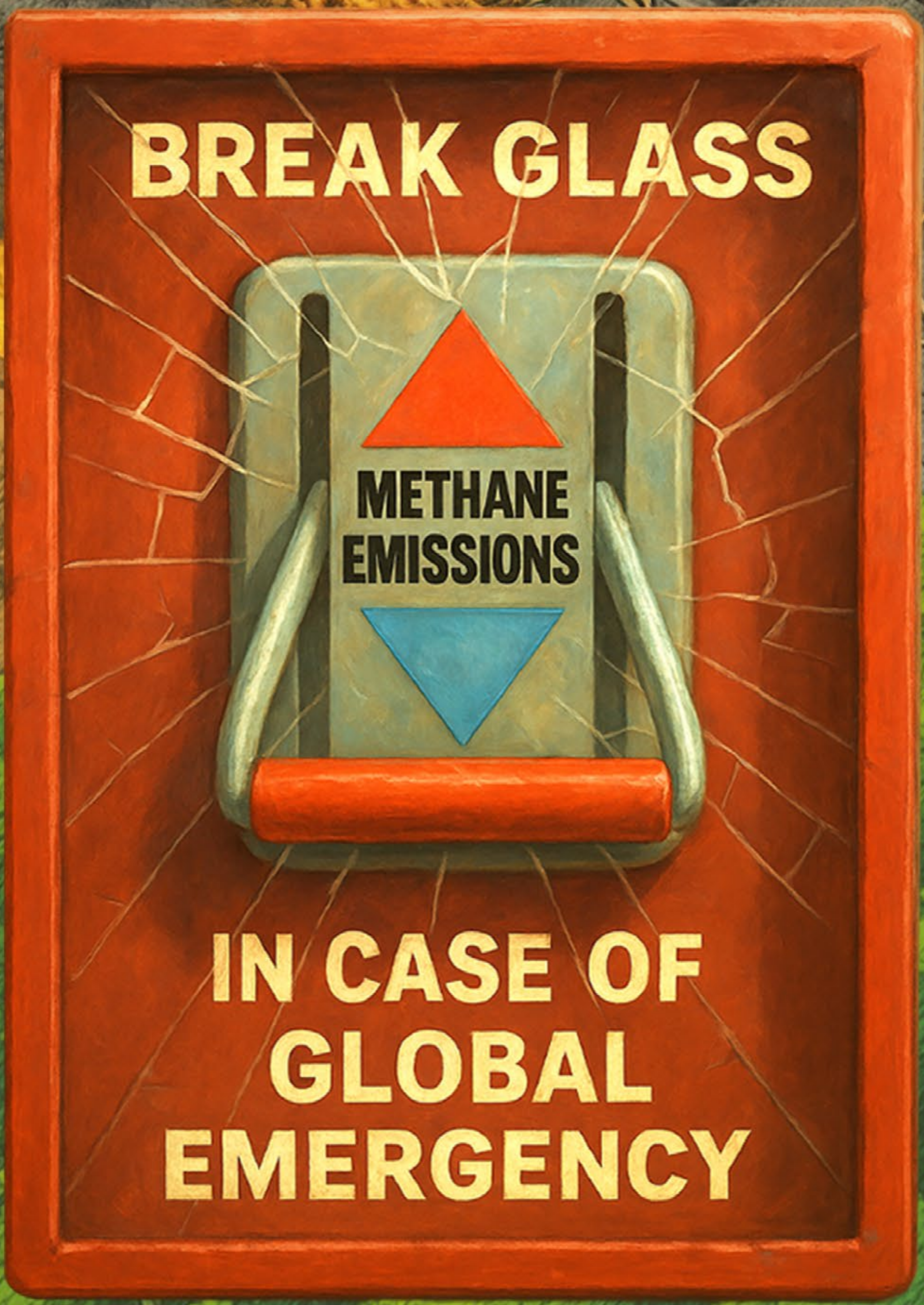
Methane: the emergency brake for climate heating



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Foreword

Stabilising the climate before it's too late

Global institutions are under immense strain. Populism thrives, diplomacy is fraying, and many governments are paralysed by domestic upheaval. The turbulence on display at this year's UN General Assembly is emblematic of the political moment we are in. Yet the science is uncompromising. From destabilising ice loss in Antarctica to record-breaking global temperatures, we are already beyond safe climate boundaries. Overshoot is no longer a theoretical risk. It is today's reality.

Reducing carbon dioxide emissions remains the defining challenge of our age. Without reaching net zero carbon dioxide (CO_2), the world has no viable future. But action on CO_2 alone will not be enough. Methane is responsible for over a third of the warming the world has experienced to date and molecule for molecule it is over 80 times as powerful as CO_2. Crucially, it also dissipates quickly, which means that cutting methane today can slow heating in our lifetimes. If we reduce emissions by 45% this decade, we could avoid 0.3°C of warming. In a world where every fraction of a degree matters, 0.3°C could be the difference between adaptation and collapse for millions. Few actions in climate policy carry such potential.

Methane is not a panacea. It is one part of a broader climate response. We must reduce all greenhouse gases to net zero, remove the excess already in the atmosphere, repair the systems tipping towards collapse, and build resilience everywhere. But methane abatement is the fastest and cheapest lever we have in this decisive decade. Many abatement interventions are low cost or even profitable, and building a stronger evidence base will only sharpen that understanding. The science already shows the direction is clear.

This is not a simple challenge. Each sector – energy, agriculture, and waste – brings its own complexities. Tackling leaks in the energy system requires rigorous regulation and enforcement. Reducing emissions from livestock and rice demands sensitive reforms that protect farmer livelihoods. Improving waste systems calls for infrastructure, finance, and behaviour change. Yet each also delivers powerful co-benefits: cleaner air, healthier diets, stronger harvests, safer cities. If we fail to grasp the nettle across all three areas, those already most vulnerable will suffer most, locked into cycles of failed crops, food insecurity, and escalating heat stress. A fair approach means large emitters moving fastest, while vulnerable regions must be supported with finance and technology, so they benefit from change rather than bear its costs.

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Methane abatement is the fastest and cheapest lever we have to slow heating in this decisive decade.

The turmoil is plain to see. Multilateral institutions are weakened, politics is polarised, and people are losing faith. But methane cuts are one of the few areas where leaders can still demonstrate progress quickly. The technology is ready, the cost is low, and the gains are rapid. Unlike the long timelines of deep decarbonisation, methane action shows visible results in years rather than generations. It is a chance to restore trust that science-based action improves lives.

Entrenched interests in the fossil fuel and agricultural sectors have resisted change for decades. They will not move without being shifted. Voluntary pledges and polite requests are not enough. Regulation, finance, and accountability must do the heavy lifting. Governments need to enforce leak detection and repair in energy systems, redirect subsidies to support sustainable farming, and invest in modern waste management. Delay only serves those who profit from the status quo. Leaders today face a test of credibility. If they cannot even act on methane, the cheapest and fastest solution available, why should citizens trust them to deliver the deeper transformations ahead. The question is not whether the world can act on methane, but whether it has the courage to do so.

As a grandfather, I do not want my grandchildren to inherit a world where we ignored every warning and squandered every chance. Methane is not the answer to everything, but it is an answer we cannot afford to ignore.

Sir David King
Founder and Chair,
Climate Crisis Advisory Group

Methane key facts – the emergency brake for a cooler planet

Cutting methane emissions will lower temperatures within years, not generations, while also delivering cleaner air, better public health, and more resilient communities. And only curbing human-made emissions can interrupt feedback loops that drive increased natural methane emissions.

A double threat

Methane is a short-lived but extremely powerful GHG – more than 80 times more potent than CO_2 in the near term – and a key driver of ground-level ozone, a toxic pollutant and GHG that harms health, crops and ecosystems. Despite its toxicity and extraordinary heat-trapping power, human-made methane emissions are continuing to rise.

A critical lever

Methane has caused about 30% of global warming since the Industrial Revolution. Because it breaks down in the atmosphere in about a decade, cutting emissions delivers rapid benefits: every reduction today slows temperature rise within years, not generations.

Rising natural emissions

Increasing human-driven sources dominate today's methane picture, but natural emissions – around 40% of the annual total, mainly from tropical wetlands – are also unexpectedly climbing.[1] As the planet warms, rainfall and water-table changes are triggering higher methane releases. This is a dangerous feedback loop: warming drives wetland emissions, which in turn drive further warming.[2]

Complementary to CO_2 action

Methane cuts provide near-term climate relief, but only deep and rapid CO_2 reductions can stabilise the climate for the long term. Both must proceed together.

Improving measurement

Traditional "bottom-up" inventories underestimate leaks and accidents. New "top-down" satellite and aircraft atmospheric measurements are closing the gap, improving accountability and targeting.

Intensity matters

Methane "intensity" – emissions per unit of production across sectors, from agriculture to fossil fuels – is emerging as a key benchmark. It exposes which producers are cleaner or more wasteful and underpins new rules such as EU restrictions on gas imports unless suppliers meet strict methane-performance standards.

Methane's unique threat

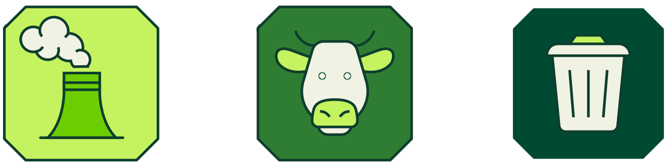
Methane is one of the most damaging greenhouse gases – and also one of the most underestimated. Its distinctive profile demands a strategy of its own, not just inclusion in broader climate policy.

A new call to action

Despite its powerful warming effect, role in toxic air pollution and short atmospheric lifetime, methane is still too often treated in policy as just another GHG. This report outlines why that approach is inadequate. By focusing on the three key sources of human-caused methane emissions, and the practical solutions already available, we show how immediate and substantial reductions can be achieved.

Our call is for a methane-specific strategy:

one that targets human-driven emissions whilst recognising that natural sources are also significant. That reality only heightens the urgency of cutting methane now.



Energy Agriculture Waste

Equity and responsibility

Methane's harms fall unevenly. Much of the pollution originates in wealthy economies, but the worst impacts are borne by the poorest and most vulnerable – through health inequalities, reduced crop yields and deeper poverty.[3]

Because tackling methane also reduces inequality, it creates a positive feedback: action improves lives immediately, and lowers both climate risks and the costs of climate mitigation. This is one of the clearest 'win-wins' of climate policy.[4]

A fair response demands global cooperation. Wealthy nations, responsible for most historic emissions, must transfer finance, know-how and technology to poorer countries. Methane abatement is achievable everywhere, but fairness and speed depend on sharing resources across borders.

Measuring methane's impact

Potency depends on timescale

The 2025 Global Methane Budget concludes that average global methane emissions are around 575 Tg CH_4 per year, about 65% of which is human-made, with a single-year peak of 608 Tg in 2020.[5]

Understanding what these methane emissions mean for climate action depends on timescale. Methane's impact can be assessed in terms of immediate impact, a 20-year 'CO_2 equivalence' impact, or a 100-year 'CO_2 equivalence' impact.

Most of the impact of any methane released will be felt within a decade.[6] While the IPCC often reports impacts over 100 years to compare a basket of greenhouse gases, in climate terms methane's influence is near-immediate.[7] The critical question is: what is the impact now of excess methane in the atmosphere?

Short-term vs long-term metrics

Global Warming Potential (GWP) is a standard greenhouse gas comparison measure, with CO_2 set at 1. On a 100-year basis (GWP100), methane is about 28 times stronger. But this underestimates its near-term force.

Over 20 years (GWP20), methane is about 80 times stronger; in fact, 1 kg of CH_4 is around 126 times more effective as a greenhouse gas as 1 kg of CO_2.[8] For this report, we take the strength of methane as a GHG at well over 80 times the impact of CO_2, which gives a realistic picture of both the risks of rising emissions and the rapid benefits if cuts are sustained.[9]

> **Why it matters:**
>
> The short lifetime of methane means every cut today delivers a measurable cooling effect within years. This immediacy is what makes methane reductions so powerful as an emergency brake.

Measuring methane intensity

Tracking and reducing methane intensity is central to a methane-specific strategy. It highlights waste, rewards cleaner producers, and helps drive rapid progress across sectors.

Methane intensity measures emissions for each unit of production. Even small amounts should be eliminated if they deliver no useful output. As the transition away from fossil fuels continues, intensity helps identify which fuels or sources are cleaner per unit produced.

Monitoring emissions across the full production chain – from extraction to storage and transport – is becoming increasingly feasible as measurement improves.

Reliable data is also driving industry benchmarking. Producers are being held accountable for reporting emissions across their operations. From 2027, for example, the EU will ban natural gas imports to member states unless suppliers prove compliance with strict methane standards, verified through contracts.[10] Other regions are focused on transparency in the fuel sector as a means of reducing emissions.[11]

Carbon dioxide reductions vs. methane reductions

Carbon dioxide (CO_2) and methane (CH_4) behave very differently in the atmosphere, and those differences shape how they must be tackled.

CO_2: long-lived and cumulative

CO_2 is abundant but relatively weak. Every tonne emitted adds to the stock already in the atmosphere, where it lingers for centuries. Partial reductions only slow the rate of growth; the total still climbs. That is why net zero is essential: only then do concentrations stop rising, and even then the cooling effect unfolds slowly over decades.

Methane: short-lived but potent

Methane is far less abundant but far more powerful. Each molecule lasts about 12 years on average, with 65% removed within that time and 95% within 20 years.[12] This means sustained cuts quickly reduce concentrations: if annual emissions fall below levels released a decade earlier, the stock in the atmosphere begins to decline. Even modest reductions have an immediate cooling effect.

The case for methane action:

Methane is over 80 times more powerful than CO_2 in the near term. Reducing methane slows warming fast, with benefits visible within years rather than generations. Unlike CO_2, there is no need to reach ‘net zero’ to see progress – every cut counts.[13] And because methane is concentrated in just a few human activities, focusing on those sectors offers the fastest route to impact.

Quantifying methane emissions and understanding their sources

Recent improvements in the measurement of methane have had real impacts on quantifying the scope of the challenges. New and refined techniques have sharpened understanding: old estimates, even those submitted as part of the UNFCCC process, tended to underestimate the volume of emissions; and, assumptions about the location and source of emissions have proved to be askew in many cases.

Measuring emissions

Methane and its sources have been difficult to measure, giving rise to the wide ranges of uncertainty in emissions estimates. Accuracy is improving, however, as techniques sharpen for measuring atmospheric concentrations, and for identifying sources of emissions. In general, human-made methane emissions have been underestimated, but recent assessments using multiple methods are giving a clearer picture. There still seems to be a gap, however, between the belief of regulators in what they have achieved, and the reality disclosed by measurement and inventory.[14] The rigour of measurement and surveillance is essential for closing that perception gap, and for planning interventions to manage methane emissions effectively.

Bottom-up and top-down approaches

Methane inventories are constructed to give a "bottom-up" measurement of methane emissions in a country, an area or an industry. Inventories multiply activity data (facilities, operations) by standardised emission factors drawn from examples of on-site measurement.[15] In contrast, "top-down" assessments use satellites and aircraft to measure methane concentrations in the atmosphere, often finding higher emissions than revealed by inventory data.[16] Reconciling the two approaches shows that bottom-up inventories frequently miss sources – especially high-emitting leaks and accidental releases.[17] Some emissions also fall between measurement methods. For example, tanks can exceed the limits of ground-based imaging, while satellites and aircraft may miss smaller plumes.[18]

Closing the gap – and measurement as a tool for policy

Bottom-up inventories rely on national and global data sources, cross-checked to avoid duplication.[19] Top-down analyses, meanwhile, measure methane already in the atmosphere – often using satellites – and then work to attribute it to sources; specialist satellites also 'see' plumes of methane if they are large enough – adding further information to the analysis. Each calculation is cross checked with other data to create the best over-all information about methane emissions and its sources.

Tools such as T-MACC curves (Temperature Marginal Abatement Cost Curves), which combine methane emissions data with abatement costs, are useful for helping policymakers rank cost-effective interventions.[20] Future work could link interventions directly to costed temperature outcomes.

Why measurement matters

Broad, routine monitoring of methane emissions, alongside targeted detection and surveillance, is vital for identifying hotspots, enforcing compliance and underpinning regulation. Satellite data alone cannot provide the definitive breakdown by region, sector or pin-point location; inventory approaches are enhanced when cross-checked against atmospheric observations.[21] While methane emissions remain somewhat uncertain in detail, we know they are high and a major cause of climate change. The challenge is to capture that information as accurately as possible so that interventions are well-informed.

The 2025 Global Methane Budget (2010–2020) shows the gap between bottom-up and top-down estimates is narrowing, with each approach adding value as a reference source.[22] In China, national estimates are now converging whichever method is used, though with wide ranges of uncertainty. The Budget recommends continuing to strengthen methane monitoring by deploying every available method – providing the foundation for accountability and regulation that ensures commitments translate into real reductions.

Methane is concentrated in just a few areas of human activity: energy, agriculture and waste

Three sectors dominate the methane picture: energy, agriculture and waste. Together they account for almost all human-made emissions and hold many practical opportunities for rapid reductions.

Globally, energy and agriculture each account for close to 40% of human-driven methane, with waste making up most of the remainder. The balance between them varies by country, and in some cases by study. Taken together, these three sectors define the core agenda for methane action. Immediate, large-scale reductions are possible if proven solutions are applied consistently.

