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NOTES

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How to Cut Methane Emissions

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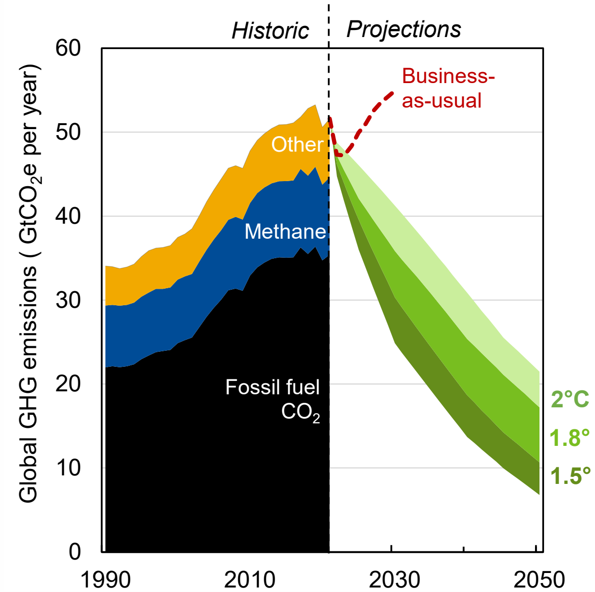
Abstract

Limiting global warming to 1.5 to 2°C above preindustrial levels requires rapid cuts in greenhouse gas emissions. This includes methane, which has an outsized impact on temperatures. To date, 125 countries have pledged to cut global methane emissions by 30 percent by 2030. This Note provides background on methane emission sources, presents practical fiscal policy options to cut emissions, and assesses impacts. Putting a price on methane, ideally through a fee, would reduce emissions efficiently, and can be administratively straightforward for extractives industries and, in some cases, agriculture. Policies could also include revenue-neutral 'feebates' that use fees on dirtier polluters to subsidize cleaner producers. A $70 methane fee among large economies would align 2030 emissions with 2°C. Most cuts would be in extractives and abatement costs would be equivalent to just 0.1 percent of GDP. Costs are larger in certain developing countries, implying climate finance could be a key element of a global agreement on a minimum methane price.

Introduction

To stabilize the climate, emissions of greenhouse gases (GHGs) including methane must be cut dramatically in this decade. In a business-as-usual (BAU) scenario without additional mitigation measures, global GHGs are expected to grow to 53 billion tonnes of carbon dioxide equivalent (CO_2e) in 2030. Fossil fuel CO_2 emissions account for most emissions (65 percent), but methane (CH_4, 20 percent), and other GHGs (15 percent) remain important. Limiting global warming to 'well below 2°C' and ideally 1.5°C (the mitigation goal of the 2015 Paris Agreement) requires that global GHG emissions be cut 25 to 50 percent below 2019 levels by 2030 (see Figure 1).[1] Most attention has been rightly focused on CO_2, given its central role in long-term warming and long life in the atmosphere. But cutting methane emissions is also paramount, not least because of its disproportionate impact on near-term temperatures. Simply put, given a lack of progress on CO_2 abatement, if methane emissions are not cut rapidly and soon there are substantive risks of irreversibly destabilizing the global climate.[2]

Figure 1. Global GHG Emissions and Targets



Source: IMF staff calculations.
Note: Excludes land use, land-use change and forestry (LULUCF) emissions. BAU = business as usual; GHG = greenhouse gas; $GtCO_2e$ = gigatonnes of CO_2 equivalent.

Most countries have pledged to cut GHGs and 125 countries have signed the Global Methane Pledge (GMP) to cut global methane emissions by 30 percent by 2030 but commitments and policies fall well short of what is needed. To date 139 countries, responsible for 83 percent of global GHGs, have proposed or set a net zero target for *total* GHGs sometime in the middle of this century.[3] Signatories to the GMP committed to taking actions to reduce global methane emissions at least 30

[1] As part of Nationally Determined Contributions (NDCs) under the Paris Agreement - see Black and others (2021); UNEP (2021).
[2] Armstrong McKay and others (2022).
[3] See https://zerotracker.net.

percent below 2020 levels by 2030.[4] But even if countries met whichever is the more stringent of their NDC pledges (where methane is included) or the GMP (assuming signatories cut their national emissions 30 percent below 2020 levels) global methane emissions in 2030 would be cut by only about 40 and 70 percent of the reductions consistent with limiting warming to 1.5°C and 2°C, respectively. This emission gap reflects a combination of:

(1) Inconsistencies between countries' 2030 GHG pledges and long-term net zero pledges;

(2) Exemptions of methane from some large emitters' NDC commitments, for example, China, India, and Russia;[5]

(3) Non-signatories to the GMP, which account for about half of the global methane emissions.

Moreover, policies to implement the pledge in signatory countries are largely in their infancy.

This Note discusses policies for cutting methane emissions at the country and global levels and their impacts.[6] The next section provides background on methane emission trends and sources. A discussion of policies for mitigating methane emissions and a quantitative assessment of the emission and cost impacts of temperature-aligned methane mitigation policies at the global and country levels follow. The final section offers brief concluding remarks. The Note contributes to previous literature[7] through its focus on practical policy issues and quantitative policy analysis. An extension of the IMF–World Bank Climate Policy Assessment (CPAT) tool is used in the analysis (see Annex 1).

Some themes from the discussion include the following:

- Putting a price on methane is generally a practical mitigation instrument for the extractive, and in some cases, agricultural sectors and can often build on business tax collection capacity.
- Direct pricing is feasible where firm-level emissions are monitored; in other cases proxy pricing can be implemented based on production levels and assumed emission rate factors, with rebates for firms demonstrating (through their own or third-party metering) lower emission rates than the default.
- Given competitiveness concerns, pricing is best introduced in a revenue-neutral way—for example, through adjustments to existing fiscal regimes for extractive industries or through feebates.
- At the global level, an international price floor arrangement would be effective from an emission and competitiveness perspective—for example, among GMP signatories.
- A uniform price on methane emissions of large emitters, rising to $70 per tonne of CO_2e in 2030, would align their emissions with the goal of staying below 2°C warming, with two-thirds of emission cuts coming from the extractive sector.
- Mitigation burdens are, however, disproportionately large on certain emerging market and developing economies, which implies that differentiated pricing and international climate finance are potentially important elements of an agreement on a minimum price on methane emissions.

Background on Methane Emissions

Contribution to Warming

Despite its shorter atmospheric residence time, methane has a much higher global warming potential (GWP) than CO_2 on time horizons of a century or less. The GWP of a GHG refers to the cumulative change in warming over time caused by an extra tonne of the gas relative to a tonne of CO_2. The GWP of methane measured over a 100-year period is estimated at about 30, meaning each tonne of methane has the same cumulative warming effect as 30 tonnes of CO_2. Although the average

[4] See www.globalmethanepledge.org for a list of signatories and an overview of the pledge.

[5] China plans to develop a methane reduction plan (and signed a bilateral declaration on methane with the US) but has not yet specified numerical emission targets.

[6] Policies for reducing CO_2 emissions are discussed in, for example, IMF (2019a,b).

[7] See UNEP (2021) for a synthesis of prior literature.

atmospheric life span of methane is 12 years—whereas that of CO_2 is about 100 years—methane traps heat radiated from the earth far more effectively than CO_2.[8] Scaling anthropogenic methane emissions by their GWP implies emissions of about 9 billion tonnes of CO_2e in 2021.[9]

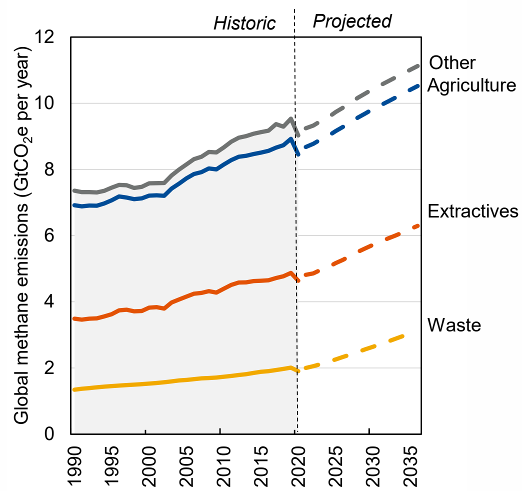
Reducing near-term methane emissions could have an immediate impact on *reducing* global temperatures and, hence, could make an outsize contribution to mitigating tipping point risks. Methane accounts for 30-40 percent of the 1.2°C rise in global average temperatures since the preindustrial era.[10] Whereas cutting CO_2 would slow temperature rises, cutting methane could have a net cooling effect due its much shorter residence time.[11] Indeed cutting methane emissions by half over the next decade could cut global temperatures in 2040 by up to 0.3°C. This would help mitigate various tipping point risks, such as the breakup of the Greenland ice sheet or Amazon rain forest destabilization—risks that have been shown to grow with rises in global temperatures, especially above 1.5°C.[12]

Global Methane Emissions & Sources

Two alternative approaches are used to measure total global methane emissions:

1. *National inventory approach (bottom-up):* This approach, which countries use to submit their emission inventories to the United Nations Framework Convention on Climate Change (UNFCCC), is based on national activity statistics (for example, fuel or agricultural production) multiplied by a methane emission factor. The latter is based on guidelines of the Intergovernmental Panel on Climate Change (IPCC), accounting for local characteristics (for example, surface versus underground mine, livestock breed and feed).[13]
2. *Atmospheric observations approach (top-down):* This approach uses, for example, remote sensing from towers, aircraft, drones, and (most importantly) satellites to monitor emissions of individual facilities and regions.[14] Atmospheric observations have been used to infer historical global emission trends and provide emission measurements at a spatial level, which can be mapped to individual facilities.[15]

Figure 2. Global Anthropogenic Methane Emissions by Sector, 1990-2035



Source: IMF staff calculations using IMF-WB CPAT.
Note: Methane projections are broadly in line with those of other studies (for example, Höglund-Isaksson and others 2020; UNEP 2021, Figure 4.1). $GtCO_2e$ = gigatonnes of CO_2 equivalent.

[8] See Forster and others (2021). The GWP estimate accounts for methane's indirect effect on producing ozone (itself a GHG), which increases the GWP about 40 percent.

[9] Atmospheric methane concentrations have increased to 1,900 parts per billion (ppb) from preindustrial levels of about 780 ppb (NOAA 2022). There are also natural sources of methane (primarily wetlands and freshwater) and withdrawals from the atmosphere (primarily from the chemical decomposition of methane into ground-level ozone in the presence of nitrogen oxides and sunlight). Higher global temperatures may have positive feedback effects on natural sources, including from permafrost melting. See Cheng and Redfern (2022) and UNEP (2021).

[10] Mar and others (2022), UNEP (2021).

[11] Cutting CO_2 emissions slows the rate of accumulation of the stock of CO_2 in the atmosphere. By contrast, substantial reductions in methane emissions could quickly reduce the stock of atmospheric methane as the stock depreciates rapidly. Intuitively, at equilibrium, deprecated methane needs to be replaced by new methane, so when emissions drop below the replacement rate the methane stock declines. See also Dreyfus and others (2022), IGSD (2022a, b).

