Methane Matters:

A comprehensive approach to methane mitigation

 This report was written and researched by the Changing Markets Foundation, the Environmental Investigation Agency and the Global Alliance for Incinerator Alternatives.

www.changingmarkets.org

www.eia-international.org

www.no-burn.org

Published in March 2022

Design: Pietro Bruni - toshi.ltd

Contents

List of abbreviations 4

List of boxes, figures infographics and tables 4

Glossary 5

Executive summary 6

1. Introduction 10

2. Tackling methane emissions in the agricultural sector 13

2.1. State of play 13

2.2. Recommended interventions 15

2.3. Co-benefits 20

3. Tackling methane emissions in the energy sector 23

3.1. State of play 23

3.2. Recommended interventions 24

3.3. Co-benefits 27

4. Tackling methane emissions in the waste sector 29

4.1. State of play 29

4.2. Recommended interventions 29

4.3. Co-benefits 36

5. Towards a global governance framework for methane: Cross-sectoral actions 41

5.1. Monitoring, reporting and verification 41

5.2. National methane action plans 42

5.3 Technical and financial assistance 42

6. Conclusion 45

7. References 49

List of abbreviations

AD	Anaerobic digestion
CH_4	Methane
CO_2e	CO_2 equivalent
COP26	2021 UN Climate Conference
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
GMA	Global Methane Assessment
Gt	Gigaton
HFC	Hydrofluorocarbon
IEA	International Energy Agency
IMEO	International Methane Emissions Observatory
IPCC	Intergovernmental Panel on Climate Change
LFG	Landfill gas
LNG	Liquefied natural gas
MRV	Monitoring, reporting and verification
MSW	Municipal solid waste
Mt	Megatonne
NDC	Nationally Determined Contribution
UNEP	UN Environment Programme

List of boxes, figures infographics and tables

Figure

Figure 4.1: Waste hierarchy for methane prevention (or alternatively for organic waste) 30

Infographics

Infographic 1.1: The science of methane 12

Infographic 4.1: Geographical distribution of methane emissions per sector 38

Table

Table 6.1: Summary table of measures 46

Boxes

Box 2.1: Corporate actors oblivious to livestock methane 15

Box 2.2: The missing roadmap 16

Box 3.1: Prioritising super emitters 27

Box 4.1: Reductions in methane emissions from composting, bio-stabilization and biologically active cover in the waste sector 32

Box 4.2: Success stories from India and South Korea 33

Box 4.3: Organic waste policy developments around the world. 34

Box 4.4: Integrating waste pickers into the formal waste economy 37

Glossary

Agroecology –promotes application of ecological concepts, principles and farming practices that mitigate climate change, work with wildlife and are respectful of farmers and communities.

Anaerobic digestion – refers to the process by which organic waste – such as animal manure and food waste - is broken down to produce biogas and biofertilizer.

Biogenic CO_2 – refers to CO_2 that is released from the combustion or decomposition of organic matter such as trees or food products, as compared to non-biogenic CO_2 that comes from fossil fuels.

Bio-stabilisation- refers to any aeration or mixing treatment that helps break down residual organic material in mixed waste and reduces its methane-generating potential before it goes to landfill.

Closed mine – refers to a mine where extracting activities have ceased.

Coal mine methane – refers to the methane released from coal and the surrounding rock strata from mining activities.

Drainage – refers to the action of removing methane-rich gas from coal or surrounding rock strata.

Enteric fermentation – refers to the digestive process in ruminant animals by which microbes in the digestive tract decompose and ferment food, producing methane as a by-product.

Flaring- refers to the controlled combustion of methane for the purpose of disposal in a device designed for said combustion.

Fugitive emission – refers to emissions of greenhouse gases that are not produced intentionally.

Incineration – refers to burning of waste at incineration facilities, which sometimes use the resulting heat to generate electricity in so-called "waste-to-energy" incineration. Different from open burning, which describes unmanaged waste burning outside of the official waste management system.

Landfills - refers to both sanitary landfills as well as unmanaged landfills and dumpsites, which have comparable methane-generating potential.

Landfill gas capture – refers to the use of piping systems to collect biogas generated in landfills for flaring or use as fuel.

'Less and better meat and dairy' – refers to reduction in consumption of meat and dairy and shift to better production methods. 'Better' means meat and dairy that is better for the environment, produced in so-called low intensity systems, better for animal welfare and better for health, i.e. non-processed meat.

Material recovery and biological treatment – refers to a bio-stabilisation process that involves the sorting out of reusable or recyclable materials from mixed waste before bio-stabilization occurs.

Municipal solid waste – refers to commercial and residential waste. Industrial, construction, and hazardous waste is typically not included.

Petrochemical – refers to a chemical product derived from crude oil or fossil fuels (coal or fossil gas).

Scope 3 emissions – refers to indirect emissions that occur in company's supply chains.

Super-emitter events or infrastructure – refers to abnormally large sources of methane emissions. These can include isolated events such as leaks at methane-generating sites, or ongoing emissions from super-emitter sites, such as landfills or dairy farms.

Ventilation shaft – refers to a vertical passage used to move fresh air underground or to remove methane and other gases from an underground coal mine

Venting- refers to the release of uncombusted methane into the atmosphere either intentionally from processes, activities or devices designed for such a purpose, or unintentionally in the case of a malfunction or geological constraints

Zero waste – refers to the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning, and with no discharges to land, water, or air that threaten the environment or human health.

Executive summary

Human-induced climate change, including more frequent and intense extreme weather events, has already caused widespread adverse impacts to nature and people, according to the Intergovernmental Panel on Climate Change (IPCC). Some of the changes experienced today are already irreversible and disproportionately affect the most vulnerable populations.[1] Approximately 3.3 to 3.6 billion people live in areas and situations that are highly vulnerable to climate change and the IPCC warns that even 1.5°C of warming, which is what the governments are aiming for, would be extremely dangerous and will present numerous risks to ecosystems and humans. Actions taken in this decade will be critical in determining the extent of global warming for the centuries to come.[2]

Methane is a short-lived but extremely potent gas – it has 82.5 times more warming potential than CO_2 over a 20-year timespan.[3] Because of its short lifespan – methane degrades in 12 years – the rapid reduction of methane emissions presents itself as a key opportunity to slow the rate of warming and help us to stay below 1.5°C of warming.

Under current policy scenarios, anthropogenic methane emissions are expected to continue to increase by more than 15% by 2030, reaching nearly 380 million tonnes per year, an 8% increase from 2020 levels.[4] Concerted efforts between countries are needed to see a drastic reduction of methane emissions at the global level and across the three high-emitting sectors: agriculture, energy and waste.[5] As a result, more than 110 countries committed to the 'Global Methane Pledge' (henceforth called 'the Pledge') – an initiative launched at the 2021 UN Climate Conference (COP26) in Glasgow. The Pledge has the collective goal of reducing global methane emissions by 30% by 2030, compared with a 2020 baseline.[6] Although a step in the right direction, this commitment falls short of the ambition needed to stay below 1.5°C warming.[7] **According to the UN Environment Programme's Global Methane Assessment (GMA), methane emissions should be reduced by at least 45% in this critical decade of climate action**.[8]

With 2030 only a few years away, this briefing provides recommendations for governments on immediate actions that can be taken in national action plans, identifying specific measures and policies to cut methane in the main methane-emitting sectors. These include models developed by scientists as well as best practice and examples of successful policies around the world. In parallel, governments should enhance global governance on methane to enable and support national action on methane, with provisions on monitoring, reporting and verification (MRV) and financial and technical assistance.

Agriculture is the largest source of anthropogenic methane emissions. Tackling the way we produce and consume food is critical to stabilising the climate to acceptable temperatures. The GMA concluded that targeted technical measures, which are already available, could reduce methane emissions in the ruminal livestock sector by around 30 million tons per year by 2030.[9] These measures focus on the production of food and include improving feed quality, manure management and rice production. However, technical measures will not suffice on their own: it is crucial that governments adopt policy measures to promote healthier diets with less and better meat and dairy and more sustainable food production systems. In addition, large meat and dairy companies must be regulated to report and reduce their methane emissions.

The energy sector presents opportunities for significant methane mitigation at zero to low cost with existing technologies and best practices. For oil and gas, this includes leak detection and repair, technology standards and bans on routine venting and flaring along with initiatives to address inactive wells through capping or capture and use. For coal, this includes measures on routine venting and flaring in ventilation shafts and drainage and degasification stations along with initiatives to address inactive coal mines. Taken together with the swift economy-wide managed phase-out of fossil fuels, the energy sector has the potential to significantly contribute to limiting temperature increase through 2030 and beyond.

The waste sector is the third-largest source of anthropogenic methane emissions worldwide, contributing roughly 20% of all such emissions. Following the waste hierarchy, organic waste prevention is the most powerful tool for reducing methane emissions, including preventing upstream emissions involved in its production, management and transport. Source separation of organic discards, coupled with composting, bio-stabilisation of residual waste and biologically active cover for landfills and dumps can reduce solid waste methane emissions by as much as 95% by 2030. Composting alone, an age-old practice utilised around the world, could reduce solid waste methane emissions by 78% by 2030. Furthermore, waste prevention, source separation and composting of organic discards can create more and better jobs than other disposal methods, as well as a more stable, dignified livelihood for workers in the informal waste sector.

In addition to the measures from different sectors, countries should set out to develop a common framework for MRV of methane emissions. To assist countries, the International Methane Emissions Observatory could provide satellite surveillance and verification services as well as an early warning system for super-emitters. Collective action on methane will also require technical assistance to policymakers as well as financial assistance to developing countries.

Reducing methane emissions across all major emitting sectors will also bring numerous co-benefits, ranging from improving public health and creating jobs to saving costs for municipalities. Because methane is a primary contributor to the formation of ground-level ozone, cutting emissions by 45% would also have the potential to prevent 255,000 premature deaths and 775,000 asthma-related hospital visits each year.[10] Importantly, measures designed to reduce methane emissions should be seen as a key trajectory to cut all greenhouse gas emissions. It is a coherent strategy that leads to the accelerated establishment of fossil-fuel-free, zero-waste societies with healthy plant-rich diets – the foundation to enable sustainable food production systems.

This briefing outlines recommendations, examples of successful policies and an overview of methane reduction potentials across all three sectors.

Delegates at the Cop26 in Glasgow.
Credit: *Wikimedia Commons*


ited Nations
mate Change
UN CLIMAT
CONFEREN
IN PARTNERSHIP WITH ITALY
United Nations
Climate Change
UN CLIMATE
CHANGE
CONFERENCE
UK 2021

1. Introduction

The year 2021 was registered as the fifth-hottest year in the past 52 years according to the EU's Copernicus Climate Change Service, while the last seven years rank as the hottest on record overall.[11] Globally, in 2021, temperatures were on average 1.2°C higher than preindustrial levels.[12]

The steady warming corresponds with the scientific consensus that increasing levels of greenhouse gases (GHGs) in the atmosphere are causing long-lasting changes to the climate system.[13] Using satellite measurements, the EU Copernicus Programme found that GHG concentrations continued to rise in 2021.[14] While the rate of increase in carbon dioxide (CO_2) levels seems to have marginally slowed down from a few years earlier, the analysis found that concentrations of methane grew at their fastest pace in two decades, with a record peak of 1,900 parts per billion in September 2021, the highest in nearly four decades of records.[15,16]

Tackling methane, the second-most important GHG after CO_2 responsible for about 0.5°C of warming today, is a low-hanging fruit for climate policy.[17] Because methane is a very potent but short-lived gas, the swift reduction of methane emissions is a key opportunity to slow the rate of warming rapidly, while fundamental efforts in society to cut more long-lasting CO_2 emissions continue.

The IPCC indicates that the scale of reduction of global methane emissions could decide whether global warming can be kept below 1.5°C and whether tipping points will be reached, which would accelerate irreversible changes to the climate system.[18,19] In light of these findings, more than 110 countries have committed to the 'Global Methane Pledge' (henceforth called 'the Pledge') – an initiative launched at the 2021 UN Climate Conference (COP26) in Glasgow – representing '*nearly half the global methane emissions*' and '*70% of global GDP.*'[20] The Pledge has the goal of '*reducing global methane emissions by at least 30% from 2020 levels by 2030 and moving towards using best available inventory methodologies to quantify methane emissions.*'[21]

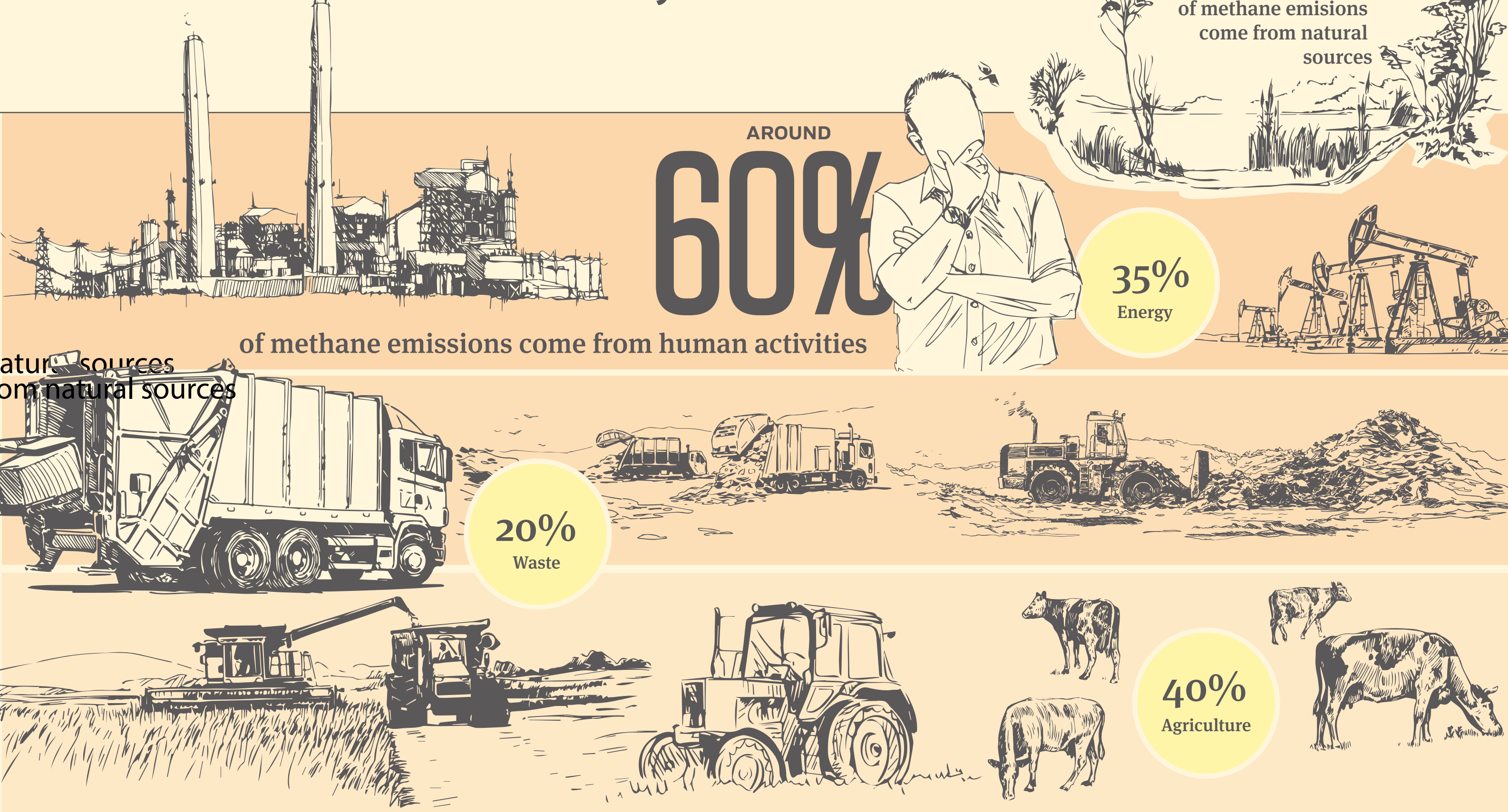
The Pledge represents an important milestone, committing signatories to collectively reduce global anthropogenic methane emissions across all sectors. Although this is a starting point for a decade of increasing ambition on methane, the Pledge unfortunately falls 10–15% short of the cuts needed to firmly ensure consistency with the 1.5°C target.[22] In April 2021, using a business-as-usual baseline, the UN Environment Programme (UNEP) calculated in its Global Methane Assessment (GMA) that '*global methane emissions must be reduced by between 40–45% by 2030 to achieve least-cost pathways that limit global warming to 1.5°C this century,*'[23]. Other studies have reinforced the idea of '*at least 45%.*' A 2021 study featured in *Carbon Brief* found that cutting methane can have a huge impact on limiting near-term warming, but using a modelling scenario that is closest to the combined impact of current Nationally Determined Contributions (NDCs) by individual countries, the study demonstrates that global methane reductions of around 50% by 2030 would likely be needed to reach a 0.2°C reduction by 2050.[24]

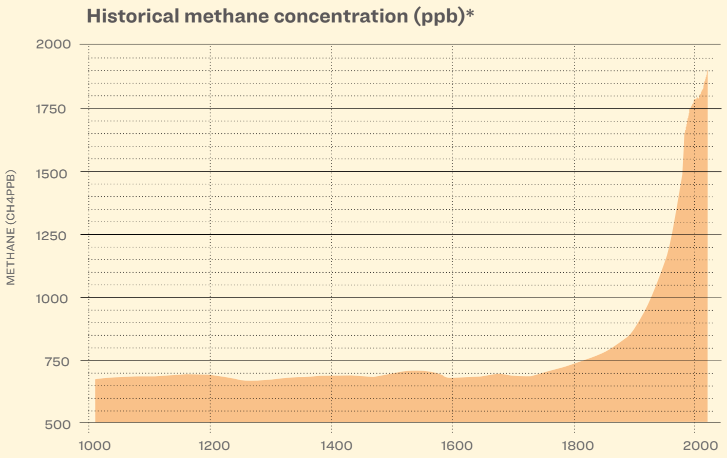
In what is so far the most detailed report on methane mitigation opportunities, the GMA estimates that 30% of the necessary 45% methane reduction could be achieved by readily available measures.[25] Importantly, 60% of these targeted measures are low cost and 50% have negative costs.[26] Both technical measures addressing methane directly and additional measures and policies that influence behaviours and change taxation systems will be needed to bring methane emissions in line with the Paris Agreement.[27]

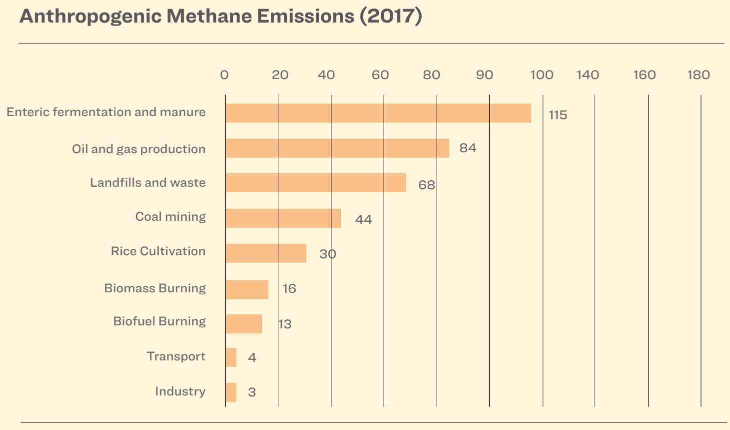
What is more, reducing methane emissions goes beyond solving the climate emergency and has been associated with tremendous co-benefits. This is in part because methane contributes to ozone formation, which is a potent local air pollutant that causes serious health problems, contributing to illnesses and premature deaths, as well as losses in agricultural harvests not only locally but on a much wider geographical scope.[28] Cutting methane by 45% would have the potential to prevent 255,000 premature deaths and 775,000 asthma-related hospital visits each year,[29] as well as increase global crop yields by 26 million tonnes per year.[30]

Methane from human activity falls into three main sectors: agriculture (40%), energy (35%) and waste (20%).[31] This report sets out immediate actions to reduce methane emissions in all three sectors, identifying policies for policymakers to go beyond the Pledge. While at the time of writing it is not yet clear how, if at all, the collective commitment in the Pledge will be transposed into national commitments, this briefing takes the view that methane reductions should be maximised across the three sectors in all countries, accompanied by a global governance framework specific to methane to deliver reductions in 2030 and beyond. This is based on a simple notion that the more methane emissions are reduced, the bigger the impact on limiting warming, buying us precious time as we decarbonise our economies. With a track record of missed targets in the past decades, hitting the 'methane emergency break' is an important climate strategy.