Methane emissions vary widely per head of population. The global average is around 46kg per person per year but the distribution is uneven (see Figure 1, where a range of countries is organised in order of methane emissions per person).[23] Lowest-income economies tend to emit far less methane per person, with the largest part of that small share from agriculture, while higher-income countries tend to show a higher proportion from energy or waste. As economies grow, the risk is that emissions - especially from energy and waste - rise sharply unless mitigation measures are put in place.

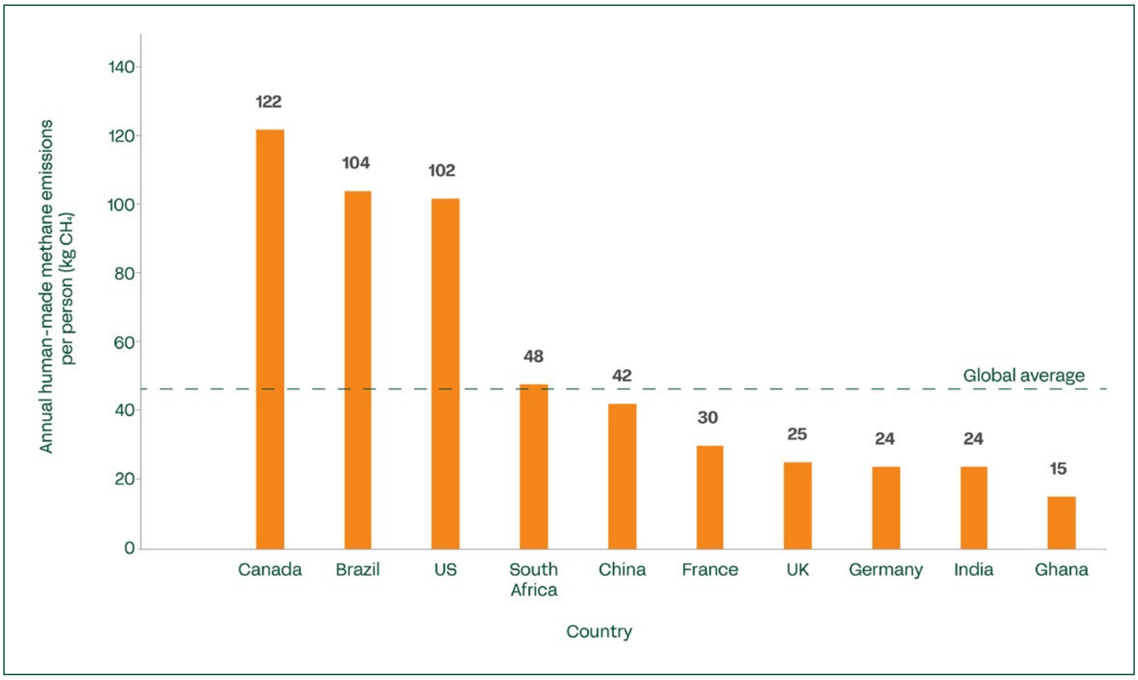


Figure 1: Indicative annual methane emissions per person, globally and in a selection of countries[25]

Regional patterns also diverge sharply (see Figure 2 where countries are arranged in order of methane emissions from the energy sector). In China, energy and agriculture contribute roughly equal shares. In Brazil, agriculture is overwhelmingly dominant. In Europe, energy emissions have fallen sharply, leaving agriculture and waste as the largest contributors.

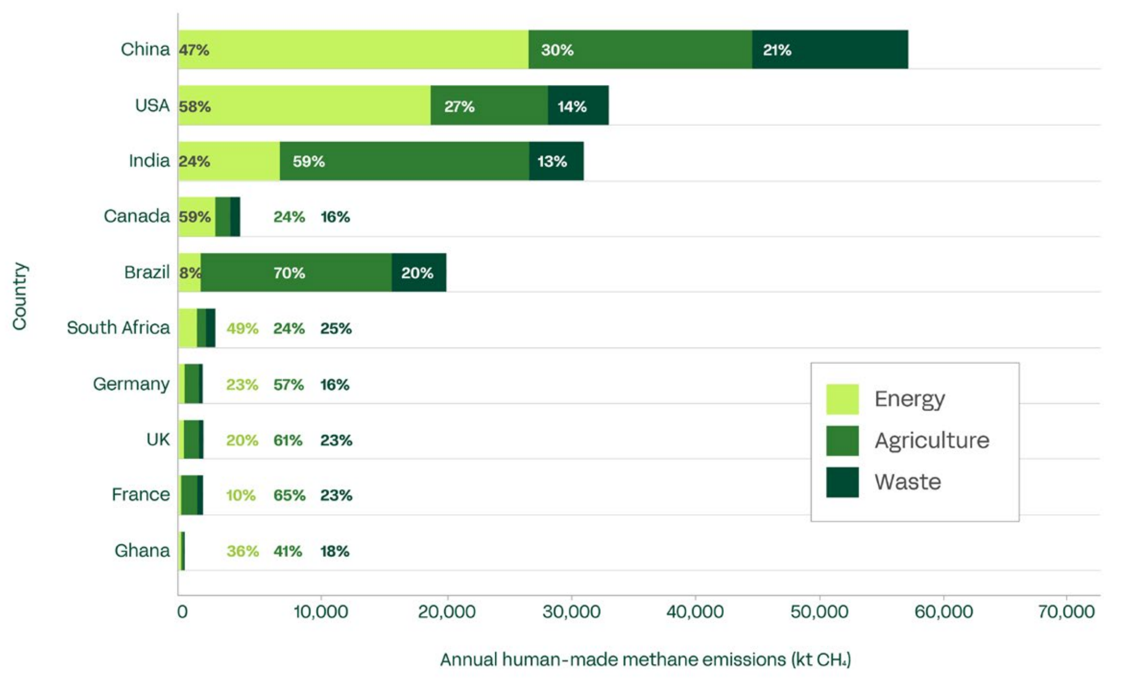


Figure 2: Indicative of annual methane emissions by sector across a selection of countries[24]

These patterns underscore both the scale of the challenge and the opportunity. While the relative balance differs by country, the same three sectors remain the global focus for effective methane action. The chapters that follow examine each in turn – energy, agriculture and waste – setting out the solutions that can cut emissions rapidly, deliver health and economic co-benefits, and apply the emergency brake on climate heating. Large and small-scale emissions management approaches

The Global Methane Pledge

Launched at COP26, the Global Methane Pledge represents an unprecedented moment of political alignment on near-term climate action.[31] By targeting methane alongside CO_2, it provides countries with a practical mechanism to deliver rapid, visible progress this decade while building momentum for the longer transition to net zero.

How the pledge works:

— Countries commit to developing national action plans and sector-specific strategies

— Focus is placed on high-impact interventions that deliver immediate climate and health benefits

— International cooperation and shared accountability are strengthened through joint monitoring and reporting

Large and small-scale emissions management approaches

Managing human-made global methane emissions requires a dual approach: addressing large industrial sources directly and steering changes in the behaviour of numerous smaller, distributed emitters.

1. **Industrial-scale emitters:** These include major players such as oil and gas companies, concentrated animal feeding operations (CAFOs), and large landfill sites. Large, well-organised industry sectors like these will fight and lobby for their own commercial interests and will expend resources and influence in order to push back against proposed measures to constrain their emissions.[26]

   Effective management of these methane sources relies on robust independent surveillance, clear regulation, continuous monitoring, and strict enforcement. This is critical in the energy sector, and equally relevant to industrial agriculture and regulated landfill operations. As methane measurement becomes more accurate and accessible, transparent standards can be integrated into production and trade systems both locally and globally.

2. **Small-scale producers and communities:** This category encompasses every household in the world, as well as millions of smallholder farmers, whose daily habits and practices influence food waste and organic waste management. Individuals are not likely to be well-informed at the outset of the impacts of methane emissions, and nor will they be aware of the immediate welfare gains that could follow take up of emissions-reduction strategies at the household and community level.

   Tackling emissions from these sources is primarily focused on capacity building, raising awareness, and supporting new household and farming practices with infrastructure and local implementation. Efforts often secure immediate improvements in community and family quality of life and health. Achieving the shift in behaviour and practices needs significant policy commitment and investment in resources.

Strategic approach to interventions

Significant and rapid reductions can be achieved by targeting industrial-level emitters who create unmitigated methane emissions. The largest methane-emitting businesses, often referred to as 'super-emitters,' could quickly reduce their output if mandated. Similar production processes globally exhibit vastly different emissions profiles depending on their regulatory environment.[27]

Funding will be required to support abatement policies and enforcement in each sector. Regulation of large industries can be funded by those sectors' very large resources, potentially in the form of a methane-specific tax.

Addressing small-scale emissions from billions of families and individuals is a more gradual endeavour, but is equally vital for comprehensive methane abatement. Education on best practices, community mobilisation, and creating an enabling environment for localised shifts are the objective. The challenge is not technical obstacles, but rather of leadership, governance, coordination, engagement, and resourcing.

Managing behaviour change and its supporting infrastructure and equipment will require government allocation of funding.[28]

Globally, methane action will be funded across borders, and there is evidence that a global emissions tax could make the methane emissions reduction less expensive for the whole global economy.[29] In the longer run, methane abatement is often cost-negative (it saves money).[30]

Recommendations

Alongside sector-specific measures, progress depends on catalysing policies that provide the rules, resources and accountability to scale proven solutions. Together they form a core part of the global strategy to cut methane emissions rapidly.

Energy

— As a priority, ban methane venting, with strict enforcement.

— Mandate regular leak detection and repair across oil and gas operations.

— Ban routine flaring and enforce standards for combustion efficiency.

— Require transparent, independent measurement, and reporting of methane emissions.

— Strengthen enforcement and deterrence: Rules are only as strong as their enforcement.

— Incentivise the capture and use of methane that would otherwise be wasted.

Agriculture

— As a priority, mandate methane management, from all large-scale animal production units and processes, with strict regulation, monitoring, and enforcement.

— Require methane capture from animal units and manure collection – with strict regulation and enforcement.

— Promote and incentivise feed additives and dietary changes that reduce livestock methane. These must be obligatory in large-scale production units, with regulation and enforcement.

— Support adoption of improved manure management and biogas systems in smallholder farms and community hubs.

— Encourage alternative rice cultivation practices (e.g. alternate wetting and drying) through subsidies and extension services.

— Reform agricultural support policies to reward emissions reductions while safeguarding farmer livelihoods.

Waste

— Create a waste management plan for every administrative area – mapping out steps to universal waste management, separation, and diversion of organic waste away from landfill.

— Introduce regulations and incentives for diversion of organic waste from landfills, including food and agricultural residues.

— Support municipalities with finance and technical assistance to meet objectives of waste management plans - scaling up waste collection, separation, and organics diversion from landfill.

— Make food system changes to support desired consumer behaviour changes.

— Create educational and practical interventions, tailored to the population's values and attitudes: reduce meat consumption and food waste.

— Ensure people are not economically excluded from making required behaviour changes; lower the price of vegetarian foods.

— Require landfill gas emissions monitoring at all landfill sites, especially at workface areas.

— Introduce mandatory targets for biogas capture from landfill sites as final step in methane management.

Policy focus

Regulation and enforcement

Surveillance, measurement, strict regulation, and enforcement will be central to cutting emissions from industrial-scale energy operations.

Incentives and innovation

Mandatory standards and surveillance in industrial-scale farming, with strict enforcement will be central to cutting concentrated emissions from key sources.

Finance for extension services to smallholders, with clear national methane targets, investment in R&D (feeds, rice hybrids), and global knowledge-sharing will drive rapid agricultural mitigation.

Local leadership and data

Empowering municipalities, mandating separation, building robust data systems, and aligning with the LOW-Methane initiative will underpin effective waste-sector action.

Energy: regulating and reducing fossil methane

> “The obstacle is not technology or economics but political will and enforcement.

The energy sector is the single most powerful lever we have to cut methane quickly.

Oil, gas and coal operations account for around 40% of human-driven methane emissions, and most of these releases come from activities that are entirely avoidable.[32] Methane escapes when companies vent gas instead of capturing it, when flares burn incompletely, and when pipelines, compressors and wells leak. In some regions, abandoned infrastructure adds to the toll. None of this is inevitable.

Many of the solutions are already in our hands. Leak detection and repair, banning routine venting and flaring, and upgrading infrastructure are proven measures. Often, they pay for themselves because captured gas can be sold. The International Energy Agency (IEA) has mapped these options in detail, and this report builds on that evidence: global energy-sector methane emissions could be cut by nearly half this decade at low or even negative cost.[33] The obstacle is not technology or economics but political will and enforcement.

Reducing methane from fossil fuels buys precious time in the wider energy transition. Every tonne avoided slows near-term warming, improves air quality and safety, and preserves gas that would otherwise be wasted. In this chapter we set out the policies and measures – from monitoring and regulation to enforcement and household interventions – that can turn those opportunities into real and rapid results.

Sector context and challenges

The energy sector is the largest industrial source of methane – and production of oil and gas continues to increase in many parts of the world. Meaning methane emissions are also growing, particularly from unconventional fossil fuel operations.

Tackling these emissions is not about technology or cost, proven solutions exist, but about overcoming persistent challenges: weak regulation and enforcement, industry resistance, and gaps in monitoring and accountability.

How those challenges play out differs across economies. In high-income countries the main issues centre on oil and gas production and transport; in rapidly growing economies coal dominates; and in lower-income contexts emissions are smaller in scale but still significant, often tied to oil production and household biofuels.

High-income countries: Emissions are primarily linked to oil and gas production, transport and consumption. In the US, energy accounts for about 58% of their very high methane emissions; in Canada, around 59% of even higher emissions per person. However, some countries emissions have been dramatically reduced through policy interventions, and are the subject of further planned constraints. These economies show what is possible in methane emissions reduction.[34] In the EU, for example, emissions have been reduced per person - from energy sources in particular. See Figure 1 and Figure 2 for these comparisons.

Rapidly growing economies: Coal production and use – both industrial and domestic – dominate. In China, energy is responsible for about 47% of total methane emissions. Coal makes up over three quarters of energy's emissions, including emissions from disused facilities.

Low-income countries: Absolute emissions are smaller, but oil production and household biofuel use (mostly wood) can both be a significant part of the picture. In Ghana, for example, offshore oil production and biofuel together make up 80% of methane emissions, split roughly evenly between the two.

Why action lags despite low cost

Many abatement measures in the energy sector more than pay for themselves. In oil and gas, around 30% of today's emissions could be avoided with actions offering rates of return above 25% – well above the thresholds companies normally seek when approving new investments.[35]

Yet several barriers hold progress back:

— **Awareness and perception:** companies may underestimate the scale of methane leakage or overestimate abatement costs.

— **Competing priorities:** other opportunities may appear higher profile or more attractive to leadership.

— **Split incentives:** equipment owners may not capture the value of methane saved, or contractual terms prevent savings from boosting revenue.

— **Access to capital:** upfront investments can be hard to secure, especially in developing economies.

— **Capacity constraints:** limited staff, services or infrastructure can slow deployment.

— **Market pathways:** in some instances there is no clear business case or route to bring captured gas into productive use.[36]

Tracking methane from space

Satellite monitoring of methane is a rapidly advancing field. A number of instruments now provide valuable data. The European Space Agency operates TROPOMI on its Sentinel satellite, while NASA runs the EMIT instrument. MethaneSAT was launched in 2024 to deliver more precise emissions data to the public, but unfortunately the satellite was lost in 2025.

TROPOMI data offers a broad, global picture of methane emissions, useful for identifying areas that warrant further study and for comparing with bottom-up data. Other satellites can provide finer detail, enabling researchers to "zoom in" on specific regions.[37] The Tanager satellite, launched in 2024, has begun to identify and quantify emissions from individual point sources.[38]

Even with greater precision, satellites cannot detect smaller methane leaks - which account for around 70% of fossil fuel sector emissions in the US, for example.[39] Intermittent leaks can also be missed. Satellite detection can also be badly affected by unhelpful weather conditions. But the ability to combine daily global records with focused regional detection is steadily improving our understanding of methane emissions worldwide.[40]

Sources of methane in the energy sector

Flaring and incomplete flaring:

Flaring is intended to combust methane fully so that none of it ends up in the atmosphere. It is often used as a means of disposal of unwanted methane where it is a byproduct of some other production process. This wastes fuel that could instead be captured and used to reduce demand for other energy sources. Flaring is heavily regulated in some economies.[41]

Incomplete flaring – where combustion is imperfect – allows methane to enter the atmosphere. Even under ideal conditions, flaring rarely achieves its target efficiency of around 98%. In the US, for example, incomplete combustion accounts for an estimated 4–10% of total oil and gas methane emissions.[42]

Venting:

A major source of methane emissions is venting – the direct release to the atmosphere of methane from fossil fuel production, transport or storage facilities. Venting is often simply a means of disposal for unwanted methane. Sometimes it is released through pipes actually intended for flaring. Venting is increasingly prohibited or heavily restricted because it represents unabated emission, but it remains widespread, undermining compliance and significantly increasing emissions.[43]

Leaks in infrastructure:

Methane also escapes through leaks in infrastructure, including pipelines, compressors, valves and storage facilities. These losses can be stopped with simple maintenance programmes. Sorting out leaks of this kind, with follow up monitoring and enforcement, allows other methane emissions to be detected more reliably.[44] New regulation and interventions can be introduced as the source of emissions becomes clearer.[45]

Coal mines:

Coal mines remain a significant source of methane emissions, even whilst many countries are working to phase them out of the energy supply system.[46] Coal consumption is likely to remain at current levels through 2025 and 2026.[47]

Abandoned wells and coal mines:

Finally, methane continues to leak from abandoned wells and disused coal mines, which can release gas for years after operations have ceased, unless they continue to be managed and maintained.[48] IEA analysis found that these sources together emitted around 8 million tonnes of methane last year – enough to rank them as the world's fourth-largest source of fossil methane.[49]

Regulation and regional patterns

The EU has introduced new rules requiring much wider measurement and reporting of methane throughout the fuel-production process.[50] These regulations make suppliers responsible for demonstrating compliance, ensuring that only low-emissions fuel can be placed on the market.[51] By doing so, the EU is already influencing global supply chains, as producers step up to meet stricter transparency and emissions standards.[52]

On-site monitoring is particularly important, as it often reveals unexpected patterns. In many cases, venting proves far more common than the 'leakage' that regulation typically targets.[53]

Modern infrastructure can dramatically reduce emissions, yet older or poorly maintained systems remain a major problem. Soviet-era oil and gas networks in Central Asia still emit thousands of tonnes of methane each year.[54]

Globally, about 70% of methane from oil and gas production comes from just ten countries, with the USA and Russia leading, and Turkmenistan and Venezuela notable for their high emission intensity.[55] These nations offer the fastest and most meaningful opportunities for reductions. China, the largest methane emitter from coal, has introduced a national methane action plan that prioritises monitoring and verification. While it does not set specific reduction targets, it establishes controls through technology and policy frameworks.[56] China's energy methane emissions peaked in 2014 and have since remained stable or declined.[57]

Beyond conventional oil and gas

Beyond mainstream oil and gas operations, several other parts of the energy system present distinct challenges for methane management. Unconventional fossil fuel production, liquefied natural gas (LNG), and new supplies of fossil methane each raise specific risks – and each requires tailored strategies to ensure emissions are eliminated.

