels reported in the literature to abate methane emissions: 30% (which can be mitigated at net zero costs), 40% (which can be mitigated at very low costs), 50%, and 60% (which are increasingly more expensive, but compared to other methane emission abatement options in other sectors still cost-efficient).

Secondly, we investigate the effect of a methane price $p_{2025}^{CH_4}$ on methane released when producing gas supplied to and consumed by Buyers Coalition countries (both produced domestically and imported). For a specific producer, the sales price reduction (*the tax*) is proportional to the methane intensity of their own upstream production. We apply a threshold value of 0.2% by volume, which translates into 1.342 ton/Mcm (1.342 kg/kcm, 38 g/mcf, 1 mcf =1000 cubic feet). For a specific producer, the methane price p_y^{CH4} $\left(\frac{€}{\text{ton CH4}}\right)$ is multiplied by the difference between their upstream methane intensity $\left(\frac{\text{ton}}{\text{Mcm}}\right)$ adjusted for abatement investments, and this threshold value. To provide an intuition for the impact of different methane prices, we relate the impact to the reference prices in the model that are a few €100 / kcm.

Consider a hypothetical country with the global average methane intensity of 86.4 Mton/4112 bcm = 21 kton per bcm (for intensity variant 5, see Table 1), this scales to 21 kg per kcm. Consider a price of $p_y^{CH4} = €2800/ton$, or €2.8/kg. The methane price in €/ kcm for this producer would then be $[21 - 1.342] \cdot €28 = €550$, which is in more than double the reference prices for 2025. However, considering variant 1 and the net zero cost abatement options only, the resulting methane price is about €65 on average, which can be brought down further by additional abatement investment. Since the model is at the country level and intensities vary a lot among countries, country-specific impacts vary drastically. Also, because of the market power assumptions and potential network bottlenecks, suppliers may not fully pass on the methane price to their customers.

Methane price values considered in the analysis are 2800 €/tCH_4 and 8400 €/tCH_4 in the year 2025 to account for different estimates for the Global Warming Potential (GWP) of methane. These values correspond to a carbon price of 100 €/tCO_2eq considering GWP values of 28 (over a 100 year time period) and of 84 (over a twenty year time period).

The methane intensity threshold value of 0.2% above which the methane price applies is a feature of the US methane fee proposal. 0.2% is also as the voluntary methane intensity target adopted by oil and gas majors like Aramco, Shell and BP as part of the so called Oil and Gas Climate Initiative [16].

We note we account for an almost complete EU boycott of Russian gas. We have assumed that the only EU countries Russia may supply are Slovakia, Czech Republic and Hungary. As a result, total Russian supply is about 12 bcm per year only (the domestic market and other import markets absorb about 100 bcm of Russian supply, and its total annual production declines by about 50 bcm.)

We explore two different configurations of Clean Buyers Coalitions: in the "EU+" coalition we include the EU plus Norway, Switzerland and the United Kingdom, and in "GMP" we include all countries of the Global Methane Pledge [1].

RESULTS

The model indicates that 32% of all methane emissions in 2025 in the oil and gas sector can be abated at net zero or negative cost, without any additional policy measures. This is a bit lower than the IEA's *Global Methane Tracker*'s value of 41% [15]. This difference can be explained by different gas price assumptions, our incomplete information on cost assumptions (our cost estimates are likely to be too high for technologies such as LDAR), or due to variations in upstream methane intensities and abatement potentials combined with different production projections in 2025 in our model compared to IEA values for 2021 [15]. All figures referred to in the following text are included in the Appendix.

A. GLOBAL METHANE EMISSION CEILING

Table 1 (above) indicates that the total abatement potential accounts for 68% of total oil and gas sector related methane emissions. We have observed that 32% of all emissions can be abated at nonpositive net costs. Hence, we implement emission ceilings that decrease global emissions by between 30% and 60%. Because 32% can be abated at nonpositive net costs, a global abatement of 30% in Fig. 1 (an emission ceiling of 70%) will effectively not induce any additional abatement investment.

The lighter colors in Figures 1 & 2 are for the lowest emission reductions / highest caps.

Fig. 1. indicates for emission ceilings representing global reductions of between 30% and 60% of the baseline methane emissions in 2025 the average cost in € per ton of methane abated. (Naturally, the *marginal* costs of increasingly larger reductions are much larger.)

