WORLD BIOGAS ASSOCIATION

Biogas: Pathways to 2030

If we do not address methane emissions from organic wastes all our efforts to tackle the climate crisis will fail. Anaerobic digestion is one of the ready to go, ready to scale technologies that can do this. The path we must take is clear.

David Newman, President
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Foreword

Now is the time of act

For decades, scientists have been warning the world about climate change. Yet, it was only in 2015 that 196 countries finally adopted a legally binding international treaty on climate change, the Paris Agreement, to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels by end of the century. To meet this target, the Intergovernmental Panel on Climate Change (IPCC) say a 45% cut in global greenhouse gas (GHG) emissions against 2010 levels is required by 2030. Current nations' climate plans, or Nationally Determined Contributions (NDCs), deliver a hopeless 1% according to an interim NDC Synthesis Report of the UNFCCC published in March 2021, almost six years from the adoption of the Paris Agreement.

We are now rapidly running out of time. In August 2020, we passed one of the many tipping points we have been warned against - the melting of Greenland's ice sheet is believed to have reached a point of no return, which means that anything done now to mitigate climate change will not stop the ice sheet from completely disappearing. The level of ice loss matches the worst-case-scenario predictions outlined by the IPCC.

We have less than a decade to change that 1% to a 45% to prevent us from reaching other tipping points. This means all countries and industries must cut GHG emissions immediately, covering all sectors and drawing on all technologies and knowledge. The **Biogas: Pathways to 2030** report draws attention to an often overlooked and yet significant climate change contributor: organic wastes. By managing these properly, nearly one quarter of this alarming shortfall can be met.

Humans directly or indirectly generate over 105 billion tonnes of organic wastes globally each year, all of which release harmful methane and other GHG emissions directly into the atmosphere as they decompose. These organic wastes include food waste, sewage and garden wastes, food and drink processing wastes, and farm and agricultural wastes. By separately collecting food waste to cut today's food waste in half, a 3% reduction in greenhouse gas emissions can be achieved. By treating and recycling all other unavoidable organic wastes through anaerobic digestion, a ready-to-use technology, we can prevent those methane emissions and generate biogas, bio-fertilisers, bio-CO_2, and other valuable bio-products. Put simply, we can turn a waste management issue into a resource. While today only 2% of these are recycled, an astonishing 10% reduction in global GHG emissions can be achieved by 2030 if we capture the readily available organic wastes across the world.

This report forms a policy tool kit aimed at helping stakeholders and policy makers manage, reduce and recycle their organic wastes as a circular economy to not just cut methane emissions from them but maximise their value, helping to put the world back on track to deliver on the ambitions of the Paris agreement. The knowledge and technology to achieve this by 2030 is already here. Governments, stakeholders and policy makers just need to decide to act. Now.

Charlotte Morton, Chief Executive WBA

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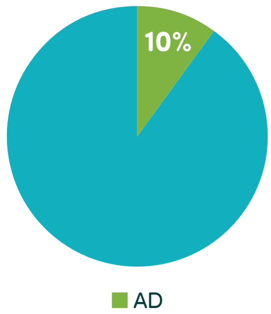
Humans directly or indirectly generate over **105 billion tonnes of organic wastes** globally each year, all of which release harmful methane and other greenhouse gas emissions directly into the atmosphere as they decompose. These organic wastes include food waste, sewage and garden wastes, food and drink processing wastes, and farm and agricultural wastes. **Today only 2% of these are treated and recycled.** By simply managing these important bioresources more effectively **we can cut global Greenhouse Gas (GHG) emissions by 10% by 2030**.

This report maps out how the global biogas industry can enable countries to deliver a 10% reduction in global GHG emissions by 2030. The pathways put humanity back on track to deliver by 2030 on the ambitions of both the Paris Agreement and UN Sustainable Development Goals (SDGs).



AD potential to abate GHG emissions by 2030

Methane accounts for 20% of all man-made GHG emissions (often measured in CO_2equivalence). Treatment of organic wastes through AD can cut 25% of all man-made methane emissions.

Therefore, by simply avoiding the methane emissions from the breakdown of organic wastes, AD can cut total GHG emissions by 5%. The remaining 5% arises from AD's ability to displace fossil fuels and artificial fertilisers.

Note: ~50-65% of total methane emissions are anthropogenic, arising from human activity. The remainder arise from nature.

AD Systems

Anaerobic Digestion (hereafter AD) is a series of biological processes in which micro-organisms digest organic wastes in the absence of oxygen, in sealed containers. It is the same natural process that we humans and mammals use to break down the food we eat in our stomachs. The process extracts the energy this organic material contains in the form of biogas, which is a mixture of methane (approx. 60%), carbon dioxide (approx. 40%) and other trace gases. The organic material left over, known as digestate or biofertiliser, is rich in organic matter and nutrients such as nitrogen, phosphate and potash. Returning all this organic material back to soil is vital for our food security, and explains why AD is at the heart of the circular economy of organic wastes.

AD systems are highly flexible, scalable and extract the greatest value out of organic wastes. AD can operate at sizes from that of a test tube to tanks of many thousands of cubic metres. As such it is adaptable and can just as well address 9 of the 17 Sustainable Development Goals[1] in the remotest parts of the global south to the organic wastes created by world cities such as New York.

Scale	Tank Size	Gas Use
Micro	0.2m³-100m³	**<20m³**: heating and cooking **>20m³**: heating or Combined Heat and Power (CHP) 3-25kWe, depending upon feedstock and loading rate. **0.2m³** tank is practical enough to provide cooking gas for a small household. **80-100m³** capacities are usually more economic to build a single fixed tank.
Small	100m³- ~1000m³	CHP ~ 10kWe-200kWe, depending upon feedstock and loading rate. Gas heating possible, as well, particularly at lower end.
Medium	~1,000m³+	CHP ~100kWe – 1MWe. Or biomethane upgrading >2.5MW
Large	~4000m³+	Biomethane upgrading 2.5 MW + (+ CHP to power AD plant)

© Table courtesy of Angela Bywater, EB-Net

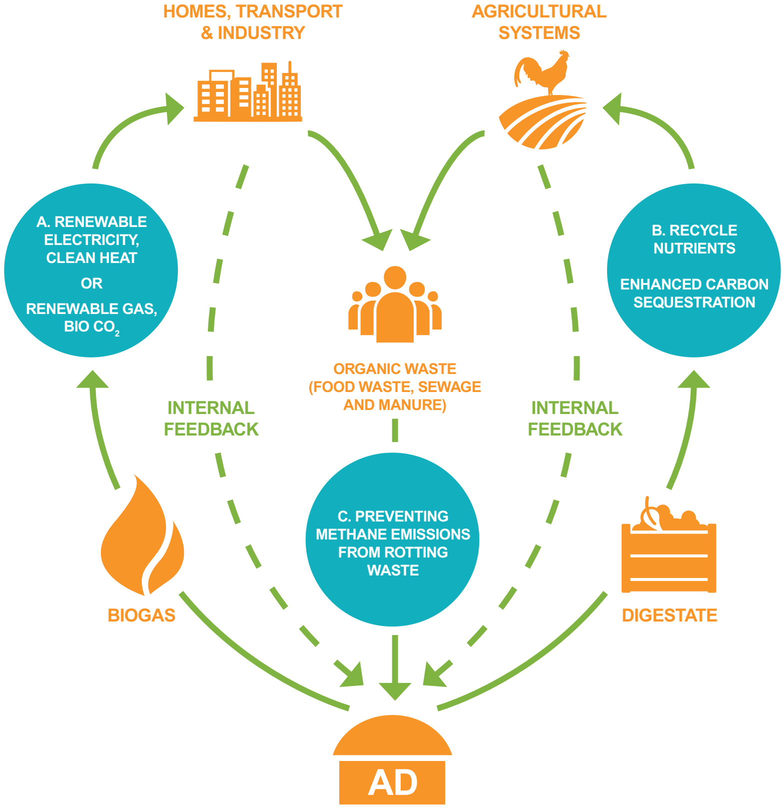
* The identification of scale is completely arbitrary since tank size/gas use are so dependent upon factors, particularly feedstock and loading rate. However, the notes provide good guides.

There are many types of AD system, depending on the feedstock. They can be designed to treat wet or dry wastes – known as wet-AD and dry-AD – or a mix of both. In countries where dry-AD is the norm the AD process often includes a composting phase.

Benefits of AD

"Biogas from anaerobic digestion is not merely a concept of production of renewable energy; it cannot be compared to a wind turbine or a photovoltaic array. Nor can anaerobic digestion be bracketed as just a means of waste treatment or as a tool to reduce greenhouse gases in agriculture and in energy. It cannot be pigeonholed as a means of producing biofertilizer through mineralisation of the nutrients in slurry to optimise availability, or as a means of protecting water quality in streams and aquifers. It is all these and more.