[12] Of 16 global and regional climate tipping points identified in McKay and others (2022), current warming makes five possible, 1.5–2°C would make a further six likely (and four possible), and 2.6°C makes an additional tipping point likely and three possible.

[13] Developed (Annex 1) economies are required to report emissions annually to the UNFCCC; there are no regular reporting requirements for developing (non–Annex 1) economies. Emission factors are based on field and laboratory measurements. For emission inventories, see: https://di.unfccc.int/detailed_data_by_party; for emission factor guidelines, see: www.ipcc-nggip.iges.or.jp/public/2006gl and www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_4_Ch4_Fugitive_Emissions.pdf.

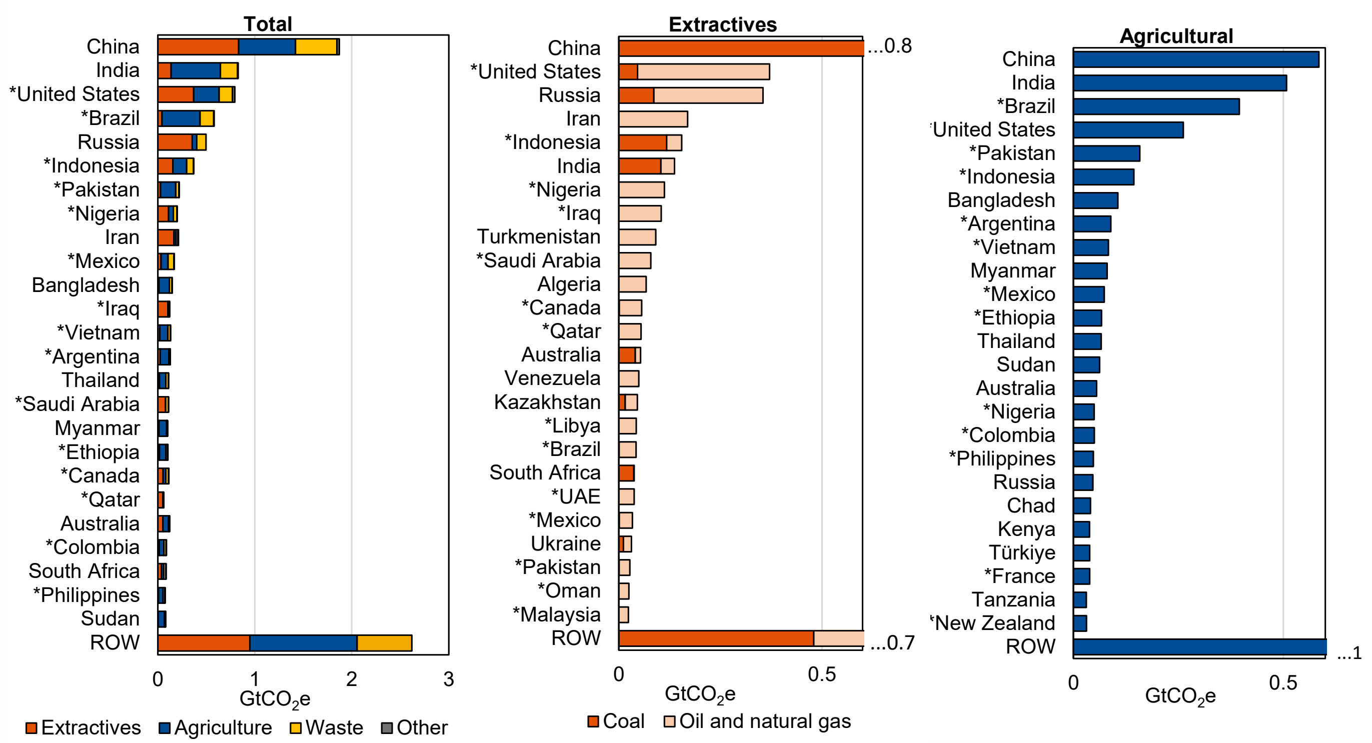
[14] UNEP (2021), Table A4.

[15] Especially when there is a small number of spatially distinct entities (e.g. coal and conventional onshore oil/natural gas production). This is more difficult when there are many entities operating closely (common for onshore US shale gas).

Atmospheric observations suggest that methane emissions have been larger than stated by inventory approaches. This implies that country submissions to the UNFCCC may significantly understate actual emissions, with the extent of underreporting most severe for the extractive sector and varying by country.[16] The emission data for each country in this Note are based on UNFCCC data for agriculture and waste (given the extensive cross-country data) and an average of the International Energy Agency (IEA)[17] and UNFCCC data for extractive emissions (see Annex 1). For comparison, extractive emissions in our data are higher by 6, 23, 54, and 36 percent for Brazil, China, India, Russia, and the United States, respectively, than those reported in the UNFCCC data.

Of global methane emissions, 35 percent are from fossil fuel extraction, 40 percent from agriculture, and 20 percent from waste (Figure 2). These shares change only moderately in BAU emission projections to 2035. If global efforts are made to efficiently align fossil fuel CO_2 emissions with limiting warming to 2°C, methane emissions from extractives would be 50 percent lower in the 2035 BAU scenario; global methane emissions would be 28 percent lower.[18]

Figure 3. Global Methane Emissions by Top Emitting Country and Sector, 2021



Sources: IMF staff calculations using CPAT.
Note:* indicates that the country is a GMP signatory. ROW = rest of the world; $GtCO_2e$= billion tonnes of CO_2 equivalent.

Methane emissions are concentrated among a handful of large-emitting countries, many of which are not signatories of the GMP (Figure 3). The top 5 and top 20 total methane emitters accounted for 45 and 70 percent of global methane emissions in 2021, respectively. And 13 of the top 20 methane emitters have so far signed the GMP. Separately, 11 of the top 20 emitters (for example, Bangladesh, Iran, Iraq, Nigeria, Pakistan, Vietnam) are not in the Group of Twenty (G20) countries, although G20

[16] See Crippa and others (2020); EPA (2019; Hoesly and others (2018); IEA (2022a); and Lauvaux and others (2022). Underreporting is largely due to methane leaks (especially by "super emitters") that are not well captured under the current measurement framework. Leaks may also contribute to underreporting in the waste sector, although most research has focused on extractives.

[17] IEA (2022a).

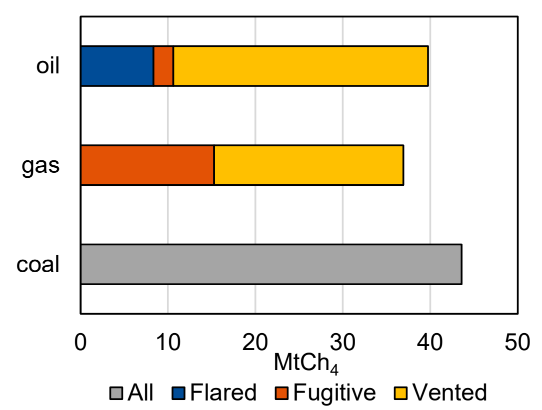
[18] IMF staff calculations using CPAT. Methane emissions from industry, transportation, and agricultural waste burning each contribute only about 1 percent to global methane emissions and are ignored here (UNEP 2021).

countries account for about 80 percent of current global fossil fuel CO_2 emissions.[19] An international coordination regime among large methane emitters (discussed later in this Note) would, therefore, involve a different set of countries than a comparable regime for CO_2 emitters. At the sectoral level, some large extractive emitters are not large agricultural emitters (for example, Canada, Iran, Iraq, Nigeria, Saudi Arabia) and vice versa in other cases (for example, Bangladesh, Ethiopia, Myanmar, Thailand, Vietnam).

Extractive Emission Sources

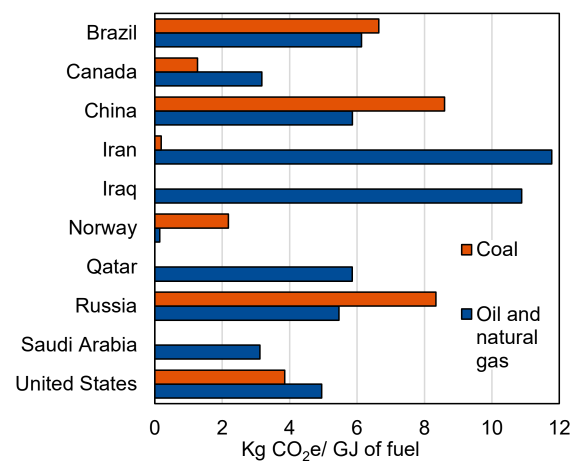
Globally, oil, natural gas, and coal operations each contributed about one-third to methane emissions from extractives in 2021 (Figure 4). About 80 percent of these emissions are "upstream" (from a mine mouth or wellhead), and 20 percent were "midstream" (from fuel processing and distribution). Venting (that is, deliberate release of unwanted methane to lower the risk of explosion when methane mixes with air) is the primary cause of upstream methane emissions. Smaller amounts are attributed to fugitive emissions (that is, unintentional leaks), such as incomplete natural gas flaring (flaring results in CO_2, rather than methane, emissions).[20] For oil and natural gas, venting accounts for about 70 percent of (upstream and midstream) emissions and fugitive leaks for 30 percent. About 90 percent of emissions from coal extraction are from operational mines[21] and 10 percent from abandoned mines. Russia and the United States together accounted for 34 percent of methane emissions from oil/natural gas operations in 2021, while China alone accounted for 57 percent of coal mine emissions (Figure 3).

Figure 4. Sources of Extractive Emissions by Activity, ~2021



Sources: IEA (2022a) and staff calculations.
Note: MtCh4 = million tonnes of methane.

Figure 5. Extractive Methane Emission Rates, Selected Countries, 2019



Source: IMF staff calculations.

Methane emission factors, expressed as CO_2e emitted per unit of energy, vary across fuels and countries (Figure 5). Methane emission factors vary, for example, with the type of well/mine, equipment, and extent of flaring. For the selected countries shown in Figure 5, methane emissions per gigajoule (GJ) of energy were about 1 kg in Canada for coal and 8 kg in Russia and varied from less than 1 kg in Norway to 12 kg in Iran for oil/natural gas. By contrast, CO_2 emissions from fuel combustion are much larger by weight at approximately 100, 70, and 60 kg per GJ for coal, oil, and natural gas, respectively.[22]

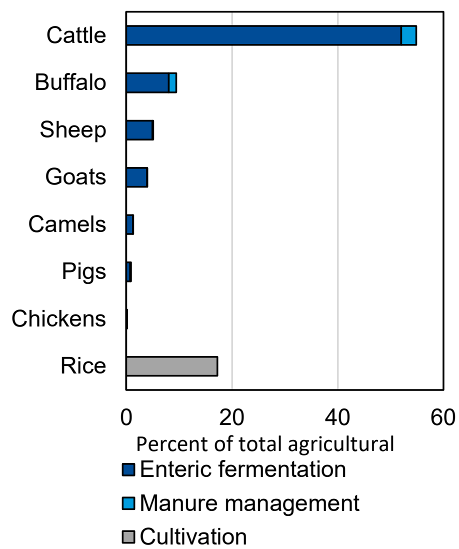
[19] Black and others (2021).
[20] A tonne of flared natural gas with complete combustion releases about three tonnes of CO_2, implying a reduction in the GWP of methane by 90 percent, while incomplete flaring leaves significant methane releases (suggesting the need for flaring performance standards). For further discussion, see GGFRP (2020) and Romsom and McPhail (2021).
[21] Methane is formed during the transformation of organic plant material into coal. Degasification systems at underground coal mines use wells to capture methane during mining activities; ventilation air also contains trace amounts of methane. In surface mines, methane leaks from coal seams directly exposed to the atmosphere. Most coal-related methane emissions come from underground mines.
[22] IMF staff calculations using CPAT.