Global total annualized investment costs for the "low-hanging fruit" reduction of 32% is about € 1.5 bln; the global average investment cost for these "low-hanging fruit" options is only € 52 / ton of CH_4 abated. For the 60% emission reduction, total investment costs are about € 8 bln, the average being three times as high at € 152 per ton of CH_4 abated. Given our multiplication factor of 1.65, this is only about € 90 / kcm. Since we do not vary technology costs, variations in regional availability of specific abatement technologies are due to baseline intensity levels, abatement potentials considering specific technologies (which are based on IEA GMT [15]), and on how methane prices affect suppliers' relative competitiveness in export markets.

Fig. 2 shows that average methane emission reduction percentages in the oil and gas sector vary regionally, and do not increase proportionally with different global reduction percentages. Regions North America, South America, Russia and Asia Pacific all but exhaust their abatement potential, whereas other regions leave more potential unused.

Other Europe has very little abatement potential, dominated by the already very low intensity of Norwegian gas (below the 0.2 volume-% threshold), and does leave a large part of remaining abatement options unused. In contrast, in the European Union, with comparatively low abatement potential as well, a large share of the abatement potential materializes, already at low emission caps. This reflects the high value of captured methane as natural gas supply given the relatively high natural gas prices in the EU.

According to the IEA GMT, Russia has the largest methane abatement potential. Our results show that under a global emission cap, a very large part of the Russian potential materializes. We note that an EU boycott of Russian gas would remove the pressure of an EU methane price to incentivize Russia to abate.

B. CLEAN BUYERS COALITION

In the analysis in this section, a global emission ceiling is not imposed. Instead, we implement a methane price proportional to upstream methane intensities (above a threshold value) for various coalitions of countries, considering two levels of methane leakage intensities (variants 1 and 4).

Fig. 4 shows regional abatement in kton for methane prices 2800 & 8400 €/ton CH_4, intensity variants: "1" (IEA GMT upstream gas) & "4" (IEA GMT upstream oil & gas), and clean gas buyers coalitions EU+ & Global Methane Pledge (GMP) countries. The darker columns of each pair in Fig 4. are for the lower intensity case, variant 1. We observe that, at a lower intensity, both a larger coalition and a higher CH_4 price result in more abatement globally. At higher intensity, we do again observe that a larger coalition results in more abatement, however, a higher methane price affects different regions differently and results in *lower* abatement globally.

Additionally, for both methane prices, global abatement is lower at high intensity (var. 4) than at lower intensity (var. 1).

The lower abatement for higher prices and higher intensities may seem counterintuitive. An explanation is that, in many countries, even after abatement investment, the methane leakage intensity would still be so high that the applicable methane price will put them at a competitive disadvantage. Therefore, rather than abating, such countries would divert export flows to non-coalition countries. And for exports to non-coalition countries, there are no incentives to abate.

Fig. 4 illustrates this by showing the supply breakdown in 2025 for the EU as a whole. The stacked column to the left provides the reference supply break down without any policy in place. The next four columns show results for buyer coalition EU+. For low-intensity variant 1 and either CH_4 price, total supply is hardly affected, although some dirty suppliers are partly pushed out of the market by cleaner ones (and, some smaller ones, for instance Iran, only supply in the reference and are pushed out of the market completely). For the higher intensity variant 4, and especially the higher methane price, total supply goes down significantly (-14%, from 421 to 363 bcm), and several African suppliers divert their supplies away from the EU. Qatar, which according to the IEA GMT [15] has rather low intensity to begin with, becomes a major supplier to the EU.

The four columns to the right show the supply breakdown for the EU as a whole for the extended buyers coalition GMP. Here, we see that inclusion of other large importing countries, notably Japan and South Korea, reduces the possibilities for supply countries to divert their trade flows and avoid abating. Total EU supply with Buyers Coalition GMP, intensity variant 1, and price 2800 €/ton CH_4 is even a little higher than in the reference. For higher intensities and higher prices, we see the same overall trend as for Buyers Coalition EU+, but somewhat moderated because dirty EU suppliers now have fewer options to divert supplies to. Still, as the EU is the largest importing region and China did not sign the Global Methane Pledge, the projected drop in supply to the EU would be more than 11%.

The prices in the GGM model are based on long-term equilibrium prices; hence the prices in Fig. 5 may seem low for natural gas market observers of recent trends. Still, we include the price for Germany and Japan in the different cases to illustrate the impact of the methane pricing on market prices. The reference prices in the model without policy in place are € 214 per kcm in Germany, and € 237 in Japan. Naturally, methane pricing and a higher assumed methane intensity result in price increases in Germany, of up to 26% in the most extreme case. In turn, Japan benefits from a Buyers Coalition that it would not be part of, with slightly lower prices by up to 4%. In contrast, when participating in coalition GMP, Japan faces a price increase of up to 15%.