The multifunctionality of this concept is its clearest strength. Sustainable biogas systems include processes for treatment of waste, for protection of environment, for conversion of low-value material to higher-value material, for the production of electricity, heat and of advanced gaseous biofuel. Biogas and anaerobic digestion systems are dispatchable and as such can facilitate intermittent renewable electricity." **IEA[2]**



[1] https://sdgs.un.org/goals
[2] www.ieabioenergy.com/blog/publications/the-role-of-anaerobic-digestion-and-biogas-in-the-circular-economy/

Overview

Time and carbon budgets are running out. We have 10 years left to prevent runaway global warming, say the world's leading scientists[3]. Failure to act will result in worse droughts, floods, extreme heat events and poverty for hundreds of millions of people, animals and wildlife. This will mean mass climate-related migrations and brain drains, as energy, food and health insecurities erupt around the world, as the world is already starting to see. However, a just and affordable transition is possible. The scientists are supported in this view by the world's leading economists Joseph Stiglitz and Lord Nicholas Stern. The 'Build Back Better' paper[4] the pair released in 2020 was supported by treasury chiefs at over 250 national banks and government ministries.

The decade of decarbonisation

The Paris Agreement commits countries to achieve carbon neutrality by 2050, to achieve a balance after 2050 between atmospheric inputs of greenhouse gases by emission sources and removal into sinks (forests, oceans, and soil, which could be combined with technologies to extract and sequester carbon dioxide from power plants). This was signed by 197 countries in 2015, with the ambition to keep global warming below 2°C, to avoid the worst but not all the negative impacts of climate change (hence countries are now being asked to target 1.5°C). But most countries are way off target, according to the Climate Action Tracker[5]. That is why we need to act harder and faster over this decade.

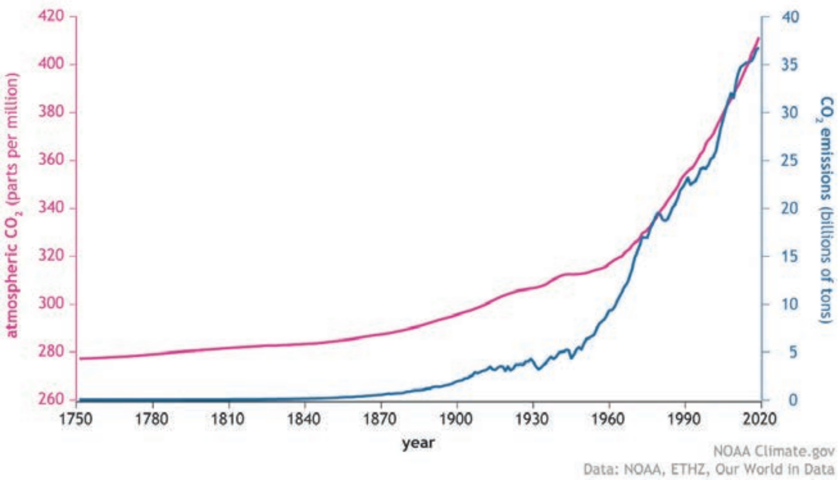
The two key drivers of global warming are widely accepted to be emissions of CO_2 (~80%) and methane (~20%) caused by human activity, although NOx and other such emissions also have a forcing effect. Addressing methane holds the key to success. This is because of the different life cycles of the greenhouse gases, during which they remain actively warming the planet. While methane typically stays in the atmosphere for 35 years, its global warming potential is far greater than CO_2. As a consequence, one tonne of methane released over the next decade is equivalent to releasing 83 tonnes of CO_2. The International Energy Agency, European Commission and US Environmental Protection Agency are among many concerned parties calling for urgent action and for methane to be high on the agenda at COP 26 in Glasgow.

The scale of the problem

To tackle the challenge of methane emissions we need to capture and treat the 105 billion tonnes of organic wastes directly or indirectly generated by human activity every year. By simply managing these important bioresources more effectively **we can cut global GHG emissions by 10% by 2030**.

Anaerobic digestion (AD) is recognised by multiple agencies as the solution, including;

- UN - "it is a win-win-win-win-win technology, ready to go, ready to scale"
- IEA – "AD sits at the heart of the circular economy, you can't close loops without it"
- EC Methane Strategy – "AD and biogas should be incentivised to address the methane crisis"



CO_2 in the atmosphere and annual emissions (1750-2019)

[3] www.ipcc.ch/sr15

[4] www.ox.ac.uk/news/2020-05-05-building-back-better-green-covid-19-recovery-packages-will-boost-economic-growth-and

[5] https://climateactiontracker.org/countries/

Recycling organic wastes through AD is a nature-based solution that is part of the natural carbon lifecycle. Fossil fuels disturb the natural carbon lifecycle by putting carbon that nature has stored underground over millennia back into the atmosphere. It is the burning of fossil fuels over the past 150 years that has increased the amount of carbon in the atmosphere to its current level, which is causing Climate Change. All carbon within organic materials above ground originates from the atmosphere; and so digesting organic wastes and using all the outputs – biogas, bio-CO_2 and bio-fertiliser - simply completes the carbon cycle.

When organic wastes are recycled through an AD plant, carbon savings are delivered across multiple fronts:

(1) the harmful GHG emissions they would otherwise emit are prevented

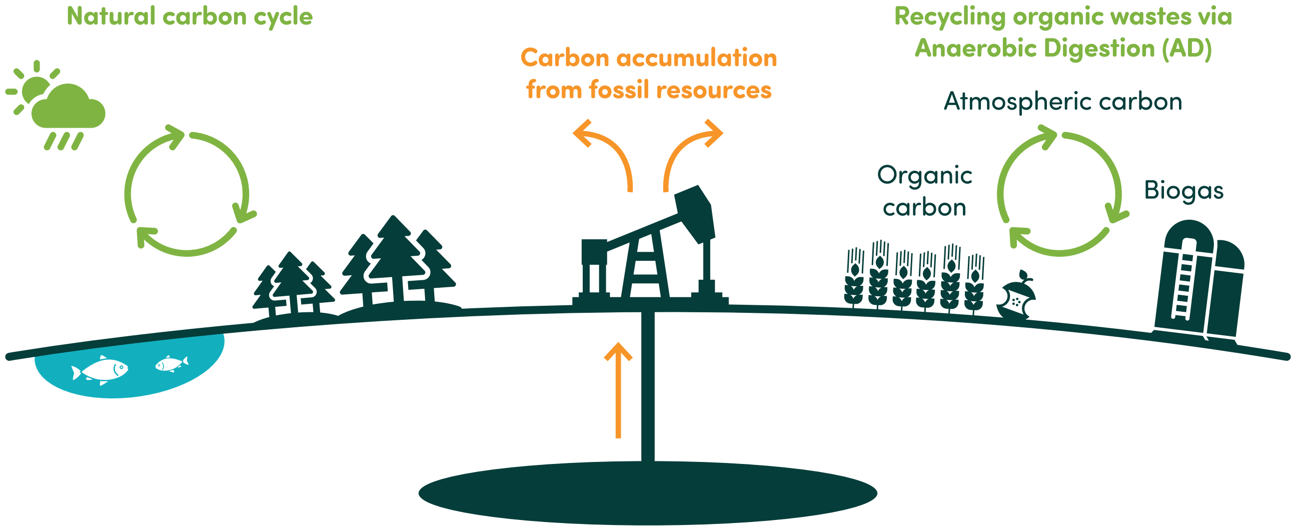
(2) the energy they contain is extracted in the form of biogas, which is a mixture of biomethane and CO_2, displacing fossil sources of energy and associated CO_2

(3) the nutrients within organic wastes are recycled into an organic fertiliser (or 'digestate'), replacing the need for artificial fertilisers which are very energy intensive to produce

(4) the carbon in the digestate is returned to soil

(5) Unlike fossil fuels, which are extracted from the ground, the carbon in biogas originates from the atmosphere and is contained within the organic wastes

(6) CO_2 can be captured and stored, making the process carbon negative and actively reversing carbon emissions. Alternatively, CO_2 gas may be used within industry – e.g. food and drinks manufacture, refilling fire extinguishers etc – or to create platform chemicals. CO_2 and biomethane are also compatible with a hydrogen future and the creation of bio-based fuels for aviation and shipping.



The Pathways

This report is not prescriptive. It reflects the fact that different countries are on vastly different stages of their biogas journey. Denmark, for instance, is approaching 30% capacity while Bangladesh is just at the start of its journey. To that end, it sets out:

(1) the policy mechanisms to create an enabling environment to capture organic wastes, prevent methane emissions from them and turn them into valuable resources;

(2) opportunities arising from an emerging asset class and sustainable frameworks from institutional funds;

(3) and what the sector must do itself to enable the required growth.

Policy Mechanisms

The major barrier to growth of the AD industry is the fact that its many services are not recognised or rewarded financially. Treating organic wastes through AD tackles air pollution, which the Organisation for Economic Co-operation and Development (OECD) estimates costs $2.6 trillion and results in 6-9 million premature deaths worldwide each year, where children are one of the most vulnerable groups. It improves water quality and associated clean-up costs.[6] The biofertiliser produced from recycling nutrients improves the carbon capture capability of soils and improves biodiversity by mitigating the use of mineral fertilisers and pesticides. It creates skilled jobs and boosts rural economies. Yet AD is primarily viewed as a renewable energy generator at the expense of these beneficial health, environmental and social impacts.