The Science of Methane – Key Facts







*2 Degrees Institute. 2021.Global CH4 Levels. [Online] https://www.methanelevels.org/

2. Tackling methane emissions in the agricultural sector

2.1. State of play

The single largest contributor to anthropogenic methane emissions is the livestock sector, where around 32% of all man-made methane emissions are estimated to originate from the digestive system (known as enteric fermentation) and manure management of large, farmed animals (cattle, in particular).[32] Together with rice cultivation, the agriculture sector accounts for about 40% of anthropogenic methane emissions.[33] Major contributors include Southeast Asia, Brazil, China and Europe, which together account for nearly 50% of global livestock-related methane emissions.[34] However, it is important to also consider the political dimension of livestock emissions. For example, the Institute for Agriculture and Trade Policy reports that the EU, US and New Zealand alone account for 46% of global dairy production and that companies headquartered in the Global North account for the lion's share of global emissions related to dairy, making these governments the best placed to drive transition.[35]

The Food and Agriculture Organization (FAO) estimated agricultural emissions at 146 million tonnes in 2018 but more-recent estimates, which developed a new model for calculating emissions from rice cultivation, found that the figure is probably closer to 156 million tons.[36] Under 'business-as-usual' scenarios, rising demand for food is set to increase these emissions due to a growing human population and increasing demand for animal protein as incomes rise.[37] These are set to rise by as much as 38% between 2010 and 2050, meaning that by 2050, if applied to the FAO conservative figure of 146 million tonnes, we will face agricultural methane emissions of roughly 200 million tons per year. A recent study demonstrated that even in mitigation pathways that limit warming to 1.5°C, the contribution of future livestock methane emissions to global warming in 2050 remains significant, about a third of that from future net CO_2 emissions. Therefore, if left unaddressed, future livestock methane emissions will significantly constrain the remaining carbon budget and the ability to meet the 1.5°C temperature goal of the Paris Agreement.[38]

Credit: *We Animals media*

BOX 2.1: **Corporate actors oblivious to livestock methane**

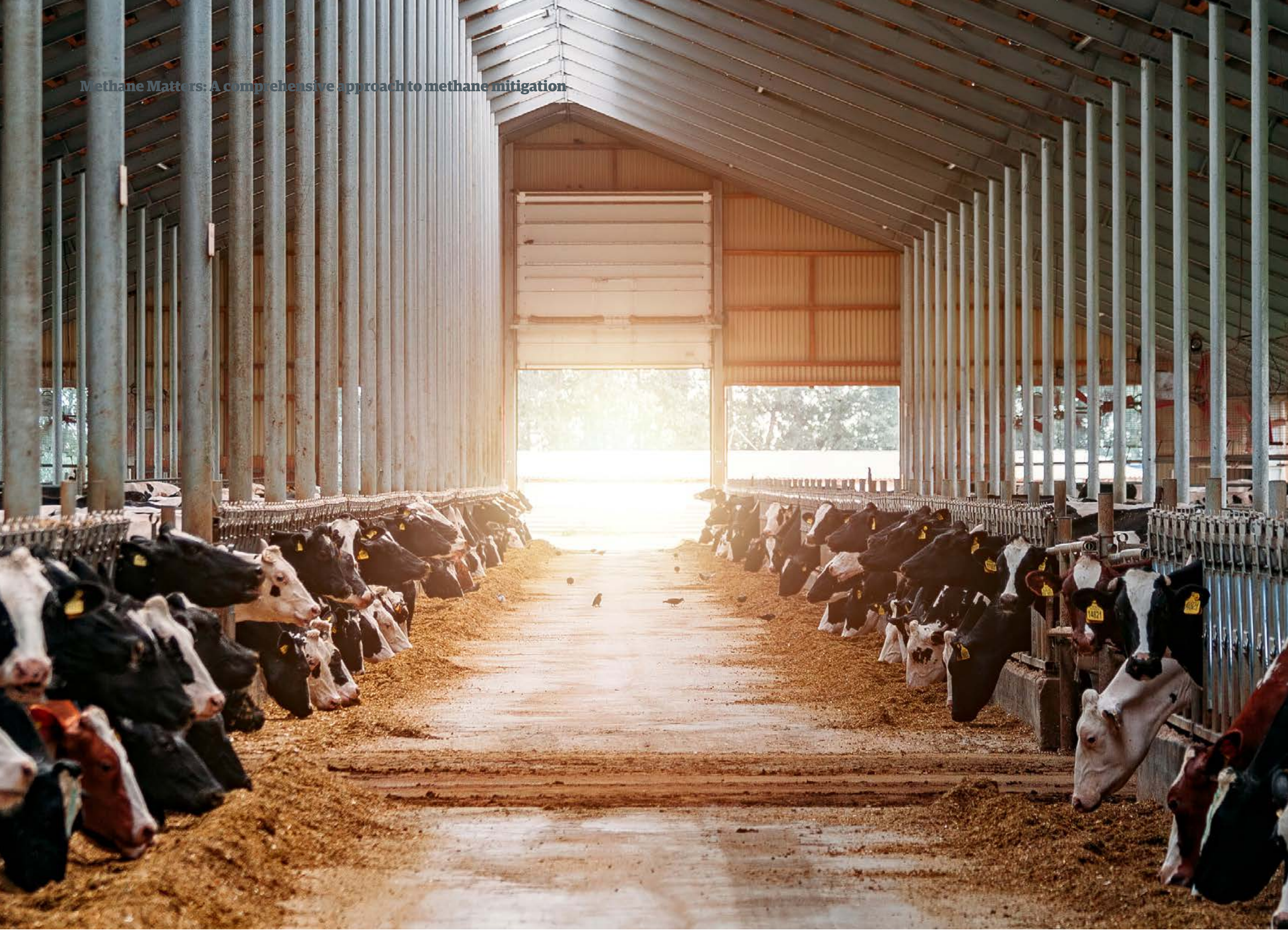
While in the energy sector, 'Big Oil' companies started to feel the pressure and have committed to report their methane emissions, this is not the case for global meat and dairy corporations. A 2018 study found that the five largest meat and dairy companies combined (Cargill, Dairy Farmers of America, Fonterra, JBS and Tyson) are already responsible for more annual GHG emissions than BP, ExxonMobil or Shell.[39] In 2021, the Changing Markets Foundation assessed 20 of the largest meat and dairy companies and found that none of them either reports methane emissions or has meaningful and concrete targets or action plans to reduce them. These disappointing trends were confirmed by the Coller FAIRR Protein Producer Index, which reported that 86% of major meat and dairy suppliers (out of 49 assessed in total) fail to declare or set meaningful reduction targets for all GHG emissions, including those in their supply chain (scope 3 emissions). Only 18% of companies were found to partially report their methane emissions. FAIRR, whose mission is to support and steer investors towards responsible private investment, concluded that despite pockets of leadership and innovation, the animal agriculture sector is unprepared for the decade of transition on climate change and risks looking '*outdated and unattractive*' to investors.[40]

Given the scope of agricultural emissions today and their predicted increases, cutting agricultural methane emissions becomes critical to stabilising the climate to acceptable temperatures. However, despite these stark warnings by scientists, few countries have set targets or are implementing policies to reduce livestock emissions in absolute terms.[41] In 2021, the Changing Markets Foundation[42] analysed methane reporting and policies of 18 countries crucial in the debate around reducing emissions from livestock industries. The results of the analysis demonstrated that governments have yet to grasp the importance of drastic methane reduction measures in general and in the livestock sector in particular. Although most countries report their livestock methane emissions separately, these have been relatively stable or have even increased in some countries. Furthermore, none of the countries has science-based methane reduction targets across all sectors, whereas only two countries (New Zealand and Uruguay) have set fairly weak methane emissions reduction targets for the livestock sector. Although a vast majority of countries include agriculture in their reporting, they lack concrete measures and action plans to transform the way they consume and produce food, including shifts to healthier and more sustainable diets with less and better meat and dairy.

This lack of appetite to tackle agricultural methane is reflected in the Pledge. Although the official announcement[43] of the Pledge by EU and US leaders does mention agriculture and livestock specifically, their focus is very much on technical solutions at farming level (e.g. feed additives) and incentivising biomethane production. It fails to mention the much more significant reductions that could be achieved by reducing livestock numbers through a systemic transition to healthier diets. A recent investigation by Unearthed revealed that the omission was celebrated by the US National Cattlemen's Beef Association, who considered the weak approach as '*a win*', as the livestock industry and the lobby representing it consider itself '*relatively unscathed*' by the Pledge.[44] This is a missed opportunity, as the GMA concluded that targeted technical measures, which are already available, could reduce methane emissions in the ruminal livestock sector by around 30 million tons per year by 2030. However, policy measures designed to influence behaviours, including implementing a shift to healthier diets, could reduce emissions by a further 65–80 million tons over the next few decades. This is almost half of the 180 million tons of annual reductions required to avoid 0.3°C of global heating by the 2040s, contributing significantly to global efforts to limit any temperature rise to 1.5°C.

2.2. Recommended interventions

Authors of the GMA confirm that to achieve a 45% reduction by 2030, a combination of targeted measures and additional measures – i.e. those that reduce methane without primarily targeting it – are needed across all sectors, but especially in agriculture. This is because technical solutions to reduce methane associated with livestock are less readily available than in other major methane-emitting sectors.[45]



Credit: *Shutterstock*

BOX 2.2: **The missing roadmap**

FAIRR, a membership-based investor network representing $48 trillion worth of investment, reported that investors are concerned about the lack of a clear policy roadmap for the agricultural sector to align itself to the 1.5°C target.[46] While the energy sector has a clear roadmap set by the International Energy Agency's NET Zero by 2050 initiative, investors are calling for a similar roadmap for the agriculture and land-use sector. Such a tool would help evaluate the risks of stranded assets more accurately and divert capital to prioritise investments in opportunity sectors such as sustainable protein.

2.2.1. Targeted measures in the livestock sector

It is vital to change how meat and dairy products are produced to keep global temperatures below 1.5°C,[47] in line with the 'better meat and dairy' approach.[48] Better production must go together with a reduction in demand for animal products in line with dietary health guidelines. When it comes to tackling livestock methane emissions specifically, governments should consider adopting the following measures targeting producers and processors to reduce emissions from suppliers.

Technical methane-abatement activities in the livestock sector predominantly focus on three areas: feed, animal health and husbandry, and improved manure management. While some of these solutions could offer cost-effective mitigation pathways, it is worth noting that there are significant variations in estimates of how much mitigation can be achieved through currently available methods and their associated costs,[49] and therefore should be implemented alongside other additional measures (see following sections).

2.2.1.1. Feed quality, additives and supplements

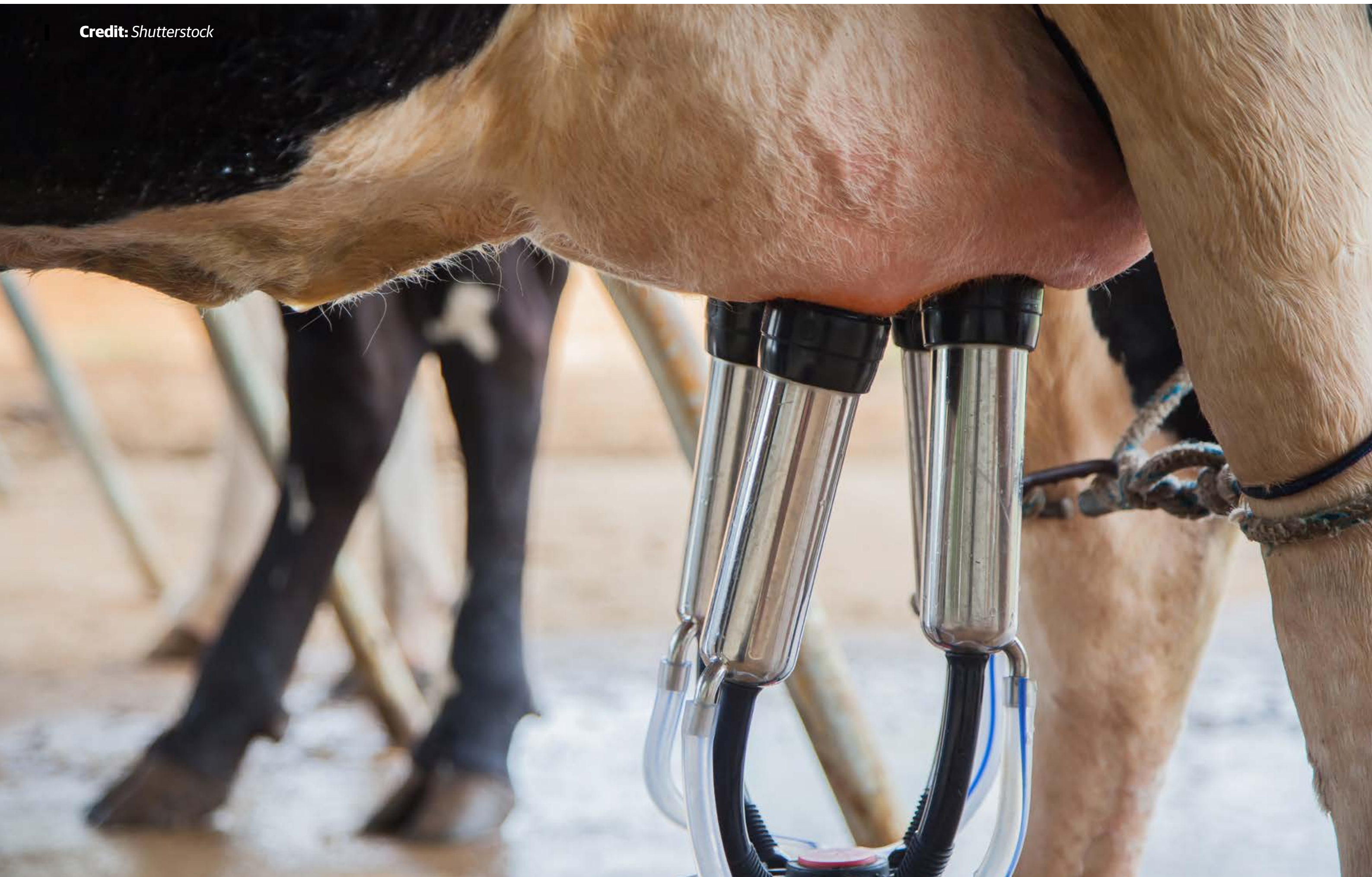
Methane-reducing feed additives and supplements are designed to inhibit the bacteria in the rumen so as to reduce enteric methane emissions. While some look promising, many of these new feed additives are in early stages of development and their effectiveness has yet to be proven.[50] In February 2022, the feed additive Bovaer was authorised for marketing on the EU market,[51] following previous approvals in Chile and Brazil.[52]

2.2.1.2. Animal health and husbandry

The improvement of animal health and the associated increase in productivity have also been identified as a way to reduce methane emissions. This includes, for example, selective breeding, increased use of veterinary services and proactive herd health planning, but access (and costs) to such tools is varied across the world.[53]

2.2.1.3. Improving manure management

Manure represents around 10% of the livestock sector's emissions.[54] Solutions to reduce methane through better manure management exist. Current best practices include covering the outdoor slurry storage and shortening storage time and filtration of the air from the storage facility.[55] Conversion to biogas with the use of anaerobic digesters has also been championed by industry and policymakers as a driver for a more circular economy and the valued-added deployment of agricultural residues. Its roll-out across farms, however, still faces significant barriers (economic, institutional and technical) in both developed and developing countries[56] and there are risks associated with biogas production – transporting biomethane is expensive and complicated. Digesters that are not carefully maintained can also leak (leading to reduction of emissions savings), explode or break down.[57] Most



Credit: *Shutterstock*

importantly, environmental groups, while acknowledging the benefits of biogas, warn that anaerobic digestion (AD) could become an additional subsidy to industrial intensive-farming operations, while it fails to address wider issues associated with factory farming beyond methane emissions, such as animal welfare.[58]

2.2.1.4. Herd-size reduction

While technical measures have limitations and uncertainties with regards to emission reductions, reduction of the number of animals remains the most significant solution to reduce absolute emissions from the livestock sector. This has recently been recognised by the Dutch government as a means to reduce the emissions of another very potent greenhouse gas common in animal agriculture – nitrogen oxide. The Netherlands, which is one of Europe's biggest meat and dairy producers and exporters, has announced a €25 billion plan to reduce livestock numbers by 30% and curb ammonia pollution due to an overload of manure.[59] In a similar vein, Germany has also announced plans to reduce livestock numbers on farms.[60] This is critical in achieving food systems in which the principle of 'less but better meat' is embraced and could bring a number of co-benefits.