Reminding the reader that the methane price for unabated gas is about €50 / kcm for average intensity gas under variant 1, but over €500 / kcm of natural gas for the dirtiest suppliers in variant 4; the available abatement options are largely beneficial, but flexibility of (dirty) exporters to divert their supplies absorbs some of the costs.

Conclusions

We have investigated two policy types that can be considered to reduce global methane emissions from the oil and gas sector: a global cap on methane emissions, and a methane price implemented by a Clean Buyers Coalition. We use a detailed global gas market model allowing investment in methane emission abatement measures in country specific abatement potentials and technologies. We find that regions are affected differently and that a Clean Buyers Coalition can trigger major investment in methane abatement measures and, hence, much reduced emissions. However, a methane price must be balanced against available abatement potentials as upstream suppliers lacking low-cost abatement options rather avoid abatement investments and, instead, re-direct their exports to non-coalition importers.

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APPENDIX: FIGURES

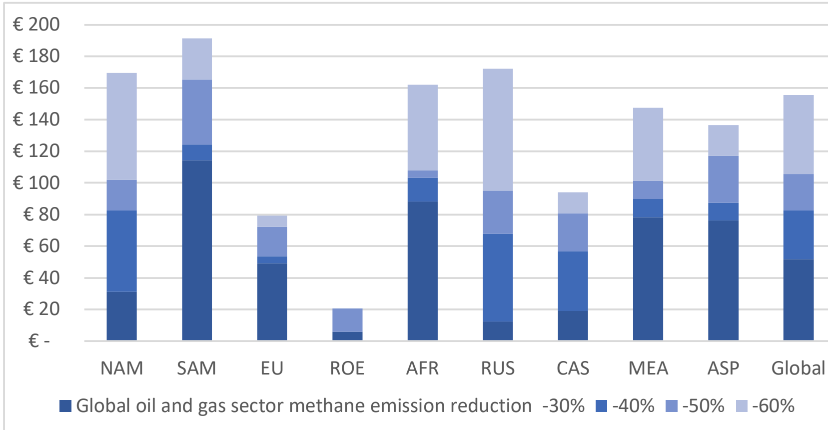

Figure 1. The average cost in € per ton of methane abated, for emission ceilings representing global reductions between 30% and 60% of baseline oil and gas sector methane emissions in 2025 (using intensity variant 5)

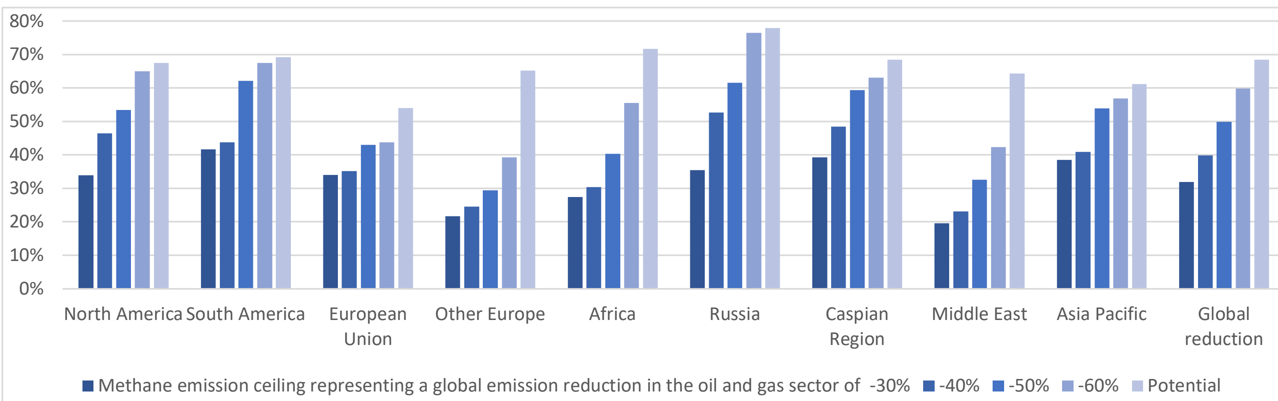

Figure 2. Regional methane emission reduction in the oil and gas sector for different global reduction percentages, as well as the maximum abatable percentage (column Potential, the right column of each regional group of columns).