An international carbon tax and trading scheme would be the most efficient means to price AD's services into the market and reflect AD's position at the heart of the circular economy. However, this will require a great deal of political will and global cooperation. It is therefore proposed as an end-goal, achievable towards the end of the decade, to set the industry up for ongoing success and independent viability, beyond the changeable whims of national governments.

We cannot wait until then to act. In the intervening years it is vital that countries commit to treating their organic wastes through AD in their respective Nationally Determined Contributions (NDCs).

One million tonnes of...	Biogas potential (GWh)	Decarbonisation potential (tonnes CO_2e)
Food waste	1,008	826,000
Sewage sludge	814	704,000
Livestock waste	412	161,000
Crop residues	2,378	450,000
Sequential crops	2,610	747,000

A raft of policies is needed across the different aspects of the AD industry to achieve these benefits, covering organic material recycling policies, digestate policies, and biogas utilisation policies. An overarching framework would look like this (page 8).

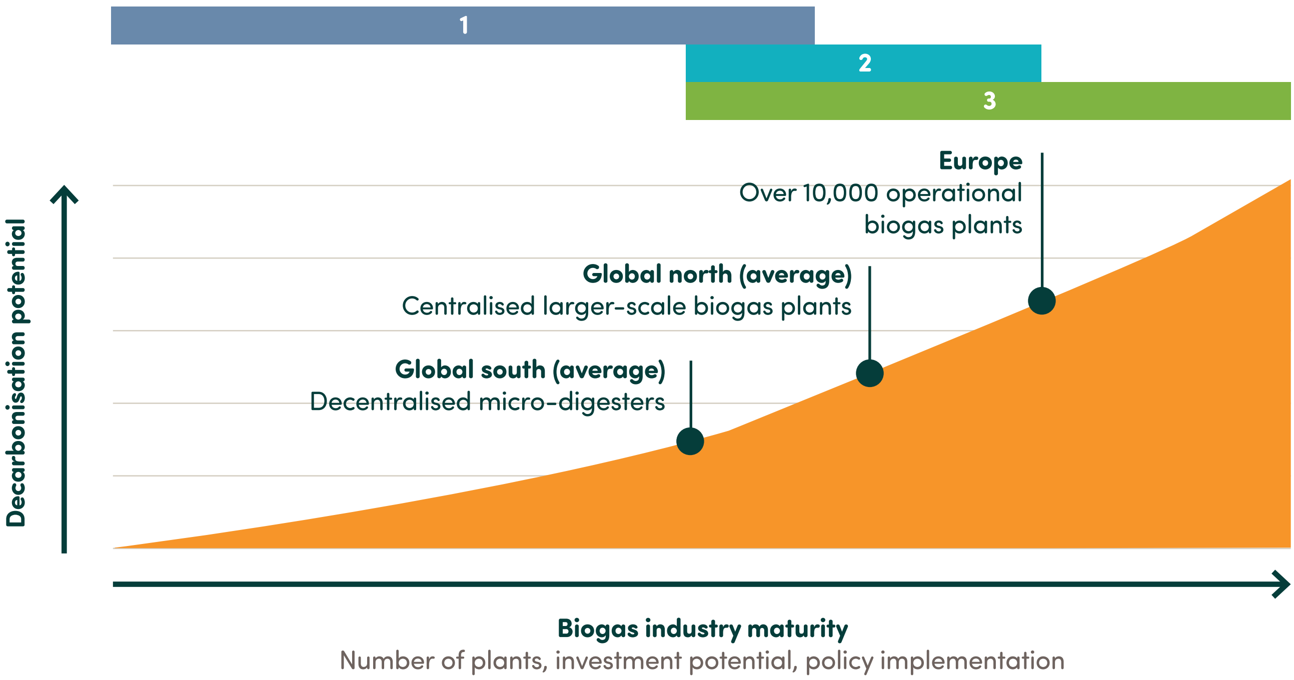
[6] www.oecd.org/env/air-pollution-to-cause-6-9-million-premature-deaths-and-cost-1-gdp-by-2060.htm

Overarching Policy Timeline

(1) Commitment to biogas in NDCs, backed by tariffs
Biogas should be incorporated into NDCs and backed up by effective national policies to incentivise growth in the industry targetting the recovery of organic material and nutrients to return to soils; the generation of biogas for energy and transport; and CCUS from biogenic wastes. At the early stages of biogas industry development these support mechanisms, for use and/or generation of biogas, bio-CO_2 and digestate should take the form of direct financial support, most likely a tariff. It is vital that infrastructure to support the industry growth, such as collection of organic wastes, accompanies the development of the industry to ensure there is sufficient feedstock available for AD plants.

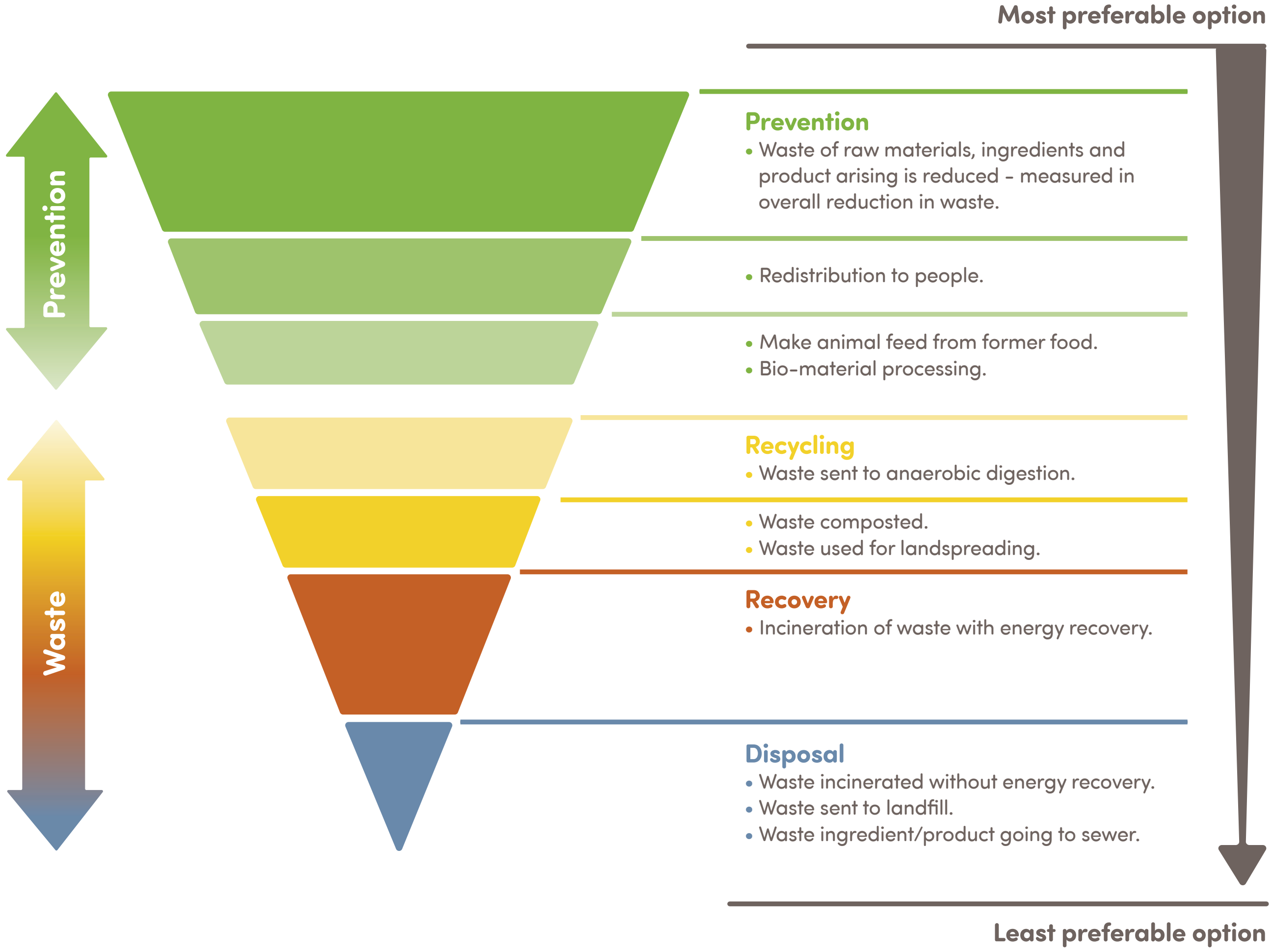
(2) Transition to more market based policy support
As the industry grows and matures, policy can move away from direct subsidy to facilitate a market for the environmental benefit delivered by the biogas industry, while enabling the national biogas industries to become independent of direct subsidy. This should be accompanied by the balanced removal of all direct support for the fossil industry to ensure there is a level playing field before any subsidies for biogas are removed. It will also be beneficial for governments to clearly set out their support for and backing of the biogas and organic waste recycling industry in a clear strategy to provide investor confidence as direct subsidies are tapered away.