Unconventional fossil fuel production

Unconventional sources of oil, petroleum and fossil methane – shale oil, tar sands, and hydraulic fracture (fracking) – usually carry higher carbon and methane footprints than conventional fuels.[58] Crude oil from tar sands produces significantly more CO_2 emissions than conventional oil, largely because extraction is highly energy-intensive. Similarly, shale oil generates high greenhouse gas emissions in production, with methane leaks, flaring and the energy intensity of operations all playing a part.

Fossil methane produced as fuel from fracking also involves high emissions during production – making it a carbon-intensive choice overall, even though at the point of combustion it releases relatively low CO_2 compared with other fossil fuels.[59]

LNG: high emissions in production and transportation

Fossil methane is often compressed and liquefied for transport as liquefied natural gas (LNG), enabling use far from its production site. For example, the EU imports LNG from the US and other producers. Liquefaction and shipping are highly energy-intensive (especially if powered by fossil fuels) and are prone to methane leaks throughout the process.[60]

Emissions from LNG supply can be cut by more than 60% using technologies available today. Electrification of compression processes reduces the emissions footprint, for example. But to achieve such reductions requires upfront investment and attention across the whole chain: upstream production, processing, pipelines, liquefaction, shipping and regasification.[61]

The exact emissions vary widely by source and supply route, and by the extent of abatement practices deployed.[62] The LNG industry has the technical ability to deliver zero-methane LNG. Buyers are starting to demand transparency and to shift towards low- or zero-methane providers as national net-zero commitments advance.

The EU's new regulations will make low-methane LNG the norm for imports. Other buyers should follow this lead to force a global market shift towards the lowest possible greenhouse gas footprint – and to ensure informed choices between LNG and renewable alternatives. In a net zero world, there will still be a reduced role for fossil gas, but all such gas must be produced and consumed with zero methane emissions.

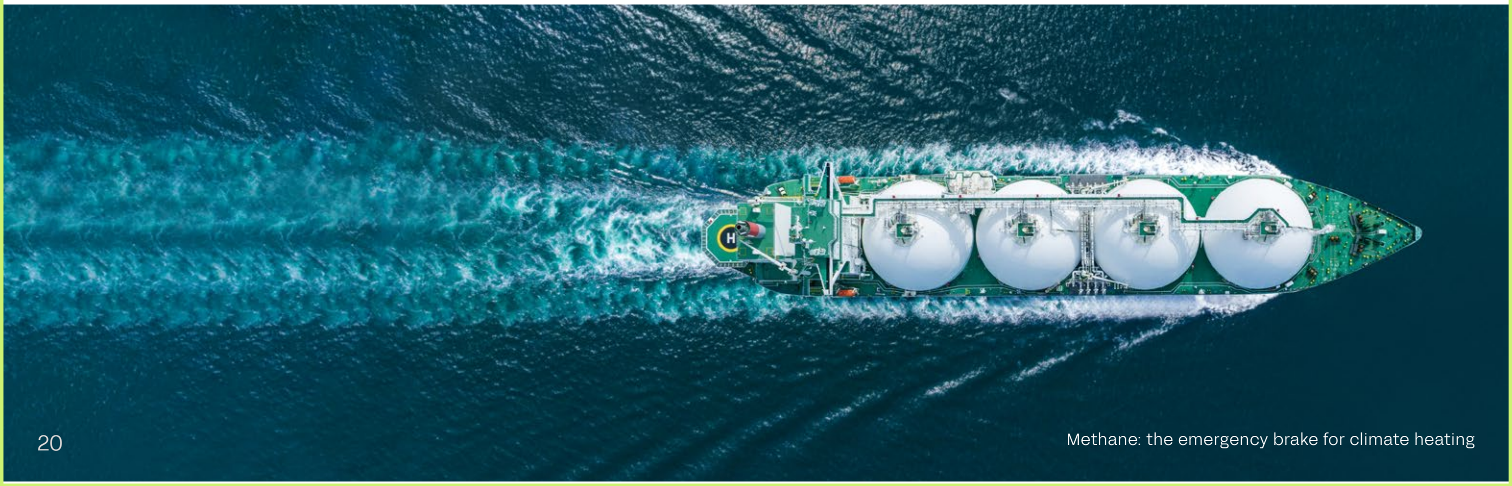
Methane as a byproduct from existing fossil fuel production should be distinguished from intentionally produced LNG or fossil gas. Where methane arises as a byproduct, using it as fuel is preferable to venting or flaring. In the context of a long-term transition away from fossil fuels, making full use of byproducts makes both economic and climate sense. By contrast, LNG must always be scrutinised for transparency and lifecycle emissions.

New supplies of fossil methane

The global aim is to phase out fossil fuels entirely. However, in a net zero world there will still be limited roles for fossil methane: supporting specific industrial processes and balancing renewable energy supplies. In all such cases, the gas must be produced and consumed with zero methane emissions. Carbon capture and storage (CCS) will be required to manage associated CO_2 and methane byproducts at the point of production.

Any new methane sources in rapidly growing economies (such as India) must be integrated into national net zero pathways and eventually meet the zero-emissions standard. Investment in new methane infrastructure must therefore be approached cautiously to avoid stranded assets..

By contrast, capturing methane from existing oil, gas and coal systems prevents a highly potent greenhouse gas from entering the atmosphere while providing usable fuel for power generation or vehicle fleets. Managing methane as a byproduct of legacy systems, rather than expanding production, offers an immediate, low-cost opportunity to cut emissions and support energy needs. As the transition away from fossil fuels accelerates, however, these byproducts will diminish.



Opportunity and co-benefits

Cutting methane from fossil fuels delivers rapid climate benefits at low cost, while also improving safety, air quality and energy security. The sector offers some of the fastest and most cost-effective wins available.

Many measures are low-cost or even profitable, since captured methane can be sold as a fuel. In China, for example, significant abatement is possible in the energy sector by 2030, with potential for very modest or even negative costs.[63]

Safety, health and equity:

The immediate benefits of methane reduction extend well beyond climate impact. Cutting emissions improves operational safety, reduces local air pollution, and strengthens energy security. It also contributes directly to social equity by protecting the most vulnerable from health and livelihood impacts.

Turning waste into value:

Methane capture turns a waste product into a usable resource. Where markets exist, this can generate new revenue streams, making emissions control economically viable. Even where captured gas cannot be sold, effective flaring with near-complete combustion cuts methane's short-term climate impact by more than 95%.

Market mechanisms

Economic and market mechanisms can further accelerate adoption. Carbon trading and crediting schemes, for instance, assign value to methane abatement, creating new revenue for operators while incentivising rapid reductions. A globally integrated emissions trading scheme offers the chance to reduce global costs of implementing emissions mitigation.[64]

Household cooking and biofuels use

Household biofuel use (mostly foraged wood), particularly for cooking, contributes to methane emissions alongside black carbon and other pollutants in most Global South countries. Gathering the wood is time-consuming especially for women and children, and places intense strain on environmental systems: trees and forest material are constantly harvested.

Transitioning households to cleaner energy – whether via improved cookstoves, biogas or electrification – delivers livelihood advantages, health benefits and immediate GHG emissions benefits. Costs and feasibility of different systems vary.

A focus on household biofuel consumption is a high priority for improving health outcomes, well-being for women and children, and local environmental benefits as stress on local forests is reduced. Even if the volume of methane abatement is low compared with tackling oil, coal and gas production in some of the high-emitting countries, the co-benefits make this an important intervention.

LNG as a household fuel must be evaluated extremely carefully – its production footprint is often extremely damaging in methane and other GHG and toxic emissions.[65]

Policy solutions

Technology is not the barrier; implementation is. Strong rules, rigorous monitoring and meaningful enforcement are needed to turn proven solutions into real-world reductions.

Core recommendations:

- **As a priority, ban venting, with strict enforcement:** high levels of methane emissions must be prohibited, with the burden placed squarely on producers to deliver rapid reductions.
- **Mandate regular leak detection and repair (LDAR):** Emissions must be tracked consistently, with data collected for benchmarking and monitoring progress. Best practice in surveillance should be applied across facilities.[66]
- **Ban routine flaring and enforce standards for combustion efficiency:** Again, the duty to deliver rapid reductions in emissions should fall on producers.
- **Require independent measurement, verification and reporting:** Transparent data is essential to close the gap between reported and actual performance. Some countries have already succeeded.[67]
- **Strengthen enforcement and deterrence:** Rules are only as strong as their enforcement. Where transgressions occur, penalties must be applied. Policy processes often fall short in this area.[68]
- **Incentivise the capture and use of associated methane that would otherwise be wasted:** This should include reinjection, utilisation in local power generation, or delivery to market.[69]

Enabling policies

- **Align fiscal incentives:** Adjust taxes, royalties and subsidies so that reductions are rewarded and leaks penalised, removing perverse incentives that lock in wasteful practices.
- **Embed methane-reduction standards in licensing and permitting:** Make project approval conditional on robust methane management and compliance with best practice.
- **Support international cooperation on monitoring and verification:** Expand participation in global initiatives such as OGMP 2.0 and UNEP's IMEO to strengthen transparency and accountability.
- **Facilitate investment in abatement infrastructure:** Mobilise concessional and blended finance, particularly in lower- and middle-income producer countries, and promote technology transfer to accelerate uptake.

Agriculture sector – reducing methane from farm to fork

> Solutions exist, but they require systemic approaches

Alongside energy, agriculture is one of the largest sources of human-driven methane, responsible for around 40% of global emissions, primarily from livestock, specifically ruminants and their manure (accounting for about a third of all human-made methane emissions), with rice cultivation and fertiliser use also playing their part.[70]

In many countries, agriculture is the single biggest methane contributor, particularly where livestock and rice production are central to diets and economies. Meanwhile, aquaculture – freshwater fish-farming – is a growing source of protein, and growing source of methane emissions that needs to be better understood.[71]

The challenge is intensifying. Rising global demand for meat and dairy means agricultural methane is projected to increase sharply unless action is taken. Without change, these trends will make it harder to stabilise the climate while further straining land, water and biodiversity.

Solutions exist, but they require systemic approaches. Interventions range from improving livestock feed and manure management, to transforming rice cultivation practices and cutting food loss and waste. Many measures are low-cost, deliver rapid results, and bring major co-benefits for farmers, rural economies and food security.

Reducing agricultural methane is not just about climate. It also improves human health, strengthens resilience in farming communities, and helps secure a sustainable food future. Tackling methane in food and farming is therefore one of the most important levers we have to slow warming while ensuring nutrition for a growing world.

Sector context and challenges

Agricultural methane is rooted in how food is produced. Unlike leaks from fossil fuel systems, these emissions come from living biological processes, making them harder to eliminate and deeply intertwined with food security and rural livelihoods.

The fundamental challenge: feeding the world

Climate change is caused, in part, by farming practices. However, unlike oil and gas production, food production cannot be stopped. Human populations are still increasing and, more importantly as a driver of consumption, so is preference for meat in diets. The challenge is to reduce emissions without undermining the capacity to feed the world.

This imperative is reinforced by methane's other impacts; it promotes the production of ozone, which reduces crop yields and damages human and animal health. The case for reducing agricultural methane emissions is therefore also a means of improving crop yields and securing better health and sustainable livelihoods.

Primary sources: ruminant livestock and its manure

Globally, anthropogenic activities account for close to two-thirds of methane emissions. Just over 40% of that is from agricultural sources – ruminant enteric fermentation and manure management in particular, with rice cultivation and aquaculture also important.[72] Agriculture emits a similar methane share to the fossil fuel sector.[73]

Livestock production is the largest single source of agricultural methane worldwide:

- Emissions come from enteric fermentation (digestive activity in ruminants) and from manure management.
- Around 80% of methane emissions from agriculture come from ruminant livestock (of which 35% is from beef, 30% dairy cattle, and 15% small ruminants and buffalo).[74]
- Enteric methane emissions from ruminant farm animals together with the management of their manure, and the manure of pigs, account for around a third of global anthropogenic methane emissions.[75] Studies suggest that the enteric emissions could be reduced by up to 60% with meticulously careful dietary management.[76]
- Manure management can also deliver significant reductions. Options include: improved housing systems and bedding for animals; covered storage along with treatment of ruminant and pig manure in biogas digesters; reduced storage time; and manure acidification.[77]

Rice cultivation contributes most of the remaining agricultural methane.[78] Reductions require specific water-management practices, the use of additives to inhibit methane production, and the development and use of alternative hybrid rice varieties.

A divided sector: the challenge of industrial vs smallholder farming

Agriculture is highly diverse, and distinctions of scale are essential when considering methane abatement.

On one hand, there are vast industrial-scale operations. Large facilities such as beef feedlots can hold tens or even hundreds of thousands of cattle.[79] Almost all beef consumed in the US, and a growing share in Brazil, comes from these feedlots:

> ...a vast empire of pens and troughs where up to 100,000 steers at a time spend the last three to six months of their short lives gaining up to 4 pounds a day on a diet of corn, protein supplements, and antibiotics. Everything on these farms is calculated to maximise the meat yield from each cow; from the mixture in cattle's feed, to the size of run-off channels carrying the animal's waste into giant toxic lagoons.[80]

Industrial-scale operators – including the growing number of industrial scale pig producers - are well organised and well-resourced to lobby for their interests, often resisting obligatory changes. However, these large businesses also have the capacity to implement methane-capture technologies efficiently, if mandated by strong regulation, monitoring and enforcement.

On the other hand, the sector includes billions of subsistence and small-scale farmers. While agriculture drives emissions, it is also highly vulnerable to climate change, and subsistence farmers are the most exposed. The diversity in herd size is stark: in developed economies, the typical dairy herd averages more than 100 cows, while in poorer countries two animals is more typical. In fact, over 70% of dairy farmers run small farms, accounting for about 60% of the world's dairy herd. There is an ethical imperative to support these farmers through knowledge-sharing and access to improved practices that build resilience while reducing methane.

In this mixed picture, different policy interventions will be needed to ensure both effectiveness and fairness. Best practices in feeding and breeding for reduced methane should be widely shared to support farmers at all scales.[81] However, the primary focus of regulation must remain on large-scale production. It is here that changes in feeding, manure management and breeding can deliver the quickest and most significant wins. Large producers can readily afford to implement such changes in order to keep their businesses viable within new regulatory regimes.

The global picture: regional emissions patterns

Methane emissions from livestock are found worldwide. The largest producers are in Latin America (especially Brazil) and North America, with South Asia second in scale. The US, Brazil and China are the top beef producers.[82] While China's meat production is growing rapidly, beef is not the main driver. Instead, large-scale poultry, and especially pork (where manure management is critical), have grown most quickly since the 1980s.[83]

Meanwhile, rice production is highest in Sout-East Asia, Korea and Japan (taken as one region), closely followed by South Asia, which is on par with China.[84]

These distinct patterns underscore why policy interventions must be tailored to different regional and national contexts.

Priority targets for action

Two areas stand out as quick-win targets:

— **Beef and dairy production, and all large-scale manure management**

- This is where emissions are on a dangerous trajectory and contribute the most. Feeding adjustments can reduce ruminant methane by up to 60%, and manure management can further cut emissions. Changes to diet and patterns of waste for consumers will reduce demand, leading to emissions reductions.
- Distinctions between large and small-scale beef, dairy and pork systems are critical to shaping effective, fair interventions.

— **Aquaculture**

- In some regions (most notably China) aquaculture – fish-farming – is a significant emitter of methane.[85] There are quick wins for reducing emissions, without reducing efficiency of production: optimising feeding practices and using aeration systems are cost effective measures.[86]
- A fuller understanding of the levels of methane and other GHG emissions is emerging, and further research will reveal new steps for reducing emissions whilst maintaining sustainable fish production.[87]

Opportunity and co-benefits

Cutting methane from agriculture offers some of the most powerful co-benefits of any sector. The right interventions can boost food security, improve farmer livelihoods, reduce pollution, and protect health, while also delivering rapid climate gains.