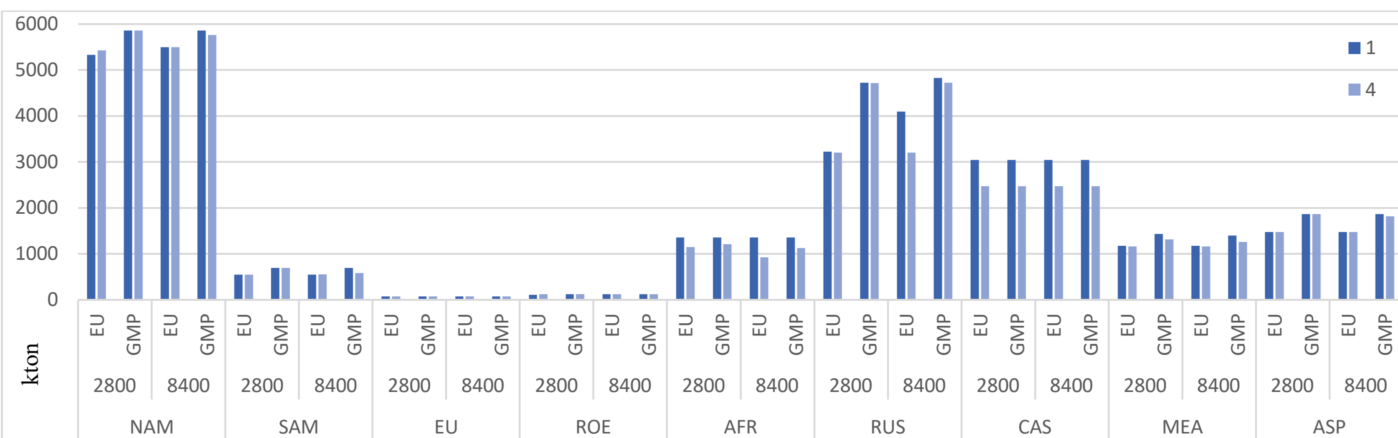

Figure 3. Regional abatement in kton for methane prices 2800 & 8400 €/ton, methane intensity variants: 1: IEA GMT Upstream Gas (the lighter colums) and intensity variant 4: IEA GMT Upstream Oil & Gas (the darker columns), and Clean Buyers Coalitions EU+ vs. Global Methane Pledge (GMP).