(3) Carbon pricing policies
Introduction of national, regional and finally global carbon trading mechanisms to create an effective market for the climate benefits delivered by the biogas industry, pricing in the value of the carbon saving delivered and enabling biogas projects to stack up financially, independent of national policy support. It is vital that the scope and methodology of carbon pricing mechanisms developed effectively cover the biogas industry, e.g. they must cover GHG emissions, methane capture and carbon sequestration from agriculture and from organic wastes generated by human activity.



Specific policy recommendations across sectors are addressed in the report in detail. A principal requirement is for all organic wastes to be subject to an agreed waste material hierarchy, such as that issued by the UN Food and Agriculture Organisation on food waste. All organic wastes should first be prevented, then recycled before recovery and disposal is considered.

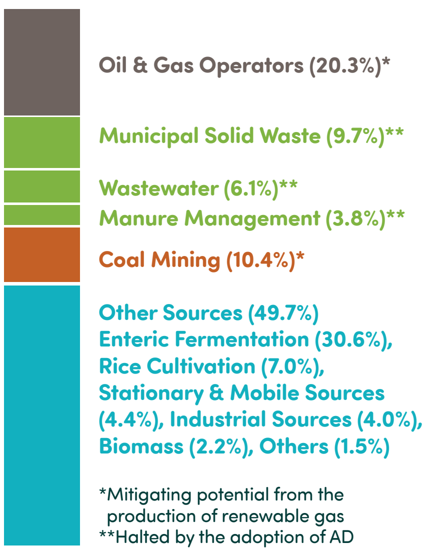
Food and drink material hierarchy



The hierarchy has proved successful in driving up levels of food waste collection across the globe, with many existing examples to draw on, from South Korea to Wales. The EU 27 + UK are to mandate it be followed from 2023. **Mismanaged food waste and wastewater is responsible for ~16% of global man-made methane emissions.**

Strategic frameworks to mitigate methane emissions, following the example of the EU's Methane Strategy, should include treatment of farm wastes through AD to cut agricultural emissions with robust domestic policies to support this. The BiogasDoneRight (BDR) model, using sequential cropping and digestate (biofertiliser) is becoming a globally recognised blueprint for this, with $10m being invested in pilot studies in the US. The BDR model reflects the "4 per 1000" principle – i.e., increasing the carbon sequestration capability of soils by 0.4% will enable nature to compensate for greenhouse gas emissions caused by human activity. In certain countries such as France, farmers are rewarded for treating their manures and slurries through AD. **Mismanaged manures and slurries and crop burning are responsible for ~11% of global man-made methane emissions.**

Estimated Global Methane Emissions from Human Activities in 2030



Renewable Finance

Finance is shifting in favour of sustainable solutions, both institutionally and within an emerging asset management class associated with the transition to a green economy, in the form of renewable infrastructure funds. Renewable infrastructure funds listed on London Stock Exchange are worth a combined £10bn and have raised more than $6bn in further capital since their listing.

Companies are increasingly concerned about the sustainability of investments so have created a methodology to measure the Environmental, Social and Governance performance of listed companies. In 'Your Guide to ESG reporting' the London Stock Exchange states, *"Once upon a time, environmental, social and governance (ESG) factors were a niche interest among asset owners, asset managers, banks, brokers and investment consultants. No longer. Investors now routinely analyse information on ESG performance alongside other financial and strategic information in order to gain a better understanding of companies' future prospects."* [7]

Examples of the FTSE Green Revenues Definitions, FTSE Green Revenues Classification System:

Energy Generation Waste to Energy
Companies generating power through the use of domestic, agricultural and commercial refuse as fuel for both thermal and non-thermal energy creation where the reduction of greenhouse gas emissions is a significant function of the power generation process either on a life-cycle analysis basis or at the point of generation.

Energy Equipment Bio Fuels
Companies providing goods, products and services including components, specialist materials, bespoke manufacturing and maintenance processes, design and operational support capabilities that enable the generation of power through the use of crops, plants and other organic materials as fuels where the reduction of greenhouse gas emissions is a significant function of the power generation process either on a life-cycle analysis basis or at the point of generation.

Energy Equipment Waste to Energy
Companies providing goods, products and services including components, specialist materials, bespoke manufacturing and maintenance processes, design and operational support capabilities that enable the generation of power through the use of domestic, agricultural and commercial refuse as fuel for both thermal and non-thermal energy creation.

This is evidenced by the shift in corporate funds, to address their emissions from production (Scope 1) and down the supply chain (Scope 3). So we see the likes of Nestlé investing in AD at its production facilities but also offering 0% finance to its raw materials' suppliers, to green the company's supply chain.

Institutionally, the World Bank is proposing to restructure its lending policies. In its discussion document 'Transformative Global Finance' it says money should go to projects that deliver the best financial results and kick start wider infrastructure development to support actions on climate change.

The UN has an Ethical Finance division, in support of delivering its Sustainable Development Goals (SDGs) which are intended to be delivered by 2030. It also has a Sustainable Finance Initiative to deliver its climate goals.

Institutional funding can fast-track a country's adoption of AD and biogas for a country starting from a low base, such as Bangladesh. A city in the country could look to fund a massive infrastructure project to tackle its food waste and wastewater, benefitting householders with renewable energy and farmers with renewable fertiliser.

Meanwhile, the UK has just announced plans to launch a Green Bond to finance the green transition reflecting the fact that major global institutions, industry bodies and policy makers, including the G20, have backed the development of this market.

[7] www.lseg.com/esg

The EU is developing a taxonomy in support of its Green Deal, in which biogas generation from organic wastes is recognised. The taxonomy seeks to create common definitions of sustainable development across its 27 member countries. It is being called on to prohibit funding for energy from waste projects in favour of AD, as the former amounts to disposal of resources that could be recycled.

National Green Banks also have a role to play. A study by the Rocky Mountain Institute found that where green banks exist they have a leverage ratio of 2.3, i.e. against $24.5bn of their own capital, $45.5bn private capital was leveraged.[8]

To draw these streams of funding toward the development of AD and biogas requires action on behalf of the industry.

What we must do to enable growth

To capitalise on this financial revolution the AD industry needs to comply with the criteria being established. That means we must come together as a cohesive global biogas industry to develop and adhere to best-in-class principles and norms associated with responsible investing (including good governance and supply chain transparency).

We should also actively contribute to science-based thought leadership around carbon pricing, accounting and reporting, and adopt methods that successfully monitor and verify the sustainability and environmental safety of our processes (thereby providing comfort to the investor community). Within that framework the industry will have to develop best available techniques and standards for operation, which will require the development of certification and training schemes.

Developing such an audit for biogas would remove one of the greatest barriers we face and spur the political will to create the enabling environment the sector needs.

The biogas industry has proved itself more than capable of delivering this. In 2019, the leaders of major biogas corporations from around the world gathered in Paris to sign the World Biogas Association's Biogas and Climate Change Commitment Declaration. The signatories pledged to put their full human, financial and technological resources behind enabling the rapid expansion of biogas in all parts of the globe to deliver the decarbonisation and associated benefits addressed in the report.

The declaration was warmly welcomed by the UNFCCC, which governs the Paris Agreement. At its full potential, the AD industry can create over 10-15 million skilled jobs around the globe and address the ambitions set out in the Paris Agreement and the UN SDGs as well as meet the desire to 'build back better' environmentally and socially from the Covid-19 pandemic.

In nature, ecologists will tell you there is no such thing as waste. AD allows human activity to attune itself to nature. We need to quantify these multiple benefits.

Conclusions

Whilst giving a recipe suitable for every country is near to impossible there are undoubtedly some common elements that nations can adopt. Just helping them to understand the necessity of capturing all the organic wastes their society produces and the value they can obtain by recycling them through AD will be a major achievement.

This report seeks to ensure that no policy maker will be able to say, "I didn't know", as they consider how the biogas industry can be adopted into their own climate change policies, specifically their Nationally Determined Contributions to maintain climate warming well below 2°C.

As the volumes of organic wastes increase due to population growth, urbanisation, change of diets, they produce ever greater amounts of harmful gases impacting our climate and air quality, above all through the uncontrolled release of methane, black carbon (soot) and ammonia. This needs to stop and AD can deliver on this now.

[8] **https://rmi.org/insight/state-of-green-banks-2020/**

If harvested, these organic wastes will provide sources of renewable energy, green CO_2 natural fertilisers and other valuable bioproducts thereby playing a multifaceted role that other renewable energies cannot. Moreover, the production of biogas is continuous (baseload) and does not suffer from the fluctuation of wind, solar and hydro sources, making biogas a perfect integrator to these. Biogas can produce heat, electricity and fuel all off-grid and depending upon the geography of installations, one or the other uses may be more beneficial.