2.2.1.5. Mandatory climate targets for meat and dairy companies

Meat and dairy production is a highly concentrated industry with a handful of companies taking up the vast majority of the market and producing the most emissions.[61] Governments can drive the transition by obligating meat and dairy companies headquartered within their jurisdiction to set science-based climate targets, which include scope 3 emissions, and action plans to meet these targets. Such action plans should include concrete measures to reduce absolute emissions and specific methane emissions mitigation measures and robust reporting.

2.2.2. Management of rice paddies

In general, the longer rice fields are continuously flooded, the greater the methane emissions. As a result, any technique that reduces continuous flooding tends to reduce methane emissions.[62] Solutions related to paddy water management such as mid-season drainage and intermittent irrigation should be promoted.[63] In addition, there is mounting evidence that ploughing in rice straw during the off-season cuts methane emissions by half compared with ploughing during the rice-growing season.[64]

The targeted measures listed above should be included in a wider set of measures designed to transform industrial farming and food systems towards agroecology. Agroecology embraces organic, permaculture and other cultivation techniques, while promoting the preservation of biodiversity and provision of habitats for local wildlife. Transformative agroecology is gaining traction and a number of studies confirm its benefits, demonstrating that it would be possible in Europe to provide healthy and culturally diverse food for Europeans, while maintaining export capacity and reducing GHG emissions from the agricultural sector by 40%.[65]

2.2.3. Policies designed to influence demand and consumer behaviours

Alongside targeted measures listed above, policies that influence behavioural changes not specifically focusing on methane, such as reducing food waste and loss (covered in section 4 on waste) and the adoption of healthy diets (plant-based diets or with a lower meat and dairy content) could drastically reduce global methane emissions. In the context of agriculture where technical measures leave a large share of emissions unabated, reducing demand for meat and dairy can play a substantial role.[66]

2.2.3.1. Policies to promote healthier diets

Global meat consumption is expected to increase by 1.4% per year through 2023[67] and on this current trajectory, associated livestock production may take up 49% of the GHG emissions budget by 2030 allowable under the 1.5°C target.[68,69] For this reason, it is crucial to focus attention on meat and dairy reduction initiatives.[70,71] A 2022 study found that if 54 high-income nations were to adopt the EAT–Lancet planetary health diet (mostly plant-based), it could cut their annual agricultural production emissions by 61% while sequestering as much as 98.3 gigatons (Gt) CO_2 equivalent (CO_2e), equal to roughly 14 years of current global agricultural emissions.[72] At the heart of the government strategies shaping food environments should be desired outcomes to make healthier and plant-rich foods more accessible, affordable and convenient – with special attention paid to more vulnerable groups. Such strategies, which should balance measures that both enable and restrict consumer choices, should first be adopted in countries where there is a clear overconsumption of meat and dairy above recommended intake (mostly in Europe and the Americas) and where food security does not rely on livestock to fulfil basic nutritional needs. As such, these governments should start with incorporating elements of sustainability into their national dietary health guidelines as these have the potential '*to guide institutions, both public and private, in setting the parameters for food environments, which in turn influence what food we buy and eat*'[73] and must adopt accompanying strategies for their implementation. For example, public procurement can be instrumental in deploying demand for plant-based products over meat products. This involves developing legally binding standards for public food procurement across all public institutions: schools, hospitals, government institutions, prisons and public canteens can choose between meat-free days (as in 40% of Swedish municipalities)[74], increasing vegetable portions in recipes, adding more plant-based options or offering a plant-based meal as the daily special, all of which would help to normalise plant-rich options, highlight the shifting trend and increase support for stronger policy options. Governments can also impose national targets for meat sales reduction in supermarkets and end subsidies towards harmful intensive-farming practices. Finally, governments should consider fiscal measures, from incentives (rewards of monetary value such as subsidies or vouchers) to disincentives such as taxes on meat products. A recent poll demonstrated that 70% of Western Europeans would be supportive of a tax system that would make products such as meat more expensive and reduce taxes on healthy products like vegetables and fruits.[75]

Credit: *Shutterstock*

2.2.3.2. Research and development of plant-based foods and other meat analogues

Changing Markets found that 18 out of the 20 companies assessed in its report have made at least some investments in plant-based and cultured meat alternatives.[76] This is a growing sector: the global meat substitutes sector was worth $20.7 billion in 2020 and is expected to rise to $23.2 billion by 2024.[77] While plant-based diets still represent a niche in a global context, compared with the overall growth in meat consumption, it is nonetheless an important market that could be rapidly grown through innovation, leading to increasingly competitive pricing and wider availability of alternative protein products. What is more, these trends could be accelerated through support from public policies that address climate, environmental and health concerns to ensure that industry moves forward.[78] However, such investments need to be paired up with public policies aiming at reducing meat consumption and promoting healthy diets, as so far pledges by meat companies investing in plant-based foods are too small and do not really aim to replace animal-based food.[79]

2.3. Co-benefits

Measures aiming at reducing methane emissions from agriculture, whether targeted or behavioural, amplify a whole set of associated benefits. In particular, reduction in meat and dairy production and consumption include the following:

2.3.1. Improved public health

The EAT–Lancet Commission found that globally, consumption of red meat is much higher than what is considered to be healthy and sustainable. However, overconsumption is not homogenous around the globe: it is six times higher than what is considered to be healthy in North America; four times in Europe and central Asia, while Latin America ranks third just after Europe – exceeding the level needed for a healthy and sustainable diet. South Asia currently ranks lowest in the world for red meat consumption, whereas levels of consumption are considered to be sustainable and healthy in sub-Saharan Africa.[80] There is an accumulated body of evidence that shows a clear link between high intake of red and processed meats and a higher risk for heart disease, certain types of cancer, diabetes and premature death.[81] Reducing overconsumption of red meat should therefore also be a priority from public health perspective and can lead to significant reduction in public spending in many countries.

2.3.2. Reduction of other GHG emissions associated with meat production – CO_2 and nitrous oxide

The global food system is responsible for more than a third of anthropogenic GHG emissions, but meat production in particular plays a disproportionate role as animal farming, as well as livestock feed, is responsible for 57% of all food production emissions.[82] The difference in emissions between meat and plant production is stark – in producing 1kg of wheat, 2.5kg of GHGs are emitted, whereas a single kizzzlo of beef creates more than 70kg of emissions.[83] Beef alone accounts for a quarter of emissions produced by raising and growing food.[84] In addition, nitrogen fertiliser used for cattle grazing causes the release of CO_2 and nitrous oxide.[85] The latter gas is very potent and is also emitted by stored manure.[86] Reduction in meat production would therefore help cut other harmful GHGs.

2.3.3. A fairer and more sustainable land use

Globally, about 80% of agricultural land is used to raise animals or the crops to feed them, although livestock produces less than 20% of the world's supply of calories.[87] Large animals such as cattle take longer to grow and reproduce, meaning that their production requires more feed and land than other livestock. The conversion of land for beef production and animal feed is a leading cause of deforestation in many tropical regions, often the most vulnerable to climate change. Because deforestation involves the release of long-held stores of CO_2, it is closely linked with global heating (see previous section). It takes around 100 times more land to produce a kilocalorie of beef or lamb than plant-based alternatives, just like it takes almost 100 times more land to produce a gram of protein from beef or lamb than peas or tofu.[88] The large land conversion dedicated to livestock production, in addition to causing deforestation and conflict with local communities and indigenous groups in some parts of the world,[89] is also associated with soil erosion (either because of monoculture farming or over-grazing)[90] and to dead zones in the ocean. While it is worth noting that not all land use for livestock production could be used for growing other type of foods, ground-breaking studies[91] have demonstrated that it would be possible to feed everyone in the world a nutritious diet on existing croplands if we saw a widespread shift towards plant-based diets. Importantly large land-use reductions would be possible even without a fully vegan diet: cutting out beef and mutton only would free up close to half of current agriculture land use.[92]

Credit: *Shutterstock*

3. Tackling methane emissions in the energy sector

3.1. State of play

At the global level, the energy sector emits about 129 million tons of methane per year.[93] For gas, which is itself predominantly methane, methane emissions occur throughout the supply chain, including during extraction, processing, liquefaction, regasification, transmission, storage and distribution. For oil and coal, for which methane is a co-product or by-product, methane emissions occur primarily at or around the oil pad or coal mine during extraction and processing. The energy sector has been identified as a main contributor to the rapid acceleration of atmospheric methane despite methane emissions being chronically underreported, with the International Energy Agency (IEA) estimating that emissions from the energy sector in 2021 were about 70% higher than reported by national governments.[94]

To stay within 1.5°C, the GMA confirms the need to reduce global methane emissions by 40–45% by 2030. In the energy sector, methane mitigation coupled with the a swift deployment of clean and efficient technologies could reduce the sector's contribution by around 75% between 2020 and 2030 – and cost-effectively.[95] The GMA found that more than 80% of the mitigation in the energy sector could be implemented at negative or low cost, with further reductions appropriate for 2040 and 2050 in line with climate-neutrality objectives, making the energy sector very appealing for policymakers.[96] To do so, however, countries will need to develop and adopt policies and measures to reduce methane emissions from oil, gas and coal extraction and infrastructure – both domestically and abroad.

In 2021, China was the biggest emitter of methane emissions in the energy sector followed by Russia and the US.[97] Some countries and regions, however, such as the EU, are not important producers of methane emissions within their borders but contribute to significant emissions abroad by importing fossil fuels from high-methane-emitting countries with no requirements for market access.[98] While some actions have been taken to reduce methane emissions from the energy sector, for example Norway put limits on routine flaring decades ago and the EU, Canada and US recently announced or proposed new regulations, a much more systematic approach is needed and much more is needed. [99,100,101,102]

3.2. Recommended interventions

In the energy sector, national methane action plans should consist of distinct strategies with policies tailored to reduce methane emissions from fossil fuels.

3.2.1. Phase-out fossil fuel production and consumption

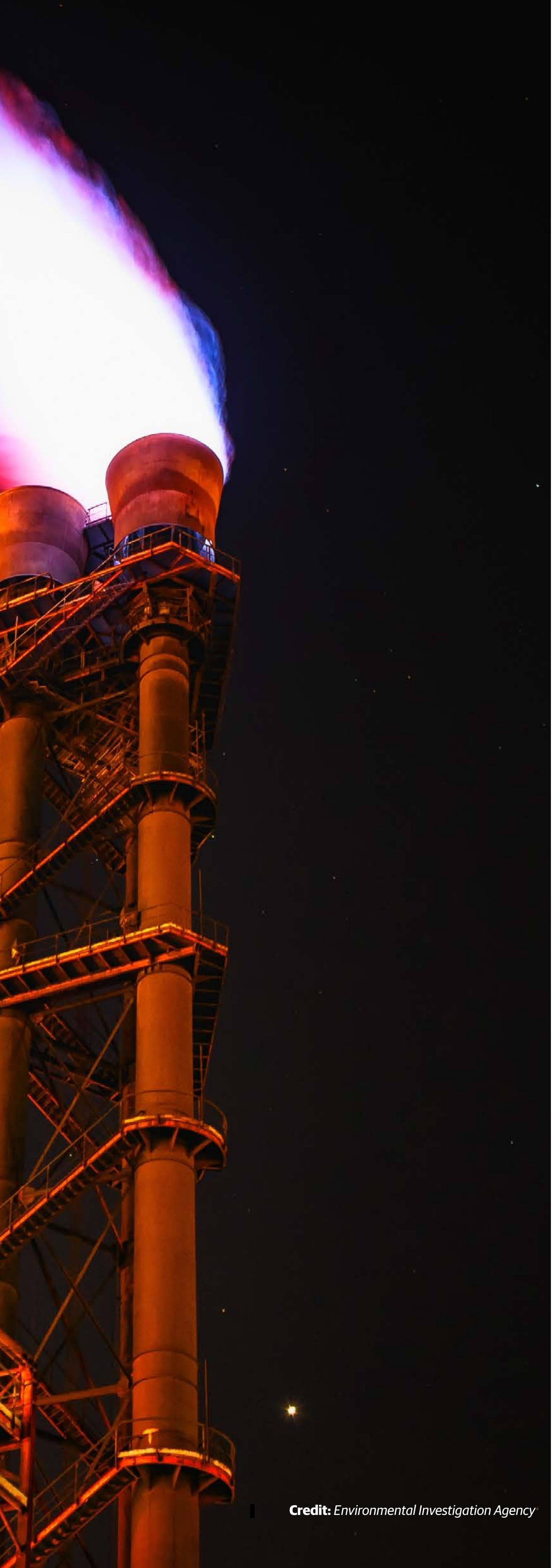
By far the most important and direct pathway to reduce methane emissions in the energy sector is through the managed phase-out of fossil fuels – essential to our transition to a low-carbon economy in the coming decades. To this end, in tandem with methane mitigation measures in oil, gas and coal (see next sections), countries should develop and adopt measures to rapidly transition away from fossil fuels, essentially keeping methane in the ground. On the supply side, this includes immediate cessation of new exploration and production and the prompt phase-out of existing production in line with the objectives of the Paris Agreement. Such a phase-out could take a worst-first approach: retiring a quarter of global coal mine capacity with the highest intensity of leaks would halve coal mine methane emissions.[103] On the demand side, this includes comprehensive sectoral plans to phase out fossil fuel consumption, with timelines and targets tailored to each sector (e.g. electricity, heating, industry and transport) and deployment of alternatives.

3.2.2. Methane mitigation – oil and gas

Measures to address methane emissions from oil and gas are known and proven but must be mainstreamed across all countries and industrial actors. Because it is impossible to prevent methane emissions from oil and gas extraction and infrastructure, the only true prevention of methane pollution is to prevent oil and gas extraction in the first place.

3.2.2.1. Leak detection and repair

Fugitive methane emissions exacerbate the climate impact of oil and gas. For example, when leakage along the supply chain exceeds 3%, the climate impact of gas is worse than that of coal in power generation.[104] Mandatory leak detection and repair is therefore a primary lever to mitigate methane emissions in active oil and gas extraction and infrastructure, coupled with minimum requirements on check frequency, repair periods, re-surveying, emission inventories, record-keeping and reporting. More frequent leak detection and repair is associated with increased methane emission reductions: 40% for annual checks, 60% for semi-annual checks, 80% for quarterly checks and 90% for monthly checks.[105] Citizen complaints and scientific research such as overflights, satellite monitoring and site visits can inform regulators and operators about emissions.



Credit: *Environmental Investigation Agency*

3.2.2.2. Venting and flaring

Limits on routine venting and flaring is another primary lever to reduce methane emissions in active oil and gas extraction and infrastructure. Venting is the intentional release of methane into the atmosphere and flaring is the burning of gas, and is also a source of black carbon, another super-pollutant. With rare exceptions, routine venting can be banned and equipment that is designed to vent, replaced. Flaring should only be allowed where reinjection, on-site utilisation or dispatch to market is not possible. To prevent methane slippage during unavoidable flaring, flaring efficiency standards should be put in place to control the quantity of combusted methane and reduce 'methane slippage.'

3.2.2.3. Technology standards

Technology standards reduce emissions associated with the normal operation of certain equipment, such as compressors and pneumatic devices, by mandating the use and replacement of higher emitting components with lower emitting alternatives. IEA has found that a '*range of alternative technologies can perform the same function as these components, but with lower or zero emissions*' and therefore '*regulations that limit emissions from certain types of equipment or that require their replacement with lower or zero-emitting alternatives can reduce emissions significantly*.'[106]

3.2.2.4. Inactive wells

Inactive wells are a climate menace, emitting methane unless properly remediated, reclaimed or plugged and then monitored. For example, the US has some 3.2 million inactive oil and gas wells, which together emitted 281 kilotons in 2018 or the equivalent of 6.3 Megaton (Mt) CO_2e (though US regulators note that figure could be as much as three times higher).[107] Inventories of inactive wells should be undertaken and policies adopted to ensure their remediation, reclamation or plugging and monitoring.

3.2.3. Methane mitigation – coal

Methane emissions from coal are primarily linked to underground mining activities. In both active and inactive coal mines, the vast majority of the methane emissions occur through ventilation shafts and drainage and degasification stations, constituting the main avenues for lowering methane concentrations.[108] In 2018, the IEA estimated that 40 million tonnes of methane leaked from operational coal mines,[109] surpassing the climate impact of shipping and aviation combined. Moreover, methane emissions are also emitted from inactive coal mines. In the US alone, there has been a reduction of 62% of the total number of producing coal mines since 2008; addressing closed mines becomes only more urgent as more and more coal mines are shut down.

3.2.3.1. Venting in ventilation shafts

Underground mines have ventilation systems, where ventilators pump atmospheric air into the mine, diluting the methane that is released from coal seams during mining activities. The resulting mixture is emitted as exhaust through ventilation shafts – otherwise referred to as ventilation air methane. The ventilated gas contains diluted concentrations of methane, often less than 0.5%,[110] which can be destroyed through oxidation.[111] Venting via ventilation shafts should therefore be banned and the methane destroyed or collected and integrated into gas distribution systems.

3.2.3.2. Venting and flaring in drainage and degasification stations

Coal mines are equipped with drainage and degasification stations to collect methane emissions and lower the methane concentration in the air. Venting and flaring from those stations should be prohibited, except in case of an emergency. Instead, methane could be captured and used for power generation or destroyed. Effective gas drainage also reduces the risk of gas outbursts or explosions.[112]

3.2.3.3. Inactive coal mines

Numerous abandoned or unused coal mines exist throughout the world and continue to emit long after use. It is estimated that, even ten years after mining has ceased, methane from non-flooded mines is emitted at approximately 40% of emissions recorded at the time of closure.[113] Inventories of inactive coal mines should therefore be undertaken and policies adopted either to flood the coal mine or to capture and use the leaking methane.

3.2.4. Methane emissions associated with imports

Major importers could also play an important role in reducing methane emissions globally. Many of the biggest consumers of fossil fuels do not produce the fossil fuels themselves but import them. For example, the EU relies on imports for 70% of its hard coal consumption, 97% of its oil consumption and 90% of its gas consumption.[114] According to the IEA, the EU imports of oil and gas in 2020 contributed around 9,000 Mt of methane emissions (252Mt CO_2e),[115] surpassing the CO_2 emissions from 56 coal-fired power plants.[116] This is ten times more than the 1 Mt (25.8Mt CO_2e) of methane emissions from oil and gas that occur in the EU.[117,118] For its part, Japan is the fifth-largest gas consumer and largest liquefied natural gas (LNG) buyer with imports representing about 21% of the global net LNG imports.[119] In 2019, Japan was the fifth-largest oil consumer, fourth-largest crude oil importer and third-largest importer of coal.[120] For major importers, the above policies recommended at the national level should be extended to cover imports as a condition to market access.