Improving food security and yields

Methane reduction in agriculture directly improves crop yields by lowering ozone pollution, which damages plants and reduces harvests. Estimates suggest global crop yields could rise by 26 million tonnes a year if methane is reduced.[88] This makes action a win-win for both climate and food supply.

Better health and cleaner air

Solutions to reducing methane emissions in the agricultural sector will include dietary education for people, encouraging more plant-based or other meat consumption. This has direct health co-benefits, reducing cardio-vascular disease, cancer and other diet-related non-communicable diseases.[89]

Methane emissions also contribute to the formation of ground-level ozone, a toxic pollutant harmful to human and animal health. Cutting agricultural methane therefore reduces rates of respiratory illness, improves animal welfare, and lowers the burden on health systems.

Economic benefits for farmers

Many interventions bring direct financial gains for farmers at both ends of the scale. Improved animal husbandry can increase productivity for smallholders, while for large, intensive operations, manure management systems such as biogas digesters can provide renewable energy, cutting fuel costs and generating additional income.

Resilience, equity and biodiversity

Reducing methane also strengthens rural resilience. For smallholders, access to improved breeds, feeds and manure practices supports sustainability in the face of climate pressures. For large-scale producers, better management reduces environmental risks and can improve social licence to operate.

Many agricultural methane-reduction practices restore soils, improve water quality and protect habitats – helping to halt biodiversity loss and support more sustainable food systems.[90]

Regional opportunities

The balance of solutions will vary by region. In Latin America and the US, tackling ruminant livestock emissions is paramount. In South Asia and China, reforms to rice cultivation, aquaculture and pork production offer major gains. In Africa, where subsistence farmers are most vulnerable, low-cost measures that build both resilience and productivity are priorities.

Policy recommendations

Policy must distinguish between industrial-scale operations and smallholder farms, while combining regulation, education and land-use safeguards. Interventions should target the biggest emitters first, while supporting farmers everywhere, with resources as needed, to adopt sustainable practices.

Core recommendations

On-farm actions and technology

- **Mandate methane management in industrial farming:** Regulate large-scale beef and dairy facilities as industrial operations, requiring strict methane surveillance and enforcement. Mandate the capture of emissions from both animals and manure, and enforce with penalties for non-compliance.
- **Improve manure management:** Require systems such as biogas digesters, reduced storage times, covered storage and improved bedding to minimise methane release. Mandate and enforce adherence to emissions standards in all large-scale farms.
- **Promote better feeding practices:** Encourage digestible feeds and improved husbandry to reduce methane per kilo of ruminant meat or litre of milk.
- **Deploy feed additives:** Support research and approval of supplements such as seaweed, and promote locally proven dietary adjustments that significantly reduce ruminant methane.
- **Promote equitable interventions:** Ensure policies distinguish between industrial-scale production and smallholder farming, recognising their different capacities and needs.
- **Support small-scale and family farms:** Share, resource and promote improved practices that reduce methane emissions and build resilience, recognising different capabilities and needs. Mitigation strategies can cut emissions by 60% – and in some cases up to 75%.[91]
- **Aquaculture emissions:** Mandate monitoring and mitigation (e.g. aeration, feed optimisation) to cut methane from fish farming.

Land-use and environmental safeguards

- **Protect land from expansion:** Enforce land-use regulations to prevent further expansion of beef and dairy farming onto new farmland, avoiding emissions linked to land-use change.

Demand-side measures

- **Educate on diets and health:** Inform citizens about the high methane footprint of beef and dairy compared with other foods, and the health risks of high red-meat consumption. Promote dietary shifts toward lower-emission, healthier options. Change the "choice environment" to support healthy and low emissions diets.
- **Cut food waste:** Run education campaigns and incentives to radically reduce food waste across households and retailers.

Enabling policies

- **Sub-national leadership:** Empower provinces, districts and municipalities to implement context-specific agricultural methane policies, from livestock regulation to rice-cultivation practices.
- **National regulation:** Set clear country-level targets for agricultural methane reduction, aligned with national climate and food-security strategies.
- **Finance and incentives:** Provide support for smallholders to access improved seeds, breeds, feeds and manure systems, and use subsidies or carbon markets to reward methane-cutting practices.
- **Data and monitoring:** Strengthen systems to measure methane from livestock, manure and rice, with transparent reporting for accountability.
- **Global alignment:** Connect national action to international initiatives (e.g. the Global Methane Pledge), ensuring support for knowledge transfer and equitable participation.
- **Research and innovation:** Invest in developing and scaling feed additives, rice hybrids, and locally adapted practices that can deliver durable reductions.

Waste – cutting emissions through collection, diversion and capture

> “ If left unchecked, emissions from landfill could increase by 70%

Methane emissions from waste represents one of the greatest untapped opportunities in climate action – a problem that is growing fast but one that can be tackled with straightforward, proven solutions.

The waste sector is the third-largest source of human-driven methane, responsible for almost 20% of global emissions.[92] The bulk comes from landfills and open dumps, where organic material breaks down in oxygen-starved conditions. Methane from waste is widely distributed across inhabited regions around the world, and it is growing rapidly as populations expand and consumption rises.[93]

If left unchecked, emissions from landfill could increase by 70% by 2050 compared with 2020 levels.[94] Almost half of municipal solid waste is organic material that could be put to better use. Meanwhile, one-third of all food produced globally is lost or wasted – a squandered resource that, once dumped in landfill, becomes a major driver of methane.[95]

The scale of the problem is enormous, but the initial costs of intervention in the waste sector are low, and in the longer term, costs become very low, or even net negative (creating economic and social benefits or profits).[96]

While the hierarchy of solutions is clear, implementation is rarely straightforward. Waste methane abatement is shaped by local realities: whether infrastructure exists, how systems are financed, who is responsible for delivery, and how communities participate. Success depends on overcoming structural, political and behavioural barriers that vary widely across regions and income levels.

Proven solutions: the waste hierarchy

The pathway to action follows a simple hierarchy: prevent organic waste, divert what remains, and capture methane only as a last resort.[97] Each step delivers crucial benefits, leading to emissions reductions that help to return the world to a safer future. Prevention, as the first and largest step, is critical.[98]

1. Prevention: avoiding organic waste

Food waste is the single largest driver of methane in the waste sector. Globally, around one-third of food produced is thrown away.[99] This is a major climate issue; and it also wastes the land, water, fertiliser, energy and labour that went into production.

- **Upstream losses** occur before food reaches the consumer. In many low- and middle-income economies, poor storage, handling and lack of cold-chain systems mean food spoils before it gets to market. Investment in distribution infrastructure is therefore essential to prevent methane emissions before they start.[100]
- **Consumer-level waste** dominates in wealthy economies, where households and retailers discard edible food. Portion control, healthier diets and consumer awareness campaigns can cut waste substantially.[101]
- **Policy interventions** must reduce wasteful purchasing patterns, ensure edible food is redirected to vulnerable groups, and make sure inedible food is recycled into compost, biochar or biogas.[102] Landfill should be the very last resort.[103]

Every tonne of organic waste that is prevented or diverted reduces methane, improves food security and health, and saves resources.[104] In the US, around 60% of landfill methane comes from wasted food[105] In European countries, diversion of organics from landfill is shown to be the single most effective abatement strategy, potentially reducing waste-sector emissions by 30%.[106]

2. Diversion: separating and re-using organics

Where food and garden waste cannot be prevented, it must be kept out of landfill. Source separation – bins, collection systems, and clear rules – is the foundation. With the right infrastructure and public buy-in, organic waste can be transformed into value:

- **Compost** enriches soils, improves harvests and reduces fertiliser demand.
- **Biogas digesters** convert organics into energy for cooking, transport or electricity. Some municipalities already fuel waste-collection trucks with methane captured from organic waste.

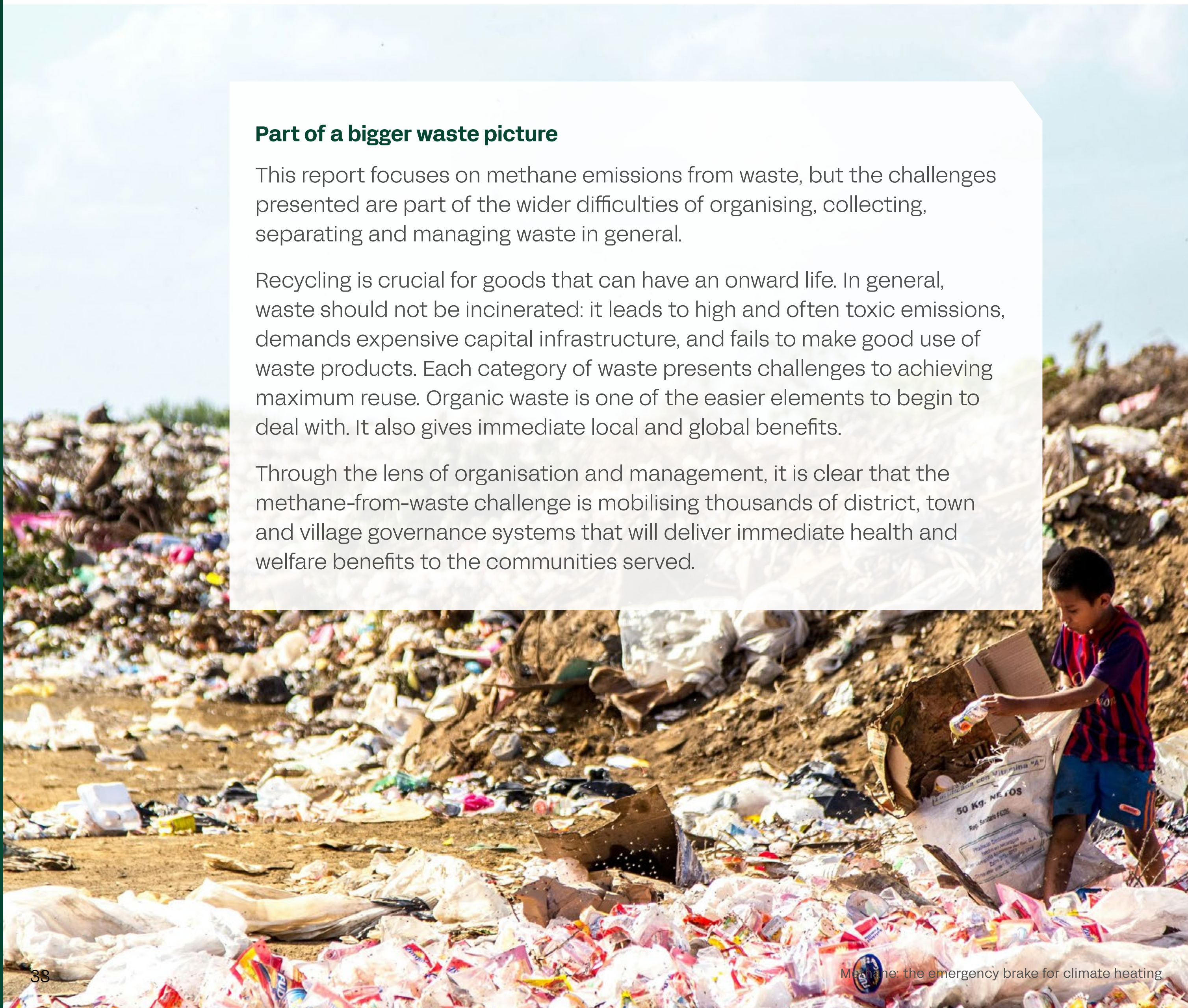
Diversion systems also create local jobs, lower municipal costs and reduce urban health risks.[107] They are most effective when paired with strong public education and transparent accountability.

3. Capture: a last resort

Even the best landfill gas capture systems leak 30–40% of methane.[108] That said, some organic waste will always find its way to landfill, and prompt recovery of methane at landfill sites following arrival will deliver rapid emission reductions at modest cost.[109]

Simple technologies for flaring or gas collection at landfill can reduce emissions from existing sites, particularly at the working face - the most active source of methane - and often the least regulated.[110] The importance of measurement and capture here is increasingly understood – and new measures are coming into effect in countries from Canada to the EU.[111]

Capture should always come last in the hierarchy: a complement to, not a substitute for, prevention and diversion.[112]



Part of a bigger waste picture

This report focuses on methane emissions from waste, but the challenges presented are part of the wider difficulties of organising, collecting, separating and managing waste in general.

Recycling is crucial for goods that can have an onward life. In general, waste should not be incinerated: it leads to high and often toxic emissions, demands expensive capital infrastructure, and fails to make good use of waste products. Each category of waste presents challenges to achieving maximum reuse. Organic waste is one of the easier elements to begin to deal with. It also gives immediate local and global benefits.

Through the lens of organisation and management, it is clear that the methane-from-waste challenge is mobilising thousands of district, town and village governance systems that will deliver immediate health and welfare benefits to the communities served.

Obstacles to implementation

While the waste sector offers some of the lowest-cost and most effective methane abatement options, scaling them presents barriers. Progress depends on addressing practical, financial and governance challenges.[113]

Infrastructure and finance:

Waste methane is rising fastest where populations are growing most quickly and where collection systems are weakest – often in the least wealthy countries. Building universal waste management requires upfront investment in bins, trucks, depots and staff.[114] Although the ultimate cost to society is low or zero, the perception of cost is a major barrier.[115] A methane-specific emissions tax has been proposed as one way of unlocking resources for immediate abatement. Governments must fund waste management in all communities.

Governance and equity:

Waste management requires coordination across multiple levels of government and society. A central mandate can set ambition, but delivery relies on towns, districts and villages. Without clear roles and sustainable financing, progress stalls. Informal settlements, which are often fastest-growing, must be integrated into planning. Collaboration with informal workers – who already provide crucial services – is essential for both equity and effectiveness.[116]

Behaviour change:

Changing how people handle waste is just as important as building infrastructure. Citizens must buy less food, waste less, and comply with separation and diversion rules. Public education campaigns and adjustments to "choice environments" – so that healthier, plant-based foods are affordable and waste sorting is simple – will make these behaviours more likely.[117] Without attention to fairness, people risk being excluded from making the required changes.[118]

Measurement and monitoring:

Robust data systems are essential. Without accurate, transparent measurement of methane volumes and sources, interventions cannot be targeted or tracked. Transparent reporting at the municipal and national level is a prerequisite for accountability and regulation.

Opportunity and co-benefits

Reducing methane from waste is not just a climate measure. It also improves health, creates jobs, lowers municipal costs, and makes cities cleaner and more liveable.

Core benefits of action

Measures for prevention, diversion, energy recovery and better landfill management – with measuring and monitoring of methane emissions – all reduce emissions and create a cleaner, safer environment. Each step along the pathway brings incremental improvements to neighbourhoods and communities.[119] Technically feasible measures such as waste separation and processing can often be achieved with little expense, and sometimes at net benefit. They contribute to community well-being, create jobs, and help avoid the costs and risks of unmanaged waste.

Reducing methane emissions also lowers ozone concentrations in communities, cutting rates of illness and premature death.[120] A comprehensive waste management strategy rapidly improves health and quality of life, while opening opportunities such as tourism, commercial activity and outdoor leisure.