Investment in AD also has long-term security. Biogas is compatible with a hydrogen future. Low carbon biomethane can be converted into green hydrogen, or hydrogen can be converted to biomethane when mixed with biogas' CO_2. In this way biogas is future-proofed, adapting to the energy needs of the future.

The beauty of AD is its versatility. It can be installed on a micro level to recycle a household's waste, and for cities large scale merchant facilities can recycle 500,000 million tonnes annually. It can handle wet or dry wastes, or a mix of both, and can be used in conjunction with composting depending on the soil requirements in a given geographical area. It extracts the greatest value out of organic wastes and turns them into valuable renewable resources.

Each Government when reviewing its NDC under the Paris Climate Treaty should include the collection and recycling of organic wastes among its target instruments. The collection of urban food wastes, the reduction of uncontrolled burning of stubbles and harvesting of animal manures are all part of the policy landscapes which bring us greater sustainability and better-quality air, water and soil outcomes. Governments should therefore not simply measure biogas in terms of the cost of the kilowatt hour or megajoule of heat, but in the overall beneficial outcomes biogas produces through the whole range of its environmental services and wider benefits to humanity.

Above all, this is a technology that exists today. Can we afford not to take an opportunity to reduce global emissions by 10% by 2030, and at the same time improve our energy and food security and create millions of new green jobs worldwide?

Decarbonisation and defossilation

Throughout this Executive Summary, the term 'decarbonisation' is used to convey the act of cutting net GHG emissions. It conveys AD's ability to recycle carbon from atmosphere, while reducing the need to use non-renewable fossil resources. 'Decarbonisation' therefore encompasses the term 'defossilisation', which relates more specifically to cutting the use of fossil resources – i.e., preventing old carbon stored in fossil coal, oil and gas from entering the atmosphere.

Glossary

Anaerobic Digestion (AD)
Also known as *biomethanisation*
The breakdown of organic matter in the absence of oxygen to produce biogas and digestate.

Business as usual (BAU)
This term is used to describe the future trajectory of emissions based on present-day systems. It assumes that new policies, regulations, or initiatives are not introduced to tackle and curb greenhouse gas emissions.

Bio-CO_2
Carbon dioxide produced in anaerobic digestion, which makes up a component part of biogas (25-50%), and can be separated out in the biogas upgrading process for use in industrial processes.

Bio-CNG
Compressed natural gas made from biomethane, often used as a transport fuel.

Bioenergy Crops
Crops primarily grown to generate renewable energy, that can additionally benefit soil health and structure.

Biogas
A product of the anaerobic digestion process, composed of a mix of methane (50-75%), carbon dioxide (25-50%) and small amounts of other gases.

Bio-LNG
Liquefied natural gas made from biomethane, often used as a transport fuel.

Biofertiliser
See *Digestate*

Biomethane
Also known as *Renewable Natural Gas (RNG)*
Methane produced in anaerobic digestion, which makes up a component of biogas (50-75%). Upgrading biogas separates the biomethane from the bio-CO_2 and other gases such that it can be injected directly into the gas grid or converted into bio-CNG or bio-LNG for use as a transport fuel.

Circular economy
A circular economy is based on the principles of recycling our waste, keeping products and materials in use and regenerating natural systems. It minimises the need to extract raw materials and minimises waste, i.e., material that is never used again.

Digestate
Also known as *biofertiliser*
The residual organic matter produced in the anaerobic digestion process, which is rich in nutrients and can be used as a natural fertiliser. Digestate comprises both a solid and liquid fraction, each containing various concentrations of nutrients.

Direct Air Capture (DAC)
A process of capturing CO_2 directly from the ambient air (as opposed to capturing from point sources) and generating a concentrated stream of CO_2 for sequestration or utilisation.

Global North
The global north consists of the richest and most industrialised countries – for the most part, they are in the northern part of the world.

Global South
The global south consists of the poorer and least industrialised countries – for the most part, they are in the south part of the world.

Greenhouse Gases (GHG)
Gases - such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) - whose emission into the atmosphere drives climate change. For the purposes of this report, GHG relates only to gas emissions caused by human activity.

Incineration
Also known as *Energy from Waste (EfW)*
Waste is combusted to recover some energy from materials. While preferable to landfill, incineration prevents recycling of materials and emits high levels of GHGs.

Just Transition
A green energy transition that proactively manages the inevitable shift to sustainable systems that respects not just the environmental urgency but also equality, social justice and democratic voice.

Landfill
Waste is buried within large pits in the ground. Materials are not recycled and organics rot, emitting methane gas. Landfill is the least preferable waste management pathway for all wastes.

Lignin
Organic compound found in woody plant material. This tough material is not well-suited to digestion using wet AD technology.

Nationally Determined Contribution (NDC)
Signatories of the Paris Agreement are required to submit an NDC once every five years, detailing how they are reducing their GHG emissions to help limit global warming to less than 2°C – but preferably less than 1.5°C.

Renewable Natural Gas (RNG)
See *Biomethane*

Chapter 1: Introduction and Background

There is no time to waste in the fight against climate change. All countries and industries must cut greenhouse gas (GHG) emissions immediately, covering all sectors and drawing on all technologies and knowledge. Often overlooked, organic waste represents a key sector in urgent need of decarbonisation.

Humans directly or indirectly generate over 105 billion tonnes of organic wastes globally each year, all of which release harmful methane and other greenhouse gas emissions directly into the atmosphere as they decompose. These organic wastes include food waste, sewage and garden wastes, food and drink processing wastes, and farm and agricultural wastes. Today only 2% are treated and recycled. By simply managing these important bioresources more effectively we can cut global (GHG) emissions by 10% by 2030.

This report maps out how the global biogas industry can enable countries to deliver a 10% reduction in global GHG emissions by 2030. The pathways put humanity back on track to deliver by 2030 on the ambitions of both the Paris agreement and UN Sustainable Development Goals.

This reports aims to provide policymakers worldwide with a toolkit of policies. It details all the environmental and socio-economic benefits available through the recycling of organic wastes through AD and identifies how policy can encourage the uptake of AD to tackle key issues. Considering every country will be at a different stage of development, the following graph displays our overarching policy recommendations in order of implementation, thus forming a pathway. See Overarching Policy Timeline, p17.

Subsequent chapters detail recommendations specific to key aspects of the AD supply chain: International and national climate policy (chapter 3), Feedstock management policy (chapter 4), Digestate policy (chapter 5), and Biogas utilisation policy (chapter 6).

1.1 Introduction

While the industrial revolution brought countries and their economies closer than ever before, it also established a deep-rooted dependence on fossil resources worldwide. For more than 100 years these energy dense fossil resources enabled whole regions to be powered from a single power plant, people to be transported around the world in a matter of hours and the creation of highly versatile products such as plastics cheaply at scale. There was no stopping the fossil industry: any country's wealth and success would be transformed overnight by the discovery of black gold.

Today, the global economy remains dominated by these unsustainable resources. The only difference is that now, in the 21st Century, we are witnessing the catastrophic impacts of the unrestricted use of these fossil resources – severe droughts, floods and hurricanes are occurring increasingly frequently, habitats everywhere are contaminated with plastics from the highest mountain tops to the bottom of the ocean, and biodiversity is being lost across the world at an alarming rate. The current rate of environmental change is driving a mass extinction event, at a scale not seen since a meteor wiped out the dinosaurs some 66 million years ago. The world and its people are on a fatal trajectory and if they want to survive must make every effort to shake their addiction to fossil resources. With ~80% of global energy still deriving from fossil fuels, this proportion is unlikely to change unless disruptive policies are enacted swiftly[9,10].

The answer is simple and well understood – we must leave all remaining fossil resources in the ground. There is already more than enough carbon in our soils, plants, animals and atmosphere for society to continue to thrive, and technologies which can provide us with sustainable alternatives to fossil fuels and products. This concept is commonly referred to as '**defossilisation**', cutting the extraction and use of fossil resources. Immediate and widespread defossilisation can help mitigate the worst impacts of climate change and embed the principles of a circular economy throughout global systems, whereby carbon is recycled in various forms to meet our various needs. Energy can be generated from multiple non-fossil dependent technologies and products and chemicals can be produced from organic sources and biorefining.