Agricultural Emission Sources

Globally, cattle accounted for 55 percent of agricultural methane emissions in 2019, other livestock (for example sheep, pigs) 22 percent, and rice cultivation 17 percent (Figure 6). About 90 percent of livestock emissions are from enteric fermentation (the breakdown of plant materials during digestion in ruminants) and 10 percent from manure management (the decomposition of organic material when manure is handled in lagoons and holding tanks). Paddy rice cultivation produces methane when flooded fields prevent oxygen from penetrating the soil, creating conditions for methane-emitting bacteria. Methane emissions account for nearly half of total GHGs from the agricultural sector.[23]

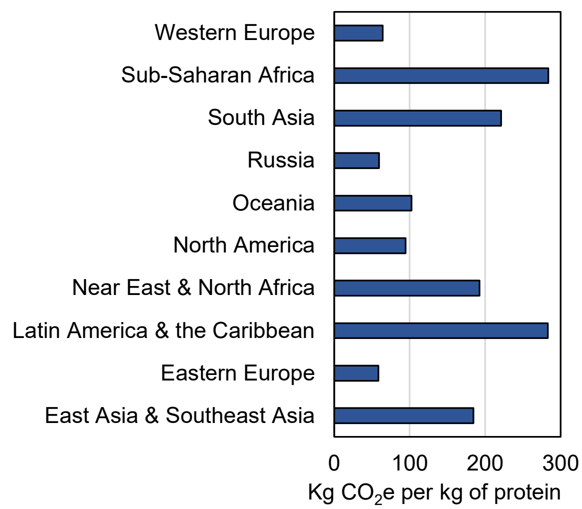
The emission intensity of livestock production varies significantly across regions (Figure 7). For example, methane emissions for cattle vary from 25 kg of CO_2e per kg of protein in eastern Europe to 200 kg CO_2e in Sub-Saharan Africa, in part reflecting differences in the productivity of livestock operations.

Figure 6. Sources of Agricultural Methane Emissions by Activity, 2019



Sources: FAOSTAT (2022) and IMF staff calculations.

Figure 7. Methane Emission Rates from Cattle by Region, 2017



Sources: FAO (2017) and IMF staff calculations.
Note: Kg CO_2e = kilograms of CO_2 equivalent.

Waste

Landfill leaks account for 70 percent of global methane emissions from waste sites. Incineration accounts for another 10 percent and leaks from wastewater systems for 20 percent.[24]

Policy Instruments for Mitigating Methane Emissions

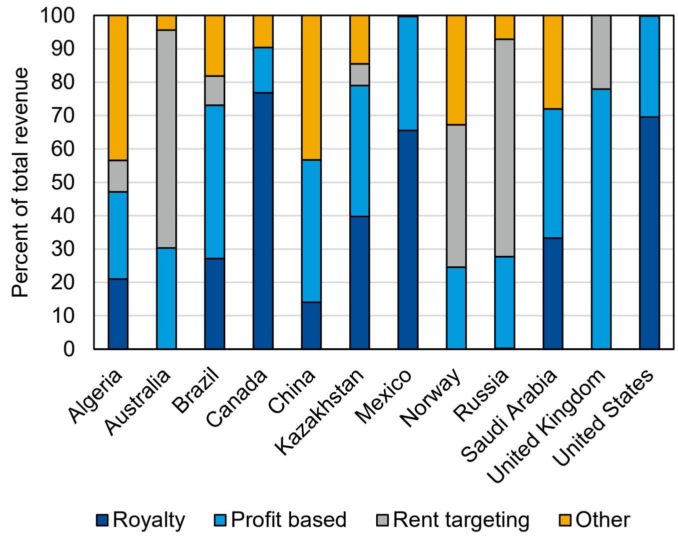
There are various options for mitigating methane emissions through reductions in the emission intensity of production and of domestic (household and industrial) demand. Reductions in emission intensity can be achieved through technological means, including flaring or capturing methane (for own use in power generation or for sale to the natural gas grid or mobile processing units) at extraction or manure sites, electrifying extraction processes and replacing natural gas pumps, improving leak detection and repair systems, upgrading distribution infrastructure, switching to higher-productivity livestock, and enhancing livestock feed through additives (for example, seaweed). For cutting demand, responses include shifting from fossil fuel combustion to renewables and nuclear energy, from meat to crop-based diets, recycling, domestic composting of organic materials, and reducing packaging. However, demand responses generally play a minor role in efficient mitigation policy for extractives (given the modest

[23] From UNFCCC inventories.
[24] UNEP (2021).

product price increases from methane policies). Annex 2, Table A1, provides a summary of these behavioral responses.[25]

Although there are many policy instruments for reducing methane emissions, this Note focuses mostly methane fees or variants thereof. These can be easily integrated into existing fiscal regimes, especially on oil and natural gas extraction (Figure 8). Such instruments can limit administrative burdens by building on existing business tax regimes (or perhaps farm assistance programs).[26] A fee is potentially the most efficient instrument when it comes to exploiting behavioral responses to reduce emissions and offers greater rewards for technological innovation than regulation.[27] A fee is also practical, at least for the extractive sector, which accounts for the bulk of near-term low-cost mitigation opportunities, because it can be integrated into existing fiscal regimes. However, the fee needs to be modified when firm-level emissions are not directly observed. The main options for addressing competitiveness concerns are also discussed below. Alternative mitigation instruments, such as emission rate regulations and technology requirements, are discussed in Box 1,[28] and a discussion of initiatives in the private sector and financial markets is included in Annex 5.

Figure 8. Fiscal Regimes for Oil/Natural Gas Extraction in Large-Emitting Countries, 2021



Sources: IMF staff calculations using Fiscal Analysis of Resource Industries model.
Note: "Other" includes state participation. Fiscal regimes may vary by project, location, or when the project license/contract was awarded. Coal royalties are not shown, but average rates are 3.5, 5.3, 3.4 percent for advanced, emerging market, and developing economies, and 6 and 14 percent for China, and India, respectively (IMF staff calculations). Rent-targeting mechanisms are much less common for coal extraction, but the standard corporate tax rates generally apply.

Methane Fees: Implementation Issues

Methane taxes could be levied directly on emissions… In this case, firms might be required to develop their own emission-metering capacity and to remit taxes based on their reported emissions—facilities would be subject to random or periodic government inspections, with penalties for non-compliance with reporting requirements.

…or, in the interim, indirectly on production, scaled by default emission factors and allowing low-emission-rate firms to petition for rebates. In this case, firms might be subject to proxy emission fees based on observable output and/or input and default emission factors. To encourage reductions in emission intensity, firms would be permitted to monitor and report emission rates (based on their own, or third-party, certification) and petition for a lower tax (or partial rebate from a previously paid tax) if their emission rates are below the default. Rebates could also be linked to the use of observable technologies (for example, methane capture) or production methods (for example, more productive livestock herds).[29] Default emission factors could be based on zero-mitigation scenarios or worst-performing firms to ensure that all firms have incentives to cut their emissions below the default rate.

[25] See also IGSD (2022a). Direct atmospheric removal of methane may become possible in the future (Jackson and others 2021).
[26] This Note provides high-level policy guidance, but sector- and country-specific considerations, particularly administrative capacity, and level of informality, are crucial when considering the nuances of policy design and timing.
[27] See Fischer, Parry, and Pizer (2003).
[28] See also Munnings and Krupnick (2017) for further discussion on mitigation instruments for natural gas extraction.
[29] If the government does not have the ability to properly audit self-reported emissions by firms, a rebate program could lead to fraud and may be less suitable. With this in mind, it is important that governments increase their capacity to monitor emissions.

Box 1. Beyond Methane Fees: Alternative Instruments to Cut Methane Emissions

This Note focuses on fees and their variants for cutting methane emissions as they are regarded as the most flexible and cost-effective instruments for abatement. However, numerous other options exist.

Emission trading systems (ETSs) are a quantity-based analog of a methane tax. Under an ETS, firms are required to hold allowances for their emissions, the government caps the supply of permits, and trading among firms establishes the permit price. ETSs can provide certainty regarding future emissions, whereas prices vary with market conditions. Where governments have already established ETSs for CO_2 emissions from the energy sector (e.g., California, EU, Korea, New Zealand), they could be extended to cover methane emissions. However, future permit prices are uncertain, which may deter investments with high up-front costs, such as methane capture technologies. This could be partially addressed through gradually rising price floors. In addition, permit trading is needed to promote least-cost abatement. But markets may be too thin or subject to manipulation, especially where there are few firms or transaction costs are high. Countries may also lack the institutional capacity to implement and monitor ETSs.

Emission rate regulations restricts firms' methane emissions per unit of output, for example to a standard based on the best-performing firms in the industry. Regulations do not charge firms for their unabated emissions, which limits the impact on production costs and competitiveness. Credit trading among firms (allowing firms falling short of the standard to purchase credits from firms exceeding the standard) could promote cost-effective emission reductions across firms facing differing abatement costs. But again, trading markets may be thin, and state capacity too low to monitor compliance effectively.

Technology mandates could be used, for example, requiring extractive operators to install methane capture technologies. However, this approach is generally not cost-effective given varying costs of installing specific technologies across firms (depending, for example, on site-specific options for use of captured gas) and incomplete coverage of emissions (existing firms may be exempt due to the high cost of retrofitting).

Subsidies could be provided to incentivize technology adoption. These are more flexible as firms are not forced to adopt technologies, though this approach imposes a fiscal cost on the government.

Offsets can cover methane-emitting sectors by linking them to carbon taxes or ETSs, but this approach has limitations and could even increase emissions. With offsets, entities covered by carbon pricing could partially avoid cutting their own emissions by paying for mitigation projects in other sectors, such as in agriculture or extractives. The purpose of the offset is not to reduce total emissions to shift the location of abatement to more cost-effective sources. However, offsets may not be "additional" in that the project would have happened without the payment. For example, a project to capture methane and use the gas for on-site power generation might have gone ahead anyway on economic grounds without an offset payment. In this case, the offset provision will *increase* total emissions.