3.2.5. Petrochemicals

Petrochemicals account for 14% and 8% of total primary demand for oil and gas, respectively and will become the world's biggest driver of oil demand – ahead of trucks, aviation and shipping.[121] Given that oil and gas are significant contributors to methane emissions – and the naphtha and natural gas liquids found in the oil and gas are products used to produce petrochemicals – the petrochemical sector should be subject to the same measures as the energy sector. Addressing methane emissions from petrochemical production is also a critical first step towards reducing the overall climate impact from plastics, which estimates predict will generate 56 000 million tonnes of CO_2e emissions by 2050, corresponding to 10–13% of the global carbon budget to stay within 1.5°C.[122]

3.3. Co-benefits

3.3.1. Fossil fuel phase-out leads to the reduction of air pollutants and improved public health

Phasing out fossil fuels is not only needed to reduce methane emissions, it is paramount to reduce emissions of CO_2 and other air pollutants, linked with the extraction and use of fossil fuels. Phasing out fossil fuel could lead to the avoidance of 3.6 million deaths per year worldwide from outdoor air pollution.[123] Reduction in premature deaths and disease caused by air pollution will also lead to lessening of healthcare costs and the availability of funds for public policies to promote good health, such as for transitioning to renewable energy systems.[124]

3.3.2. Employment opportunities

Mitigating methane emissions creates employment opportunities for high-quality and local jobs. For example, leak detection and repair not only creates jobs but have also been found to promote better paying jobs, with the median hourly wage for workers in the methane mitigation industry at $30.88, compared with $19.60 for all US jobs.[125]

BOX 3.1: **Prioritising super-emitters**

'Super-emitter' events and infrastructure contribute disproportionately to global methane emissions. In the energy sector, 5% of methane leaks contribute to 50% of the emissions.[126]In the waste sector, super-emitter landfills can have similarly outsized impacts. A recent aerial survey of California showed that just 10% of the state's infrastructure was responsible for as much as 60% of the point-source methane emissions, with landfills contributing more than both dairy and fossil fuel operations.[127] GHGSat's satellites have observed landfills releasing large volumes of methane at locations across North America, Europe, Latin America and Asia. One site, near Jakarta, Indonesia, was measured emitting 15 900 kg per hour, equivalent to nearly 400 000 kg per hour of carbon dioxide. In Madrid, high-resolution satellites detected 8800 kg of methane per hour leaking from landfill sites in August 2021 – the highest observed in Europe by GHGSat.[128] Addressing super-emitters is therefore an important undertaking, with the International Methane Emissions Observatory (IMEO) and other satellite surveillance initiatives playing a potentially significant role in detecting and notifying national authorities and companies. Companies should also be required to have in place a set of measures and protocols to eliminate the super-emitting event upon notification.

Credit: *Shutterstock*

4. Tackling methane emissions in the waste sector

4.1. State of play

The waste sector is the third-largest source of anthropogenic methane emissions worldwide, contributing roughly 20% of all such emissions.[129,130,131] Methane in the waste sector is produced when biodegradable material, including food, garden clippings, human waste, wood and paper break down in dumpsites, landfills or sewage treatment environments that restrict oxygen.

Municipal solid waste (MSW) is of particular concern, as it is responsible for the majority of waste sector emissions.[132] In some regions, landfills are even the primary source of all methane emissions.[133] While wastewater is also a significant contributor, methane reduction strategies in solid waste represent three to six times the mitigation potential of wastewater and should be the priority for policy.[134]

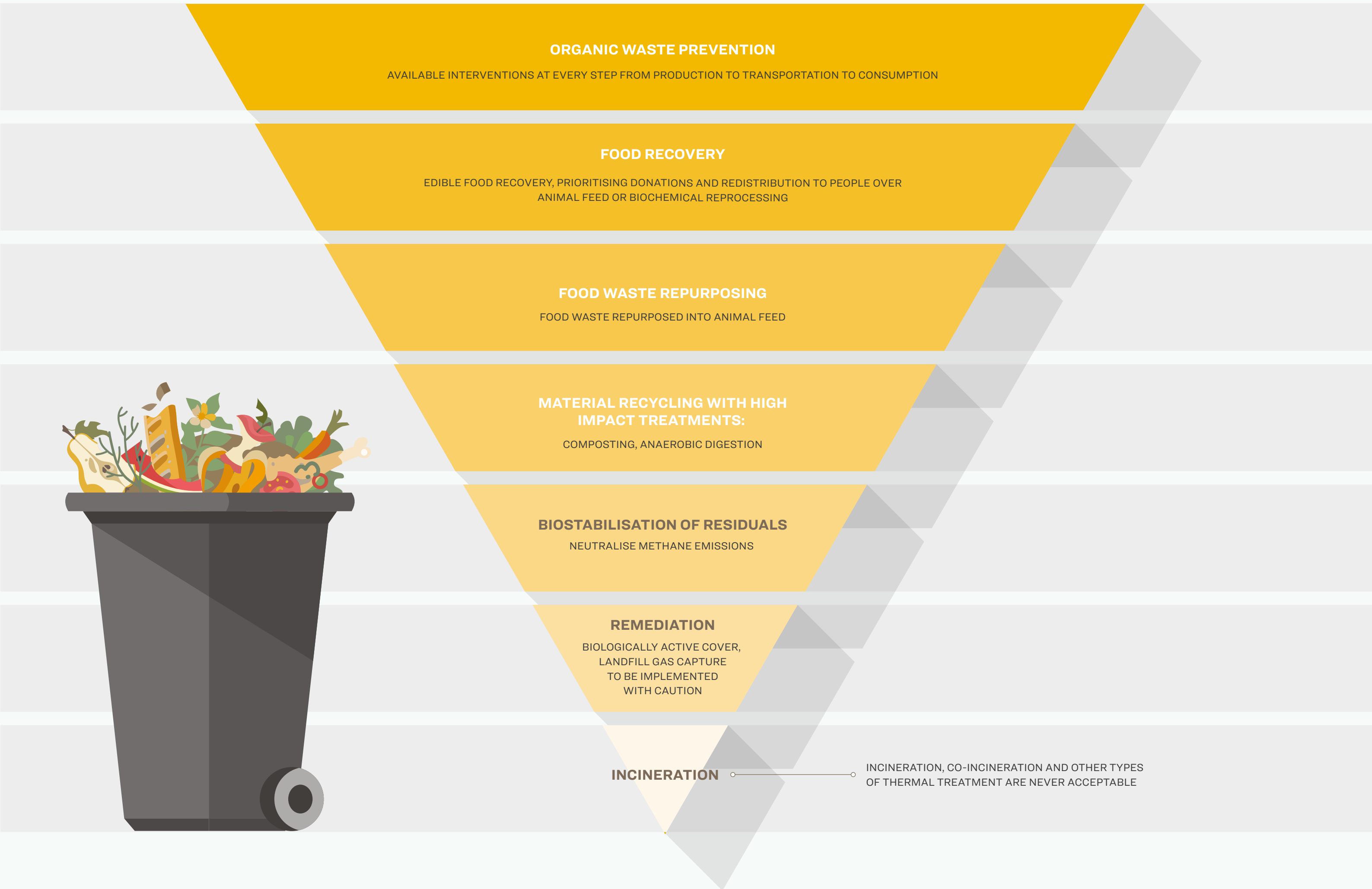
It should be noted that there is significant uncertainty around methane emissions from landfills and dumps. Emission rates can vary by as much as six orders of magnitude, depending on temperature, moisture and organic content, making direct measurement challenging.[135] Models developed to estimate emissions in lieu of direct measurements, such as the IPCC's 'first-order decay model,' have also been criticised as inaccurate.[136] New satellite monitoring techniques are improving estimation accuracy, but until they are more widely utilised, we must rely on existing literature while keeping the above limitations in mind.

4.2. Recommended interventions

The most important strategies for mitigating solid waste methane emissions – organic waste reduction, source separation and treatment of organic discards – are low cost, scalable and easy to implement anywhere in the world.

A useful tool for prioritising these strategies is the waste hierarchy, which orders interventions based on environmental impact and supports a larger transition towards a zero-waste circular economy. Using the hierarchy to manage organic discards can reduce solid waste methane emissions with significant co-benefits, all while avoiding costlier, riskier alternatives like landfill gas capture and waste incineration.

FOOD WASTE HIERARCHY



4.2.1. Fundamentals

4.2.1.1. Waste prevention and source separation of organic discards

Waste prevention is the most important methane reduction strategy in the waste sector; every tonne of organic material that never enters the waste stream avoids the methane that it would have generated in a landfill, as well as the upstream emissions involved in its production and transport. Food waste, which is responsible for 10% of all GHG emissions worldwide[137] and a majority of solid waste methane emissions[138] is especially important to avoid. Opportunities for waste prevention are available at every step of the supply chain for organic goods, from amending subsidies that encourage food overproduction, to instituting demand-planning programmes or food donation mandates in supermarkets, to educating consumers about waste prevention.[139,140] France's recent food-waste-prevention law, for example, fines supermarkets that exceed a set cap for discarded food.[141]

4.2.1.2. Waste recovery

Where direct prevention fails, recovery is the next best option – discarded food can be redirected to people in need or repurposed for preserved products like jams. Collaboration between food banks, grocery stores and local government in Milan, Italy, for example, has led to 130 million tonnes of food waste saved annually in just three years, putting the city well on its way to achieving its goal of 50% food waste reduction by 2030.[142,143]

4.2.1.3. Waste separation

Even with effective waste prevention programmes in place, some organic waste will still be generated. For this discarded material, source separation – where organic discards are separated out from other waste at their point of

Credit: *GAIA*

generation (homes, businesses etc.) – is critical. Source-separated organic waste needs to be separately collected, ensuring a clean stream of organic material ideal for high-impact treatment methods such as composting, AD and diversion to animal feed, which can be done on site, at decentralised, community-scale facilities or at larger, centralised facilities depending on local capacities and needs.

4.2.1.4. Animal feed out of waste

Similarly, diverting organic discards to feed livestock avoids landfill methane emissions and can displace conventional, energy-intensive feed crops (see section 2). Though estimates of the methane reduction potential of using organic discards for animal feed are lacking, one life cycle analysis found that the practice can deliver greater overall GHG reductions than composting or AD.[144,145]

4.2.2. High-impact treatments

4.2.2.1. Composting

Unlike landfills, well-managed compost operations produce minimal amounts of methane, most of which is destroyed by bacteria.[146,147,148] Composting can prevent as much as 99% of methane emissions that would otherwise be released from landfills,[149,150] greatly reducing waste sector emissions. Where possible, decentralised, on-site management is considered best practice, but there are composting units and methods for all contexts.[151]

BOX 4.1: Reductions in methane emissions from composting, bio-stabilisation and biologically active cover in the waste sector

Based on mean emission factors drawn from academic literature, composting alone could reduce MSW methane emissions by 78%. All three mitigation strategies together could reduce MSW methane emissions by 95%, for an overall waste sector emission reduction of 58%. Figures assume 80% implementation of composting, 70% implementation of bio-stabilisation and 70% implementation of biologically active cover for landfills. While not included on this table, waste prevention remains the most effective intervention of all. See the appendix for sources and additional figures.

Intervention	Mean reduction in methane emissions from MSW	Mean reduction in methane emissions from entire waste sector (61% of waste sector emissions are from MSW)[152]
Composting	78%	48%
Composting + bio-stabilisation of residuals	90%	55%
Composting + bio-stabilisation + biologically active cover	95%	58%

BOX 4.2: **Success stories from India and South Korea**

Governments around the world are already demonstrating that rapid implementation and high organic waste diversion rates are possible. In Thiruvananthapuram, India, the city government began a campaign in 2014 to enforce separate organic waste disposal and treatment. Through extensive outreach and education as well as subsidies to set up small-scale treatment units (compost piles, kitchen bin composters, micro-anaerobic digesters etc.), the city achieved 80% participation in organic waste separation in the residential sector and 88% in the commercial sector within five years.[153] The vast majority of this organic waste is managed at decentralised home or community-scale facilities, greatly reducing collection and management spending.[154] Thiruvananthapuram's success has become a model for the entire state of Kerala, shaping waste policy for the state's 34 million people.

In South Korea, the capital city of Seoul led the way for the country by diverting more than 90% of its food waste from landfill as early as 2004, just nine years after a pay-as-you-throw law, where waste fees are charged based on the amount of waste generated, spurred serious diversion efforts in the city.[155] By 2005, the rate had risen to 96%.[156] This high diversion rate is now reflected across the country, with 95% of all food discards nationwide going to composting, animal feed or biofuel production.[157]

4.2.2.2. Anaerobic digestion

In some cases, AD – where organic discards are intentionally broken down in the absence of oxygen to produce methane for fuel – can be a suitable complement or alternative to composting. Unlike landfills, which constantly leak methane into the atmosphere, anaerobic digesters are sealed vessels that collect methane until it is burned as fuel, converting it into biogenic CO_2. AD also generates a small proportion of residual organic matter, called digestate, which can be composted and used as soil amendment. AD is often well suited for dense areas with large amounts of organic discards and little room for composting facilities, but has higher capital costs and requires more technical training to operate.[158] Cheaper, small-scale AD units have also been employed with great success in remote communities with less-reliable access to energy grids in countries such as Bangladesh, India and China.[159]

However, it is worth highlighting foreseeable AD pitfalls such as landfilling AD digestate, flaring AD biogas instead of using it as fuel, burning fossil fuels to increase processing temperatures, digesting new, energy-intensive agricultural crops, rather than organic discards and perceived or actual competition with renewable wind and solar energy. As highlighted in section 2, AD in the agricultural sector can also provide perverse incentives for continued manure or organic waste generation, undercutting other options, for example waste reduction or composting.[160] AD, therefore, can work well with a clean organic waste stream in certain areas, but, like composting, needs to be integrated in an overall zero-waste system that prioritises prevention.

BOX 4.3: **Organic waste policy developments around the world.**

- **A 2018 amendment to the EU's Waste Framework Directive** has set promising goals for organic waste management in all 27 EU member states. The Directive's mandate to separately collect all organic waste by the end of 2023 has already driven significant increases in separate collection rates and the European Commission is planning to adopt the additional goals of reducing food waste by 50% by 2030 and developing legally binding targets for food waste reduction.[161,162]

- **India's 2016 MSW Management Rules** mandate that households and businesses separate organic waste at source and that local governments facilitate separate collection, transport and processing through composting or AD, prioritising decentralised facilities. The rules also direct the Department of Agriculture to facilitate compost utilisation.[163]

- **A 2016 mandate in California, US** requiring that all households and businesses compost their food waste went into effect in 2022. Diverting this waste, which accounts for 30–40% of all waste in the state, will reduce all organic waste sent to landfill by 75% by 2025 and reduce state-wide GHG emissions by millions of tonnes each year.[164]

- **The Organic Waste National Strategy of Chile, launched by the Ministry of Environment in 2021** aims to reduce the organic fraction of MSW sent to landfills by 66% within two decades. The target includes goals for households, communities, schools, urban parks and public institution offices.[165]

Credit: *Shutterstock*

4.2.3. Additional mitigation measures

4.2.3.1. Bio-stabilisation

Given that some organic discards will still remain in residual waste streams even after source separation and treatment of organics, residual waste should never be landfilled without first undergoing biological stabilisation. This can include simple mixing and aeration techniques or more complex material recovery and biological treatment systems. In this way, bio-stabilisation provides a final screen for organic material, including contaminated or 'dirty' organics still in the residual waste stream.

4.2.3.2. Biologically active cover for remaining emissions

Even when complete diversion of organics is achieved, ongoing methane emissions from past discards buried in landfills will still need to be addressed, as landfills can continue to emit methane for decades after they have stopped accepting new waste.[166] Fortunately, active landfills are responsible for the majority of emissions and emissions from closed landfills – also known as legacy emissions – only represent about 9% of the problem.[167] A growing body of research suggests that biologically active cover – a layer of compost or other organic material over landfills – can greatly reduce these emissions. By fostering communities of microbes that digest methane as it rises

up from the landfill below, biologically active cover can reduce landfill emissions by 63% on average.[168,169,170,171] Depending on environmental conditions, it can even generate 'negative' emissions by drawing down methane from the atmosphere.[172,173]

4.2.3.3. Avoiding landfill gas capture and waste incineration

A final method for remediating methane emissions – which should only be explored after the implementation of zero-waste strategies – is gas capture from existing landfills.

In this process, landfills are equipped with tubes that allow some of the landfill gas (LFG), which is composed of 35–50% methane,[174] to be collected and piped to the surface. From there it can either be flared or burned for energy, converting the contained methane to CO_2. Capture efficiencies can vary significantly, however, with 10–65% of the target methane escaping into the atmosphere[175] and additional fugitive emissions arising from leaky pipes and transportation infrastructure.[176,177] LFG capture is more carbon-intensive than composting and AD[178] and should be employed with caution. In some cases financial incentives to collect LFG have motivated waste management companies or municipalities to redirect organic discards from diversion programmes (such as animal feed or composting) back to landfills to increase LFG production.[179,180]

Incineration should never be used to manage organic discards. Incineration is highly polluting, expensive and carbon-intensive, with large capital costs and high operational costs incurred from covering pollution control, air quality monitoring, wastewater management and ash disposal.[181] These costs often lead to incineration facility closures and have drained municipal budgets of hundreds of millions to more than a billion US dollars in some cases,[182] compared with composting, which tends to have lower waste management costs and has very low capital costs.[183,184,185] Incineration also fares very poorly from a climate perspective. While it can save methane emissions from organic discards, it generates huge amounts of fossil-based CO_2 when plastics and synthetic textiles burn in mixed municipal waste.[186] When used for energy production, so called 'waste-to-energy' incinerators generate more GHG emissions per unit of energy produced than any other energy source.[187] For these reasons, source separation and treatment of organic discards is always preferable to LFG capture and incineration.

4.3. Co-benefits

Organic waste prevention, source separation and separate treatment all synergise with larger zero-waste goals and generate many co-benefits as part of a transition to a new, circular economy and sustainable food system.