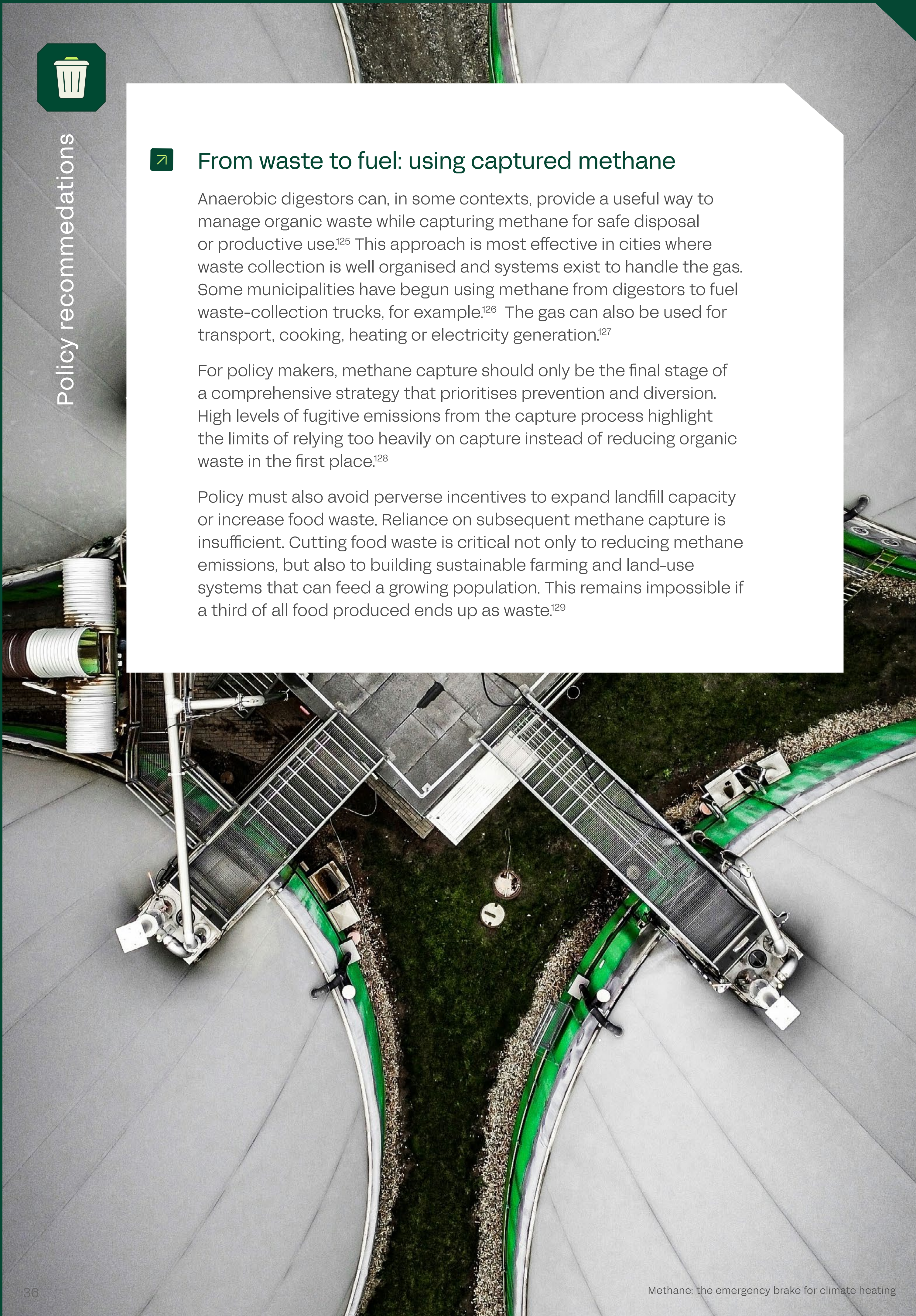
Regional opportunities

In the Global North, the immediate opportunity lies in combining organic waste diversion with rigorous methane capture at landfill sites. Where regulation is enforced, methane emissions drop to much lower levels.[121]

In the Global South, the priority is to establish the foundations of waste management – reducing and separating waste so that organic material is systematically diverted from landfill before methane emissions escalate.[122]

What communities gain

- **Safer lives and livelihoods:** More sanitary conditions reduce health risks and create greater opportunities for safe green public spaces.
- **Community pride and investment:** Cleaner neighbourhoods encourage residents to invest in their homes and surroundings.
- **Sustainable economic growth:** Regular waste management creates new jobs and attracts enterprise to clean and safe environments.
- **Healthier, more resilient communities:** Action to cut methane pollution leads to stronger, healthier and more resilient societies worldwide.[123]
- **Reduced flood risk:** Formalising and organising waste management lowers the risk of flooding.[124]



From waste to fuel: using captured methane

Anaerobic digestors can, in some contexts, provide a useful way to manage organic waste while capturing methane for safe disposal or productive use.[125] This approach is most effective in cities where waste collection is well organised and systems exist to handle the gas. Some municipalities have begun using methane from digestors to fuel waste-collection trucks, for example.[126] The gas can also be used for transport, cooking, heating or electricity generation.[127]

For policy makers, methane capture should only be the final stage of a comprehensive strategy that prioritises prevention and diversion. High levels of fugitive emissions from the capture process highlight the limits of relying too heavily on capture instead of reducing organic waste in the first place.[128]

Policy must also avoid perverse incentives to expand landfill capacity or increase food waste. Reliance on subsequent methane capture is insufficient. Cutting food waste is critical not only to reducing methane emissions, but also to building sustainable farming and land-use systems that can feed a growing population. This remains impossible if a third of all food produced ends up as waste.[129]

Policy recommendations

The solutions and tools already exist. Clear rules, devolved authority and strong data systems can scale up proven practices and lock in rapid, verifiable reductions.

Core recommendations

Systems and infrastructure

- **Create a waste management plan for every administrative area:** Map out steps to universal collection, separation, and diversion of organic waste away from landfill, with timelines and accountability.
- **Mandate universal collection:** Require comprehensive nationwide waste collection, devolving responsibility to local governments and supporting implementation with budgets, facilitation and technical capacity.
- **Separate waste at source:** Require households, businesses and institutions to separate organics and reusables from residual waste, ensuring systems are managed at the devolved level.
- **Divert organics into safe processes:** Channel food and agricultural residues into composting, anaerobic digestion or biochar, keeping them out of landfill.
- **Introduce regulations and incentives for diversion:** Back mandates with financial incentives to accelerate take-up, including subsidies for composting and penalties for landfilling organics.
- **Support municipalities with finance and technical assistance:** Provide dedicated funding and know-how to help cities and towns meet waste-management plan objectives, scaling up collection, separation and diversion.
- **Adopt standards for landfill gas monitoring and capture:** All landfill sites must meet clear technical standards for continuous monitoring and minimum capture rates.
- **Integrate informal systems:** Recognise and support the role of informal waste workers and settlements, progressively aligning practices with national standards and universal services.

Landfill management

- **Require compliance with landfill gas monitoring standards:** Ensure continuous measurement of methane emissions at all landfill sites, with particular focus on working-face areas where emissions are highest.
- **Introduce mandatory targets for biogas capture:** Set clear capture targets for landfill sites as the final stage in methane management, once prevention and diversion options have been maximised.

Demand-side and behavioural measures

- **Educate and engage communities:** Run educational and practical interventions tailored to cultural values and attitudes, enabling high rates of compliance with separation and diversion.
- **Make food-system changes to support behaviour shifts:** Reform policies and pricing to reduce food waste and encourage healthier, plant-based diets. Ensure no one is economically excluded from making these changes, for example by lowering the cost of vegetarian foods.

Enabling policies

Management of methane emissions from waste is, at its core, about separation and accountability.[130] Fast, verifiable progress depends on strong governance and clear rules:

- **Sub-national leadership:** Mandate and empower waste management at village, district and city level, including collection, sorting and treatment.
- **National regulation:** Set country-level targets and rules such as landfill bans, diversion mandates and standardised collection systems.
- **Data systems:** Require robust data collection to measure emissions and monitor progress.
- **Global alignment:** Link national policies to the LOW-Methane initiative, contributing to the goal of cutting waste-sector emissions by 1 million tonnes by 2030.[131]
- **Technology safeguards:** Prohibit reliance on incineration or waste-to-energy models that lock in emissions, while encouraging well-designed biogas projects where appropriate.

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Endnotes

1. See for example, Nature Communications, Lin et al (2024) 'Recent methane surges reveal heightened emissions from tropical inundated areas' https://www.nature.com/articles/s41467-024-55266-y ; also see Earth Systems Science Data, Saunois et al (2025) 'Global Methane Budget' Table 3 page 1885 and related discussions. https://essd.copernicus.org/articles/17/1873/2025/

2. For a discussion about feedback as an important factor, as well as observations about the importance of targeted methane reductions alongside decarbonisaton, see: **Frontiers in Science, Shrindell et al (2024) 'The Methane Imperative'** https://www.frontiersin.org/articles/10.3389/fsci.2024.1349770/full This and the publication mentioned at 1. above discuss the proportions discuss the proportions of natural and manmade methane emissions, and the likely feedback and underlying drivers of increased emissions of methane from natural sources.

3. The UNEP with Climate and Clean Air Coalition 2021 report argues that over 250,000 deaths a year can be avoided with the combined impacts of rapid methane abatement, and over half a million medical emergencies from asthma can be avoided. Yield losses of around 26 million tonnes can be avoided as well. UNEP, Climate Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' Page 6 https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

4. The cost of mitigating emissions of GHGs is found to be very sensitive to social conditions, with more equal societies able to deliver solutions at lower cost. See Environmental Science and Policy, Hof et al (2017) 'Global and regional abatement costs of Nationally Determined Contributions (NDCs) and of enhanced action to levels well below 2 °C and 1.5 °C' https://www.sciencedirect.com/science/article/pii/S1462901116308978

5. See Earth Systems Science Data, Saunois et al (2025) 'Global Methane Budget 2000 – 2020' the Abstract, page 1875. https://essd.copernicus.org/articles/17/1873/2025/

6. For the first ten years after methane is emitted its Global Warming Potential (GWP) and its Global Temperature Potential (GTP) are about the same. GTP falls more rapidly than GWP after that, and if the aim is to minimise temperature rise GTP is more relevant than GWP. If the main focus of study is to achieve net zero emissions by 2050, then 'GTP25' is most useful (giving a temperature impact in 25 years from now). There is no correct choice – but we use a factor of over 80 because we are interested in the temperature impact over the next ten years or so of methane released now.

7. In its 2013 Synthesis Report the IPCC said of GWP-100 (effects taken over a 100 year period), 'there is no scientific argument for selecting 100 years compared with other choices.' Figure 8.32 shows the relative impacts of global annual emissions of different gases (using 2008 emissions data) depending on timescale selection. In a 'GWP-10' scenario (effects taken over a 10 year period) the impact of methane emissions is greater than that of CO2. Page 719. https://www.ipcc.ch/report/ar5/wg1/ See, also, for example, Energy, Science and Engineering, Howarth (2014) 'A Bridge to Nowhere: methane emissions and the greenhouse gas footprint of natural gas' https://scijournals.onlinelibrary.wiley.com/doi/full/10.1002/ese3.35#ese335-bib-0034; and Royal Society of Chemistry, Balcombe et al (2018) 'Methane emissions: choosing the right climate metric and time horizon' 'Introduction' section, where the radiative forcing of methane is 120 times that of CO2 and the implications of that figure for different climate impacts explained Page 1323. https://pubs.rsc.org/en/content/articlepdf/2018/em/c8em00414e

8. Ibid. See Table 3 for range of impacts attributed to methane, depending on timescales. Page 1328.

9. For a detailed run down of the complexities of evaluating methane's effectiveness as a GHG, see especially 'Forward-facing comparisons' section in: Real Climate, Gavin (2021) 'The definitive CO2/CH4 comparison post' https://www.realclimate.org/index.php/archives/2021/09/the-definitive-co2-ch4-comparison-post/ For a more technical analysis of the radiative forcing of methane and its absorption of solar radiation, see Geophysical Research Letters, Byrom et al (2022) 'Methane's Solar Radiative Forcing' https://www.researchgate.net/publication/362131266_Methane's_Solar_Radiative_Forcing See also Environmental Research Letters, Lynch et al (2020) 'Demonstrating GWP*: a means of reporting warming-equivalent emissions that captures the contrasting impacts of short- and long-lived pollutants' https://iopscience.iop.org/article/10.1088/1748-9326/ab6d7e

10. The text of the new regulation is summarised by IEA: IEA (2025) 'EU regulation on the reduction of methane emissions in the energy sector' https://www.iea.org/policies/18209-eu-regulation-on-the-reduction-of-methane-emissions-in-the-energy-sector

11. For example, the CLEAN Initiative launched in Japan and South Korea in 2023 aims for transparency in the LNG market. It is driven by LNG purchaser companies who are national energy providers. See Nikkei Asia, Yamamoto et al (2024) 'Japan, South Korea LNG buyers seek transparency on methane emissions' https://asia.nikkei.com/business/energy/japan-south-korea-lng-buyers-seek-transparency-on-methane-emissions

12. Methane is removed from the atmosphere by the process of oxidation in reaction with hydroxyl radicals. The oxidation creates byproducts of water and CO_2. Although CO_2 is also a greenhouse gas, it is so much less powerful than methane, the net effect is to reduce the warming effect of the atmosphere. See Spark Climate Solutions (undated) 'How methane removal works' https://www.sparkclimate.org/methane-removal/primer/how. This article about emissions related to food contains 'Metrics to quantify greenhouse gas emissions' explaining approaches to quantification of the impact of methane emissions. Our World in Data, Ritchie (2020) 'The carbon footprint of foods: are differences explained by the impacts of methane?' https://ourworldindata.org/carbon-footprint-food-methane

13. A clear explanation of the GWP* as a measure of methane rate of reduction is found in Oxford Martin School, Lynch et al (2019) 'Net Zero for Agriculture: Oxford Martin Programme on Climate Pollutant' https://oms-www.files.svdcdn.com/production/downloads/academic/201908_ClimatePollutants.pdf

14. See, for example, One Earth, Olczak et al (2023) 'A global review of methane policies reveals that only 13% of emissions are covered with unclear effectiveness' https://www.sciencedirect.com/science/article/pii/S2590332223001951#:~:text=Global%2C%20sectoral%2C%20and%20regional%20emission,derived%20from%20different%20satellite%20observations.&text=While%20tackling%20methane%20emissions%20is,yet%20undergone%20a%20thorough%20assessment.&text=Because%20of%20the%20underreporting%20in,and%20evaluation%20of%20methane%20policies.

15. See IEA (2025) 'Global Methane Tracker' page 46. https://iea.blob.core.windows.net/assets/2c0cf2d5-3910-46bc-a271-1367edfed212/GlobalMethaneTracker2025.pdf

16. See for example a study in Europe of methane emissions from oil and gas production in Romania, one of the largest producers in the EU. The use of top-down and bottom-up calculations suggested that methane emissions had previously been under reported. Atmospheric Chemistry and Physics, Maazallahi et al (2025) 'Airborne in situ quantification of methane emissions from oil and gas production in Romania' https://acp.copernicus.org/articles/25/1497/2025/ ; and in South America, where the previous under-estimate of livestock emissions in bottom-up inventories was revealed by top-down analysis of satellite data. Atmospheric Chemistry and Physics, Hancock et al (2025) 'Satellite quantification of methane emissions from South American countries: a high-resolution inversion of TROPOMI and GOSAT observations' https://acp.copernicus.org/articles/25/797/2025/

17. See preprint discussion of the reconciliation process in relation to global fossil fuel methane emissions from oil, gas and coal exploitation. Earth System Science Data Preprint, Scarpelli et al (2025) 'Using new geospatial data and 2020 fossil fuel methane emissions for the Global Fuel Exploitation Inventory (GFEI) v3' https://essd.copernicus.org/preprints/essd-2024-552/ . Similarly, a reconciliation of data is attempted for China. In 2014 China submitted its inventory of methane emissions to the UNFCCC. Itemised by source, this set a baseline from which strategic management of methane could be calculated. In 2019 a sophisticated 'inverse' analysis of TROPOMI satellite data showed that the 2014 inventory underestimated China's methane emissions by about 21%. The TROPOMI analysis showed that the inventory 'bottom up' approach had underestimated methane emissions from oil, gas, livestock, waste and rice paddies. However, the inventory had actually overestimated the methane emissions from coal and coal-mining. Atmospheric Chemistry and Physics, Chen et al (2022) 'Methane emissions from China: a high-resolution inversion of TROPOMI satellite observations' https://acp.copernicus.org/articles/22/10809/2022/ . TROPOMI is on board the Sentinel-5 Precursor satellite – operated jointly by the European Space Agency and the Netherlands Space Office. Sentinel 5 Precursor falls under the Copernicus programme which is a joint effort of the ESA and the European Commission. See TROPOMI website for further details. https://www.tropomi.eu/

18. See for example, report showing the gap between aerial and OGI surveys: Environmental Science and Technology, Tyner et al (2021) 'Where the Methane is - Insights from Novel Airborne LiDAR Measurements Combined with Ground Survey Data' https://pubmed.ncbi.nlm.nih.gov/34251207/#:~:text=Results%20reveal%20a%20surprising%20distinction,/bottom%2Dup;%20venting.

19. Some of the main databases relied up in bottom up inventories are listed in Earth System Science Data, Saunois et al (2025) 'The Global Methane budget 2000 – 2020' page 1881 onwards https://essd.copernicus.org/articles/17/1873/2025/

20. To see a Marginal Abatement Cost Curve in practice, see for example, IEA (2022) 'Marginal abatement cost curve for oil and gas methane emissions by mitigation measure, 2022' https://www.iea.org/data-and-statistics/charts/marginal-abatement-cost-curve-for-oil-and-gas-methane-emissions-by-mitigation-measure-2022

21. There is diverse evidence for the tendency for bottom-up inventories, alone, to underestimate methane emissions. See for example: in relation to the USA – Environmental Science and Technology, Maasakkers et al (2023) 'A Gridded Inventory of Annual 2012–2018 U.S. Anthropogenic Methane Emissions' https://pubs.acs.org/doi/10.1021/acs.est.3c05138 ; Journal of Geophysical Research: Atmospheres, Peischi et al (2016) 'Quantifying atmospheric methane emissions from oil and natural gas production in the Bakken shale region of North Dakota' https://onlinelibrary.wiley.com/doi/abs/10.1002/2015JD024631 ; or Journal of Geophysical Research: Atmospheres, Peischi et al (2018) 'Quantifying Methane and Ethane Emissions to the Atmosphere From Central and Western U.S. Oil and Natural Gas Production Regions' https://onlinelibrary.wiley.com/doi/abs/10.1029/2018JD028622 and Geophysical Research Letters, Varon et al (2019) 'Satellite Discovery of Anomalously Large Methane Point Sources From Oil/Gas Production' https://onlinelibrary.wiley.com/doi/abs/10.1029/2019GL083798 . China has also underestimated emissions in the past. For a summary, see Salata Institute at Harvard University, Chen et al (2023) 'Research Brief: Updating Estimates of Methane Emissions: The Case of China' https://salatainstitute.harvard.edu/updating-estimates-of-methane-emissions-the-case-of-china/ Emissions from gas rich coal mines in China have been underestimated. See Nature Climate Change, Liu et al (2024) 'Large methane mitigation potential through prioritized closure of gas-rich coal mines' https://www.researchgate.net/publication/380129744_Large_methane_mitigation_potential_through_prioritized_closure_of_gas-rich_coal_mines ; As part of an evaluation of China's methane mitigation potential, the gaps between top-down and bottom-up calculations are considered. See Nature Communications, Khanna et al (2024) 'An assessment of China's methane mitigation potential and costs and uncertainties through 2060' https://www.nature.com/articles/s41467-024-54038-y . In North Africa and Middle East, bottom-up inventories have underestimated methane emissions by about 35%, unevenly distributed across countries. See Atmospheric Chemistry

and Physics, Chen et al (2023) 'Satellite quantification of methane emissions and oil–gas methane intensities from individual countries in the Middle East and North Africa: implications for climate action' https://acp.copernicus.org/articles/23/5945/2023/ ; The IEA reports as a 'key finding' that methane emissions are 'widely underreported'. See: IEA (2025) 'Global Methane Tracker: Key findings' https://www.iea.org/reports/global-methane-tracker-2025/key-findings .