Public investment for adoption of methane reduction technologies may be needed, especially when extractive activities are conducted by state-owned enterprises (SOEs). However, SOEs should be subject to regulatory or pricing policies to promote emission reductions on par with private sector companies.

Incentives for decarbonizing food systems may be especially important for countries with large agricultural emissions and low or limited institutional capacity. This could include shifting from livestock to plant-based agriculture. For example, although about half of African countries signed the Global Methane Pledge, capacity for emission monitoring and reporting systems, as well as tax collection, is severely constrained in many cases, not least because of the high degree of informality and large share of family/subsistence agriculture. Similarly, in many Latin American countries (Argentina is a notable exception), governments do not collect business taxes or administer farm support programs and do not have data on farm-level output/input. In these cases, strategies might focus on farm-level inducements to switch to more productive herds, better feed, and to crop-based production, as well as consumer-level incentives to shift from meat to plant-based diets or even meat products with certified low emissions intensity.

For extractives, revenue-neutral methane taxes are most technically feasible where upstream fiscal regimes are already established and the spatial dispersion of firms facilitates use of atmospheric metering technologies. All the top 25 methane emitters from oil/natural gas extraction have fiscal regimes that, loosely speaking, are designed to maximize government revenue while limiting deterrents to investment and production, though regimes vary in their reliance on royalties, corporate income or profit-based taxes, and rent-targeting taxes—see Figure 8. Production taxes related to methane emission rates could be integrated into royalties, while countries without royalties likely have the fiscal room to accommodate a methane tax as these regimes are currently more friendly to investment.[30] Indeed, most oil and natural gas sector regulators already monitor venting and flaring, and a methane tax could build on this capacity—Norway provides a good prototype (see Box 2).

Box 2. Methane Taxes in Norway[31]

The Norwegian government imposes a tax, currently equivalent to about $50 per tonne of CO_2e, on methane emissions from oil and natural gas operators on the Norwegian Continental Shelf. Firms are required to measure and report their emissions and remit taxes to the Norwegian Petroleum Directorate. Several factors were favorable to the implementation of the methane tax, including the following:

- Upstream operations on the shelf account for about 95 percent of the methane emissions from the sector.
- There are close links between the government and the industry: although there are about 30 firms paying the tax, the largest by far is Equinor, in which the government has a two-thirds share.
- Firms use similar equipment, and their output is homogeneous, which facilitates procedures for consistently calculating emissions across firms.
- While developing guidelines for emission data collection and reporting, Norwegian regulators held extensive consultations with industry, research institutions, and other actors capable of independently verifying emission measurement.

The Norwegian model for emission reporting may pave the way for future implementation of methane taxes in other countries. In the United States, for example, the recently passed Inflation Reduction Act includes a methane fee rising to $50 per tonne of CO_2e in 2026. However, the average effective tax on total methane emissions from the extractive sector will be much lower since the tax applies to (1) oil and natural gas producers but not coal producers; (2) large-emitting firms already subject to methane emission reporting requirements, which account for less than half of total oil/natural gas emissions; and (3) firms with emissions above a threshold of 25,000 tonnes of methane.

If capacity and technological barriers make it impractical to directly measure emissions, the extractive sector may be well-suited for an interim proxy fee. This could work by assuming emission intensities based on a limited number of observable project characteristics (for example, installed equipment, drilling technique, reservoir type), which are then scaled by production to determine the tax base. The proxy tax would need to be coupled with investments to improve measurement capacity, with the intention of transitioning to direct measurement in the medium term. This two-step approach broadly aligns with the measurement policies in the EU Methane Strategy and Oil and Gas Methane Partnership, generally following the evolution of Norway's methane fee.[32] Nevertheless, the assumptions to determine emission intensities and processes to ensure that installed technologies are operational would ultimately impact the effectiveness of the policy.[33]

Super emitters and abandoned extractive sites are best addressed with supplementary regulations, penalties, and cleanup projects. The term "super emitter" refers to large extractives facilities with chronic leakage rates (for example, due to damaged or poorly maintained pipeline infrastructure). These sites can usually be detected through atmospheric measurement[34] and could be addressed through supplementary emergency measures such as immediate shutdowns or large penalties until leakage rates are reduced. As on-site monitoring improves, these emissions could then be included

[30] A methane tax could be built into a generally applicable law (and model production-sharing contract if relevant) including a clause that forbids contracts to offer exemptions from such taxes.

[31] Sources: www.iea.org/reports/methane-tracker-2020/improving-methane-data and www.taxpayer.net/energy-natural-resources/methane-fee-in-the-inflation-reduction-act-of-2022.

[32] See EC (2022) and OGMP (2020).

[33] A simplified version of the US Greenhouse Gas Reporting Program (GHGRP) methodology for determining emission factors could be used in the near term, ideally with adjustments for country-specific conditions and considering the fact that the GHGRP has been shown to understate emissions. See EPA GHGRP Subpart W for more (EPA 2022).

[34] They are usually excluded from reporting for the UNFCCC and account for up to 12 percent of methane emissions from oil and natural gas production according to Lauvaux and others (2022).

in the methane tax base. Emissions from abandoned mines and wells could be capped through publicly funded projects[35] or liability requirements, while firms currently operating sites could be subject to capping requirements when the site is shut down. Regulations that require the installation of cost-effective emission abatement technologies should also be implemented.[36]

For agriculture, a proxy fee could be applied to methane emissions where data are available on farm-level output (for example, livestock classes and rice) or input and default emission factors. These fees may be feasible when the government already administers business taxes and/or support programs, at least for large producers in the sector. In countries with limited capacity for agriculture, however, strategies may need to focus on farm- and consumer-level incentives, for example, for more productive livestock and shifting from livestock to plant-based food (see Box 1).

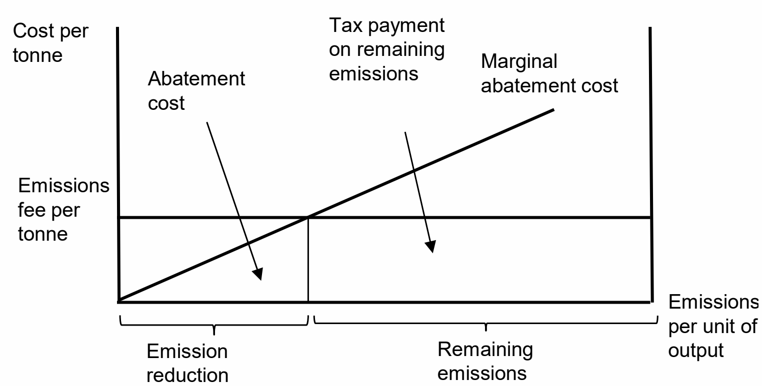
Where countries have specific targets for methane emissions (for example in NDCs), tax trajectories could be aligned with these targets, while in other cases tax rates can be harmonized with energy-related CO_2 taxes to promote cost-effective reductions across GHGs. In the former case, methane tax trajectories can be assessed using (1) country-level projections of future production levels and methane emission rates and (2) assumptions about which behavioral responses are promoted by the tax and the degree of responsiveness to emission pricing. For emission intensity, price responsiveness can be inferred from studies of marginal abatement cost schedules. For demand responses, what matters is the proportionate increase in consumer prices and price elasticities of demand (with international prices and elasticities considered for globally traded goods, such as oil, natural gas, and some agricultural products—see Annex 1). Where countries have targets for reducing total GHGs, tax rates per tonne of CO_2e could be equalized, with the price trajectory inferred from a joint assessment of projections and price responsiveness combining all GHGs.

The case for applying methane fees to waste may be less compelling. For this sector, regulations can better mimic the effects of a tax, given the more limited number of mitigation responses for reducing waste emissions (Annex 2) though, again, the tax may be more effective in incentivizing innovation. In addition, taxes applied to waste site emissions would not promote reductions in waste generated by households and businesses.

Competitiveness/Leakage Concerns

Part of the attraction of a methane fee compared with other instruments is that it would promote reductions in demand and the emission intensity of production in the extractive and agricultural sectors; it would also raise revenue (Figure 9). The tax would reward all behavioral responses for reducing emissions per unit of production. Additionally, it would do so cost-effectively, as the emission price—or incremental cost per tonne from reducing emissions—should be equalized across these responses.

Figure 9. Production Cost Increases from Methane Fee



Source: IMF staff.

Production costs increase both because of abatement costs (corresponding to the integral under the marginal cost schedule) and the tax payment on remaining emissions, resulting in a decrease in demand. For illustration, for a 30 percent emission reduction, tax payments account for about 80 percent of the production cost increase and abatement costs for about 20 percent (from simple geometry).

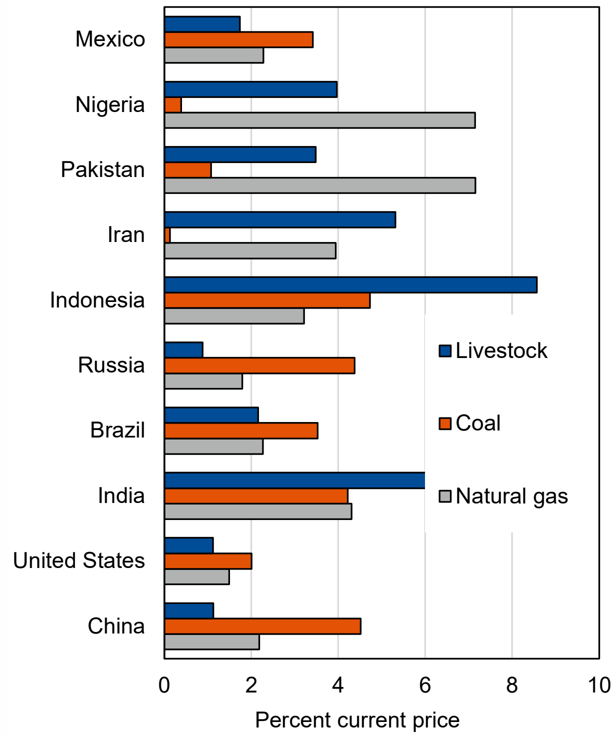
[35] For example, the Biden administration allocated $1.15 billion from the 2021 infrastructure package to cap methane leaks from 130,000 abandoned US oil and natural gas wells.
[36] See IEA (2021).

Extractives and agriculture are trade-exposed sectors, however. Markets for oil and, to some degree, coal, natural gas, and agricultural products are integrated at the international level, which limits the scope for domestic producers to pass abatement costs/methane tax payments into higher domestic producer prices. This has three notable consequences:

- Domestic demand responses may be muted. Indeed, where countries are price takers in international markets, methane taxes cause switching from domestic to foreign production without reducing domestic demand (see Annex 3).
- Domestic producers may suffer from a loss of competitiveness as their per-unit production costs rise relative to foreign producers (which, in turn, could provoke political backlash).
- Reductions in domestic emissions may be partially offset by increases abroad (i.e., so-called emission leakage).

However, competitiveness impacts are generally modest (Figure 10). For example, a \$70 methane fee per tonne of CO_2e in 2030 increases coal and natural gas production costs by about 1–7 percent and livestock costs by 1–8 percent across selected countries. Proportionate cost increases are higher where countries have higher emission factors and lower baseline producer prices.