4.3.1. Cost savings for municipalities

Organics represent the largest component of global waste streams;[188] organic waste prevention and source separation, therefore, can greatly reduce the volume of material sent to landfills or incinerators. This in turn avoids the costly construction of new disposal infrastructure. When it comes to alternative treatment options, composting is cost-effective, has low start-up costs and requires less land area than landfills.[189] In countries where governments are expanding waste services, the low cost of composting can free up funds for expanded waste collection coverage. Finished compost can also be sold to help cover operational costs. Decentralised treatment can save further resources spent on collection, transportation fuel and traffic, and large infrastructure.[190]

4.3.2. Avoiding pollution

Landfills and incinerators are responsible for leachate leakage, water contamination, fires, air pollution and toxic ash all over the world,[191,192,193] and are often sited in low-income communities and communities of colour.[194] Organic waste prevention, source separation and separate treatment reduce reliance on these polluting practices.

4.3.3. Reducing further climate emissions

Organic source separation reduces contamination in recycling waste streams, increasing recycling rates and driving further GHG savings.[195] Finished compost sent to gardens and farms returns organic matter and nutrients to the soil, boosting its carbon sequestration capacity, resistance to flood and drought and reducing irrigation and tilling needs.[196] When compost replaces synthetic fertilisers, the impact is even greater, saving energy and reducing emissions of nitrous oxide, a powerful GHG.[197]

4.3.4. Creating jobs and fostering social benefits.

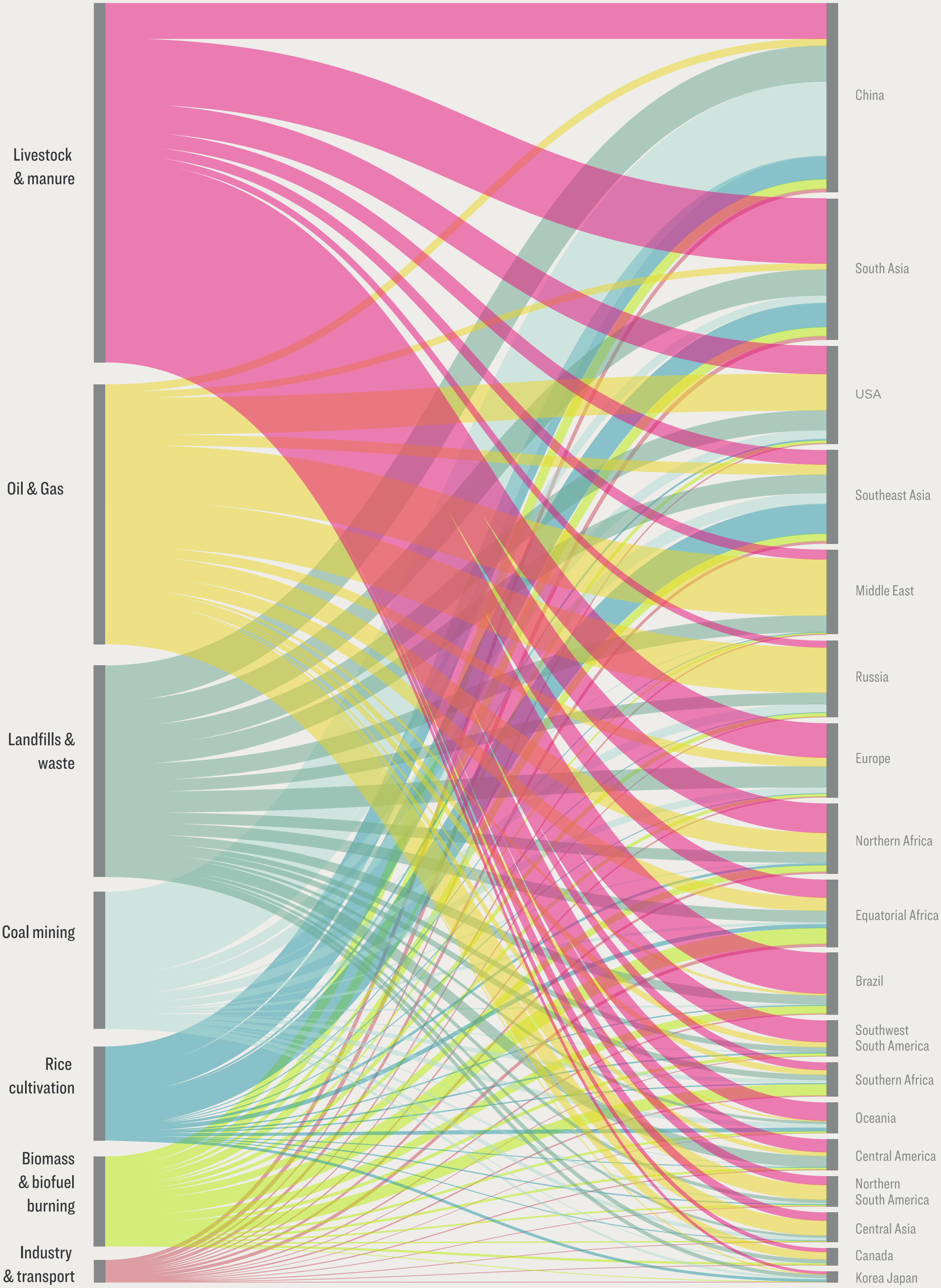
Holistic prevention, donation and recovery programmes can not only reduce methane emissions but also support local food production, create jobs in education and outreach, and improve local access to healthy food.[198] Compared with landfilling and incineration, separate organic waste treatment methods such as composting can create three times as many jobs on a tonne-for-tonne basis,[199] contributing to stronger and healthier local economies.

BOX 4.4: **Integrating waste pickers into the formal waste economy**

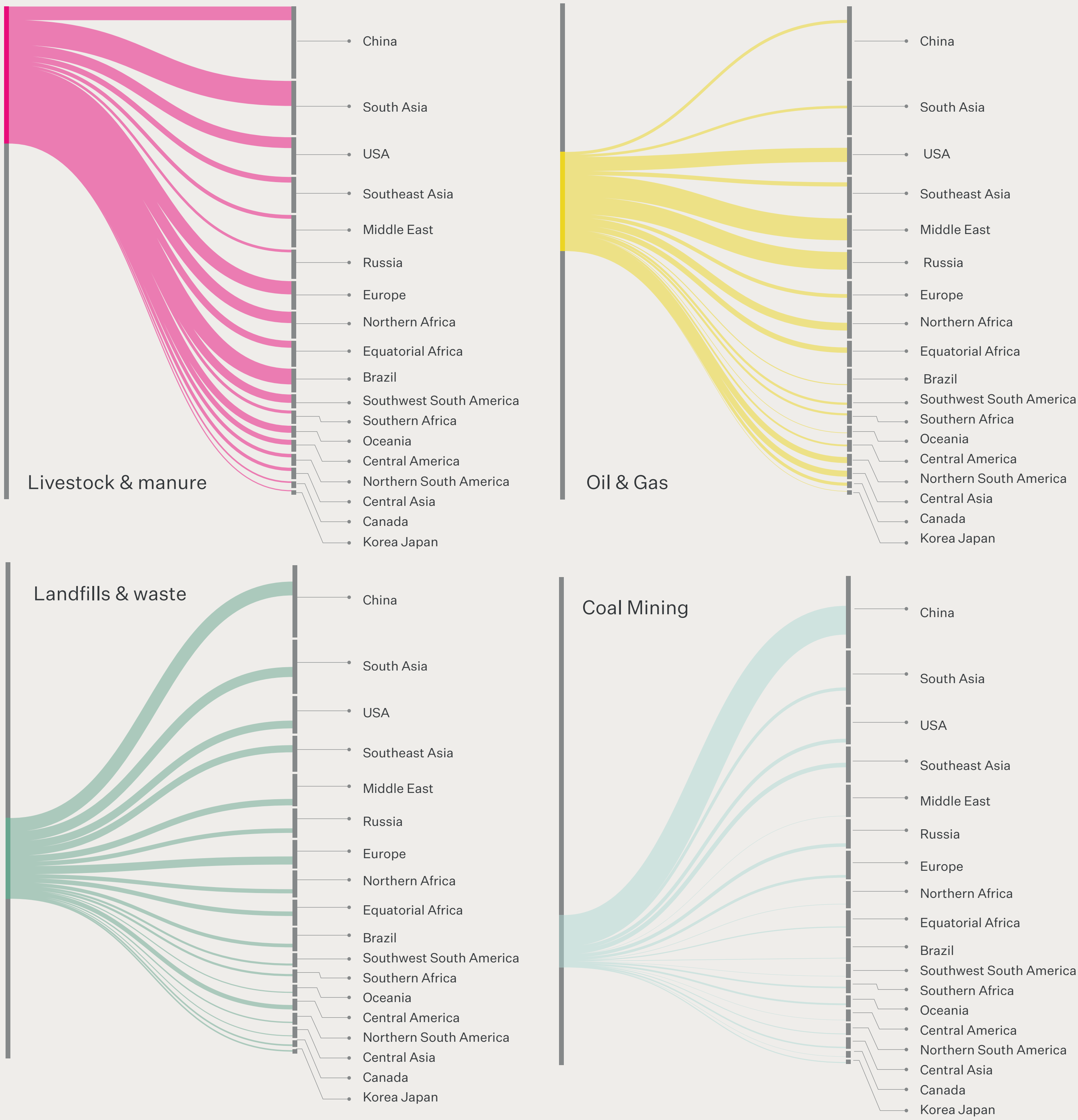
Separate organic waste management offers an opportunity to integrate and support informal sector workers who have provided valuable waste management services to their communities for decades. New jobs in collection, outreach and education, compliance monitoring and processing at decentralised or centralised facilities can provide stable livelihoods at higher rates than conventional disposal methods.[200] These jobs can also provide a critical alternative livelihood to plastic collection as the world moves to implement other, zero-waste goals such as plastic reduction.

Credit: *GAIA*

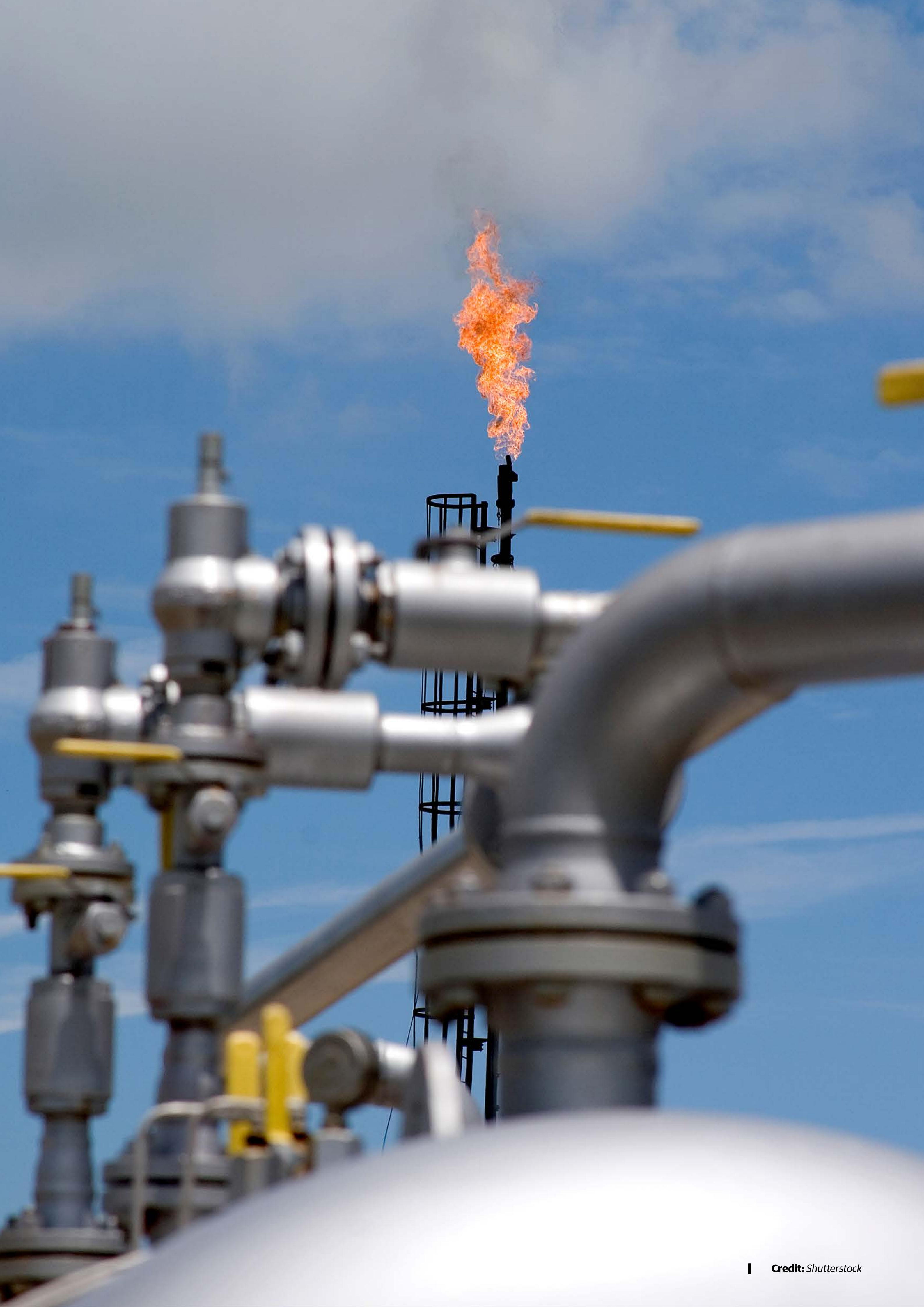
GEOGRAPHICAL DISTRIBUTION OF METHANE EMISSIONS BY SECTOR



Source: Calculated from Integrated Carbon Observation System (ICOS) (2021) Supplemental data to global methane budget 2000-2017. [ONLINE] Available at: https://www.icos-cp.eu/GCP-CH4/2019



Geographical zones of methane emissions



Credit: *Shutterstock*

5. Towards a global governance framework for methane: Cross-sectoral actions

Building upon the Pledge, to deliver enduring methane emission reductions at scale, countries must enhance global governance on methane, built upon three foundation pillars: (1) measurement, reporting and verification (MRV); (2) national methane action plans; and (3) technical and financial assistance. The development of a global governance framework should be undertaken in parallel with domestic actions but with the goal of providing an overarching framework to measure progress towards common objectives and international cooperation, enabling domestic action and promoting implementation.

5.1. Monitoring, reporting and verification

An accurate MRV framework is the foundation of any effective global governance framework on methane. To date, actual methane emissions from agriculture, energy and waste have escaped scrutiny from regulators and policy-makers, with many countries relying on lower-tier methodologies based on outdated and generic emission factors, leading to chronic underreporting in these sectors. MRV of methane requires substantial update and uptake, with a prompt progression to the use of higher-tier methodologies and incorporation of new technologies such as satellite, aerial and ground based. Developing well-functioning and accurate MRV systems will require early investment and support to institutionalise MRV into the industrial and bureaucratic landscape and make it regular and systematic, while ensuring its utility as a performance and planning tool.

To this end, coordination and collaboration with relevant entities should be undertaken to mainstream higher-tier methodologies for each emission source, such as the IPCC and, in the energy sector, UNEP's Oil and Gas Measurement Partnership 2.0. To assist countries with verification, the IMEO can play a role, providing satellite surveillance and verification services as well as an early warning system for super-emitters. The emergence of satellite surveillance is dramatically increasing the amount of methane emissions data available with greater accuracy, spatial detail, quantification and timelines. National reporting by countries to a central clearing house, such as a secretariat, would make the data accessible to scientists, economists, policymakers and civil society and improve implementation, compliance and enforcement.

5.2. National methane action plans

To achieve global objectives, countries should adopt national methane action plans, setting out country-specific sectoral policies and measures and transposing international commitments. Tailored to the national context, and supported by a robust MRV framework, the submission of national methane action plans could constitute the main pathway for reducing methane emissions over time. Because the mitigation potential in different sectors and countries varies considerably – depending on the presence of livestock, landfills and fossil fuel production – countries should be expected to make their fair contribution based on a common metric, such as currently available measures, which the GMA found could reduce methane emissions by as much as 45% by 2030.[201] For methane reductions beyond 2030, the GMA further found that the mitigation potential from all sectors is expected to increase, which could then form the basis for periodic review and update – a ratcheting mechanism to secure methane reductions over the longer term.

On a practical level, national methane action plans can be developed independently, with each country setting out to adopt currently available measures, before being integrated into NDCs as a stand-alone section. This would mirror the approach taken for hydrofluorocarbons (HFCs) under the Kigali Amendment, whereby HFCs are controlled under the Montreal Protocol on Substances That Deplete the Ozone Layer but have been integrated into several NDCs as a stand-alone section.[202] The first round of NDCs were delivered in 2020 and are subject to periodic review and update every five years, allowing for easy incorporation.

5.3. Technical and financial assistance

Collective action on methane emissions will require technical assistance to be made available to all policymakers and financial assistance to developing countries.

Policymaking should be based on the best available science. This can be achieved through a dedicated scientific body that focuses on the range of issues associated with methane emission reductions, one that brings together the relevant scientific and technical expertise to inform the decisions of policymakers. This body would be expected to undertake periodic comprehensive assessments on progress towards common objectives and produce ad hoc reports on specific issues, as needed – for example the feasibility of lowering methane emissions from livestock using algae-based feed. Technical assistance can be further enhanced by relying on existing international bodies, such as UNEP, the Climate and Clean Air Coalition and the FAO among others.

Financial assistance to developing countries will also be required to support implementation. Following the collective experience of various multilateral environmental agreements, stable and predictable funding for enabling activities is a critical component of any effective global governance framework and can be bundled into the following categories:

5.3.1. Institutional strengthening

Institutional strengthening increases the ability of governments to perform their essential functions and has become synonymous with support provided to ensure consistent and dedicated staffing within governments, for example 'focal points.'

5.3.2. Capacity-building and training

Capacity-building and training are closely related to compliance, providing the skills, knowledge and tools to individuals and governments to implement their obligations and commitments competently and with greater effectiveness.[203] Given the range of issues related to methane, capacity-building and training should feature prominently and be administered in an adaptive framework to remain responsive and relevant. In the report *Post-Rio+20 review of environmental governance within the United Nations system* (2014), the Joint Inspection Unit identifies the lack of '*dedicated resources for capacity-building*' as a major shortcoming in all multilateral environmental agreements with the exception of the Montreal Protocol, which is widely considered to be the most successful.[204]

5.3.3. Monitoring, reporting and verification

The global governance framework for methane will require MRV. Financial support to enable countries to undertake MRV, including oversight of the companies operating within their jurisdictions, is paramount.

5.3.4. Policy development and implementation

The development and implementation of national policies to deliver methane emission reductions in each sector is at the heart of the international governance framework and financial support should be provided to undertake these activities.