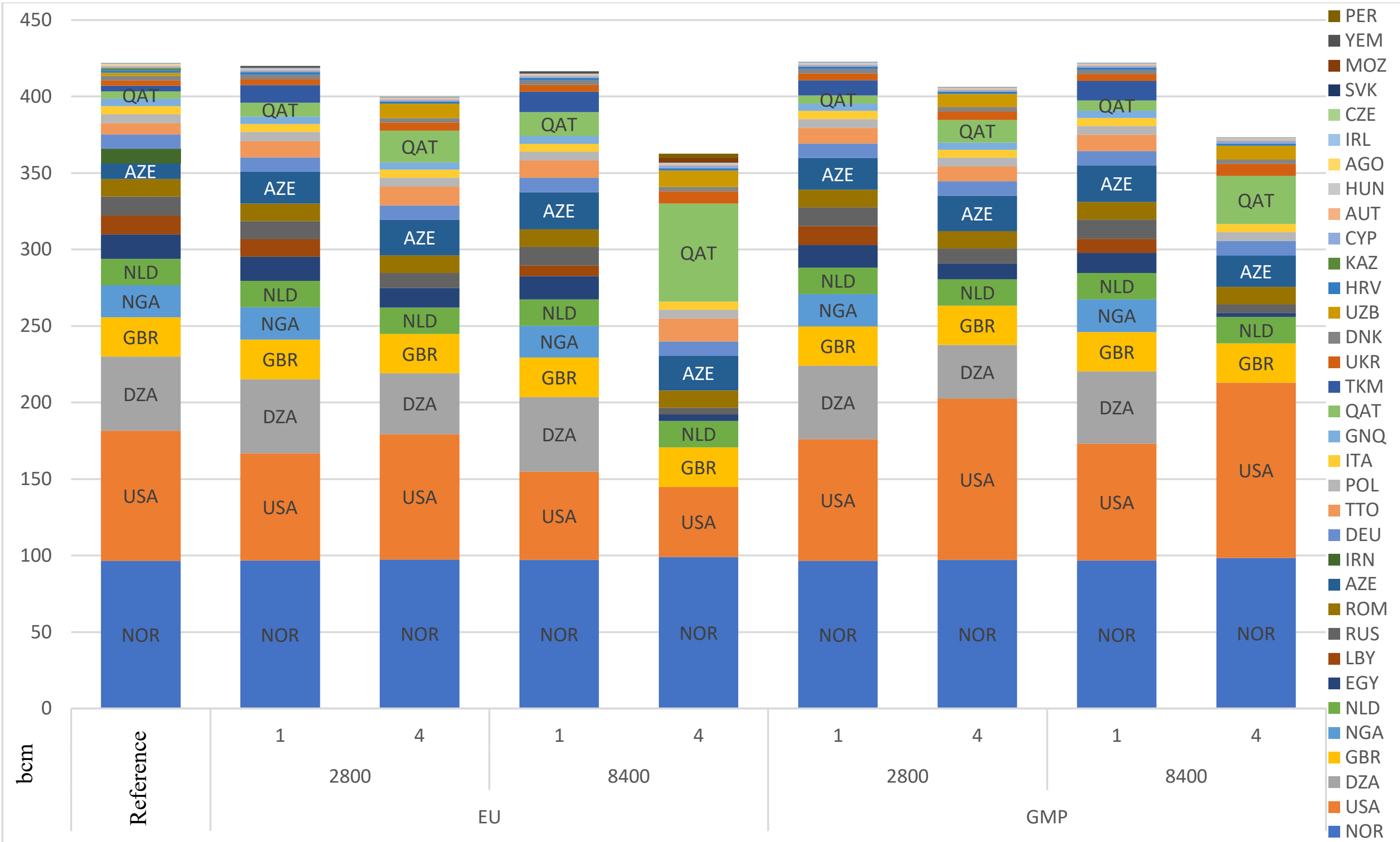

Figure 4. Supply breakdown EU 2025 by supplying country, for the reference projection, and Clean Buyers Coalitions EU+ vs. Global Methane Pledge (GMP), methane prices 2800 & 8400 €/ton, and methane intensity variants: 1: IEA GMT Upstream Gas and 4: IEA GMT Upstream Oil & Gas.

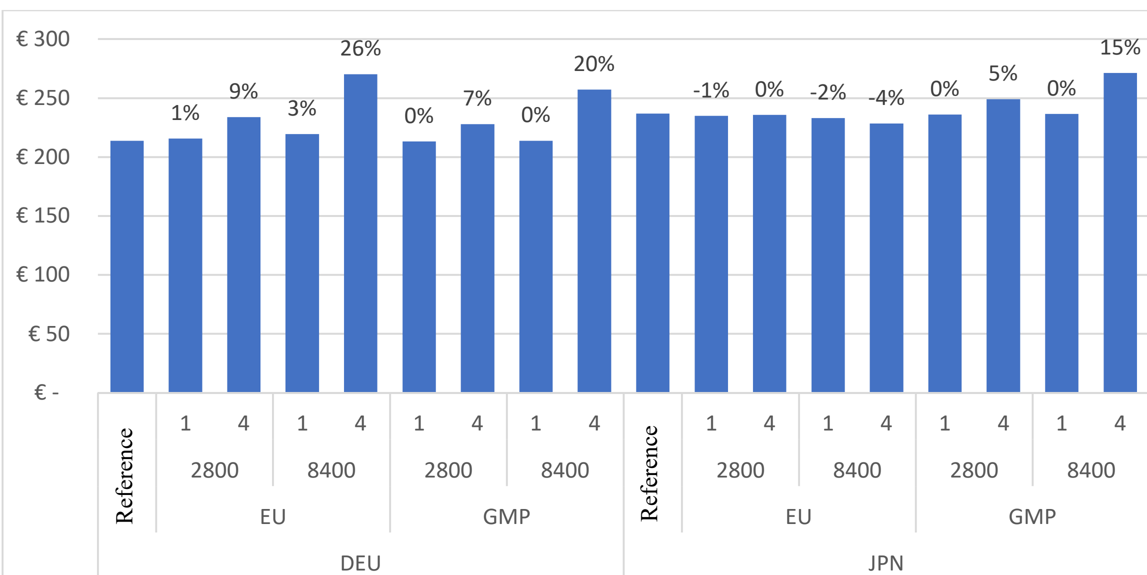

Figure 5. Prices ($/kcm) in Germany and Japan, for Clean Buyers Coalitions EU+ vs. Global Methane Pledge (GMP), methane prices 2800 & 8400 €/ton, and methane intensity variants: 1: IEA GMT Upstream Gas and 4: IEA GMT Upstream Oil & Gas (the darker columns).