Figure 10. Production Cost Increases for \$70/tonne CO_2e Methane Fee for Selected Products and Countries, 2030



Source: IMF staff calculations using CPAT.
Note: Impacts on consumer prices are smaller (about 1–4 percent for coal and natural gas) since the post-production costs to process and distribute the goods can be significant, resulting in a larger denominator when calculating the percentage change. "Livestock" refers to the average price increase of beef, veal, pork, and poultry meat weighted by their production volumes.

Leakage could counteract the methane emission reductions from reduced domestic production. This would occur, for example, if the increase in foreign production fully offsets the reduction in domestic production and the emission intensity of domestic and foreign production were the same. If most of the domestic emission reduction comes from reduced emission intensity of production, rather than migration of production from the domestic economy to foreign economies (which is the case for extractives), then the overall emission leakage rate will be modest. As a result, to complement methane fees, countries may consider policies to address competitiveness and leakage impacts.

Options for Addressing Competitiveness/Leakage Concerns

To address leakage and competitiveness concerns, countries could consider implementing a border methane adjustment (BMA). A BMA is analogous to the border carbon adjustment in the context of carbon pricing,[37] which, for example, is being implemented in the EU. The BMA would impose a per-unit charge on imported fuels or agricultural products equal to the domestic methane fee times a methane emission factor. This factor could be based on the estimated actual emission rates of the exporting country, the emission rate of the importing country, a global average, or some variation thereof. The BMA could also rebate charges on domestic exports, though this should be based on an industry (rather than firm-specific) emission factor to maintain incentives for domestic exporters to reduce their emission intensity. A BMA enables the methane tax to be passed forward into higher prices for domestic

[37] See Keen, Parry, and Roaf (2021) and Parry and others (2021).

consumers and helps neutralize the relative change in production costs for domestic producers vis-à-vis foreign producers, thereby limiting competitiveness and leakage effects. See Annex 3.

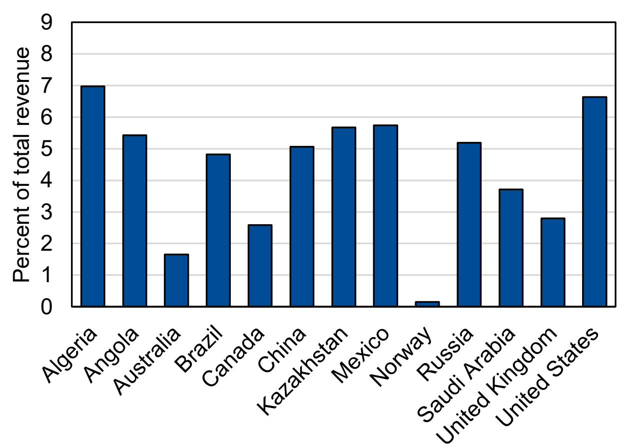
Administrative, legal, and equity concerns may render BMAs impractical, however:

- Administrative complexities are involved in applying charges to each imported product from each country, especially if country-specific, rather than domestic, emission factors are used.
- Equity concerns arise if the same emission price is imposed on advanced and developing economies, given the differentiated responsibilities of developing economies under the UNFCCC framework.
- Legal uncertainties arise from possible challenges to BMAs under World Trade Organization (WTO) rules (if the BMA is interpreted as a protectionist rather than environmental measure).[38]

A simpler and more practical approach is to make the fee revenue-neutral. In effect, this mitigates, for the average firm, the tax payment on its remaining emissions, which dampens the increase in domestic production costs and switching from domestic to foreign production. Note, however, that unlike with a methane tax, there is no domestic demand response. Sector-specific revenue recycling options include the following:

- **For extractives,** reducing production-based or other distortive elements of the broader fiscal regime to keep the discounted value of tax revenues from the sector constant. These cuts would be limited, however. Revenues from a \$70 methane tax in 2030 would amount to only 1–6 percent of projected revenues collected under business tax regimes for oil and natural gas for the majority of the countries shown in Figure 11.
- **For agriculture**, revenues could be returned in proportion to the value of output across all farm production. This preserves the increase in the production cost of livestock relative to that of plant-based production.

Figure 11. Revenues from \$70 Methane Tax for Oil and Natural Gas Relative to Revenue from Existing Fiscal Regime, 2030



Source: IMF staff using the Fiscal Analysis of Resource Industries (FARI) model.

Another promising option is feebates, which impose a sliding scale of fees on firms with above-industry-average emission rates and provide rebates for firms with below-average emission rates.[39] These instruments are the fiscal analog of emission rate regulations with tradable allowances (see Box 1) but automatically promote cost-effectiveness without the need for trading markets, since all firms face the same incremental reward for reducing emissions. Feebates do not charge the average firm for its remaining emissions and, therefore, do not promote demand responses. However, this also means that they help address competitiveness concerns by limiting production cost increases. Their small impact on energy and agricultural prices also minimizes short-term inflationary risks. Feebates are most effective when firm-level emissions can be directly monitored, but they could also be linked to observable mitigation technologies or production methods.

Last, an internationally agreed minimum methane price would be the most effective mechanism for addressing domestic demand, competitiveness, and leakage concerns. This approach would be more efficient than a unilateral system of BMAs, as it could price all methane emissions (including in traded products from all willing countries). Prices could be better harmonized across countries, considering equity considerations. Furthermore, such a scheme should be less likely to be challenged

[38] See Parry and others (2021) for further discussion of legal aspects.

[39] Under a feebate, firms would be charged a fee equal to the methane emission price times the difference between their emission rate and the industry average emission rate and multiplied by their production level. See Parry (2021) for further discussion.

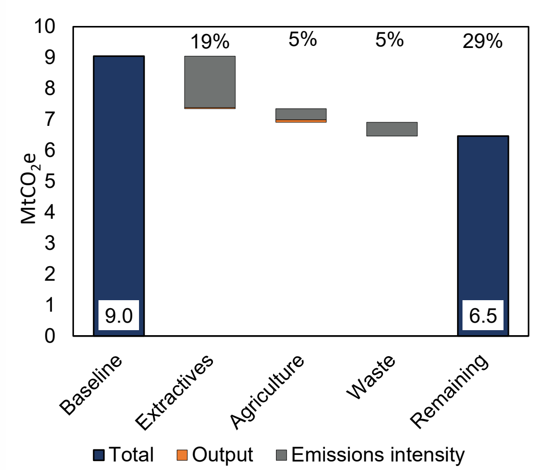
legally at the WTO. Significant challenges to setting up and monitoring the arrangement would need to be overcome, however. See Annex 4 for further discussion.

Quantitative Assessment of Methane Policies

A policy scenario is considered, with a fee starting in 2024 at $10 per tonne of CO_2e and increasing $10 per tonne each year to reach $70 per tonne by 2030. The scenario applies to the top 35 methane-emitting countries (henceforth "T35"). This includes the top 25 overall emitters plus an additional 5 large emitters (each for extractives and agriculture). T35 countries account for 85 percent of BAU global methane emissions in 2030. The scenario involves methane taxes for the extractive and agricultural sectors and a regulation that reduces landfill emissions (with a shadow price or incremental mitigation cost equal to $70 per tonne).[40]

The scenario cuts T35 methane emissions by 2.5 billion tonnes below BAU in 2030, or about 30 percent (Figure 12). This would align methane for large emitters in 2030 with limiting temperature rises to below 2°C, though further action would be needed for a 1.5°C–aligned pathway. The scenario provides a useful benchmark indicating the pattern of emission reductions by sector, type of behavioral response, and country under a least-cost approach.

Figure 12. Global Methane Reductions by Sector/Response under $70/tonne Fee, 2030



Source: IMF staff using CPAT (see Annex 1).
Note: The figure shows the difference between emissions in the business-as-usual scenario and remaining emissions with the methane tax and the emission reductions decomposed by sector. Mt CO_2e = tonnes of CO_2 equivalent.

Mitigation burdens are calculated by estimating welfare costs of abatement. Welfare costs are a standard metric used by economists and, in this analysis, correspond to integrals under marginal abatement cost schedules for cutting methane emissions.[41] These can be interpreted as the annualized costs of using cleaner technologies, net of any economic benefits (such captured gas sales). Costs are then expressed as (but distinct from) a percentage of GDP. Costs may be overstated as they do not account for broader market failures due to firms failing to invest in profitable mitigation technologies.[42] In addition, the estimates do not account for offsetting domestic environmental co-benefits. For instance, recent studies suggest that reductions in low-level ozone concentrations from lower methane emissions have significant health and productivity benefits.[43] On the other hand, costs will be understated to the extent less efficient instruments are used (for example, due to practical constraints on methane pricing).

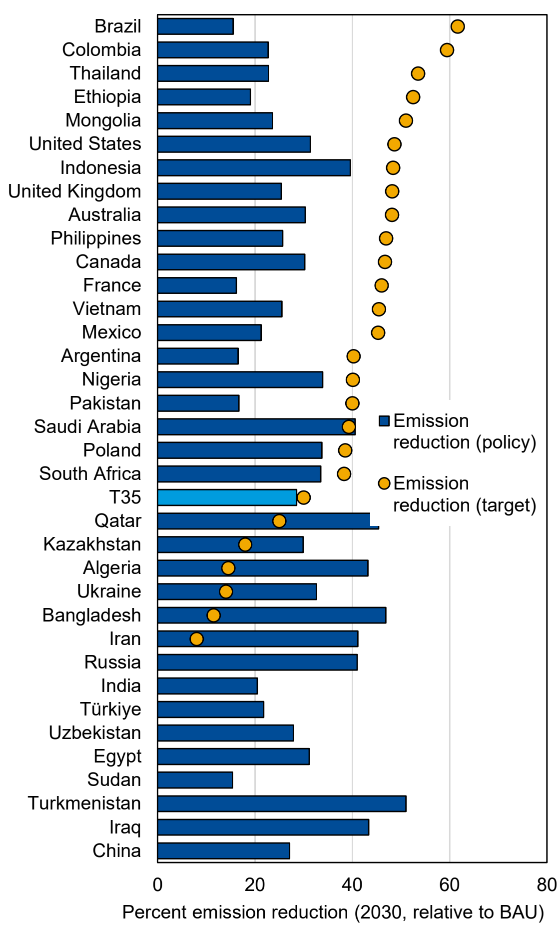
Of the simulated T35 emission reductions, the extractive sector accounts for 66 percent, while the agricultural and waste sectors account for 17 percent each. The disproportionately large emission reduction in extractives reflects the greater preponderance of low-cost mitigation opportunities for reducing methane intensity at the mine mouth or wellhead and along the natural gas transmission infrastructure.[44] About a third each of the total emission reductions for extractives comes from coal, oil, and natural gas production. In contrast, in agriculture, there is limited scope for technological measures to reduce emissions from enteric fermentation and manure management.[45] Last, most emission reductions

[40] The international price increases for fossil fuels and agricultural products drive the domestic demand responses in these sectors. International price increases are assumed equal to the product of the average, sector-specific methane emission factors (across the T35 countries) and the global average methane price. If the methane tax applied only to GMP countries, the global methane emission reduction would be only about half as large.
[41] For more discussion on the relationship between abatement costs and welfare costs see Morris, Paltsev, and Reilly (2012).
[42] See, for example, IEA (2022b), Figure 1.4. Hidden costs, such as needed infrastructure to distribute captured methane and transaction costs, may in some cases explain why seemingly profitable investments are not made.
[43] UNEP (2021).
[44] See also IGSD (2022a).
[45] See also IPCC (2019). For example, seaweed feed additives to reduce enteric fermentation may need to be farmed.

come from reduced emission intensity rather than reductions in output. Reduced emission intensity accounts for 95 and 80 percent of the response in the extractive and agricultural sectors, respectively.