5.3.5. Pilot and demonstration projects

A pilot project refers to the initial small-scale implementation of a larger project to work out issues and roadblocks before full-scale implementation. A demonstration project refers to those that promote technological innovations or best practices through development and analysis of a live project, building a body of evidence upon which to base future decisions. Pilot and demonstration projects should be used to support a wide variety of innovative approaches towards reducing methane emissions, informing policies and priorities.

Financial assistance to developing countries should also be supplemented by targeted technical assistance from implementing and bilateral agencies. Enlisting implementing and bilateral agencies to support developing countries with implementation and compliance leverages investment, enhances its effectiveness and increases the likelihood of taking on new commitments. In addition, by virtue of working across countries and regions, implementing and bilateral agencies are typically well placed to facilitate best practices and knowledge exchanges.

Credit: *Shutterstock*

6. Conclusion

As global temperatures continue to rise, scientists have identified that cutting methane emissions as the quickest way to limit near-term warming. The Pledge, announced in 2021, reflects the commitment of more than 110 countries to reduce methane emissions by 30% by 2030. However, to limit global warming to 1.5°C, the world must exceed this commitment by reducing methane emissions by at least 45% in the next eight years, if not more, while also bringing more countries on board.

For these reasons, in this critical decade for climate action, the Pledge should not be seen as the end of a journey but just the beginning. Through readily available and often low-cost interventions in the largest methane-generating sectors – agriculture, energy, waste – countries can reduce methane emissions with sector-specific actions and approaches to livestock and rice paddy management, oil, gas and coal extraction and infrastructure, and organic waste diversion from landfills. But to deliver enduring methane emission reductions at the scale required, countries must not hesitate to take the additional step of developing a dedicated global governance framework for methane, built upon three foundation pillars: (1) MRV; (2) national methane action plans; and (3) technical and financial assistance.

In the words of Professor Dave Reay, from the Edinburgh Climate Change Institute, meeting climate goals "*will need every climate action trick in the book*" and cutting methane should be on page one.[205] As methane mitigation is the most important climate action governments can take in this decade, we are calling on them to implement these measures as a matter of priority.

MRV

Harmonisation

- definitions
- methodologies
- formats and templates
- standards

Measurement in agricultural sector

- continuous monitoring of a number of large farms over a year to better understand methane emissions patterns
- improved global inventory

Measurement in energy sector

- oil and gas
  - exploration and production
  - gathering and processing
  - liquefaction and regasification
  - transmission and storage
  - distribution
- coal
  - ventilation shafts
  - drainage stations
  - fissures in strata

Measurement in waste sector

- landfill
  - satellite monitoring techniques, complemented with periodic in situ ground truthing
  - LFG capture and fugitive emission rates
- waste management system
  - total amount of organic waste produced by person/year
  - total amount of food and garden waste that is separated at source and collected
  - total amount of food and garden waste that is sent to high-impact treatments, e.g. compost, ad and total amount of compost and digestate
  - total amount of biodegradables in residual waste per person/year
  - percentage or tonnage of residual waste that is bio-stabilised before landfilling
  - disposal: Amount of mixed waste being landfilled or incinerated

IMEO

- satellite surveillance and verification
- super-emitter detection and alert

National reporting

- inventories and emissions
- national methane action plans and measures

MITIGATION

Agriculture

- improvement of feed
- better animal health and husbandry
- improved manure management
- herd-size reduction
- regulation of meat and dairy companies headquartered within countries' jurisdictions
- rice paddies
- policies to promote healthier diets
- promotion of R&D of plant-based foods and other meat analogues

Energy

- oil and gas
  - leak detection and repair
  - restrictions on venting and flaring
  - technology standards
  - inactive wells
  - super-emitters
  - petrochemicals
- coal
  - venting ban – ventilation shafts
  - venting and flaring ban – drainage and degasification stations
  - inactive coals mines

Waste

- waste prevention
- waste separation
- high-impact treatments (e.g. composting and AD)
- production of animal feed out of waste
- promotion of bio-stabilisation
- use of biologically active cover for remaining emissions
- avoid LFG capture and incineration

Super-emitters

- Increased satellite surveillance
- Improved companies' response protocols

FINANCIAL AND TECHNICAL ASSISTANCE

Scientific and technical assessment bodies

- periodic comprehensive assessments
- ad hoc reports

Financial assistance to developing countries

- enabling activities
  - capacity-building and training
  - MRV
  - policy development and implementation
  - pilot and demonstration projects
  - institutional strengthening

Implementing and bilateral agencies

- technical assistance
  - capacity-building and training
  - MRV
  - policy development and implementation
  - pilot and demonstration projects
- best practices and knowledge exchanges

Table 6.1: *Summary table of measures*

APPENDIX: SOURCES FOR WASTE SECTOR CALCULATIONS

Table A1. Sources for waste sector methane (CH4) reduction calculations

	Emission factors	Units/description	Source
Landfill – direct emissions	204	kg CH4/wet tonne organic waste	Adhikari et al. 2010[206]
	227	kg CH4/wet tonne organic waste	Zhao et al. 2019[207]
	122	kg CH4/wet tonne organic waste	Zhao et al. 2019[207]
	95	kg CH4/wet tonne organic waste	Themelis & Ulloa 2007[208]
	111.5	kg CH4/wet tonne organic waste	Zhao et al. 2019[207]
Compost – direct emissions	4	kg CH4/wet tonne organic waste	Adhikari et al. 2010[206]
	0.29	kg CH4/wet tonne organic waste	Amlinger et al. 2008[209]
	0.24	kg CH4/wet tonne organic waste	Amlinger et al. 2008[209]
	0.05	kg CH4/wet tonne organic waste	Amlinger et al. 2008[209]
	0.6	kg CH4/wet tonne organic waste	Amlinger et al. 2008[209]
	2.4	kg CH4/wet tonne organic waste	Andersen et al. 2010[210]
	0.05–6.8	kg CH4/wet tonne organic waste	Boldrin et al. 2009[211]
	0.03–1.5	kg CH4/wet tonne organic waste	Boldrin et al. 2009[211]
	0.02–1.8	kg CH4/wet tonne organic waste	Boldrin et al. 2009[211]
	0.03–8	kg CH4/wet tonne organic waste	Boldrin et al. 2009[211]
	0.8–2.2	kg CH4/wet tonne organic waste	Amlinger et al. 2008[209]
AD – fugitive emissions	0–1.34	kg CH4/wet tonne organic waste	Møller et al. 2009[212]
	1	kg CH4/wet tonne organic waste	UNEP 2010[213]
Bio-stabilisation – reduction efficiency	81–88%	% reduction in CH4 generation potential	de Araujo Morais et al. 2008[214]
	50–74%	% reduction in CH4 generation potential	Pan & Voulvoulis 2007[215]
	83–91%	% reduction in CH4 generation potential	De Gioannis et al. 2009[216]
	95%	% reduction in CH4 generation potential	Lornage et al. 2007[217]
	65%	% reduction in CH4 generation potential	Lornage et al. 2007[217]
Biologically active cover – reduction efficiency	47–100%	% reduction in CH4 emissions	Boldrin et al. 2009[211]
	10–100%	% reduction in CH4 emissions	Lou & Nair 2009[218]
	64%	% reduction in CH4 emissions	Stern et al. 2007[219]
	55%	% reduction in CH4 emissions	Barlaz et al. 2004[220]

Composting was chosen as the main organics treatment in this analysis due to its ease of implementation, scalability and the availability of data on compost emission factors. AD was found to have similar methane mitigation potential relative to landfilling and there were insufficient data on animal feed diversion to include it in the analysis.

7. References

1 Intergovernmental Panel on Climate Change (2022) Summary for policymakers report [ONLINE] Available at: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

2 Intergovernmental Panel on Climate Change (2022*) Summary for policymakers report* [ONLINE] Available at: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

3 Intergovernmental Panel on Climate Change (2013) *Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change: Anthropogenic and natural radiative forcing*. p 714 [ONLINE] Available at: https://www.ipcc.ch/report/ar5/wg1/here

4 Höglund-Isaksson, L., Gómez-Sanabria, A., Klimont, Z., Rfaj, P. and Schöpp, W.(2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe –results from the GAINS model*. *Environmental Research Communications*, 2(2): 025004 [ONLINE] Available at: https://iopscience.iop.org/article/10.1088/2515-7620/ab7457/meta

5 UN Environment Programme (2021) *New global methane pledge aims to tackle climate change*. [ONLINE] Available at: https://www.unep.org/news-and-stories/story/new-global-methane-pledge-aims-tackle-climate-change

6 The White House Briefing Room (2021) Remarks by President Biden at an Event Highlighting the Progress of the Global Methane Pledge [ONLINE] Available at: https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/11/02/remarks-by-president-biden-at-an-event-highlighting-the-progress-of-the-global-methane-pledge/

7 Stockholm Environment Institute (2021) "*The Global Methane Pledge is a good start*" [ONLINE] Available at: https://www.sei.org/about-sei/press-room/cop26-global-methane-pledge/

8 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

9 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

10 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

11 *NY Times* (2022) 2021 hottest year, 10 January 2022. [ONLINE] Available at: https://www.nytimes.com/2022/01/10/climate/2021-hottest-year.html

12 *NY Times* (2022) 2021 hottest year, 10 January 2022. [ONLINE] Available at: https://www.nytimes.com/2022/01/10/climate/2021-hottest-year.html

13 Intergovernmental Panel on Climate Change (2014*) Climate Change 2014: Synthesis Report* [ONLINE] Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

14 Space.com (2022) Satellites reveal record high methane concentrations despite reduction pledges. 11 January 2022, [ONLINE] Available at: https://www.space.com/climate-change-methane-high-despite-reduction-pledges

15 *NY Times* (2022) 2021 hottest year, 10 January 2022. [ONLINE] Available at: https://www.nytimes.com/2022/01/10/climate/2021-hottest-year.html

16 New Scientist (2022) Record levels of greenhouse gas methane are a 'fire alarm moment', 7 January 2022 [ONLINE] Available at: https://www.newscientist.com/article/2303743-record-levels-of-greenhouse-gas-methane-are-a-fire-alarm-moment/#ixzz7HZmhtjUQ

17 McCabe, D. and Smith, S. (2021) *IPPC's new assessment report highlights the urgency of sharp reductions in methane*. Clean Air Task Force, 11 August 2021. [ONLINE] Available at: https://www.catf.us/2021/08/ipccs-new-assessment-report-highlights-the-urgency-of-sharp-reductions-in-methane/

18 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

19 UNEP and Climate and Clean Air Coalition (2021) Assessment of environmental and societal benefits of methane reductions. [ONLINE] Available at: https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions

20 The White House Briefing Room (2021) *Remarks by President Biden at an Event Highlighting the Progress of the Global Methane Pledge* [ONLINE] Available at: https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/11/02/remarks-by-president-biden-at-an-event-highlighting-the-progress-of-the-global-methane-pledge/

21 The White House Briefing Room (2021) *Remarks by President Biden at an Event Highlighting the Progress of the Global Methane Pledge* [ONLINE] Available at: https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/11/02/remarks-by-president-biden-at-an-event-highlighting-the-progress-of-the-global-methane-pledge/

22 Stockholm Environment Institute (2021) "*The Global Methane Pledge is a good start*" [ONLINE] Available at: https://www.sei.org/about-sei/press-room/cop26-global-methane-pledge/

23 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

24 Forster, P. (2021) Guest Post: The Global Methane Pledge needs to go further to help limit warming to 1.5C, *Carbon Brief* [ONLINE] Available at: https://www.carbonbrief.org/guest-post-the-global-methane-pledge-needs-to-go-further-to-help-limit-warming-to-1-5c

25 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

26 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

27 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

28 Van Dingenen, R., Crippa, M., Janssens-Maenhout, G., Guizzardi, D. and Dentener, F. (2018) Global trends of methane emissions and their impacts on ozone concentrations, EUR 29394 EN. Luxembourg: Publications Office of the European Union.

29 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

30 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

31 UNEP (2021) New global methane pledge aims to tackle climate change. [ONLINE] Available at: https://www.unep.org/news-and-stories/story/new-global-methane-pledge-aims-tackle-climate-change

32 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

33 UNEP (2021) *Global Methane Assessment: Summary for decision makers*. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf

34 Changing Markets Foundation (2021) *Blindspot: How lack of action on livestock methane undermines climate targets.* [ONLINE] Available at: http://changingmarkets.org/wp-content/uploads/2021/10/Blindspot_methane-English.pdf

35 IATP (2020) *Milking the planet: How big dairy is heating up the planet and hollowing rural communities*. [ONLINE] Available at: https://www.iatp.org/milking-planet

36 Searchinger, T., Herrero, M., Yan, X., Wang, J., Dumas, P., Beauchemin, K., Kebreab, E. (2021) *Opportunities to reduce methane emissions from global agriculture*. Princeton University. [ONLINE] Available at: https://scholar.princeton.edu/sites/default/files/methane_discussion_paper_nov_2021.pdf

37 Reisinger, A., Clark, H., Cowie, A., Emmet-Booth, J., Gonzales Fischer, C., Herrero, M., Howden, M. and Leahy, S. (2021) *How necessary and feasible are reductions of methane emissions from livestock to support stringent temperature goals?,* The Royal Society Publishing. [ONLINE] Available at: https://royalsocietypublishing.org/doi/10.1098/rsta.2020.0452

38 Reisinger, A., Clark, H., Cowie, A., Emmet-Booth, J., Gonzales Fischer, C., Herrero, M., Howden, M. and Leahy, S. (2021) *How necessary and feasible are reductions of methane emissions from livestock to support stringent temperature goals?,* The Royal Society Publishing. [ONLINE] Available at: https://royalsocietypublishing.org/doi/10.1098/rsta.2020.0452

39 IATP (2018) *Emission impossible* [ONLINE] Available at: https://www.iatp.org/sites/default/files/2018-08/Emissions%20impossible%20EN%2012.pdf

40 Fairr (2021) Meat & Dairy Results Sour Cop26 Ambitions on Methane and Deforestation [ONLINE] Available at: https://www.fairr.org/article/meat-dairy-results-sour-cop26-ambitions-on-methane-and-deforestation/

41 Reisinger, A., Clark, H., Cowie, A., Emmet-Booth, J., Gonzales Fischer, C., Herrero, M., Howden, M. and Leahy, S. (2021) *How necessary and feasible are reductions of methane emissions from livestock to support stringent temperature goals?,* The Royal Society Publishing. [ONLINE] Available at: https://royalsocietypublishing.org/doi/10.1098/rsta.2020.0452

42 Changing Markets Foundation (2021) *Blindspot: How lack of action on livestock methane undermines climate targets.* [ONLINE] Available at: http://changingmarkets.org/wp-content/uploads/2021/10/Blindspot_methane-English.pdf

43 The White House Briefing Room (2021) *Remarks by President Biden at an Event Highlighting the Progress of the Global Methane Pledge* [ONLINE] Available at: https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/11/02/remarks-by-president-biden-at-an-event-highlighting-the-progress-of-the-global-methane-pledge/

44 Unearthed (2022) Beef lobbyists celebrate methane 'win' at Cop26 [ONLINE] Available at: https://unearthed.greenpeace.org/2022/03/07/biden-methane-pledge-beef-climate-lobying/

45 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Global Methane Assessment: Benefits and costs of mitigating methane emissions*. Nairobi: United Nations Environment Programme. [ONLINE] Available at: https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf

46 Wright, H. (2021) Are we Missing a Roadmap to 1.5C for Agriculture?, *Fairr*, 26 October 2021 [ONLINE] Available at: https://www.fairr.org/article/are-we-missing-a-roadmap-to-1-5c-for-agriculture/

47 Feedback (2021) *Living well on leftovers*. [ONLINE] Available at: https://feedbackglobal.org/wp-content/uploads/2021/07/Feedback-PositionPaper-LivingWellonLeftovers-23July21_2.pdf

48 Eating Better (2021) *Sourcing better: A pathway to less and better meat and dairy*. [ONLINE] Available at: https://www.eating-better.org/uploads/Documents/Sourcing_Better_Framework.pdf

49 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Model website*. [ONLINE] Available at: http://shindellgroup.rc.duke.edu/apps/methane/

50 Searchinger, T., Herrero, M., Yan, X., Wang, J., Dumas, P., Beauchemin, K., Kebreab, E.(2021) *Opportunities to reduce methane emissions from global agriculture*. Princeton University. [ONLINE] Available at: https://scholar.princeton.edu/sites/default/files/methane_discussion_paper_nov_2021.pdf

51 DSM (2022) *DSM receives landmark EU market approval for its methane-reducing feed additive Bovaer.* [ONLINE] Available at: https://www.dsm.com/corporate/news/news-archive/2022/dsm-receives-eu-approval-Bovaer.html

52 DSM (2021) *DSM receives first full market authorizations for methane-reducing feed additive Bovaer for beef and dairy in Brazil and Chile*. [ONLINE] Available at: https://www.dsm.com/anh/en_US/news-events/press-releases/2021/2021-09-09-dsm-receives-first-full-market-authorizations-for-methane-reducing-feed-additive-bovaer-for-beef-and-dairy-in-brazil-and-chile.html

53 Global Research Alliance on Agricultural Greenhouse Gases (2014) *Reducing greenhouse gas emissions from livestock: Best practice and emerging options*. [ONLINE] Available at: https://globalresearchalliance.org/wp-content/uploads/2014/12/LRG-SAI-Livestock-Mitigation_web2.pdf

54 Food and Agriculture Organization (2013) Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities. [ONLINE] Available at: https://www.fao.org/3/i3437e/i3437e.pdf

55 Andeweg, K & Reisinger, A. (2014) *Reducing greenhouse gas emissions from livestock: Best practice and emerging options.* Global Research Alliance on Agricultural Greenhouse gases. [Online] https://globalresearchalliance.org/wp-content/uploads/2014/12/LRG-SAI-Livestock-Mitigation_web2.pdf

56 Nevzorova, T., Kutcherov, V. (2019) Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review, *Energy Strategy Reviews*, Vol. 26 [ONLINE] Available at: https://www.sciencedirect.com/science/article/pii/S2211467X19301075

57 Splitter, J. (2022) America has a manure problem, and the miracle solution being touted isn't all that it seems, *The Guardian*, 20 January 2022 [ONLINE] Available at: https://www.theguardian.com/us-news/2022/jan/20/manure-natural-gas-pipeline-factory-farms-greenwashing

58 Splitter, J. (2022) America has a manure problem, and the miracle solution being touted isn't all that it seems, *The Guardian*, 20 January 2022 [ONLINE] Available at: https://www.theguardian.com/us-news/2022/jan/20/manure-natural-gas-pipeline-factory-farms-greenwashing