[9] www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=TPESbySource

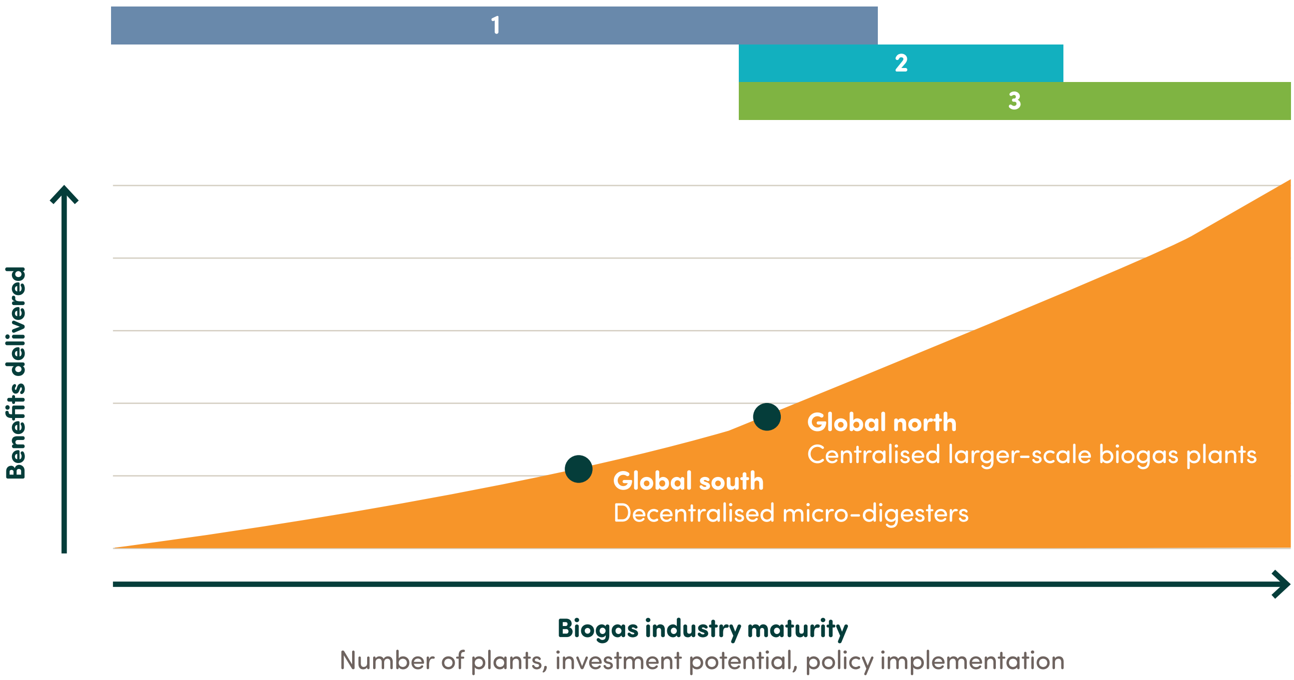
[10] www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf

Overarching Policy Timeline

(1) Commitment to biogas in NDCs, backed by tariffs
Biogas should be incorporated into NDCs and backed up by effective national policies to incentivise growth in the industry, targeting the: recovery of organic material and nutrients to return to soils; generation of biogas for energy and transport; and CCS/CCUS from biogenic wastes. At the early stages of biogas industry development these support mechanisms, for use and/or generation of biogas, bio-CO_2 and digestate should take the form of direct financial support, most likely a tariff. It is vital that infrastructure to support the industry growth, such as collection of organic wastes, accompanies the development of the industry to ensure there is sufficient feedstock available for AD plants.

(2) Transition to more market-based policy support
As the industry grows and matures, policy can move away from direct subsidy to facilitate a market for the environmental benefits delivered by the biogas industry, while enabling national biogas industries to become independent of direct subsidy. This should be accompanied by the balanced removal of all direct support for the fossil industry, ensuring there is a level playing field, before any biogas subsidies are removed. It will also be beneficial for governments to clearly set out their support for and backing of the biogas and organic waste recycling industry in a clear strategy to provide investor confidence as direct subsidies are tapered away.

(3) Carbon pricing policies
Introduction of national, regional and finally global carbon trading mechanisms to create an effective market for the climate benefits delivered by the biogas industry, pricing in the value of the carbon savings delivered and enabling biogas projects to stack up financially, independent of national policy support. It is vital that the scope and methodology of carbon pricing mechanisms developed effectively cover the biogas industry, e.g. they must cover GHG emissions, methane capture and carbon sequestration from agriculture and from organic wastes generated by human activity.



Carbon emissions responsible for 91% of global warming

CO_2 – Carbon dioxide	Relative contribution to emissions = **75%**
CH4 – Methane	Relative contribution to emissions = **16%**

Methane emissions are 85 times worse than CO_2 over a 20-year period

Decarbonisation

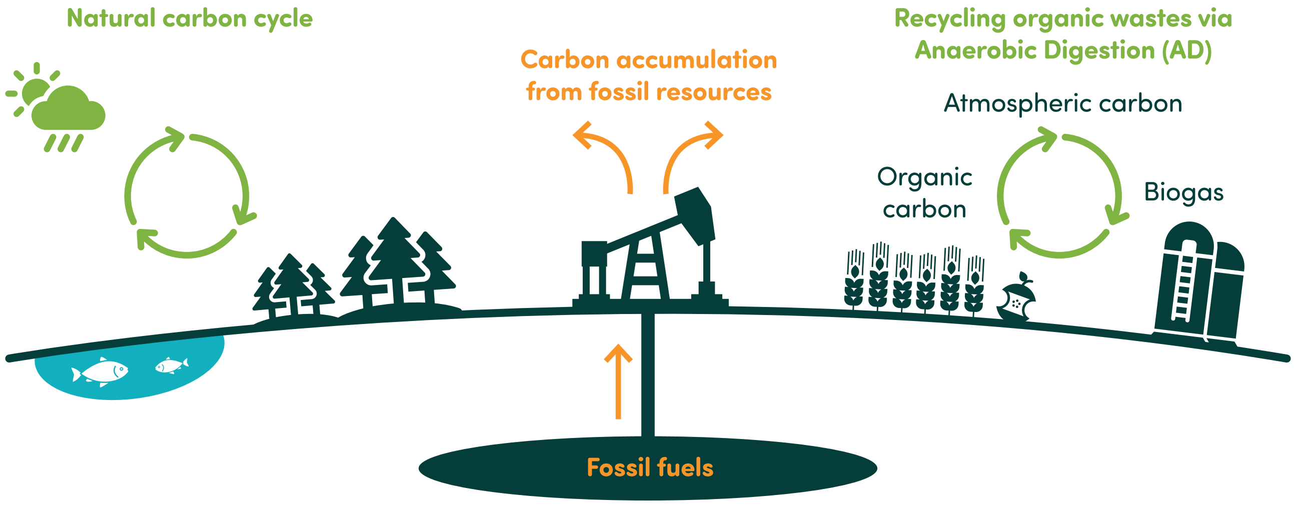
This term encompasses reductions to both CO_2 (carbon dioxide) and CH_4 (methane) emissions. As carbon dioxide is less harmful than methane, decarbonisation may also relate to the conversion of methane to less harmful gases.

While preventing the movement of fossil carbon from the earth's crust to the atmosphere is vital, we must also consider where carbon is within the ecosystem and what form it is in – is carbon locked-up in a tree's biomass? Or is it in the atmosphere in the form of carbon dioxide gas? Defossilisation pairs well with '**decarbonisation**', with the latter relating more specifically to the amount of carbon in the atmosphere and its relative impact on climate change. Rotting waste emits methane – a potent GHG with a global warming potential 28-36 times greater than carbon dioxide (CO_2) over a 100-year period[11]. Preventing the emission of methane and/or converting it into less harmful gases, such as CO_2, would constitute decarbonisation. First, stop adding more fossil-carbon to the planet's carbon budget (defossilisation), and second, manage carbon within our ecosystems to minimise its global warming potential (decarbonisation).

Plants and trees can extract carbon from the atmosphere while supporting biodiversity, mitigating floods, stabilising soil against desertification and cleaning the air. Soil can sequester carbon and provide the growing medium required for crops and whole ecosystems. Technologies, such as anaerobic digestion (AD), can prevent methane from being released into the atmosphere from poorly managed organic wastes, such as livestock manures and slurries, human sewage and food waste. AD captures this methane in the form of biogas which, when used as fuel, releases CO_2 – a less potent GHG.

In fact, when focusing in on the first 20 years of being emitted, atmospheric methane is 85-87 times more harmful than carbon dioxide. It is, therefore, critical to address methane emissions immediately.