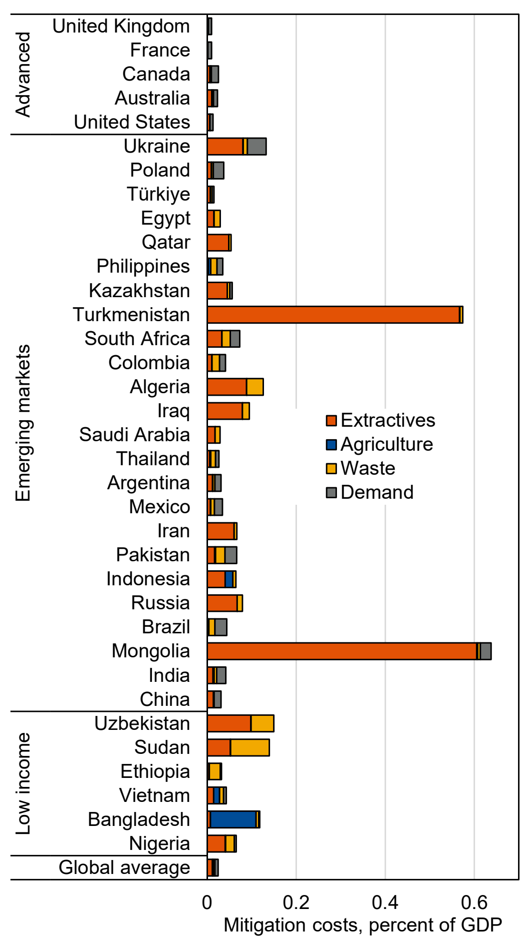
Emission reductions are inequitably distributed across countries, however, with somewhat larger cuts in developing compared with developed economies (see Figure 13). Emission reductions below BAU levels in 2030 under the methane tax are 16–32 percent across high-income countries (Australia, Canada, France, UK, US); reductions exceed 40 percent in various emerging market and developing economies (for example, Algeria, Bangladesh, Indonesia, Iran, South Africa, Turkmenistan). Proportionate reductions in (nationwide) methane emissions are larger in countries where extractives are the dominant source of BAU emissions and smaller in countries where agriculture is the dominant emission source. Emission reductions exceed countries' pledged reductions in 7 cases and fall short of them in 20 cases—9 countries do not have (binding) pledges.

Figure 13. Emission Reductions by T35 Country under Uniform Fee, 2030



Source: IMF staff calculations using CPAT.
Note: Emissions targets are the greater of the GMP or NDCs (assuming methane falls in proportion to all GHGs). Targets are missing if countries have a target but meet it in the BAU scenario or have no target. BAU = business as usual; GHG = greenhouse gas; GMP = Global Methane Pledge; NDC = Nationally Determined Contribution; T35 = top 35 methane emitters.

Figure 14. Mitigation Costs by T35 Country under Uniform Fee, 2030



Source. IMF staff calculations using CPAT.
Note: Costs are the annualized cost of using cleaner but more expensive technologies. They differ from GDP effects (the latter includes investment and trade effects). Global average is a weighted average using 2021 (or most recent) GDP. T35 = top 35 methane emitters.

…and so are mitigation burdens (see Figure 14). Mitigation costs are less than 0.1 percent of GDP in high-income countries but exceed 0.5 percent of GDP in certain developing economies with large extractive industries relative to total GDP (Mongolia and Turkmenistan). The cost disparity across countries reflects not only the larger percentage of emission reductions in emerging market and developing economies but also the generally higher methane intensity of their GDP in the BAU. At the global level, mitigation costs are about 0.1 percent of GDP.

Differentiated pricing and financial/technological support are likely to be key elements of an international agreement on minimum methane pricing. Varying methane taxes according to broad country groupings classified by development level would promote a more progressive distribution of emission reductions and mitigation costs. Support from high-income countries would also likely be needed to entice emerging market and developing economies into a minimum pricing regime. This might take the form, for example, of donor support (linked to verifiable emission reductions or technology adoption) and/or international transfer of methane mitigation technologies.

Conclusion

Cutting methane emissions is critical to stabilizing the global climate. The rising frequency of climate-related disasters, increasing knowledge of climatic tipping point risks, emerging technologies for monitoring emissions, and the GMP have raised the profile and importance of reducing methane emissions.

This Note has emphasized the potential role of methane fees—or variants of fees. These can be integrated into existing fiscal regimes in the extractives sector, where the bulk of the low-cost mitigation opportunities in the near term are located. There are various options for addressing competitiveness concerns (for example, revenue recycling and feebates), though an international agreement on minimum emission prices could be most effective in scaling up global action. Methane pricing might also be viable in the agricultural sector, at least where most farms are already covered by business taxes or farm assistance programs. Beyond pricing there are other options for addressing methane through regulatory and subsidy approaches (Box 1) while various initiatives in the private sector and financial markets are also helping combat methane emissions (Annex 5).

Global and national strategies for cutting methane emissions need to be fleshed out, but the GMP provides a potential platform for discussion. Some countries will pursue pricing and others non-pricing approaches. Thus, operational methodologies for comparing efforts across countries need to be approved. Continued refinement of methane monitoring technologies is needed, particularly atmospheric measures that can better map readings to specific emission sources. Successful methane abatement programs, such as Norway's methane tax, need to be disseminated, along with the lessons that can be drawn for other countries. Financing would need to be part of an international agreement, given that mitigation costs would fall disproportionately on emerging market economies. Last, dialogue is needed on design issues for internationally coordinated mitigation regimes as well as strategies for advancing critical methane abatement technologies.

References

Armstrong McKay, D.I., A. Staal, J.F. Abrams, R. Winkelmann, B. Sakschewski, S. Loriani, I. Fetzer, S.E. Cornell, J. Rockström, and T.M. Lenton, 2022. “Exceeding 1.5°C Global Warming couldTtrigger Multiple Climate Tipping Points.” *Science*. September 9. 377(6611).

Black, Simon, Ian Parry, James Roaf, and Karlygash Zhunussova. 2021. “Not Yet on Track to Net Zero: The Urgent Need for Greater Ambition and Policy Action to Achieve Paris Temperature Goals.” Staff Climate Note 2021/005, International Monetary Fund, Washington, DC.

Cheng, Chin-Hsien, and Simon A. T. Redfern. 2022. “Impact of Interannual and Multidecadal Trends on Methane-Climate Feedbacks and Sensitivity.” *Nature Communications* 13: 3,592.

Crippa, M., D. Guizzardi, M. Muntean, E. Schaaf, E. Solazzo, F. Monforti-Ferrario, J. Olivier, and E. Vignati. 2020. “Fossil CO2 and GHG Emissions of all World Countries: 2020 Report.” Joint Research Centre, European Commission, Brussels.

Dreyfus, Gabrielle B., X. Yangyang, Drew T. Shindell, Durwood Zaelke, and Veerabhadran Ramanathanf, 2022. “Mitigating Climate Disruption in time: A Self-Consistent Approach for Avoiding both Near-Term and Long-Term Global Warming.” *Proceedings of the National Academy of Sciences* 119. https://doi.org/10.1073/pnas.2123536119.

European Commission (EC). 2022. “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy to Reduce Methane Emissions.” Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122077630&uri=CELEX:52020DC0663.

Food and Agricultural Organization of the United Nations (FAO). 2017. “Global Livestock Environmental Assessment Model (GLEAM).” Rome. www.fao.org/gleam/en.

Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). 2022. Statistical Database. Rome.

Fischer, Carolyn, Ian Parry, and William A. Pizer. 2003. “Instrument Choice for Environmental Protection when Technological Innovation Is Endogenous.” *Journal of Environmental Economics and Management* 45: 523–45.

Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D. Lunt, T. Mauritsen, M. Palmer, M. Watanabe, M. Wild, H. Zhang, and others. 2021. “The Earth’s Energy Budget, Climate Feedbacks, and Climate Sensitivity.” In *Climate Change 2021: The Physical Science Basis—Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* 923–1054. Cambridge, UK: Cambridge University Press.

Global Gas Flaring Reduction Partnership (GGFRP). 2020. *Global Gas Flaring Tracker Report*. World Bank, Washington, DC.

Harmsen, M. J. H. M., D. P. van Vuuren, D. R. Nayak, A. F. Hof, L. Höglund-Isaksson, P. L. Lucas, J. B. Nielsen, P. Smith, and E. Stehfest. 2019. “Long-Term Marginal Abatement Cost Curves of Non-CO2 Greenhouse Gases.” *Environmental Science and Policy* 99: 136–49.

Hoesly, Rachel M., Steven J. Smith, Leyang Feng, Zbigniew Klimont, Greet Janssens-Maenhout, Tyler Pitkanen, Jonathan J. Seibert, and others. 2018. “Historical (1750–2014) Anthropogenic Emissions of Reactive Gases and Aerosols from the Community Emissions Data System (CEDS).” Geoscientific Model Development 11: 369–408.

Höglund-Isaksson, L., A. Gómez-Sanabria, Z. Klimont, P. Rafaj, and W. Schöpp. 2020. “Technical Potentials and Costs for Reducing Global Anthropogenic Methane Emissions in the 2050 Timeframe—Results from the GAINS Model.” *Environmental Research Communications* 2: 025004.

Institute for Governance and Sustainable Development (IGSD). 2022a. *A Primer on Cutting Methane: The Best Strategy for Slowing Warming in the Decade to 2030*. Working paper. Washington, DC.

Institute for Governance and Sustainable Development (IGSD). 2022b. *The Need for Fast Near-Term Climate Mitigation to Slow Feedbacks and Avoid Tipping Points: Critical Role of Short-lived Super Climate Pollutants To Address the Climate Emergency*. Background Note. Washington, DC.

Intergovernmental Panel on Climate Change (IPCC). 2014. *Fifth Assessment Report*. Geneva.

Intergovernmental Panel on Climate Change (IPCC). 2018. “Summary for Policymakers.” In *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. Geneva.

Intergovernmental Panel on Climate Change (IPCC). 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva.