59 Levitt, T. (2021) Netherlands announces €25bn plan to radically reduce livestock numbers, *The Guardian*, 15 December 2021 [ONLINE] Available at: https://www.theguardian.com/environment/2021/dec/15/netherlands-announces-25bn-plan-to-radically-reduce-livestock-numbers

60 *Deutsche Welle* (2021) Germany sees battle over cheap meat flare up, 29 December 2021 [ONLINE] Available at: https://www.dw.com/en/germany-sees-battle-over-cheap-meat-flare-up/a-60281299

61 IATP (2018) *Emission impossible* [ONLINE] Available at: https://www.iatp.org/sites/default/files/2018-08/Emissions%20impossible%20EN%2012.pdf

62 Searchinger, T., Herrero, M., Yan, X., Wang, J., Dumas, P., Beauchemin, K., Kebreab, E.(2021) *Opportunities to reduce methane emissions from global agriculture*. Princeton University. [ONLINE] Available at: https://scholar.princeton.edu/sites/default/files/methane_discussion_paper_nov_2021.pdf

63 International Food Policy Research Institute (2009) *Agriculture and Climate change: Reducing methane emissions from irrigated rice*. [ONLINE] Available at: https://www.ifpri.org/publication/agriculture-and-climate-change-reducing-methane-emissions-irrigated-rice

64 Searchinger, T., Herrero, M., Yan, X., Wang, J., Dumas, P., Beauchemin, K., Kebreab, E.(2021) *Opportunities to reduce methane emissions from global agriculture*. Princeton University. [ONLINE] Available at: https://scholar.princeton.edu/sites/default/files/methane_discussion_paper_nov_2021.pdf

65 IDDRI (2018) *An agroecological Europe in 2050: Multifunctional agriculture for healthy eating: Findings from the Ten Years for Agroecology (TYFA) modelling exercise*. [ONLINE] Available at: https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Etude/201809- ST0918EN-tyfa.pdf

66 United Nations Environment Programme and Climate and Clean Air Coalition (2021) Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. [ONLINE] Available at: https://www.ccacoalition.org/sites/default/files/resources/2021_Global-Methane_Assessment_full_0.pdf

67 Packaged Facts (2020) *Global Meat & Poultry Trends*. [ONLINE] Available at: https://www.packagedfacts.com/Global-Meat-Poultry-Trends-13012951/

68 Harwatt, H. (2018) Including animal to plant protein shifts in climate change mitigation policy: a proposed three-step strategy. *Climate Policy* [ONLINE] Available at: https://doi.org/10.1080/14693062.2018.1528965

69 Harwatt, H., Ripple, W. J., Chaudhary, A., Betts M. G., Hayek, M. N. (2019) Scientists call for renewed Paris pledges to transform agriculture. *Lancet Planet Health* [ONLINE] Available at: http://dx.doi.org/10.1016/S2542-5196(19)30245-1

70 Bailey, R., Froggatt, A. & Wellesley, L. (2014) *Livestock – Climate Change's Forgotten Sector.* London: The Royal Institute of International Affairs. [ONLINE] Available at: https://www.chathamhouse.org/sites/default/files/field/field_document/20141203LivestockClimateChangeForgottenSectorBaileyFroggattWellesleyFinal.pdf

71 Wollenberg et al (2016) Reducing emissions from agriculture to meet the 2°C target. *Global Change Biology* 22: 3859–3864. [ONLINE] Available at: https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13340

72 Sun, Z., Scherer, L., Tukker, A. *et al.* Dietary change in high-income nations alone can lead to substantial double climate dividend. *Nat Food* **3,** 29–37 (2022).[ONLINE] Available at: https://www.nature.com/articles/s43016-021-00431-5

73 Pushkarev, N. (2021) *Dietary guidelines for co-benefits: A case for European action*. [ONLINE] Available at: https://epha.org/dietary-guidelines-for-co-benefits-a-case-for-european-action/

74 Wellesley, L., Froggatt, A. and Happer, C. (2015) *Changing climate, changing diets: Pathways to lower meat*

consumption. Chatham House, the Royal Institute of International Affairs. [ONLINE] Available at: http://eprints.gla.ac.uk/113170/1/113170.pdf

75 TAPPC (2021) *70% West Europeans want politicians to change food price VAT*. https://www.tappcoalition.eu/nieuws/15698/majority-west-european-citizens-have-appetite-for-a-meat-tax---supporting-farmers-and-consumers-

76 Changing Markets Foundation (2021) *Blindspot: How lack of action on livestock methane undermines climate targets.* [ONLINE] Available at: http://changingmarkets.org/wp-content/uploads/2021/10/Blindspot_methane-English.pdf

77 Euromonitor International (2021) *The future of meat: Is consumption really decreasing?* [ONLINE] Available at: https://go.euromonitor.com/rs/805-KOK-719/images/The%20Future%20of%20Meat_Webinar.pdf?utm_campaign=WB_19_10_17_Future_of_Meat&utm_medium=Email&utm_%20source=0_Auto-Response_Email&mkt_tok=ODA1LUtPSy03MTkAAAF_prxEvNMXKdY3xCZNKV8evAKyA2A0VZ4nflwvRGsgTk28udC4wb_-neEJ7wl5dfQXSrN5KANNivMI9A4dbxp_VjJCV9pw1zp4NZ9sR1wtEuio2Lw

78 Social Market Foundation (2021) *Raising the steaks: Developing a market for alternative protein in the UK*. [ONLINE] Available at: https://www.smf.co.uk/wp-content/uploads/2021/09/Raisingthe-steaks-Sep-2021.pdf

79 Torrella, K. (2022) Big Food is ready to sell you more plant-based meat, *Vox*, 21 January 2022 [ONLINE] Available at: https://www.vox.com/future-perfect/22883795/food-industry-plant-based-vegan-meat-dairy-climate-pledges

80 CarbonBrief (2020) *What is the climate impact of eating meat and dairy?* [ONLINE] Available at: https://interactive.carbonbrief.org/what-is-the-climate-impact-of-eating-meat-and-dairy/

81 Harvard Health Publishing (2020) What's the beef with eating red meat? [ONLINE] Available at: https://www.health.harvard.edu/staying-healthy/whats-the-beef-with-red-meat

82 Xu, X., Sharma, P., Shu, S. *et al.* (2021) Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nat Food* **2,** 724–732[ONLINE] Available at: https://www.nature.com/articles/s43016-021-00358-x

83 Milman, O. (2021) Meat accounts for nearly 60% of all greenhouse gases from food production, study finds, *The Guardian,* 13 September 2021 [ONLINE] Available at: https://www.theguardian.com/environment/2021/sep/13/meat-greenhouses-gases-food-production-study

84 Xu, X., Sharma, P., Shu, S. *et al.* (2021) Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nat Food* **2,** 724–732 [ONLINE] Available at: https://www.nature.com/articles/s43016-021-00358-x

85 CarbonBrief (2020) *What is the climate impact of eating meat and dairy?* [ONLINE] Available at: https://interactive.carbonbrief.org/what-is-the-climate-impact-of-eating-meat-and-dairy/

86 Shankman, S. (2019) What is nitrous oxide and why is it a climate threat?, *Inside Climate News*, 11 September 2019 [ONLINE] Available at: https://insideclimatenews.org/news/11092019/nitrous-oxide-climate-pollutant-explainer-greenhouse-gas-agriculture-livestock/

87 Poore, J. & Nemecek, T. (2018) *Reducing food's environmental impacts through producers and consumers.* [ONLINE] Available at: https://www.science.org/doi/abs/10.1126/science.aaq0216

88 Ritchie, H. (2021), If the world adopted a plant-based diet we would reduce global agricultural land use from 4 to 1 billion hectares, *Our World in Data*, 4 March 2021 [ONLINE] Available at: https://ourworldindata.org/land-use-diets

89 Heirich Böll Stiftung (2021*) The Meat Atlas*; facts and figures about the animals we eat [ONLINE] Available at: https://eu.boell.org/sites/default/files/2021-09/MeatAtlas2021_final_web.pdf?dimension1=ecology

90 Woldeab, R. (2019) *Industrialized meat production and land degradation: 3 reasons to shift to a plant-based diets, Population Education*, 19 December 2019 [ONLINE] Available at: https://populationeducation.org/industrialized-meat-production-and-land-degradation-3-reasons-to-shift-to-a-plant-based-diet/

91 Poore, J. & Nemecek, T. (2018) *Reducing food's environmental impacts through producers and consumers.* [ONLINE] Available at: https://www.science.org/doi/abs/10.1126/science.aaq0216

92 Poore, J. & Nemecek, T. (2018) *Reducing food's environmental impacts through producers and consumers.* [ONLINE] Available at: https://www.science.org/doi/abs/10.1126/science.aaq0216

93 International Energy Agency (2020) *Methane emissions from oil and gas*. [ONLINE] Available at: https://www.iea.org/reports/methane-emissions-from-oil-and-gas#tracking-progress

94 IEA (2022) *Global Methane Tracker 2022*. [ONLINE] Available at: https://www.iea.org/reports/global-methane-tracker-2022/overview

95 International Energy Agency (2021) *Net Zero by 2050: A roadmap for the global energy sector*. p 14. [ONLINE] Available at: https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

96 Climate and clean air coalition, United Nations Environment Programme (2021) *Global Methane Assessment*. p 97, paragraph 2 and 6. [ONLINE] Available at: https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report

97 IEA (2022) *Global Methane Tracker 2022*. [ONLINE] Available at: https://www.iea.org/reports/global-methane-tracker-2022/overview

98 European Commission (2021) *Impact assessment report accompanying the proposal for a Regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector.* p 6. [ONLINE] Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12581-Climate-change-new-rules-to-prevent-methane-leakage-in-the-energy-sector_en

99 Capterio (2020) *Tackling flaring: Lessons from the North Sea.* p 3 [ONLINE] Available at: https://capterio.com/wp-content/uploads/2020/10/20201008-Tackling-flaring-Lessons-from-the-North-Sea-final.pdf

100 European Commission (2021) *Proposal for a Regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector*. [ONLINE] Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12581-Climate-change-new-rules-to-prevent-methane-leakage-in-the-energy-sector_en

101 Government of Canada (2021) *Canada confirms its support for the Global Methane Pledge and announced ambitious domestic actions to slash methane emissions*. [ONLINE] Available at: https://www.canada.ca/en/environment-climate-change/news/2021/10/canada-confirms-its-support-for-the-global-methane-pledge-and-announces-ambitious-domestic-actions-to-slash-methane-emissions.html

102 USEPA (2021) *Controlling air pollution from the oil and natural gas industry*. [ONLINE] Available at: https://www.epa.gov/controlling-air-pollution-oil-and-natural-gas-industry

103 International Energy Agency (2021) *Curtailing methane emissions from fossil fuel operations.* p 46. [ONLINE] Available at: https://iea.blob.core.windows.net/assets/585b901a-e7d2-4bca-b477-e1baa14dde5c/CurtailingMethaneEmissionsfromFossilFuelOperations.pdf

104 European Commission (2018) *In-depth analysis in support of the Commission Communication COM (2018) 773: A clean planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy*. p 51, footnote 128. [ONLINE] Available at: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

105 US Environmental Protection Agency (2016) *Background technical support document for the final new source performance standards*. 42–52. [ONLINE] Available at: https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-7631

106 International Energy Agency (2021) *Methane emissions in oil and gas: Tracking report*. [ONLINE] Available at: https://www.iea.org/reports/methane-emissions-from-oil-and-gas

107 Reuters (16 June 2020) *Special report: Millions of abandoned oil wells are leaking methane, a climate menace*. [ONLINE] Available at: https://www.reuters.com/article/us-usa-drilling-abandoned-specialreport/special-re-

port-millions-of-abandoned-oil-wells-are-leaking-methane-a-climate-menace-idUSKBN23N1NL

108 Kholod, N., Evans, M., Pilcher, r. Roshchanka, V., Ruiz, F., Coté, m., Collings, R. (2020) *Global methane emissions from coal mining to continue growing even with declining coal production*. *Journal of Cleaner Production*, 256: 120489. [ONLINE] Available at: https://www.sciencedirect.com/science/article/pii/S0959652620305369

109 International Energy Agency (2019) *Work energy outlook 2019*. p 248. [ONLINE] Available at: https://iea.blob.core.windows.net/assets/98909c1b-aabc-4797-9926-35307b418cdb/WEO2019-free.pdf

110 US Environmental Protection Agency (2019) *Ventilation air methane (VAM) utilization technologies*. [ONLINE] Available at: https://www.epa.gov/sites/default/files/2017-01/documents/vam_technologies-1-2017.pdf.pdf

111 US Environmental Protection Agency (2019) *Ventilation air methane (VAM) utilization technologies*. [ONLINE] Available at: https://www.epa.gov/sites/default/files/2017-01/documents/vam_technologies-1-2017.pdf.pdf

112 UNECE (2016) *Best practice guidance for effective methane drainage and use in coal mines*. p 23. [ONLINE] Available at: https://unece.org/DAM/energy/cmm/docs/BPG_2017.pdf

113 Kholod, N., Evans, M., Pilcher, r. Roshchanka, V., Ruiz, F., Coté, m., Collings, R. (2020) *Global methane emissions from coal mining to continue growing even with declining coal production*. *Journal of Cleaner Production*, 256: 120489. [ONLINE] Available at: https://www.sciencedirect.com/science/article/pii/S0959652620305369

114 European Commission (2021) *Impact assessment report accompanying the Proposal for a Regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector and amending Regulation (EU) 2019/942*. p 79. [ONLINE] Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12581-Climate-change-new-rules-to-prevent-methane-leakage-in-the-energy-sector_en

115 European Commission (2021) *Impact assessment report accompanying the proposal for a regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector.* p 6. [ONLINE] Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12581-Climate-change-new-rules-to-prevent-methane-leakage-in-the-energy-sector_en

116 USEPA (2021) *Greenhouse gas equivalencies calculator*. [ONLINE] Available at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

117 European Commission (2021) *Impact assessment report accompanying the proposal for a regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector.* p 6. [ONLINE] Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12581-Climate-change-new-rules-to-prevent-methane-leakage-in-the-energy-sector_en

118 European Commission (2021) *Impact assessment report accompanying the proposal for a regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector.* p 6. [ONLINE] Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12581-Climate-change-new-rules-to-prevent-methane-leakage-in-the-energy-sector_en

119 International Trade Administration (2022) *Japan: Country commercial guide, liquefied natural gas*. [ONLINE] Available at: https://www.trade.gov/country-commercial-guides/japan-liquefied-natural-gas-lng

120 US Energy Information Administration (2020) *Country analysis executive summary: Japan*. [ONLINE] Available at: https://www.eia.gov/international/content/analysis/countries_long/Japan/japan.pdf

121 International Energy Agency (2018) *The future of petrochemicals: Towards more sustainable plastics and fertilizers*. pp. 11, 27. [ONLINE] Available at: https://www.iea.org/reports/the-future-of-petrochemicals

122 Center for International Environmental Law (2019) *Plastic and climate: The hidden costs of a plastic planet*. p 2. [ONLINE] Available at: https://www.ciel.org/plasticandclimate/

123 Lelieveld, J., Klingmüller, K., Pozzer, A., Ramanathan, V.(2019) Effects of fossil fuel and total anthropogenic emission removal on public health and climate, *PNAS* [ONLINE] Available at: https://www.pnas.org/doi/10.1073/pnas.1819989116

124 Health and Environment Alliance (2017), *Hidden Price Tags: How ending Fossil fuel Subsidies would benefit our Health*. [ONLINE] Available at: http://sdg.iisd.org/news/report-highlights-health-benefits-of-phasing-out-fossil-fuel-subsidies/

125 Datu (2014) *The emerging US methane mitigation industry*. p 5. [ONLINE] Available at: https://www.edf.org/sites/default/files/us_methane_mitigation_industry_report.pdf

126 European Commission (2020) *EU Strategy to reduce methane emissions*. p 6. [ONLINE] Available at: https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf.

127 Duren, R. M., Thorpe, A. K., Foster, K. T., Rafiq, T., Hopkins, F. M., Yadav, V. & Miller, C. E. (2019) California's methane super-emitters. *Nature*, 575(7781): 180–184.

128 The European Space Agency (2021) *Satellites detect large methane emissions from Madrid landfills*. [ONLINE] Available at: https://www.esa.int/Applications/Observing_the_Earth/Satellites_detect_large_methane_emissions_from_Madrid_landfills

129 Intergovernmental Panel on Climate Change (2021) *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* [ONLINE] Available at: https://www.ipcc.ch/report/ar6/wg1/#FullReport

130 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions.* [ONLINE] Available at: https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions

131 Höglund-Isaksson, L., Gómez-Sanabria, A., Klimont, Z., Rafaj, P. & Schöpp, W. (2020) Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe–results from the GAINS model. *Environmental Research Communications*, 2(2). [ONLINE] Available at: https://doi.org/10.1088/2515-7620/ab7457

132 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Global Methane Assessment*.

133 Jeong, S., Cui, X., Blake, D. R., Miller, B., Montzka, S. A., Andrews, A. & Fischer, M. L. (2017) Estimating methane emissions from biological and fossil- fuel sources in the San Francisco Bay Area. *Geophysical Research Letters*, 44(1): 486–495. [ONLINE] Available at: https://doi.org/10.1002/2016GL071794

134 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Global Methane Assessment*.

135 National Academies of Sciences, Engineering, and Medicine (2018) *Improving characterization of anthropogenic methane emissions in the United States*. [ONLINE] Available at: https://doi.org/10.17226/24987

136 National Academies of Sciences, Engineering and Medicine (2018) *Improving characterization of anthropogenic methane emissions*.