*Note, throughout this report the term '**decarbonisation**' is used to convey the act of cutting net GHG emissions, and therefore encompasses **defossilisation** (unless specified otherwise).*

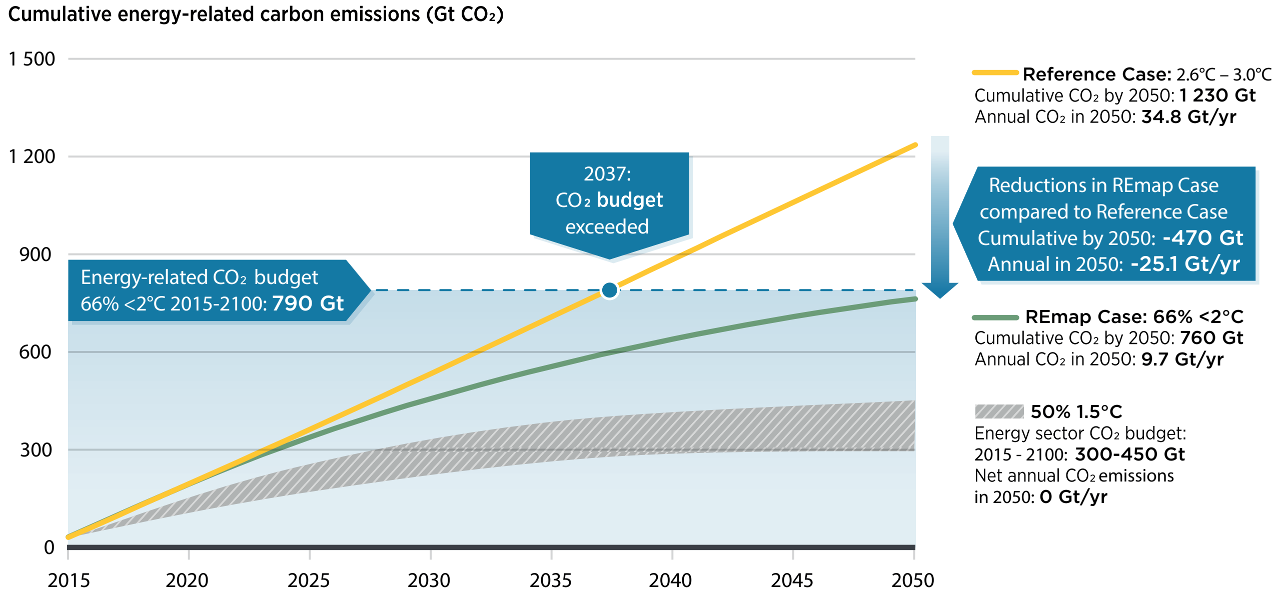


Similarly to natural systems, anaerobic digestion (AD) recycles carbon. Carbon is the building block to all living organisms. Originally sourced from the atmosphere, carbon is passed through food chains, from plants to animals. By treating organic wastes through AD, we gain valuable products before returning atmospheric carbon back to the environment. The extraction and use of fossil fuels transfers carbon from deep within the earth's crust to our atmosphere, where it accumulates; this one-way movement of carbon is predominantly responsible for climate change.

[11] www.epa.gov/climate-indicators/climate-change-indicators-global-greenhouse-gas-emissions

1.2 Carbon budget

As we witness the intensification of climate change's impacts, the need to urgently cut GHG emissions becomes ever more apparent. The international climate treaty agreed in Paris in 2015 and since entered into force now encourages nations to take sufficient action to prevent warming greater than 2°C, but preferable less than 1.5°C, by 2100. The International Renewable Energy Agency (IRENA) calculates[12] that the planet will exceed its carbon budget in 2037 relative to the target to keep global warming within 2°C by 2100 if countries continue business-as-usual (BAU). The Paris Agreement target becomes harder to achieve as each day passes. Urgent action is needed across all sectors.



Taken from IRENA report, Global Energy Transformation: A Roadmap to 2050[13]

Policy makers from every country must address the same question: how can we break free from our dependence on fossil resources? Uprooting centuries old systems and changing the behaviour of our citizens – encouraged over decades by clever marketing to buy and travel more – is daunting. Many may feel overwhelmed by the scale of the challenge. Moreover, achieving this transition in a just way requires substantial backing at all scales, from countries to individuals, and from radical action to smaller incremental changes. It requires the rapid adoption of new technologies, new systems and new skills, and a degree of certainty to gain consensus. Yet society is on course to exceed the 2°C carbon budget in a little over 15 years – heralding in a new world of economic, environmental, health, political and social instability – making the need to act now critically urgent.

As a global society, there is no alternative. We must decarbonise and defossilise our system, such that atmospheric carbon stops increasing. We must also halt biodiversity loss. The cost of inaction is of a magnitude far greater than the cost of an immediate, proactive transition. The good news is that a just, green transition offers superb opportunities and a raft of positives: new jobs, cleaner air and water, food and energy security, innovation and new technologies, biodiversity restoration, and far greater resilience to unforeseen phenomena such as Covid-19. A country's economy will no longer depend on the presence of fossil resources within its territory. Those countries who start now will be the leaders of tomorrow.

[12] https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

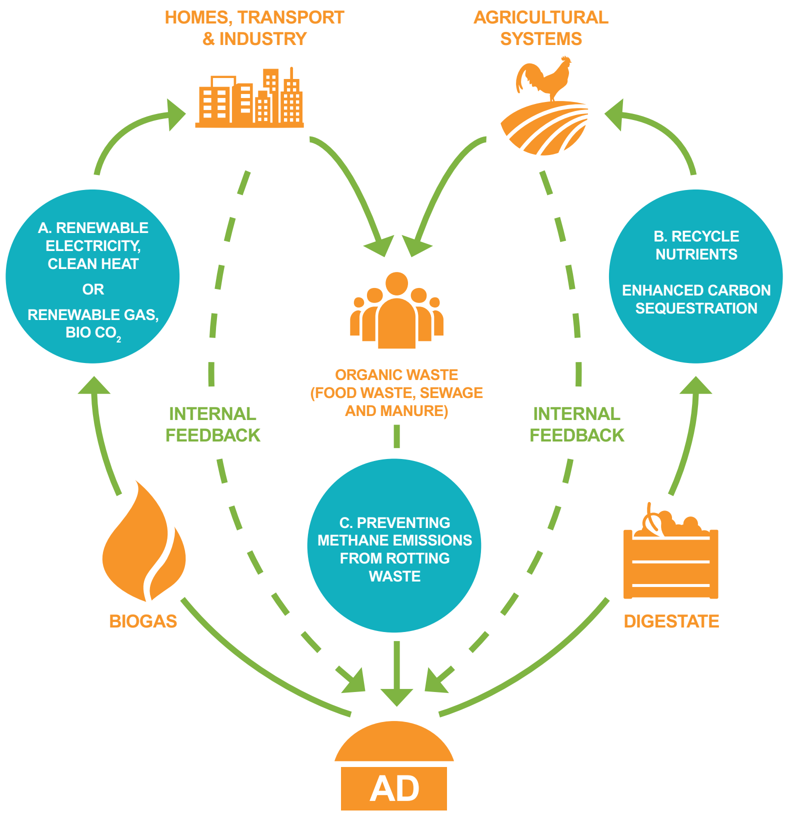
[13] https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf

It isn't easy. Policy makers face multiple challenges to creating a sustainable economy, such as: the reduction of economic activity caused by the Covid-19 epidemic and the constraints this inflicts on Government budgets[14]; increased inequality and the need to ensure poorer communities have access to energy[15]; declining or historically low fossil fuel prices, which make transitioning away from them relatively more expensive[16]; new and abundant sources of (above all) natural gas in most regions[17]; centralised energy production and distribution systems dependent on vast and ageing grids[18]; dominant positions in many economies of fossil fuel producers facing the risk of stranded assets[19]; subsidy systems still heavily favourable to the production and consumption of fossil fuels, in the order of 2 to 3 times the subsidies invested in renewable energy sources.[20]

1.3 The role of organic waste management and AD

As highlighted earlier, if unmanaged, all organic wastes produce harmful methane emissions as they decompose. However, if collected and recycled through anaerobic digestion (AD), these emissions are prevented and the wastes turned into valuable green resources, such as biogas, biomethane, bio-CO_2, natural fertilisers and other valuable bio-products. AD is simply the natural process that takes place when biodegradable materials break down in the absence of oxygen. It is the same process that cows – and we humans – use to break down our food. It has been used for millennia; evidence suggests biogas was first used to heat baths in Assyria nearly 3,000 years ago.

Described by the UNFCCC as a "win-win-win-win-win industry", AD is a ready to use technology capable of delivering both **defossilisation AND decarbonisation.** Most importantly, because it is a technology which is already widely used today, it is capable of delivering its full potential – a reduction in global GHG emissions of at least 10% - by 2030. The industry would also create 10-15 million new green jobs, decarbonise difficult sectors such as heat, transport and agriculture, and improve every country's energy and food security.



[14] www.un.org/development/desa/dpad/publication/world-economic-situation-and-prospects-april-2020-briefing-no-136/

[15] www.worldbank.org/en/topic/poverty/brief/projected-poverty-impacts-of-COVID-19

[16] www.eia.gov/outlooks/steo/pdf/steo_text.pdf

[17] www.naturalgasintel.com/coronavirus-wreaks-havoc-on-markets-enverus-more-optimistic-on-oil-demand/

[18] www.epa.gov/energy/centralized-generation-electricity-and-its-impacts-environment

[19] www.iea.org/reports/the-oil-and-gas-industry-in-energy-transitions

[20] https://energypost.eu/400bn-in-global-fossil-fuel-consumption-subsidies-twice-that-for-renewables/

The following explains how the process delivers both defossilisation and decarbonisation:

Anaerobic Digestion's (AD) ability to deliver...

Defossilisation

Energy – AD generates biogas, a gaseous mix of biomethane and bio-CO_2. This renewable fuel displaces the need to extract fossil resources for energy. Biogas is composed of 55-65% biomethane, chemically identical to fossil natural gas, and can therefore be used to heat homes via a national gas grid, to fuel gas vehicles, or generate electricity and heat via a combined heat and power (CHP) unit.