International Energy Agency (IEA). 2021. “Driving Down Methane Leaks from the Oil and Gas Industry: A Regulatory Roadmap and Toolkit. Paris. https://iea.blob.core.windows.net/assets/465cb813-5bf0-46e5-a267-3be0ccf332c4/Driving_Down_Methane_Leaks_from_the_Oil_and_Gas_Industry.pdf.

International Energy Agency (IEA). 2022a. Global Methane Tracker. Paris. www.iea.org/reports/methane-tracker.

International Energy Agency (IEA). 2022b. “Curtailing Methane Emissions from Fossil Fuel Operations.” Paris. www.iea.org/reports/curtailing-methane-emissions-from-fossil-fuel-operations.

International Monetary Fund (IMF). 2019a. *Fiscal Monitor: How to Mitigate Climate Change.* Washington, DC, October.

International Monetary Fund (IMF). 2019b. “Fiscal Policies for Paris Climate Strategies—From Principle to Practice.” IMF Policy Paper, Washington, DC.

International Monetary Fund (IMF). 2021. “Strengthening the Climate Information Architecture.” IMF Staff Climate Note 2021/003, Washington, DC.

Jackson, Robert B., Sam Abernethy, Josep G. Canadell, Matteo Cargnello, Steven J. Davis, Sarah Féron, Sabine Fuss, Alexander J. Heyer, Chaopeng Hong, Chris D. Jones, H. Damon Matthews, Fiona M. O'Connor, Maxwell Pisciotta, Hannah M. Rhoda, Renaud de Richter, Edward I. Solomon, Jennifer L. Wilcox and Kirsten Zickfeld. 2021. “Atmospheric Methane Removal: A Research Agenda.” *Philosophical Transactions of the Royal Society A*: 379(2210).

Keen, Michael, Ian Parry, and James Roaf. 2021. “Border Carbon Adjustments: Rationale, Design and Impact.” IMF Working Paper 21/239, International Monetary Fund, Washington, DC.

Lauvaux, T., C. Giron, M. Mazzolini, A. D’Aspremont, R. Duren, D. Cusworth, D. Shindell, and P Ciai. 2022. “Global Assessment of Oil and Gas Methane Ultra-Emitters.” *Science* 375: 557–61.

Mar, K. A., C. Unger, L. Walderdorff, and T. Butler. 2022. "Beyond CO_2 Equivalence: The Impacts of Methane on Climate, Ecosystems, and Health." *Environmental Science and Policy* 134: 127–36.

McKay, David I. Armstrong, Arie Staal, Jesse F. Abrams, Ricarda Winkelmann, Boris Sakschewski, Sina Loriani, Ingo Fetzer, Sarah E. Cornell, Johan Rockström, and Timothy M. Lenton. 2022. "Exceeding 1.5°C Global Warming Could Trigger Multiple Climate Tipping Points." *Science* 377 (6611): eabn7950. https://doi.org/10.1126/science.abn7950.

Morris, Jennifer, Sergey Paltsev, and John Reilly. 2012. "Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model." *Environmental Modeling & Assessment* 17 (4): 325–36. https://doi.org/10.1007/s10666-011-9298-7.

Munnings, Clayton, and Alan Krupnick. 2017. "Comparing Policies to Reduce Methane Emissions in the Natural Gas Sector." RFF Report, Resources for the Future, Washington, DC.

National Oceanic and Atmospheric Administration (NOAA). 2022. "Increase in Atmospheric Methane Set Another Record during 2021." US Department of Commerce, Washington, DC.

Network for Greening the Financial System (NGFS). 2022. "Final Report on Bridging Data Gaps." Technical document, Paris.

Oil and Gas Methane Partnership (OGMP). 2020. "Mineral Methane Initiative OGMP2.0 Framework." www.ogmpartnership.com/sites/default/files/files/OGMP_20_Reporting_Framework_0.pdf.

Parry, Ian. 2021. "The Critical Role of Feebates in Climate Mitigation Strategies." In *No Brainers and Low-Hanging Fruit in National Climate Policy*, edited by F. Caselli, A. Ludwig, and R. van der Ploeg, 217–44. London: Center for Economic Policy Research.

Parry, Ian, Simon Black, and James Roaf. 2021. "Proposal for an International Carbon Price Floor among Large Emitters." IMF Staff Climate Note 2021/001, International Monetary Fund, Washington, DC.

Parry, Ian, Peter Dohlman, Cory Hillier, Martin Kaufman, Kyung Kwak, Florian Misch, James Roaf, and Christophe Waerzeggers. 2021. "Carbon Pricing: What Role for Border Carbon Adjustments?" IMF Staff Climate Note 2021/004, International Monetary Fund, Washington, DC.

Romsom, E., and K. McPhail. 2021. "Capturing Economic and Social Value from Hydrocarbon Gas Flaring and Venting: Evaluation of the Issues." UNU-WIDER Working Paper 2021/5, United Nations University World Institute for Development Economics Research, Helsinki.

United Nations Environment Program (UNEP). 2021. "Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions." UNEP and Climate and Clean Air Coalition, Nairobi.

United States Environment Protection Agency (EPA). 2019. "Global Non-CO_2 Greenhouse Gas Emission Projections and Mitigation Potential: 2015–2050." Washington, DC.

United States Environmental Protection Agency (EPA). 2022. 40 CFR Part 98 Subpart W, Mandatory Reporting of Greenhouse Gases: Petroleum and Natural Gas Systems. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98/subpart-W.

Annex 1. Extension of the Climate Policy Assessment Tool (CPAT) for Methane Analysis

CPAT is a model developed jointly by IMF and World Bank staff members over the past several years. The main CPAT model provides analysis of mitigation policies for the major energy sectors on a country-by-county basis for 188 countries. It projects use of fossil fuels and CO_2 emissions as well as various environmental and economic impacts of carbon pricing and other climate mitigation instruments. CPAT is parameterized so that emission projections and behavioral responses are about in the midrange of those from the broader energy modeling literature and econometric estimates of income and price elasticities for fossil fuel products. CPAT does not explicitly model the gradual adjustment of capital stocks over time—instead the focus is on a snapshot for 2030 with full adjustment to mitigation policies.

CPAT was extended for this analysis to include projections and abatement cost functions for methane emissions from the extractive, agricultural, and waste sectors. Methane emission factors from UNFCCC data were used for agriculture and waste (given the extensive cross-country data) and an average of the UNFCCC and International Energy Agency[46] data was used for extractive emissions (given the greater degree of underreporting in UNFCCC data suggested by satellite data for this sector). Emission factors are assumed to decline by 0.25 to 0.50 percent a year in the BAU for all but coal, reflecting autonomous technological improvements according to the EPA (2019) marginal abatement cost curve (MACC) projections.[47]

Country-level production of agriculture, fossil fuels, and waste is projected forward. Future coal, oil, and natural gas production is estimated using 2019 values and in proportion to future growth in fuel demand at the global level for oil and natural gas (where international markets are largely integrated) and at the domestic level for coal (where they are not) relative to demand in 2019.[48] BAU agricultural production is assumed to change in proportion to global food demand in a future year according to FAO projections (FAOSTAT, 2022). BAU waste amounts at the country level in future years change based on GDP growth, with income elasticities specific to a country's income grouping. Production is adjusted downward under the methane fee scenario according to the commodity price increase induced by the methane fee and the assumed price elasticity of demand.

CPAT does not model specific technologies underlying the behavioral responses presented in Annex 2. Instead, four functional forms are specified for the methane emission factors of coal, oil/natural gas, agriculture, and waste where the emission factor is declining in the price on methane emissions. Specifically, constant elasticity specifications are used (where the elasticity is negative). This implies that the decline in the emission factor is falling at higher levels of emission prices, or, conversely, that the MACCs for cutting emission rates are convex. The elasticity values are initially estimated at the country and sector-specific level (using MACCs from the US Environmental Protection Agency [EPA]) and then adjusted across all countries so that, at a global level, the percentage reductions in emission intensity in response to pricing are approximately consistent with midrange estimates from recent studies.[49] This results in behavioral response functions that are specific to each country-sector pair (for example, coal in the United States). MACCs are assumed to have a zero intercept, which rules out the possibility of broader market failures due to firms not exploiting investments that are profitable in the absence of mitigation policy.

Domestic demand responses to methane taxes depend on the proportionate increase in retail prices from methane charges and product price elasticities. For the analysis of an internationally coordinated methane tax, international prices for coal, oil, natural gas, livestock, and rice are assumed to increase by the global average emission factor for that product times the methane tax. The proportionate

[46] IEA (2022a).

[47] The emission factor for coal is kept constant as a greater proportion of mining is conducted in underground mines, which have significantly greater emission factors than open-pit mines.

[48] The BAU emission projections make an adjustment for the effect of the COVID-19 pandemic. Emission growth may be proportionately larger/smaller in countries with relatively low/high costs of additional extraction—accounting for this would, however, only moderately affect BAU estimates of methane emissions from the extractive sector.

[49] Specifically, three studies reported in UNEP (2021)—Harmsen and others (2019), IEA (2022a), and EPA (2019).

increase in domestic prices is, then, given by the increase in international prices divided by the domestic retail price in the BAU scenario. Product price elasticities are all taken to be between –0.3 (gasoline and diesel) and about –0.5 (agriculture, coal, natural gas). Given constant elasticity demand functions, this implies, for example, that price increases of 10 and 20 percent would reduce demand by 5 and 9 percent, respectively (under a –0.5 elasticity assumption).

Annex 2. Behavioral Responses for Mitigating Methane Emissions

Table A1. Classification of Mitigation Responses

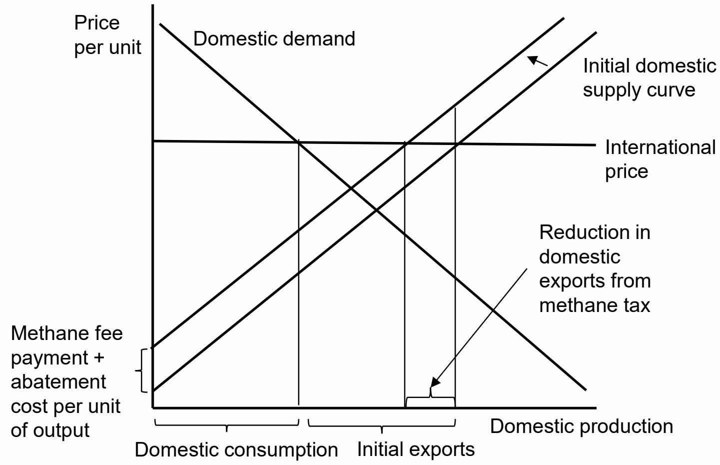
	Reducing the emission intensity of production/acitivity	Reducing domestic demand
Fossil fuels		
	Oil and gas	
	· flaring vented gas from wells (produces CO_2 instead of methane)	· reducing domestic energy demand
	· capture and utilization of vented methane for on-site power or sales	
	· leak detection and repair to reduce fugitive emissions during gas processing and distribution; replace pressurized gas pumps, controllers, pneumatic devices with electric systems, replace compressor seals	· shifting from fossil fuels to renewables and other non-fossil energy
	· cap abandoned wells	
	Coal	
	· pre-mining degasification and air methane oxidization	
	· flaring vented gas	
	· flooding abandoned mines	
Agriculture		
	· reducing enteric fermentation through changes in feed (e.g., seaweed additives) and enhanced livestock productivity (e.g., switching to higher-productivity breeds).	· reducing domestic food demand (e.g., through reduced waste)
	· manure treatments (covering, composting, using for biogas)	· shifting from meat- to plant-based diets
	· reducing water intensity of rice paddies (e.g., by periodic draining)	
Waste		
	· collection and flaring of landfill gas	· reducing demand for packaging/food
	· upgrade wastewater treatment	· increased recycling of products and composting of organic waste

Sources: UNEP (2021); and IMF staff.