137 Gikandi, L. (2021) *10% of all greenhouse gas emissions come from food we throw in the bin.* [ONLINE] Available at: https://updates.panda.org/driven-to-waste-report

138 Brown, S. (2016) Greenhouse gas accounting for landfill diversion of food scraps and yard waste. *Compost Science & Utilization*, 24(1): 11–19. [ONLINE] Available at: https://doi.org/10.1080/1065657X.2015.1026005

139 Zero Waste Europe and Slow Food (2021) *Reducing food waste at the local level: Guidance for municipalities to reduce food waste within local food systems.* [ONLINE] Available at: https://www.slowfood.com/wp-content/uploads/2022/01/Guidance-on-food-waste-reduction-in-cities-EN.pdf

140 ReFED (n.d.) *Roadmap to 2030: Reducing US food waste by 50%.* [ONLINE] Available at: https://refed.org/food-waste/the-solutions/#roadmap-2030

141 Zero Waste Europe (2020) *Zero waste Europe factsheet: France's law for fighting food waste.* [ONLINE] Available at: https://zerowasteeurope.eu/wp-content/uploads/2020/11/zwe_11_2020_factsheet_france_en.pdf

142 Bottinelli, S. (2021) The city of Milan's Local Food Hubs reduce 130 tonnes of food waste a year, and win Earth-

Shot Prize. *Food Matters Live*, 18 October 2021. [ONLINE] Available at: https://foodmatterslive.com/discover/article/milan-local-food-hubs-reduce-130-tonnes-of-food-waste-a-year-and-win-earthshot-prize

143 Food Policy di Milano (2021) *"Milan Food waste hub" won Prince William's Earthshot Prize*. [ONLINE] Available at: https://foodpolicymilano.org/en/milan-food-waste-hub-won-prince-williams-earthshot-prize/

144 Salemdeeb, R., Zu Ermgassen, E. K., Kim, M. H., Balmford, A. & Al-Tabbaa, A. (2017) Environmental and health impacts of using food waste as animal feed: A comparative analysis of food waste management options. *Journal of Cleaner Production*, *140*: 871–880. [ONLINE] Available at: https://doi.org/10.1016/j.jclepro.2016.05.049

145 Broom, D. (2019) South Korea once recycled 2% of its food waste. Now it recycles 95%. *World Economic Forum*, 12 April 2019. [ONLINE] Available at: https://www.weforum.org/agenda/2019/04/south-korea-recycling-food-waste/

146 Cabanas-Vargas, D. D. & Stentiford, E. I. (2006) Oxygen and CO2 profiles and methane formation during the maturation phase of composting. *Compost Science & Utilization*, 14(2): 86–89. [ONLINE] Available at: https://doi.org/10.1080/1065657X.2006.10702269

147 Jäckel, U., Thummes, K. & Kämpfer, P. (2005) Thermophilic methane production and oxidation in compost. *FEMS Microbiology Ecology*, 52(2): 175–184. [ONLINE] Available at: https://doi.org/10.1016/j.femsec.2004.11.003

148 Hermann, B. G., Debeer, L., De Wilde, B., Blok, K. & Patel, M. K. (2011) To compost or not to compost: Carbon and energy footprints of biodegradable materials' waste treatment. *Polymer Degradation and Stability*, 96(6): 1159–1171. [ONLINE] Available at: https://doi.org/10.1016/j.polymdegradstab.2010.12.026

149 Boldrin, A., Andersen, J. K., Møller, J., Christensen, T. H. & Favoino, E. (2009) Composting and compost utilization: accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, 27(8): 800–812. [ONLINE] Available at: https://doi.org/10.1177/0734242X09345275

150 Zhao, H., Themelis, N., Bourtsalas, A. & McGillis, W. R. (2019) *Methane emissions from landfills.* Columbia University [ONLINE] Available at: https://www.researchgate.net/publication/334151857_Methane_Emissions_from_Landfills

151 Nair, S. K. (2022) *Back to Earth. Composting for various contexts. GAIA - Global Alliance for Incinerator Alternatives*. [ONLINE] Available at: https://www.no-burn.org/wp-content/uploads/2022/01/Back-to-Earth-Organics-Manual_Spread.pdf

152 Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B. & Zhuang, Q. (2020) The global methane budget 2000–2017. *Earth Systems Science and Data*, 12: 1561–1623. [ONLINE] Available at: https://doi.org/10.5194/essd-12-1561-2020

153 Thiruvananthapuram Municipal Corporation (2019) *Status of solid and liquid waste management*. Thiruvananthapuram: TMC.

154 Thiruvananthapuram Municipal Corporation (2019) *Status of solid and liquid waste management*.

155 Seoul Metropolitan Government (2021) *Food waste generation and treatment status statistics in Seoul.* [ONLINE] Available at: https://data.seoul.go.kr/dataList/371/S/2/datasetView.do

156 Korea Resource Recirculation Information System (2021) *Current status of national waste generation and disposal (living, workplace, general).* [ONLINE] Available at: https://www.recycling-info.or.kr/rrs/stat/envStatList.do?menuNo=M13020201

157 Glachen, R. (2020) How South Korea is composting its way to sustainability: Automated bins, rooftop farms, and underground mushroom-growing help clean up the mess. *The New Yorker*, 2 March 2020. [ONLINE] Available at: https://www.newyorker.com/magazine/2020/03/09/how-south-korea-is-composting-its-way-to-sustainability

158 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Global Methane Assessment*.

159 Paul, A. S. (2021) Thanks to high LPG price, homemakers turn to biogas. *The Hindu*, 11 September 2021. [ONLINE] Available at: https://www.thehindu.com/news/cities/Thiruvananthapuram/thanks-to-high-lpg-price-homemakers-turn-to-biogas/article36401902.ece

160 Zero Waste International Alliance (2017) *Choosing between composting and anaerobic digestion: Soil, fuel or both?* [ONLINE] Available at: https://zerowasteeurope.eu/library/choosing-between-composting-and-anaerobic-digestion-soil-fuel-or-both/

161 European Union (2008) *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.* [ONLINE] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20180705

162 European Commission (2021) *A farm to fork strategy*. [ONLINE] Available at: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en

163 Government of India Ministry of Environment, Forest and Climate Change (2016) Ministry of Environment, Forest and Climate Change Notification. *The Gazette of India*, 8 April 2016 [ONLINE] Available at: https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf

164 CalRecycle (2022) *California's short-lived climate pollutant reduction strategy.* [ONLINE] Available at: https://www.calrecycle.ca.gov/organics/slcp

165 Chilean Ministry of the Environment (2021) *National Strategy for Organic Waste: Chile 2040.* [ONLINE] Available at: https://economiacircular.mma.gob.cl/wp-content/uploads/2021/03/Estrategia-Nacional-de-Residuos-Organicos-Chile-2040.pdf

166 Agency for Toxic Substances and Disease Registry (2001) *Landfill gas primer: An overview for environmental health professionals*. [ONLINE] Available at: https://www.atsdr.cdc.gov/hac/landfill/html/ch2.html

167 Powell, J. T., Townsend, T. G. & Zimmerman, J. B. (2016) Estimates of solid waste disposal rates and reduction targets for landfill gas emissions. *Nature Climate Change*, 6(2): 162–165. [ONLINE] Available at: https://doi.org/10.1038/nclimate2804

168 Boldrin, A., Andersen, J. K., Møller, J., Christensen, T. H. & Favoino, E. (2009) Composting and compost utilization: Accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, 27(8): 800–812. [ONLINE] Available at: https://doi.org/10.1177/0734242X09345275

169 Lou, X. F. & Nair, J. (2009) The impact of landfilling and composting on greenhouse gas emissions–a review. *Bioresource Technology*, 100(16): 3792–3798. [ONLINE] Available at: https://doi.org/10.1016/j.biortech.2008.12.006

170 Stern, J. C., Chanton, J., Abichou, T., Powelson, D., Yuan, L., Escoriza, S. & Bogner, J. (2007) Use of a biologically active cover to reduce landfill methane emissions and enhance methane oxidation. *Waste Management*, 27(9): 1248–1258. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2006.07.018

171 Barlaz, M. A., Green, R. B., Chanton, J. P., Goldsmith, C. D. & Hater, G. R. (2004) Evaluation of a biologically active cover for mitigation of landfill gas emissions. *Environmental Science & Technology*, 38(18): 4891–4899. [ONLINE] Available at: https://doi.org/10.1021/es049605b

172 Lou, X. F. & Nair, J. (2009) The impact of landfilling and composting on greenhouse gas emissions–a review.

173 Stern, J. C., Chanton, J., Abichou, T., Powelson, D., Yuan, L., Escoriza, S. & Bogner, J. (2007) Use of a biologically active cover to reduce landfill methane emissions and enhance methane oxidation.

174 Johannessen, L. M. (1999) *Guidance note on recuperation of landfill gas from municipal solid waste landfills*. Washington DC, USA: International Bank for Reconstruction and Development/World Bank.

175 Stanisavljević, N., Ubavin, D., Batinić, B., Fellner, J. & Vujić, G. (2012) Methane emissions from landfills in Serbia and potential mitigation strategies: a case study. *Waste Management & Research*, 30(10): 1095–1103. [ONLINE] Available at: https://doi.org/10.1177/0734242X12451867

176 The Landfill Gas Expert (2019) *Fugitive emissions of methane and landfill gas explained.* [ONLINE] Available at:

https://landfill-gas.com/fugitive-emissions-of-methane-landfill-gas

177 Inter-American Development Bank (2009) *Guidance note on landfill gas capture and utilization* [ONLINE] Available at: https://publications.iadb.org/publications/english/document/Guidance-Note-on-Landfill-Gas-Capture-and-Utilization.pdf

178 Barton, J. R., Issaias, I. & Stentiford, E. I. (2008) Carbon: Making the right choice for waste management in developing countries. *Waste management*, 28(4): 690–698. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2007.09.033

179 Global Alliance for Incinerator Alternatives (n.d.) *Clean development mechanism funding for waste incineration: Financing the demise of waste worker livelihood, community health, and climate* [ONLINE] Available at: https://www.no-burn.org/wp-content/uploads/Clean-Development-Mechanism-Flyer.pdf

180 Global Alliance for Incinerator Alternatives (2013) *Recycling jobs: Unlocking the potential for green employment growth*. [ONLINE] Available at: https://www.no-burn.org/wp-content/uploads/2021/03/Recycling-Jobs-Unlocking-Potential-final.pdf

181 Global Alliance for Incinerator Alternatives (2021) *The high cost of waste incineration.* [ONLINE] Available at: www.doi.org/10.46556/RPKY2826

182 Global Alliance for Incinerator Alternatives (2021) *The high cost of waste incineration.*

183 The New School Tishman Environment and Design Center (2019) *US solid waste incinerators: An industry in decline.* [ONLINE] Available at: https://grist.org/wp-content/uploads/2020/07/1ad71-cr_gaiareportfinal_05.21.pdf

184 Tavernise, S. (2011) City council in Harrisburg files petition of bankruptcy. *The New York Times*, 12 October 2011. [ONLINE] Available at: https://www.nytimes.com/2011/10/13/us/harrisburg-pennsylvania-files-for-bankruptcy.html

185 Morris, J. (2005) Comparative LCAs for curbside recycling versus either landfilling or incineration with energy recovery. *The International Journal of Life Cycle Assessment*, 10(4): 273–284. [ONLINE] Available at: https://doi.org/10.1065/lca2004.09.180.10

186 Tangri, N. V. (2021) Waste incinerators undermine clean energy goals. *Earth ArXiv* [ONLINE] Available at: https://doi.org/10.31223/X5VK5X

187 Tangri, N. V. (2021). Waste incinerators undermine clean energy goals. *Earth ArXiv* [ONLINE] Available at: https://doi.org/10.31223/X5VK5X

188 Kaza, S., Yao, L., Bhada-Tata, P. & Van Woerden, F. (2018) *What a waste 2.0: A global snapshot of solid waste management to 2050*. Washington: World Bank Publications. [ONLINE] Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/30317/211329ov.pdf

189 United Nations Environment Programme and Climate and Clean Air Coalition (2021) *Global Methane Assessment.*

190 Government of India Ministry of Environment, Forest and Climate Change (2016) Ministry of Environment, Forest and Climate Change notification. *The Gazette of India*, 8 April 2016. [ONLINE] Available at: https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf

191 Ma, S., Zhou, C., Pan, J., Yang, G., Sun, C., Liu, Y. & Zhao, Z. (2022) Leachate from municipal solid waste landfills in a global perspective: Characteristics, influential factors and environmental risks. *Journal of Cleaner Production*, 333: 130234. [ONLINE] Available at: https://doi.org/10.1016/j.jclepro.2021.130234

192 Bihałowicz, J. S., Rogula-Kozłowska, W. & Krasuski, A. (2021) Contribution of landfill fires to air pollution: An assessment methodology. *Waste Management*, 125: 182–191. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2021.02.046

193 Global Alliance for Incinerator Alternatives (2019) *Pollution and health impacts of waste-to-energy incineration.* [ONLINE] Available at: https://www.no-burn.org/wp-content/uploads/Pollution-Health_final-Nov-14-2019.pdf

194 Global Alliance for Incinerator Alternatives (2019) *Pollution and health impacts of waste-to-energy incineration*.

195 Zero Waste Europe (2018) *The story of Parma: Case study.* [ONLINE] Available at: https://zerowasteeurope.eu/library/the-story-of-parma/

196 Favoino, E. & Hogg, D. (2008) The potential role of compost in reducing greenhouse gases. *Waste Management & Research*, 26(1): 61–69. [ONLINE] Available at: https://doi.org/10.1177/0734242X08088584

197 Favoino, E. & Hogg, D. (2008) The potential role of compost in reducing greenhouse gases.

198 Zero Waste Europe and Slow Food (2021) *Reducing food waste at the local level: Guidance for municipalities to reduce food waste within local food systems.* [ONLINE] Available at: https://www.slowfood.com/wp-content/uploads/2022/01/Guidance-on-food-waste-reduction-in-cities-EN.pdf

199 Global Alliance for Incinerator Alternatives (2021) *Zero waste and economic recovery: The job creation potential of zero waste.* [ONLINE] Available at: https://zerowasteworld.org/wp-content/uploads/Jobs-Report-ENGLISH-2.pdf

200 Global Alliance for Incinerator Alternatives (2021) *Zero waste and economic recovery: The job creation potential of zero waste.*

201 UN Environment (2021) *Global methane assessment: Cost and benefits of mitigating methane emissions*. Executive Summary. pp. 9, 10. [ONLINE] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35913/GMA.pdf

202 UNFCCC Secretariat (2021) *NDC synthesis report*. [ONLINE] Available at: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs/ndc-synthesis-report

203 Joint Inspection Unit (2014) *Post-Rio+20 review of environmental governance within the United Nations system.* JIU/REP/2014/4. p 14. [ONLINE] Available at: https://www.undocs.org/en/jiu/rep/2014/4

204 Joint Inspection Unit (2014) *Post-Rio+20 review of environmental governance within the United Nations system.* JIU/REP/2014/4. p 14. [ONLINE] Available at: https://www.undocs.org/en/jiu/rep/2014/4

205 Science Media Centre (2021) *Expert reaction to the global methane report*. [ONLINE] Available at: https://www.sciencemediacentre.org/expert-reaction-to-the-global-methane-report/

206 Adhikari, B. K., Trémier, A., Martinez, J., & Barrington, S. (2010) Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada. *Waste Management & Research*, *28*(11): 1039-1053. [ONLINE] Available at: https://doi.org/10.1177/0734242X10373801

207 Zhao, H., Themelis, N., Bourtsalas, A., & McGillis, W. R. (2019) Methane emissions from landfills. *Columbia University* [ONLINE] Available at: https://www.researchgate.net/publication/334151857_Methane_Emissions_from_Landfills

208 Themelis, N. J., & Ulloa, P. A. (2007) Methane generation in landfills. *Renewable energy*, *32*(7): 1243-1257. [ONLINE] Available at: https://doi.org/10.1016/j.renene.2006.04.020

209 Amlinger, F., Peyr, S., & Cuhls, C. (2008) Green house gas emissions from composting and mechanical biological treatment. *Waste Management & Research*, *26*(1): 47-60. [ONLINE] Available at: https://doi.org/10.1177/0734242X07088432

210 Andersen, J. K., Boldrin, A., Christensen, T. H., & Scheutz, C. (2010) Mass balances and life-cycle inventory for a garden waste windrow composting plant (Aarhus, Denmark). *Waste management & research*, *28*(11): 1010-1020. [ONLINE] Available at: https://doi.org/10.1177/0734242X09360216

211 Boldrin, A., Andersen, J. K., Møller, J., Christensen, T. H., & Favoino, E. (2009) Composting and compost utilization: accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, 27(8): 800-812. [ONLINE] Available at: https://doi.org/10.1177/0734242X09345275

212 Møller, J., Boldrin, A., & Christensen, T. H. (2009) Anaerobic digestion and digestate use: accounting of greenhouse gases and global warming contribution. *Waste management & research*, *27*(8): 813-824. [ONLINE]

Available at: https://doi.org/10.1177/0734242X09344876

213 United Nations Environment Programme (2010) *Waste and Climate Change: Global Trends and Strategy Framework* [ONLINE] Available at: https://wedocs.unep.org/20.500.11822/8648

214 de Araújo Morais, J., Ducom, G., Achour, F., Rouez, M., & Bayard, R. (2008) Mass balance to assess the efficiency of a mechanical–biological treatment. *Waste Management*, *28*(10): 1791-1800. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2007.09.002

215 Pan, J., & Voulvoulis, N. (2007) The role of mechanical and biological treatment in reducing methane emissions from landfill disposal of municipal solid waste in the United Kingdom. *Journal of the Air & Waste Management Association*, *57*(2): 155-163. [ONLINE] Available at: https://doi.org/10.1080/10473289.2007.10465317

216 De Gioannis, G., Muntoni, A., Cappai, G., & Milia, S. (2009) Landfill gas generation after mechanical biological treatment of municipal solid waste. Estimation of gas generation rate constants. *Waste Management*, *29*(3): 1026-1034. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2008.08.016

217 Lornage, R., Redon, E., Lagier, T., Hébé, I., & Carré, J. (2007) Performance of a low cost MBT prior to landfilling: study of the biological treatment of size reduced MSW without mechanical sorting. *Waste Management*, *27*(12): 1755-1764. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2006.10.018

218 Lou, X. F., & Nair, J. (2009) The impact of landfilling and composting on greenhouse gas emissions–a review. *Bioresource technology*, 100(16): 3792-3798. [ONLINE] Available at: https://doi.org/10.1016/j.biortech.2008.12.006

219 Stern, J. C., Chanton, J., Abichou, T., Powelson, D., Yuan, L., Escoriza, S., & Bogner, J. (2007) Use of a biologically active cover to reduce landfill methane emissions and enhance methane oxidation. *Waste Management*, 27(9): 1248-1258. [ONLINE] Available at: https://doi.org/10.1016/j.wasman.2006.07.018

220 Barlaz, M. A., Green, R. B., Chanton, J. P., Goldsmith, C. D., & Hater, G. R. (2004) Evaluation of a biologically active cover for mitigation of landfill gas emissions. *Environmental science & technology*, *38*(18): 4891-4899. [ONLINE] Available at: https://doi.org/10.1021/es049605b

Changing Markets FOUNDATION

environmental investigation agency

gaia