22. The Global Methane Budget project captures the decadal shifts in methane emissions from 2000–2010, into 2010–2020. To achieve the best information possible it integrates top-down and bottom-up data, explaining that earlier estimates (from previous bottom-up only analysis) have been revised as a result. In this latest version of the global evaluation, the new bottom-up inventory estimate of methane emissions is actually higher than the top-down estimation from satellite data. However, within their uncertainty ranges, the two approaches agree with one another giving confidence to the overall picture painted. Uncertainties in the inventory approach, when compared with atmospheric data, are thought to be largely explained by uncertainties around natural emissions from inland freshwater systems, natural wetlands, geological see page, and possible unresolved double counting from different sources. See: Earth System Science Data, Saunois et al (2025) 'Global Methane Budget 2000–2020' Page 1876. https://essd.copernicus.org/articles/17/1873/2025/

23. The Global Methane Budget gives about 600 Mt (million tonnes) of global methane emissions per year, of which about 360 Mt (60%) is human-made. See Earth System Science Data, Saunois et al (2025) Global Methane Budget 2000–2020' page 1875 (Abstract) https://essd.copernicus.org/articles/17/1873/2025/ . The world population is around 8 billion people. See Our World in Data (2024) 'Data: Population' https://ourworldindata.org/grapher/population . This gives around 45 kg per person per year average. The figure used in Figure 1, of around 46 kg, comes from the IEA emissions data.

24. Sources: for methane emissions - IEA methane tracker: see IEA (2025) 'Methane Tracker – Interactive database' https://www.iea.org/data-and-statistics/data-tools/methane-tracker; and for population figures - Our World in Data: see Our World in Data (2024) 'Data: Population' https://ourworldindata.org/grapher/population ..

25. Source: IEA methane tracker. See IEA (2025) 'Methane Tracker – Interactive database' https://www.iea.org/data-and-statistics/data-tools/methane-tracker.

26. For a note of the well-documented oil and gas efforts at spreading disinformation, see C40 Cities (undated) 'Disinformation: Where does climate disinformation come from?' https://www.c40.org/what-we-do/building-a-movement/disinformation/#:~:text=Influencers%2C%20trade%20associations%2C%20advocacy%20organisations,relating%20to%20the%20climate%20crisis. For a discussion of the effects of fossil-fuel production on renewable energy deployment in individual countries, see Heliyon, Ankrah et al (2025) 'A spotlight on fossil fuel lobby and energy transition possibilities in emerging oil-producing economies' https://www.sciencedirect.com/science/article/pii/S2405844024173185 ; Large agricultural industry participants have similar influence and show obstructive behaviour, with 'pervasive levels of greenwashing'. See Energy Mix, (2022) '15 Big Agribusinesses Create Nearly as Much Methane as EU: Report' https://www.theenergymix.com/top-15-food-producers-create-nearly-as-much-methane-as-eu-report/ ; and Changing Markets Foundation (2022) 'Emissions Impossible: How emissions from big meat and dairy are heating up the planet – Methane Edition' https://changingmarkets.org/report/emissions-impossible-how-emissions-from-big-meat-and-dairy-are-heating-up-the-planet-methane-edition/#:~:text=Executive%20Summary,dependent%20on%20stable%20climatic%20conditions.

27. For example, methane emissions in China in one specific area probably emanate from malfunctioning or poorly operated oil production equipment. Regulatory policy and enforcement could reduce those emissions rapidly. See: Atmospheric Chemistry and Physics, Chen et al (2022) 'Methane emissions from China: a high-resolution inversion of TROPOMI satellite observation' Page 10821. https://acp.copernicus.org/articles/22/10809/2022/ The EU Methane Regulation of 2024 creates a legal framework under which EU member states must have penalty systems in place for non-compliance in measuring, reporting and verifying emissions. These regulations will reduce emissions of methane, and industry-wide awareness raising has been implemented. See, for example, White and Case, Nordin et al (2025) 'Alert: Are you ready for the new EU rules on methane emissions in the energy sector?' https://www.whitecase.com/insight-alert/are-you-ready-new-eu-rules-methane-emissions-energy-sector#:~:text=The%20MERR%20includes%20obligations%20to,address%20methane%20super%2Demitting%20events.

28. For a wider discussion of finance and funding in methane abatement policy, see IEA (2024) 'Key findings: Delivering the 75% cut in methane emissions requires USD 170 billion in spending to 2030' https://www.iea.org/reports/global-methane-tracker-2024/key-findings ; also IEA (2025) 'Global Methane Tracker 2025: Overcoming barriers to abatement – In most cases the fossil fuel industry is in a position to cover the financing gap, but additional external support will be needed' https://www.iea.org/reports/global-methane-tracker-2025/overcoming-barriers-to-abatement ; and Climate Policy Initiative (2023) 'Landscape of Methane Abatement Finance 2023' https://www.climatepolicyinitiative.org/wp-content/uploads/2023/11/Landscape-of-Methane-Abatement-Finance.pdf

29. See discussion of emissions pricing and its potential impact on developing economies: IFS (2021) 'What is the case for carbon taxes in developing countries' https://ifs.org.uk/articles/what-case-carbon-taxes-developing-countries#:~:text=of%20this%20challenge.-,Summary,0.21%20USD%20per%20Ghanaian%20Cedi. For a review of the impact of methane abatement policies in the UK, see Gov.UK (2022) 'Notice: United Kingdom methane memorandum' https://www.gov.uk/government/publications/united-kingdom-methane-memorandum/united-kingdom-methane-memorandum

30. See UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 102 for net negative costs in energy sector, and page 96 and 102 for net

negative costs in the waste sector. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

31. See the Global Methane Pledge website, provided by the Secretariat of the Climate and Clean Air Coalition, a UN Environment Programme. Global Methane Pledge (Homepage) https://www.globalmethanepledge.org/

32. See the breakdown summarised in Figure 7 of the Global Methane Budget. Earth System Science Data, Saunois et al (2025) 'Global methane Budget 2000–2020' page 1914 https://essd.copernicus.org/articles/17/1873/2025/ Similar proportions are shown in the IEA (2025) 'Methane Tracker' https://www.iea.org/data-and-statistics/data-tools/methane-tracker

33. The IEA estimates that simple, tried and tested, policy interventions could reduce methane emissions from the energy sector by more than half if adopted globally. See IEA (22025) 'Global Methane Tracker 2025' page 27 https://iea.blob.core.windows.net/assets/b83c32dd-fc1b-4917-96e9-8cd918801cbf/GlobalMethaneTracker2025.pdf

34. In the UK, for example, emissions from off-shore oil and gas have fallen by a third since 2018, and further reductions are planned. The targets of halving emissions by 2030, and then by 90% by 2040, require 'serious investment'. See North Sea Transition Authority (2025) 'Emissions down by a third since 2018, but bold action needed to secure industry's role in transition' https://www.nstauthority.co.uk/news-publications/emissions-down-by-a-third-since-2018-but-bold-action-needed-to-secure-oil-and-gas-industry-s-leading-role-in-energy-transition/ For a discussion of the interplay between government enforcement and industry willingness to engage, see Expert Systems with Applications, Xia et al (2024) 'Carbon constraints and carbon emission reduction: An evolutionary game model with the energy-intensive sector' https://www.sciencedirect.com/science/article/abs/pii/S0957417423034188#:~:text=In%20particular%2C%20in%20the%20case%20of%20governments',greater%20for%20energy%2Dintensive%20enterprises%20under%20loose%20regulation.

35. For discussion of returns on investment in methane abatement, see IEA (2025) 'Global Methane Tracker 2025 Key Findings: Methane abatement options in oil and gas can deliver very high rates of return' https://www.iea.org/reports/global-methane-tracker-2025/key-findings

36. The obstacles to abatement are summarised by IEA, and they highlight some of the initiatives that should help to bridge the gaps. See IEA (2025) 'Global Methane Tracker 2025: Overcoming barriers to abatement' https://www.iea.org/reports/global-methane-tracker-2025/overcoming-barriers-to-abatement

37. See MethaneSAT (2024) 'Project Update: Twi New Satellite Programs Join the Climate Fight' https://www.methanesat.org/project-updates/two-new-satellite-programs-join-climate-fight#:~:text=MethaneSAT%2C%20developed%20by%20Environmental%20Defense,and%20reduce%20methane%20emissions%20faster.

38. Since being commissioned in 2024, Tanager has identified 'more than 5,500 methane plumes across nearly 3,200 sources.' See PlanetPulse (2025) 'Celebrating One Year of Tanager-1 – Tanager So Far'https://www.planet.com/pulse/celebrating-one-year-of-tanager-1/

39. See WEF report on efforts to achieve systems that detect 100kg of methane emissions per hour (kg/h): WEF (2025) 'Tackling methane emission blind spots with satellite technology' https://www.weforum.org/stories/2025/06/tackling-methane-emissions-satellite-technology/#:~:text=To%20address%20this%2C%20Nara%20Space,mechanisms%20grounded%20in%20verifiable%20evidence The MethaneSAT project update report notes that the majority of methane emissions from oil and gas production in the US come from dispersed sources. See MethaneSAT (2025) 'Study: Smaller dispersed sources account for majority of US oil and gas methane emissions' https://www.methanesat.org/project-updates/study-smaller-dispersed-sources-account-majority-us-oil-gas-methane-emissions For comparison, TROPOMI detection levels are about 0.04% of global emissions per day, and 14% across a whole year of tracking data. If an installation is a super-emitter, it is much more likely to be captured, at about 35% over a whole year. In the right conditions, a minimum of 500kg/h per pixel is the minimum that can be detected in a single TROPOMI overpass. However, the limit can be a great deal higher – up to 8800kg/h per pixel. See Science of the Total Environment, Dubey et al (2023) 'Minimum detection limits of TROPOMI satellite sensor across North America and their implications for measuring oil and gas emissions' https://www.sciencedirect.com/science/article/pii/S0048969723008380#:~:text=Highlights,America%20for%20different%20campaign%20lengths..

40. For the versatility of methane detection by satellite, see Atmospheric Chemistry and Physics, Jacob et al (2022) 'Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane' https://acp.copernicus.org/articles/22/9617/2022/#:~:text=Current%20point%20source%20imagers%20include,coverage%20and%20frequent%20return%20times.

41. For an overview of global regulation of venting and flaring, see The World Bank (2022) 'Global Methane and Flaring Regulations' https://flaringventingregulations.worldbank.org/summary-report#:~:text=Policy%20makers'%20heightened%20degree%20of%20focus%20on,across%20the%20oil%20and%20gas%20supply%20chain.

42. For an analysis of the actual efficiency of combustion across 80% of US flaring, see Science, Plant et al (2022) 'Inefficient and unlit natural gas flares both emit large quantities of methane' https://pubmed.ncbi.nlm.nih.gov/36173866/

43. Venting is generally prohibited in the UK and the EU, for example. It is being phased out in the US and is heavily restricted in Canada. See The World Bank (2023) 'Global Methane and Flaring Regulations : Case Studies' https://flaringventingregulations.worldbank.org/country-compare?country1=13&country2=28

44. In the EU leak detection and repair is mandated in its EU Methane Regulation of 2024. For an overview of methane leak management in the EU see ThermoFisher Scientific (2024) 'EMEA Regulations on Leak Detection (LDAR)' https://www.thermofisher.com/blog/mining/emea-regulations-on-leak-detection-ldar/#:~:text=The%20key%20to%20all%20of,matter%20when%20they%20are%20enacted. The EU regulations have wide-ranging impacts across the world because import regulations demand rigorous methane monitoring and regulation, irrespective of the source of imported fuel. See: GHGSAT, Opara (2024) 'What Does the New EU Methane Regulation Mean for the Global LNG Supply Chain?' https://www.ghgsat.com/en/newsroom/what-does-the-new-eu-methane-regulation-mean-for-the-global-lng-supply-chain/#:~:text=Leak%20Detection%20and%20Repair%20(LDAR)%20Requirements,authority%20within%20each%20member%2Dstate.

45. New regulations in Canada will focus on methane reductions based on actual releases of methane at sites: there is an obligation to monitor surface emissions, and to detect and respond to leaks and optimise methane recovery. The approach is described as 'performance based'. See Climate Policy Database (2024) 'Regulations Respecting the Reduction in the Release of Methane (Waste Sector) Canada (2024)' https://climatepolicydatabase.org/policies/regulations-respecting-reduction-release-methane-waste-sector Implementation of these new regulations is reckoned to have a significant negative cost: implementation will cost about $0.5 billion Canadian, whilst their social benefit is valued at $11.2 billion Canadian. See Government of Canada (2024) 'Canada Gazette, Part 1, Volume 158, Number 26: Regulations Respecting the Reduction in the Release of Methane (Waste Sector)' https://gazette.gc.ca/rp-pr/p1/2024/2024–06–29/html/reg5-eng.html

46. The link between coal use and CH4 emissions is captured in iScience, Guo et al (2025) 'Global coal trade induces large CH4 emissions' https://pmc.ncbi.nlm.nih.gov/articles/PMC11914807/#:~:text=Summary,4%20to%20mitigate%20climate%20change.

47. See IEA (2025) 'Coal: Latest findings – Global coal demand to remain on a plateau in 2025 and 2026' https://www.iea.org/energy-system/fossil-fuels/coal

48. Disused coal mines are a significant source of methane emissions and have been under-counted in emissions inventories in the past. For an overview, see Guardian, Harvey (2025) 'Abandoned infrastructure one of the biggest polluters in the world – report' https://www.theguardian.com/environment/2025/may/07/abandoned-infrastructure-one-of-the-biggest-polluters-in-the-world-report

49. The IEA Methane Tracker of 2025 included for the first time the impact of abandoned wells and mines. See IEA (2025) 'Global Methane Tracker: Key findings – Energy-related methane emissions have still not reached a definitive peak' https://www.iea.org/reports/global-methane-tracker-2025/key-findings

50. The introduction of new EU Methane Regulations on imported gas show suppliers being incentivised to produce products that embody lower methane emissions; they also show that there is a willingness by governments to secure consumer payment for a product that is lower in emissions. For the text of the regulations, see: EUR-Lex (2024) 'Document 32024R1787' https://eur-lex.europa.eu/eli/reg/2024/1787/oj/eng . For a discussion about the willingness of consumers to pay, see the shipping passengers example. The example shows the importance of raising awareness of consumers of emissions damage and options for reduction – in order for their choice to pay to be informed. See: Science Direct, Heliyon, Nyari et al (2024) 'Awareness increases acceptance and willingness to pay for low-carbon fuels amongst marine-passengers' https://www.sciencedirect.com/science/article/pii/S240584402400745X#:~:text=Alternative%20fuels%20are%20generally%20more,even%20more%20above%20the%20average.

51. The EU regulation on the reduction of methane emissions in the energy sector is summarised on the IEA website. The new regulation came into force in 2024, and from 2025 fossil fuel operators must report annual methane emissions data including those from non-operated assets. The same reporting and transparency obligations will be imposed on new import contracts to the EU from 2027. See IEA (2025) 'EU regulation on the reduction of methane emissions in the energy sector' https://www.iea.org/policies/18209-eu-regulation-on-the-reduction-of-methane-emissions-in-the-energy-sector

52. Again, see how the EU regulations have wide-ranging impacts across the world because import regulations demand rigorous methane monitoring and regulation, irrespective of the source of imported fuel. See: GHGSAT, Opara (2024) 'What Does the New EU Methane Regulation Mean for the Global LNG Supply Chain?' https://www.ghgsat.com/en/newsroom/what-does-the-new-eu-methane-regulation-mean-for-the-global-lng-supply-chain/#:~:text=Leak%20Detection%20and%20Repair%20(LDAR)%20Requirements,authority%20within%20each%20member%2Dstate.