Annex 3. Domestic Demand and Production Effects from Methane Taxes without and with BMAs—the Case of Price-Taking Countries

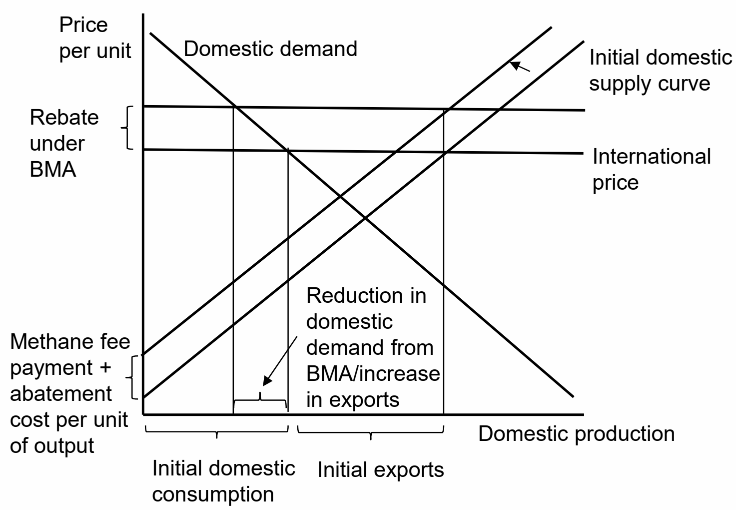
Where countries are price takers in international markets for fuel and agricultural products, methane fees by themselves cause switching from domestic to foreign production without reducing domestic demand. The domestic supply cost per unit rises by the abatement cost/methane fee payment per unit of output. Domestic demand is unaffected (as the domestic price is fixed on international markets), but domestic exports (which are supplied up to the point where the international price equals the unit production cost) fall. In response, foreign consumers will increase their purchases from other countries at the fixed international price. Figure A1 illustrates this case for a net exporting country. For the case of a net importing country, the reduction in domestic production is offset by an increase in imports, again with domestic demand unaffected.

Figure A1. Domestic Production Effect of Methane Fee for Net Exporter and Price-Taking Country



A BMA would impose a per-unit charge on any fuel or agricultural import equal to the domestic methane emission price times a corresponding methane emission factor. It would also rebate charges on domestic exports based on an industry (rather than firm-specific) emission factor, since this maintains incentives for domestic firms to reduce emission intensity. If the emission factor in the BMA formula is based on the domestic industry factor, then (1) to an approximation, there would be no change in the competitiveness of domestic versus foreign products; and (2) the methane tax with BMA would be passed forward in the form of higher prices for domestic consumers. This would promote reductions in domestic demand while leaving domestic production unchanged—see the illustration in Figure A2, in which the export rebate is assumed to fully compensate domestic producers for the methane fee.

Figure A2. Domestic Production Effect of Methane Fee and BMA for net Exporter and Price-Taking Country



Source: IMF staff.
Note: BMA = border methane adjustment.

Annex 4. An International Price Floor for Methane Emissions

Analogous to the international carbon price floor proposed by IMF staff,[50] a similar international regime might apply to methane emissions, forming the basis of a practical mechanism for implementing the GMP. The price floor would have two key features, namely a focus on:

- *A coalition of willing countries with large collective methane emissions*, such as GMP signatories, to facilitate negotiation while maintaining coverage of a large portion of global emissions
- *A minimum methane emission price that each country would need to implement*, given that emission pricing is an efficient and easily understood parameter—agreement on a price floor rather than a price level allows countries flexibility to set a higher price if this is needed to help meet a domestic methane emission target

The price floor would also need pragmatic design in three respects:

- *To accommodate the differentiated responsibilities of developing economies*, which can be done by differentiating pricing requirements according to a country's level of economic development and including robust, transparent mechanisms to transfer financial and technological assistance to low-income participants in the agreement
- *To accommodate countries for which methane pricing is difficult politically*, provided they achieve, through other instruments, a reduction in emissions equivalent to what they would have achieved had they met the price floor
- *To sequence sectoral coverage in line with institutional monitoring capacities*, including by focusing the agreement on extractive emissions initially and subsequently extending the agreement to agriculture and waste as metering capability evolves

The arrangement would need to encompass mutually agreed procedures for measuring methane emissions. Whether enforcement mechanisms are needed is not entirely clear. A BMA could provide some deterrent to cheating on the arrangement, but it would complicate its initial setting up as countries would need to agree on design issues both for the price floor and the BMA. Such a measure may not be needed since it is in countries' collective interest to secure an effective agreement with no cheating.

A pragmatically designed price floor for methane emissions may be more promising than alternative international coordination regimes:

- One alternative would be a pure price floor according to which all participants implement methane pricing at the same level. This approach would promote cost-effectiveness at the global level, but it would have less scope for addressing the differentiated responsibilities of developing economies and would exclude countries for which methane pricing is too difficult for political or institutional reasons.
- Another alternative would be a regime focused on country-level methane quotas, aligned with global mitigation objectives. This approach would be more difficult to negotiate, however, because of the much greater number of parameters (one quota per country), and it does not directly address uncertainty over specific policy actions in other countries, which is key to addressing competitiveness concerns.

There are several precedents for this type of international cooperation. They include tax floors for indirect taxes in the European Union and the Organization for Economic Co-operation and Development (OECD)/G20 Inclusive Framework on Base Erosion and Profit Shifting (BEPS) under which over 135 countries collaborate to put an end to tax avoidance strategies. From a climate mitigation perspective, precents include the 1987 Montreal Protocol which phased out substances that both depleted the ozone layer and contributed to global warming. And the 2016 Kigali Agreement is phasing out the most important fluorinated gases which also contribute to warming.

[50] See Parry, Black, and Roaf (2021).

Annex 5. The Role of the Financial Sector in Mitigating Methane Emissions

Private sector initiatives on cutting methane emissions have been building since the Paris Agreement but are still lagging. Shareholder engagement by individual investors and coalitions, mainly in the United States and Europe, has recently increased, mostly urging publicly traded extractive companies to provide better reporting on methane emissions and to reduce them (sometimes as part of broader resolutions on energy transition planning and emission reduction). Recent notable examples include the majority support of methane-specific resolutions in Chevron's and ExxonMobil's general assemblies during the 2022 proxy season.

Several measures to boost transparency on methane emissions have also been adopted by the private sector. They include the publication of indicators on emission rates and reduction targets, the use of leak detection and repair protocols, limits on routine natural gas flaring, and positions on methane policy. Leading examples involve primarily the major oil and natural gas companies in the US (for example, Chevron, Southwestern Energy) and in Europe (for example, TotalEnergies). Participation of the private sector—in the extractive and in the financial industry—has also been growing within the Global Methane Initiative.[51] However, these disclosures are still falling short in data reliability and consistency and effective integration into financial decision-making.

An increasing number of sectoral policies adopted internally by financial institutions—most notably commercial banks and asset managers—include methane-related measures. These encompass reduction targets (for example, removal of super emitters, reduction of financed methane emissions in volume and intensity); the identification and measurement of data; and the adoption of industrial techniques to monitor, measure, and reduce these emissions. The financial institutions participate in the implementation of increasing regulatory requirements for such institutions to publish their emission (including Scope 3 emissions) and/or transition plans. Benchmarking methane management helps investors assess how prepared operators in the extractive industry are for a net zero emissions world, in addition to the management of escalating climate-related risks.

Complementary financial sector policy measures can be deployed across the three blocks of the climate information architecture—data, disclosures, and taxonomies.[52] The climate information architecture, indeed, needs to reinforce the focus on methane by (1) bridging methane abatement finance data gaps; (2) reinforcing disclosures and the integration of methane-related measures into transition plans; and (3) developing taxonomies to enhance flows into methane mitigation techniques and measures. Specifically:

- *Data:* A substantial increase in the availability and reliability of methane data—mainly related to emission levels and abatement potential—is needed for financial market participants. The Network on Greening the Financial System's report on bridging data gaps[53] recommends making better use of the geospatial methane emission data available in the science community, promoting multidisciplinary collaboration and research on spatial finance, and reinforcing upskilling and capacity building on methane for financial supervisors.
- *Disclosures:* Climate-related corporate disclosures will also prove decisive as some have been incorporating methane emission reporting (within disaggregated emission data)—at the national or regional level (for example, EU, US) as well as the global level (International Sustainability Standards Board[54]). Reduction targets may also be embedded in transition plan disclosure requirements, such as in the forthcoming EU climate reporting standard.

[51] This is a voluntary international partnership that brings together national governments, private sector entities, development banks, and other interested stakeholders in a collaborative effort to reduce methane emissions and advance methane recovery and use.
[52] IMF (2021).
[53] NGFS (2022). The IMF (Monetary and Capital Markets Department) co-chaired the workstream and actively co-drafted the final report.
[54] The IMF (Monetary and Capital Markets Department) is a member of the International Sustainability Standards Board sustainability consultative committee. The reply to the consultation on the climate reporting standard proposal (including on transition plans and disaggregated emission reporting) may be found here: https://www.ifrs.org/content/dam/ifrs/project/climate-related-disclosures/exposure-draft-comment-letters/i/international-monetary-fund--imf--7fd760de-ec7a-40ae-bae4-6fb460c94096/feedback-on-issb-on-work-sustainability-and-climate-related-disclosures.pdf

- *Taxonomies:* These are crucial tools to ensure financing toward activities with high methane emission mitigation potential. These include measurement equipment, leak detection and repair programs, production site maintenance, and mitigation technologies (see Annex 2, Table A1). The EU, Association of Southeast Asian Nations, Bangladesh, South African, and Malaysian taxonomies are relevant examples. They may even reflect broader policy developments to reduce methane emissions. Given fragmentation risks—and to ensure interoperability and effectiveness of taxonomies in capital allocation, climate-related transparency, and risk management—the IMF is leading a joint project with the World Bank Group, the Organization for Economic Co-operation and Development, and the Bank for International Settlements to implement the G20 high-level principles for sustainable finance alignment approaches[55] (forthcoming guidance).

Scaling up cross-border private climate financing while reinforcing the climate information architecture for methane could strengthen scrutiny over methane emissions globally.

[55] G20 Roadmap for sustainable finance, October 2021. See: https://g20sfwg.org/roadmap/

PUBLICATIONS

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