53. For example, in ten open landfill sites in US, around 80% of methane emissions were not captured by the measurement and monitoring strategy; monitoring relied on Walking Surface Emission Monitoring (SEM). The success rate was better at closed sites – but still missed over 30% of emissions. See Science Direct, Waste Management, Omidi et al (2025) 'Most landfill methane emissions escape detection in EPA21 surface emission monitoring surveys' https://www.sciencedirect.com/science/article/pii/S0956053×2500515X

54. Saudi Arabia, Qatar, Kuwait and United Arab Emirates all have relatively low emissions of methane per capita compared with USA, lying below the global average. Norway and the Netherlands have the lowest intensity of all in oil and gas production. Turkmenistan and Venezuela have the highest intensity of methane emissions from their oil and gas production, and the USA has the highest methane emissions overall from oil and gas production. https://www.iea.org/reports/global-methane-tracker-2024/key-findings

55. China is the biggest by far in coal production and consumption. IEA (2024) 'Methane emissions tracker: Key findings' https://www.iea.org/reports/global-methane-tracker-2024/key-findings

56. See Nature Communications, Khanna (2024) 'An assessment of China's methane mitigation potential and costs and uncertainties through 2060' page 1 https://www.nature.com/articles/s41467-024-54038-y

57. The trend is explained by the link between methane and coal in China. Abandoned mines continue to cause high emissions, though they no longer provide energy. The methane intensity of shale gas production is more than twice that of conventional natural gas, and therefore the methane emissions related to natural gas have increased. Long distance pipeline transportation also increases methane emission intensity. See: Taking the Pulse: Insights on Climate Development in China, Fei (2024) 'Current Opinion: The trends in methane emissions in China's energy sector align with the emissions dynamics and spatial distribution of coal, oil and gas sectors' https://www.igdp.cn/taking-the-pulse/

58. In relation to unconventional production of fossil fuels in the US, see Journal of Geophysical Research: Atmospheres, Peischi et al (2016) 'Quantifying atmospheric methane emissions from oil and natural gas production in the Bakken shale region of North Dakota' https://onlinelibrary.wiley.com/doi/abs/10.1002/2015JD024631 ; or Journal of Geophysical Research: Atmospheres, Peischi et al (2018) 'Quantifying Methane and Ethane Emissions to the Atmosphere From Central and Western U.S. Oil and Natural Gas Production Regions' https://onlinelibrary.wiley.com/doi/abs/10.1029/2018JD028622 and Geophysical Research Letters, Varon et al (2019) 'Satellite Discovery of Anomalously Large Methane Point Sources From Oil/Gas Production' https://onlinelibrary.wiley.com/doi/abs/10.1029/2019GL083798 .

59. The GHG footprint for LNG produced in the US from shale gas extraction, the liquification process and its transportation, is typically a third higher than that of coal if methane emissions are included over a 20 year global warming potential (GWP20), according to one study. See Energy Science and Engineering, Howarth (2024) 'The greenhouse gas footprint of liquefied natural gas (LNG) exported from the United States' https://scijournals.onlinelibrary.wiley.com/doi/10.1002/ese3.1934#:~:text=Overall%2C%20the%20greenhouse%20gas%20footprint,2%2Dequivalent/MJ). These calculations exceed those of other studies, as set out by IEA in its report, where the IEA estimates a lower level of emissions. See IEA (2025) 'Assessing Emissions from LNG Supply and Abatement Options' page 7. https://iea.blob.core.windows.net/assets/5ad737ee-750d-460e-8c33-fb9140f1043d/AssessingemissionsfromLNGsupplyandabatementoptions.pdf

60. For one estimate of the high levels of emissions potentially involved in LNG production and transportation, see Energy, Science and Engineering, Howarth (2024) 'The greenhouse gas footprint of liquified natural gas (LNG) exported from the United States' https://scijournals.onlinelibrary.wiley.com/doi/10.1002/ese3.1934#:~:text=Abstract,greenhouse%20gas%20footprint%20of%20LNG.

61. The recent comprehensive estimate made by IEA of the GHG emissions in LNG production and distribution shows the reductions that can be made in emissions all along the production cycle. See IEA (2025) 'Assessing Emissions from LNG Supply and Abatement Options' page 7. https://iea.blob.core.windows.net/assets/5ad737ee-750d-460e-8c33-fb9140f1043d/AssessingemissionsfromLNGsupplyandabatementoptions.pdf.

62. The IEA report tracks the different emissions along the production process, including those in transport. Ibid. Note that the high emissions involved in transporting LNG are a significant part of the LNG lifecycle of high GHG emissions. See also SFO°C, Shin (2024) 'True Climate Impact of LNG Carriers' https://forourclimate.org/insights/20

63. See Nature Communications, Khanna (2024) 'An assessment of China's methane mitigation potential and costs and uncertainties through 2060' page 2 https://www.nature.com/articles/s41467-024-54038-y

64. Allowing for global emissions trading could reduce costs significantly. See Environmental Science and Policy, Hof et al (2017) 'Global and regional abatement costs of Nationally Determined Contributions (NDCs) and of enhanced action to levels well below 2°C and 1.5°C' https://www.sciencedirect.com/science/article/pii/S1462901116308978 .

65. The best production processes do a lot better in reducing methane emissions than the worst performers, so there is an urgent need to understand, by source, what the methane emissions for any particular supply of LNG add up to. The EU is introducing strict monitoring requirements for source-level reporting and verification of methane emissions. This sort of approach would ensure that LNG with a high methane footprint does not get pushed into use in the Global South. MiQ certification can help to identify high methane emissions in production. See for a brief explanation: MiQ, Press Release (2024) 'Grain LNG marks world-first in auditing methane emissions' https://miq.org/grain-lng-marks-world-first-in-auditing-methane-emissions/#:~:text=Ben%20Wilson%2C%20President%20of%20National,avoidable%20methane%20emissions%20this%20decade. For a critical perspective on the GHG footprint of natural gas in general, see Energy Science and Engineering, Howarth (2014) 'A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas' https://www.axa-im.com/our-stories/liquefied-natural-gas-and-energy-transition-methane-challenge

66. The challenge is to extend monitoring to landfill where emissions are currently not monitored at all, whilst also promoting best practice in monitoring – ensuring that emissions from the workface are captured, as well as those from closed up areas of sites, for example. Best practice requires walking surveys, drone technology, flux boxes and probes – all integrated to provide regular monitoring. For discussion, see Clean Air Task Force, Siegel et al (2024) 'A guide to monitoring and quantifying methane emissions from the waste sector' https://www.catf.us/2024/02/guide-monitoring-quantifying-methane-emissions-waste-sector/#:~:text=One%20would%20expect%20that%20the,and%20fix%20any%20identified%20issues.

67. Norway, for example, has achieved very low methane emissions for a petro-state. It combines high operational standards, policy action and technology deployment. Saudi Arabia and the UAE also have relatively low methane emissions. The best performers do 100 times better than the worst. See IEA (2024) Global Methane Tracker 2024: Key findings https://www.iea.org/reports/global-methane-tracker-2024/key-findings .

68. Often leaks are notified by satellite data analysts, but governments and companies do not respond to the information. This allows methane leaks to continue. Satellites are only able to identify large emissions – often from 'super-emitters' – so urgent response is important. Policy interventions must ensure that leaks are required to be fixed as soon as they are identified. For current failings, see New Scientist, Dinneen (2024) 'Satellites spot methane leaks – but 'super-emitters' don't fix them' https://www.newscientist.com/article/2456488-satellites-spot-methane-leaks-but-super-emitters-dont-fix-them/

69. For an explanation of different options for use of methane, in preference to flaring, see Methane Guiding Principles Partnership (2019) 'Reducing Methane Emissions: Best practice guide – Flaring' https://methaneguidingprinciples.org/pdf/best-practice-guide/flaring/Reducing-Methane-Emissions-Flaring-Guide.pdf

70. The Global Methane Budget assesses emissions by sector, and within sectors. Enteric fermentation and manure are discussed on page 1889; rice cultivation and its emissions is discussed on page 1890. See Earth System Science Data, Saunois et al (2025) 'Global Methane Budget 2000 – 2020' https://essd.copernicus.org/articles/17/1873/2025/

71. Aquaculture is the world's fastest growing food production system. For an overview, see EIT Food (2023) 'Is farmed fish from aquaculture a healthy source of protein?' https://www.eitfood.eu/blog/is-farmed-fish-a-healthy-source-of-protein#:~:text=Aquaculture%20is%20the%20most%20efficient,(26). For a review of the importance in the wider global food system of aquaculture (as a source of food for animals as well as humans) see Science Direct, One Earth, Hua et al (2019) 'The Future of Aquatic Protein: Implications for Protein Sources in Aquaculture Diets' https://www.sciencedirect.com/science/article/pii/S2590332219301320

72. See Table 3 of Global Methane Budget, showing the different sources of global methane emissions by category – also showing the growth of emissions from 2000–2009 to 2010–2019, with a final set of data for 2020: ibid page 1885 https://essd.copernicus.org/articles/17/1873/2025/

73. Ibid. Table 3, page 1885.

74. The Global Methane Budget puts the proportion contributed by 'Livestock and Manure' in 2020 to 'Agriculture' at around 80%. Ibid page 1885; this is close to the data summarised and quoted in this report from Journal of Microbiology and Biotechnology, Tseten et al (2022) 'Strategies to Mitigate Enteric Methane Emissions from Ruminant Animals' Figure 1, Introduction. https://pmc.ncbi.nlm.nih.gov/articles/PMC9628856/#:~:text=Dietary%20manipulation%20by%20changing%20the,intervention%20%5B32%2C%2033%5D.

75. Again, this is the Global Methane Budget figure for 'Livestock and Manure' within 'Agriculture'. See: Earth System Science Data, Saunois et al (2025) 'Global Methane Budget 2000 – 2020' page 1889. https://essd.copernicus.org/articles/17/1873/2025/

76. For a somewhat lower assessment, omitting manure management, see Animal Nutrition, Xie et al (2025) 'Mitigating enteric methane emissions: An overview oof methanogenesis, inhibitors and future prospects' https://www.sciencedirect.com/science/article/pii/S2405654525000095 ;

77. Specifically, the 60% reduction is achievable by 'meticulously selecting the type or quality of forage and optimizing the concentrate to forage ratio in feed.' Journal of Microbiology and Biotechnology, Tseten et al (2022) 'Strategies to Mitigate Enteric Methane Emissions from Ruminant Animals' Conclusion. https://pmc.ncbi.nlm.nih.gov/articles/PMC9628856/#:~:text=Dietary%20manipulation%20by%20changing%20the,intervention%20%5B32%2C%2033%5D

78. These recommendations are taken directly from 'Table 4.1 Emissions control measures included in at least one of the mitigation analyses' of UNEP, Clean Air Coalition (2022) 'Global Methane Assessment: Benefits and costs of mitigating methane emissions' page 107. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

79. These particular figures and apportionments come from the 2022 UNEP report that predates the 2025 Global Methane Budget report. The apportionments are specifically for agriculture and are broadly consistent with the Global Methane Budget data. UNEP, Clean Air Coalition (2022) 'Global Methane Assessment: Benefits and costs of mitigating methane emissions' https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

80. The US beef-herd is the largest in the world by weight, at around 13 million tons of beef from a herd of over 92 million animals. Second to the USA by weight is Brazil, with over 10 million tons of beef in a herd of 194 million animals. Note that the bulk of a US beef animal is much greater than that of an animal in Brazil. Eight out of ten of the largest production sites are in US, with one in Australia and one in Brazil. Cattle Farming, Santos (2025) 'World's largest beef cattle operations: top single-site producers' https://ruminants.ceva.pro/beef-production#:~:text=and%20consumer%20safety.-,4.,a%20traditionally%20pasture%2Dbased%20system.

81. This quote is taken from the Prix Pictet exhibition catalogue for the 'Consumption' exhibition: Prix Pictet (2014) 'Consumption' Artist's Statement, Mishka Henner https://prix.pictet.com/cycles/consumption/mishka-henner

82. See for example, the study of farms in Kenya where methane emissions varied widely according to particular feeding practices. The study showed that intensification of production was not necessary to reduce emissions: Animal: The International Journal of Animal Bioscience, Ndung'u et al (2021) 'Farm-level emission intensities of smallholder cattle production systems in highlands and semi-arid regions' https://research-information.bris.ac.uk/ws/portalfiles/portal/311940101/1_s2.0_S1751731121002913_main.pdf

83. See 'Beef Production 2023' and 'Beef and buffalo (cattle) meat production' in Our World in Data (2023) 'Meat and Dairy Production' https://ourworldindata.org/meat-production#:~:text=Beef%20and%20buffalo%20(cattle)%20meat%20production&text=Globally%2C%20cattle%20meat%20production%20has,Argentina%2C%20Australia%2C%20and%20India. For a review of current pork production methods in China, and the importance of precise feeding methods to reintroduce a level of sustainability, see: Frontiers of Agricultural Science and Engineering, Zhang et al (2025) 'Pork production systems in China: A review of their development, challenges and prospects in green production' https://www.researchgate.net/publication/350852470_PORK_PRODUCTION_SYSTEMS_IN_CHINA_A_REVIEW_OF_THEIR_DEVELOPMENT_CHALLENGES_AND_PROSPECTS_IN_GREEN_PRODUCTION ; for a discussion about the incentives and approaches that prompt improved manure management, see PubMedCentral, Zheng et al (2013) 'Managing Manure from China's Pigs and Poultry: The Influence of Ecological Rationality' https://pmc.ncbi.nlm.nih.gov/articles/PMC4132472/#:~:text=Livestock%20production%20has%20developed%20rapidly,poultry%20farming%20is%20much%20higher. And for a review of the importance of integrating manure management in to wider farming systems to make use of the nutrient potential, see Science Direct, Agriculture, Ecosystems and Environment, Chadwick et al (2015) 'Improving manure management towards sustainable agricultural intensification in China' https://www.sciencedirect.com/science/article/abs/pii/S0167880915001097#:~:text=In%20China%2C%20as%20in%20many,In%20China%2C%20ca.

84. UNEP, Clean Air Coalition (2022) 'Global Methane Assessment: Benefits and costs of mitigating methane emissions' page 32 https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

85. Aquaculture ponds in China emit around five times the level of methane when compared with other inland waterways, leaving important scope for management. For a discussion about the probable scale of methane emissions in China from aquaculture, see: Nature Communications, Earth and Environment, Zhang et al (2024) 'Inventory of methane and nitrous oxide emissions from freshwater aquaculture in China' https://www.nature.com/articles/s43247-024-01699-8

86. The impact of aeration is helpful for reducing methane emissions, but risks increasing N2O emissions. Aerated ponds generate a lower global warming potential (by 40%) than those without, with methane as the main driver. Aeration can be an effective strategy, but care must be taken to monitor overall impacts. See: Journal of Hydrology, Yang et al (2023) 'Contrasting effects of aeration on methane (CH4) and nitrous oxide (N2O) emissions from subtropical aquaculture ponds and implications for global warming mitigation' https://www.sciencedirect.com/science/article/abs/pii/S0022169422014469#:~:text=Highlights&text=Aeration%20in%20aquaculture%20ponds%20decreased,climate%20impacts%20of%20aquaculture%20pond.

87. For a review of the emergent state of knowledge about emissions from aquaculture, see for example, the Research Topic "Greenhouse Gas Emissions from Terrestrial Freshwater Ecosystems: Spatial and Temporal Hot Spots' to which the following article is a contribution: Frontiers in Water, Vroom et al (2023) 'Widespread dominance of methane ebullition over diffusion in freshwater aquaculture ponds' https://www.frontiersin.org/journals/water/articles/10.3389/frwa.2023.1256799/full For a full review of the research topic, see Frontiers in Water – Water and Climate: Research Topics, Piatka et al (2024) 'Greenhouse Gas Emissions from Terrestrial Freshwater Ecosystems: Spatial and Temporal Hot Spots' https://www.frontiersin.org/research-topics/51530/greenhouse-gas-emissions-from-terrestrial-freshwater-ecosystems-spatial-and-temporal-hot-spots/magazine

88. Every million tonnes of methane reduced avoids losses of 145,000 tonnes of wheat, soybeans, maize and rice ozone exposure every year. UNEP, Clean Air Coalition (2022) 'Global Methane Assessment: Benefits and costs of mitigating methane emissions' page 6 and 11. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

89. The World Health Organisation sets out the links between red meat consumption and cardiovascular disease and also type 2 diabetes. The risks are associated particularly with high meat consumption and when not part of a balanced diet. See: WHO (2023) 'Red and processed meat in the context of health and the environment: many shades of red and green' page 6. https://iris.who.int/bitstream/handle/10665/370775/9789240074828-eng.pdf?sequence=1&isAllowed=y The World Health Organisation classifies red meat as 'probably carcinogenic to humans'. See WHO (2015) 'Cancer: Carcinogenicity of the consumption of red meat and processed meat' https://www.who.int/news-room/questions-and-answers/item/cancer-carcinogenicity-of-the-consumption-of-red-meat-and-processed-meat

90. For an overview of the win-win links between practices such as the re-use of organic waste as fertiliser and soil and biodiversity health, see The Global Climate and Health Alliance, Veigh-Gaynor et al (2023) 'Mitigating Methane from Food and Agriculture' https://climateandhealthalliance.org/wp-content/uploads/2023/08/MethaneReport-Ag-FINAL.pdf For discussion about the mitigation of impacts of the current global food systems, see Science Direct, One Earth, Dalin et al (2019) 'Impacts of Global Food Systems on Biodiversity and Water: The Vision of Two Reports and Future Aims' https://www.sciencedirect.com/science/article/pii/S2590332219301307

91. In addition to existing feeding strategies already discussed, there is scope for further reduction in methane emissions from smallholder farms through the take up of new breeds of ruminants selected for their reduced enteric emissions. See, for example, Climate Xchange, Jenkins et al (2024) 'Breeding for reduced methane emissions in livestock' https://www.climatexchange.org.uk/wp-content/uploads/2025/01/CXC-Breeding-for-reduced-methane-emissions-in-livestock-May-2024.pdf

92. See Climate Policy Initiative, Zabeida et al (2025) 'Waste not: Time to rapidly scale methane abatement finance in the waste sector' https://www.climatepolicyinitiative.org/wastot-time-to-rapidly-scale-methane-abatement-finance-in-the-waste-sector/#:~:text=The%20waste%20sector%20is%20responsible,1.5%C2%B0C%20

warming%20scenario.

93. See UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 25. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

94. This is the projection of the World Bank, summarised by the Clean Air Task Force in 2022. See Clean Air Task Force, Siegel (2022) 'How our trash contributes to climate change – and what we can do about it' https://www.catf.us/2022/09/how-our-trash-contributes-to-climate-change/#:~:text=The%20World%20Bank%20estimates%20that,over%20the%20next%20decade%20alone.

95. One third of food production is never consumed. See UNEP (2022) 'Why the global fight to tackle food waste has only just begun' https://www.unep.org/news-and-stories/story/why-global-fight-tackle-food-waste-has-only-just-begun#:~:text=Our%20global%20food%20systems%20are,along%20production%20and%20supply%20chains.

96. See: UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 123 and page 87. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

97. The hierarchy approach is set out clearly in Global Alliance for Incinerator Alternatives, Walsh (2022) 'A Key to Rapid Methane Reductions: Keeping Organic Waste from Landfills' https://www.no-burn.org/wp-content/uploads/2022/11/GAIA_White_Paper_A_Key_to_Rapid_Methane_Reductions_FINAL.pdf . The approach is laid out in the infographic at: Climate and Clean Air Coalition (2025) 'Waste and Mitigation Hierarchy Infographic' https://www.ccacoalition.org/resources/waste-and-mitigation-hierarchy-infographic

98. A one third reduction of methane emissions from waste by 2030 (compared with 2020 levels) is a consistent feature of models that return the world to a 1.5°C compatible warming pathway. See: UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' Page 89. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

99. For the quantities of water and other resources wasted, see The Economist, M. S. L. J. (2016) 'Why wasting food is bad for the planet' https://www.economist.com/the-economist-explains/2016/08/28/why-wasting-food-is-bad-for-the-planet?utm_medium=cpc.adword.pd&utm_source=google&ppccampaignID=18151738051&ppcadID=&utm_campaign=a.22brand_pmax&utm_content=conversion.direct-response.anonymous&gad_source=1&gad_campaignid=18151761343&gbraid=0AAAAADBuq3J2MugcRVWB4tyKUeBRg_

100. See UNEP (2022) 'Amid food and climate crises, investing in sustainable food cold chains crucial' https://www.unep.org/news-and-stories/press-release/amid-food-and-climate-crises-investing-sustainable-food-cold-chains#:~:text=Amid%20food%20and%20climate%20crises%2C%20investing%20in,food%20cold%-20chain%20infrastructure%20as%20developed%20countries. And, for more detail, UNEP and FAO (2022) 'Sustainable food cold chains: Opportunities, challenges and the way forward' https://www.unep.org/resources/report/sustainable-food-cold-chains-opportunities-challenges-and-way-forward

101. Behaviour change and expectation management make a difference. In hotels for the wealthy, as an example, the nature of 'luxury' needs to be refined. The 'all you can eat' breakfast buffet is neither healthy (encouraging over-eating) nor sustainable. They produce excessive wasted food – more than double the amount typically generated by plated breakfasts. Travellers often value the concept of sustainability, inviting serious consideration of alternative ways to engender the feeling of being spoiled. See BBC Travel, Lele (2025) 'Is it time to retire the all-you-can-eat breakfast buffet?' https://www.bbc.co.uk/travel/article/20250815-the-slow-death-of-the-breakfast-buffet

102. The net result of food donation was found in one study to be more useful in reducing methane emissions than allowing food to go to anaerobic digestion. See Science Direct, Resources, Conservation and Recycling, Sundin et al (2022) 'Surplus food donation: Effectiveness, carbon footprint, and rebound effect' https://www.sciencedirect.com/science/article/pii/S0921344922001197#:~:text=Although%20UCM%20is%20unable%20to,outside%20the%20specific%20case%20study.

103. For an explanation of the importance of keeping organic waste out of landfill, see Global Alliance for Incinerator Alternatives, Walsh (2022) 'A Key to Rapid Methane Reductions: Keeping organic waste from landfills' https://www.no-burn.org/wp-content/uploads/2022/11/GAIA_White_Paper_A_Key_to_Rapid_Methane_Reductions_FINAL.pdf ; see also Compost Crew (undated) 'Digging into Methane Emissions' https://compostcrew.com/diggingintomethane/#:~:text=Our%20crew%20members%20track%20the,for%20our%20hard%2Dworking%20microbes.

104. Methane emissions from food often become fugitive emissions even at sites where methane capture infrastructure exists. This is because food waste decomposes quickly, and often faster than infrastructure can be organised to capture methane from recent waste deposits. For every 900 tonnes of food waste in landfill, 34 tonnes of fugitive methane emissions are released. See US Environmental Protection Agency (2023) 'Food Waste Management: Quantifying Methane Emissions from Landfilled Food Waste' pages 9, 11, 13. https://www.epa.gov/system/files/documents/2023-10/food-waste-landfill-methane-10-8-23-final_508-compliant.pdf

105. The US Environmental Protection Agency sets out a clear summary of the process of methane production from food waste in their Food Waste Management report. Ibid page iii for the Executive Summary.

106. For a discussion of the further potential for a 90% reduction of methane from waste by managing food waste and separating organics, see: CE Delft, van der Veen et al (2022) 'Methane reduction potential in the EU: Between 2020 and 2030' page 5 https://cedelft.eu/wp-content/uploads/sites/2/2022/06/CE_Delft_210502_Methane_reduction_potential_in_the_EU_Def.pdf

107. Methane emissions from waste are growing most rapidly in places where population growth is most rapid – and where waste collection is most poorly managed. See: UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 20. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

108. A study of Danish methane collection at landfill sites demonstrated that the efficiency of methane collection ranged from 86% all the way down to 13%, with an average of 50%. The UK and US achieved around 64% efficiency. All countries, therefore, continue to emit methane even with these collection practices. See Waste Management, Duan et al (2021) 'Efficiency of gas collection systems at Danish landfills and implications for regulators' https://www.sciencedirect.com/science/article/pii/S0956053×21006681

109. Management approaches can significantly influence the levels of emissions from landfill. See for example, Waste Management and Research, Scharff et al (2023) 'The impact of management approaches on methane emissions' https://journals.sagepub.com/doi/10.1177/0734242×231200742#:~:text=Waste%20management%2C%20in%20particular%20the,significantly%20reduce%20global%20radiative%20forcing.

110. Measurement of methane from landfill sites shows that the highest levels of emissions are found at the 'workface' – the area where activity is highest, and emissions management is hardest to organise. Typically over 50% of methane emissions arise from this working section of landfill. See, for example: Environmental Science Technology, Scarpelli et al (2024) 'Investigating Major sources of Methane Emissions at US Landfills' https://pmc.ncbi.nlm.nih.gov/articles/PMC11636198/#:~:text=Landfills%20with%20work%20face%20emissions,and%20traditional%20emissions%20accounting%20methods. Also, for example, US EPA (2024) 'Enforcement alert: EPA Finds MSW Landfills are Violating Monitoring and maintenance Requirements' https://www.epa.gov/enforcement/enforcement-alert-epa-finds-msw-landfills-are-violating-monitoring-and-maintenance#:~:text=EPA%20Investigations%20Find%20Municipal%20Solid,Gas%20Collection%20and%20Control%20System&text=This%20Enforcement%20Alert%20is%20intended,adequate%20MSW%20landfill%20cover%20integrity.

111. The EU Landfill Directive prohibits the use of landfill for any waste that is suitable for re-use or recycling from 2030. Biodegradable waste must progressively be diverted away from landfill. See EU (Undated) 'Landfill Waste' https://environment.ec.europa.eu/topics/waste-and-recycling/landfill-waste_en#:~:text=EU%20countries%20must%20implement%20national,Implementation ; Canada is aiming to reduce methane emissions from landfill by 50% below 2019 levels – by 2030. See Global Methane Pledge (2024) 'Canada – GMP Methane Action Update (September 2024)' https://www.globalmethanepledge.org/news/canada-gmp-methane-action-update-september-2024#:~:text=Agriculture%20(27%25%20of%20methane%20emissions,by%202030%20(from%202020).

112. Recovery is particularly important in countries where waste management is already well organised, and technical solutions add a final level of emissions reduction. The EU, for example, in its Waste Framework Directive, lists the hierarchy of actions against methane emissions. The Directive places 'recovery' and the 'disposal' as the last preferences for methane management. See: European Energy Agency (2022) 'Methane Emissions in the EU: the key to immediate action on climate change' section heading – 'Methane in the waste sector in EU' https://www.eea.europa.eu/en/analysis/publications/methane-emissions-in-the-eu-the-key-to-immediate-action-on-climate-change#:~:text=For%20example%2C%20landfill%20gas%20recovery%20in%20managed%20waste%20sites%20or,common%20technology%20to%20produce%20hydrogen.

113. These are some of the kinds of challenges experienced amongst the 13 cities taking part in the C40 Pathway Towards Zero Waste initiative. The 13 participant cities have a wide range of socio-economic histories and current status, and they start from very different positions. Some have little or no organised refuse collection, and some are able to contemplate decommissioning landfill sites as they get closer to a zero waste endpoint. Although each city varies in its particular challenges, the themes are often similar: organising and making progress towards the objectives of city-wide collection, treating 30% of organic waste and reducing waste emissions by 30%. See C40 Cities (2023) 'Pathway towards Zero Waste: How cities are accelerating the reduction of methane emissions' https://www.c40.org/wp-content/uploads/2024/03/C40_Pathway_Towards_Zero_Waste_Report_2023.pdf

114. The need for funding, income and investment in waste management systems is seen as an important part of developing waste systems in cities. See C40 Cities (2023) 'C40 Pathway Towards Zero Waste: How cities are accelerating the reduction of methane emissions' page 7. https://www.c40.org/wp-content/uploads/2024/03/C40_Pathway_Towards_Zero_Waste_Report_2023.pdf

115. The costs of managing waste need to be considered in the context of a business as usual scenario, where costs are projected to rise anyway - almost doubling by 2050. Tackling the waste with a view to improving lives and reducing methane emissions avoids these increased costs, and ultimately should deliver net gains. Kicking off this process is therefore a valuable opportunity. See Climate Policy Initiative, Zabeida et al (2025) 'Waste not: Time to rapidly scale methane abatement finance in the waste

sector' https://www.climatepolicyinitiative.org/waste-not-time-to-rapidly-scale-methane-abatement-finance-in-the-waste-sector/ See also: UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 96. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

116. For a discussion about the challenges of integrating the informal sector into strategies for a greener future, see Habitat International, Brown et al (2016) 'The urban informal economy, local inclusion and achieving a global green transformation' http://www.sciencedirect.com/science/article/pii/S0197397515002325 . In Amman, Jordan, efforts with recycling banks include 'trash to cash' initiatives intended to improve the lives of informal sector workers. See C40 Cities (2023) 'C40 Pathway Towards Zero Waste: How cities are accelerating the reduction of methane emissions' page 7. https://www.c40.org/wp-content/uploads/2024/03/C40_Pathway_Towards_Zero_Waste_Report_2023.pdf . http://www.sciencedirect.com/science/article/pii/S0197397515002325 In eThekwini, South Africa, the city 'has taken a conscious step to … integrate informal waste workers.' Ibid page 16.

117. For a summary taken from a wide-ranging literature review of possible interventions in support of behaviour change for effective climate policy, see University of Bath, Mitev et al (2023) 'The Implications of Behavioural Science for Effective Climate policy' Page 1 for Executive Summary, and Page 9 for detail in relation to diet change. https://www.theccc.org.uk/publication/the-implications-of-behavioural-science-for-effective-climate-policy-cast/

118. Women in particular are important in implementing behaviour change, since they tend to manage household consumption. See UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 115. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

119. The Global Methane Pledge Waste Pathway was launched in November 2022. It targets emission cuts across the entire solid waste value chain—through prevention, diversion, energy recovery, and better landfill practices. The Global Methane Initiative promotes training and resource dissemination to incrementally help with estimating emissions and monitoring and reporting. See Global Methane Pledge (Undated) 'Waste Pathway' https://www.globalmethanepledge.org/annual-report/waste-pathway# ; Technically feasible measures for reducing methane emissions, such as organic waste separation, anaerobic digestion, and methane capture could reduce emissions of methane by tens of millions of tonnes annually by 2030, up to 40% of the global total. See for example, Clean Air Coalition (undated) 'Methane: Solutions' https://www.ccacoalition.org/short-lived-climate-pollutants/methane .

120. See UNEP (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 6 https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

121. The UK, for example, reduced methane emissions from landfill sites by 75% between 1990 and 2020. This contributed to an overall reduction of methane emissions of 62%, when combined with the energy sector. Gas collection at landfill sites was important, but a tax on landfill sites, and banning organic waste from going to landfill were also important. Gov.UK (2022) 'United Kingdom methane memorandum – 3. UK progress to date' https://www.gov.uk/government/publications/united-kingdom-methane-memorandum/united-kingdom-methane-memorandum#:~:text=%5Bfootnote%2015%5D-,3.,gas%20emissions%20(52%20MtCO2e%20).&text=This%20percentage%20reduction%20is%20more,15%25%20and%2041%25%20respectively.&text=In%202020%2C%20UK%20methane%20emissions,27%20average%20(1.0%20tCO2e%20).&text=For%20the%20UK%2C%20the%20largest,4%20MtCO2e%20(or%2015%25).&text=This%20section%20will%20provide%20an,achieved%20reductions%20across%20each%20sector.&text=Source:%20BEIS%20%2C%20UK%201990%2D2020%20Greenhouse%20Gas%20Inventory.

122. This is particularly true in India, for example, where the waste sector already has the largest potential for abatement, and is likely to grow rapidly. See UNEP and Climate and Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions' page 97. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

123. See The Global Methane Hub (2025) 'Methane Emissions Reduction: Is the emergency brake on global warming' https://www.globalmethanehub.org/

124. In Bangladesh, a flood prone nation, the impact of poor waste management has been noted as a major factor in severe flooding. In particular, plastic blocks drainage and flood management infrastructure. See for example the contribution of waste management to very severe flooding in 2022. IPS, Das (2022) 'The worst flood in the region in the last 122 years' https://www.ips-journal.eu/interviews/the-worst-flood-in-the-region-in-the-last-122-years-6044/ ; see also International Society for Human Rights (2025) 'Bangladesh's Plastic Tide: A nation grappling with a mounting crisis' https://ishr.org/bangladeshs-plastic-tide-a-nation-grappling-with-a-mounting-crisis/#:~:text=Several%20factors%20contribute%20to%20Bangladesh's,of%20those%20dependent%20on%20it.

125. However, anaerobic digestors can, themselves, emit methane. See, for example, Waste Management, Wechselberger et al (2025) 'Assessment of whole-site methane emissions from anaerobic digestion plants: Towards establishing emission factors for various plant configurations' https://www.sciencedirect.com/science/article/pii/S0956053x24005786#:~:text=Biogas%20and%20biomethane%20production%20from,to%20address%20CH4%20emissions. See also National Physical Laboratory (UK), Howes et al (2025) 'Methane from Anaerobic Digestion (MEAD) Study' https://assets.publishing.service.gov.uk/media/6790fadecf977e4bf9a2f15f/mead-study.pdf

126. eThekwini in South Africa is undertaking a feasibility study for using methane capture to fuel waste collection vehicles. See C40 Cities (2024) 'C40 Pathway Towards Zero Waste: How cities are accelerating the reduction of methane emissions' Page 7. https://www.c40.org/wp-content/uploads/2024/03/C40_Pathway_Towards_Zero_Waste_Report_2023.pdf

127. For an overview of the energy potential from different kinds of organic waste, see Science Direct, Kakkar (2024) 'Transforming food waste into energy: A comprehensive review' https://www.sciencedirect.com/science/article/pii/S2590123024016293

128. See, for example, The Landfill Gas Expert (2019) 'Fugitive Emissions of Methane and Landfill Gas Explained' https://landfill-gas.com/fugitive-emissions-of-methane-landfill-gas#:~:text=Landfill%20Gas%20Industry%20Data%20on,to%20be%200.42%20per%20cent.

129. For an analysis suggesting that the one third figure probably underestimates real food losses, which are probably up to 40%, see World Resources Institute, Goodwin et al (2024) 'How Much Food Does the World Really Waste? What We Know – and What We Don't' https://www.wri.org/insights/how-much-food-does-the-world-waste#:~:text=agriculture-,Food%20Loss%20and%20Waste,gas%20emissions%20warming%20the%20planet.

130. See, for example, UNEP, Clean Air Coalition (2021) 'Global Methane Assessment: Benefits and costs of mitigating methane emissions - Technical Controls: Waste' page 107. https://www.ccacoalition.org/sites/default/files/resources//2021_Global-Methane_Assessment_full_0.pdf

131. The LOW- Methane initiative (Lowering Organic Waste Methane) was launched at COP28. It aims to unlock over $10 billion in public and private investment, and to provide leadership and guidance. See press release, Global Methane Pledge (2023) 'Lowering Organic Waste Methane Initiative (LOW-Methane)' https://www.globalmethanepledge.org/news/lowering-organic-waste-methane-initiative-low-methane#:~:text=At%20COP28%2C%20a%20coalition%20of,on%20the%20Global%20Methane%20Pledge.