Fertiliser – AD produces digestate, a renewable fertiliser rich in key nutrients, nitrogen, phosphorus, and potassium (NPK), recovered from the nutrients in the input organic material. Digestate reduces the need to manufacture non-renewable mineral fertilisers. Much of the world's artificial nitrogen fertiliser is produced through the Haber-Bosch cycle, a process which takes fossil gas and vast amounts energy (and associated CO_2 emissions) to fix nitrogen in the form of ammonia.

Bio-CO_2 – Several industrial processes require pure carbon dioxide, for example food and drinks manufacturing. Much of the industrial-grade CO_2 is sourced from the manufacture of artificial fertilisers via the typically fossil-dependent Haber-Bosch cycle. Biogas is composed of 35-45% carbon dioxide, which can be easily captured to supply industries with bio-CO_2.

Bio-products – Refining biogas can create syngas, a gaseous mix consisting primarily of hydrogen and carbon monoxide. Predominantly formed using fossil fuels, syngas is a key component of countless petrochemical products, from specialist fuels to plastics and lubricants. By displacing natural gas, biogas can sustainably provide the compounds required to create these important products.

Decarbonisation

Waste management – Organic wastes rot and release potent GHGs, such as methane, directly into the atmosphere. By capturing these wastes and treating them through AD instead, these otherwise harmful GHGs are converted into valuable bioresources. When biomethane is combusted, bio-CO_2 is released, a far less potent gas than methane.

Food waste – If organic wastes are not separated out from other municipal wastes, this valuable bioresource is often sent to landfill. Here, methane is emitted to the atmosphere and toxic chemical leachate seeps into nearby waterways.

Wastewater – Raw sewage emits GHGs, pollutes ecosystems and spreads disease. AD can prevent all these unnecessary impacts, while supporting local communities' health and economy.

Livestock manure and slurry – Farms worldwide often spread raw manure directly to land untreated. This practice emits vast quantities of methane (CH_4) and nitrous oxide (N_2O) – gases with respectively a global warming potential of up to 36 and 298 times worse than CO_2 over a 100-year-period. AD cuts these direct emissions while returning the nutrients and valuable organic matter found in manure back to land.

Crop residues – Typically, these agricultural wastes are either left to rot (releasing CO_2 and methane) or burnt, releasing harmful particulate matter into the atmosphere. Again, AD can avoid these emissions while delivering ecosystem services.

Carbon capture – All organic materials are made from carbon drawn from the atmosphere. AD plants consequently concentrate carbon in one place, where carbon dioxide concentrations may be 1,000-times greater in an AD tank compared to the open air. In the near future, technologies could permanently store this captured carbon, preventing its contribution to GHG emissions. This is a much more energy and cost-effective approach than Direct Air Capture (DAC) which requires larger scale infrastructure to concentrate CO_2.

Carbon neutral or carbon negative

In its truest sense, AD is a carbon neutral technology. All the carbon contained in organic materials is derived from the atmosphere and returned to the environment via AD's various products, such as biogas and biofertiliser. However, carbon accounting schemes are increasingly recognising AD's ability to deliver negative carbon emissions, in the right circumstances (e.g., EU's Renewable Energy Directive II or "REDII"). There are two main mechanisms in which AD can be considered carbon negative:

1) **When you compare the life cycle emissions from AD with other pathways for organic wastes (e.g., landfill).** As detailed above, when rotting wastes are recycled through AD, methane emissions from them are minimised, the use of fossil fuels is displaced, and the need for artificial fertilisers is cut. Moreover, the biogas' CO_2 can be used within industrial processes or permanently stored via carbon capture, utilisation, and storage (CCUS) technology. When all these emission savings are accounted for, AD becomes carbon negative versus business-as-usual (BAU).

2) **When carbon concentrated within an AD tank is permanently stored, via carbon capture and storage (CCS) technology.** Atmospheric CO_2 assimilated into organic materials can be permanently captured, such that it no longer contributes to returns to the atmosphere as a greenhouse gas. It subtracts carbon from a country's carbon budget. By all definitions, this process is carbon negative – actively reversing global GHG emissions.

Capturing carbon

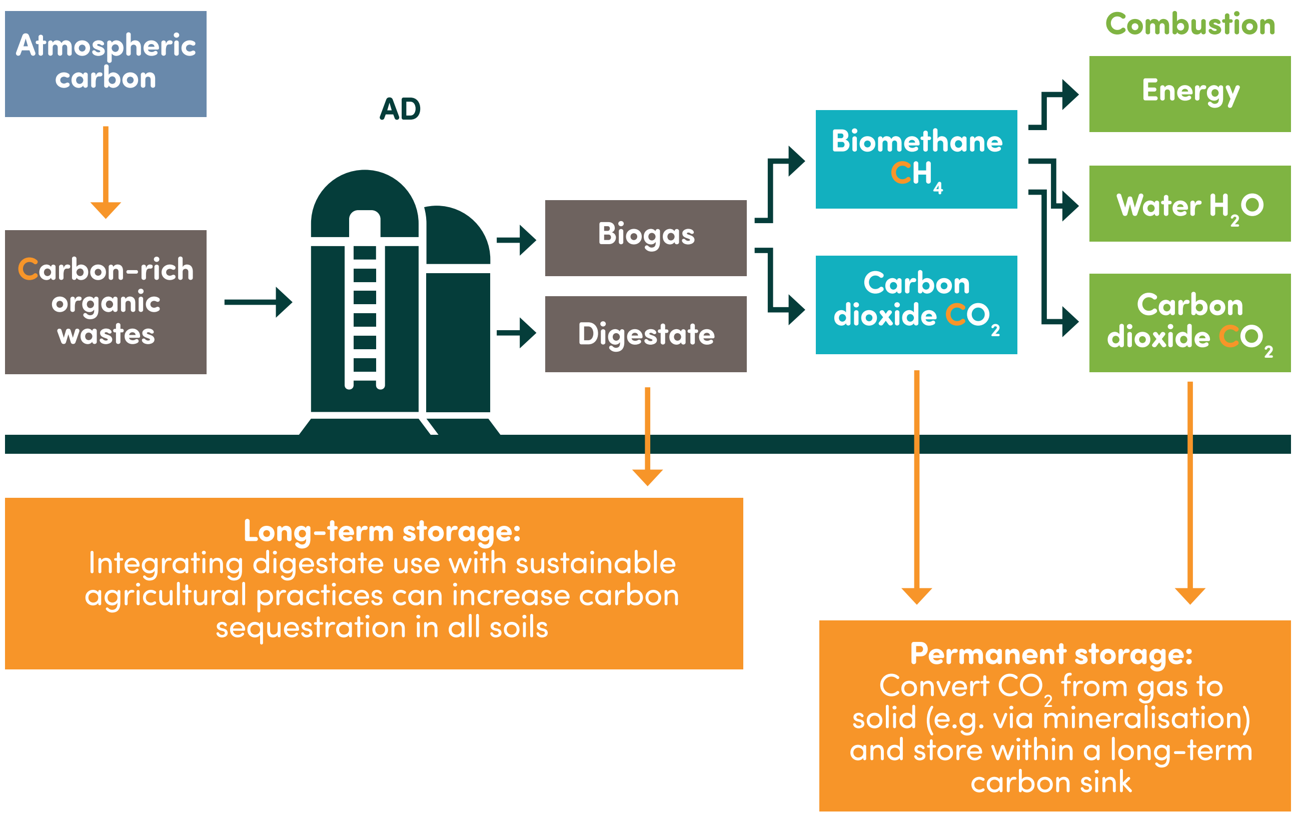
Carbon capture and storage (CCS) technology will likely play a critical role in meeting long term carbon budgets as reducing emissions may not be enough to prevent the worst impacts of climate change. Instead, CCS may be required to lock carbon away in long-term stores; much like fossil resources were over the last several million years. This technology therefore does not pertain to the utilisation of carbon with industrial processes, such as the manufacture of food and drink.

AD plants can become a **carbon hub**. Organic wastes contain carbon taken from the atmosphere. This carbon-rich material is fed into a digester and CO_2 is captured. CCS technology can subsequently lock this carbon away – preventing the carbon from re-entering the atmosphere and driving climate change. This combination of energy generation and carbon capture is often referred to as **BECCS** – i.e., Bioenergy with Carbon Capture and Storage.

CCUS vs CCS

Carbon Capture, Utilisation and Storage (CCUS) encompasses all technologies which manage captured carbon, where that carbon is used within industrial processes or permanently stored; **Carbon Capture and Storage (CCS)** refers only to the latter. Utilisation technologies can help displace the use of fossil-derived carbon, for example CO_2 gas produced from the manufacture of artificial fertilisers. Storage technologies aim to lock carbon away from the atmosphere for at least one hundred years.

Both CCUS and CCS must play a key role in decarbonising economies worldwide.

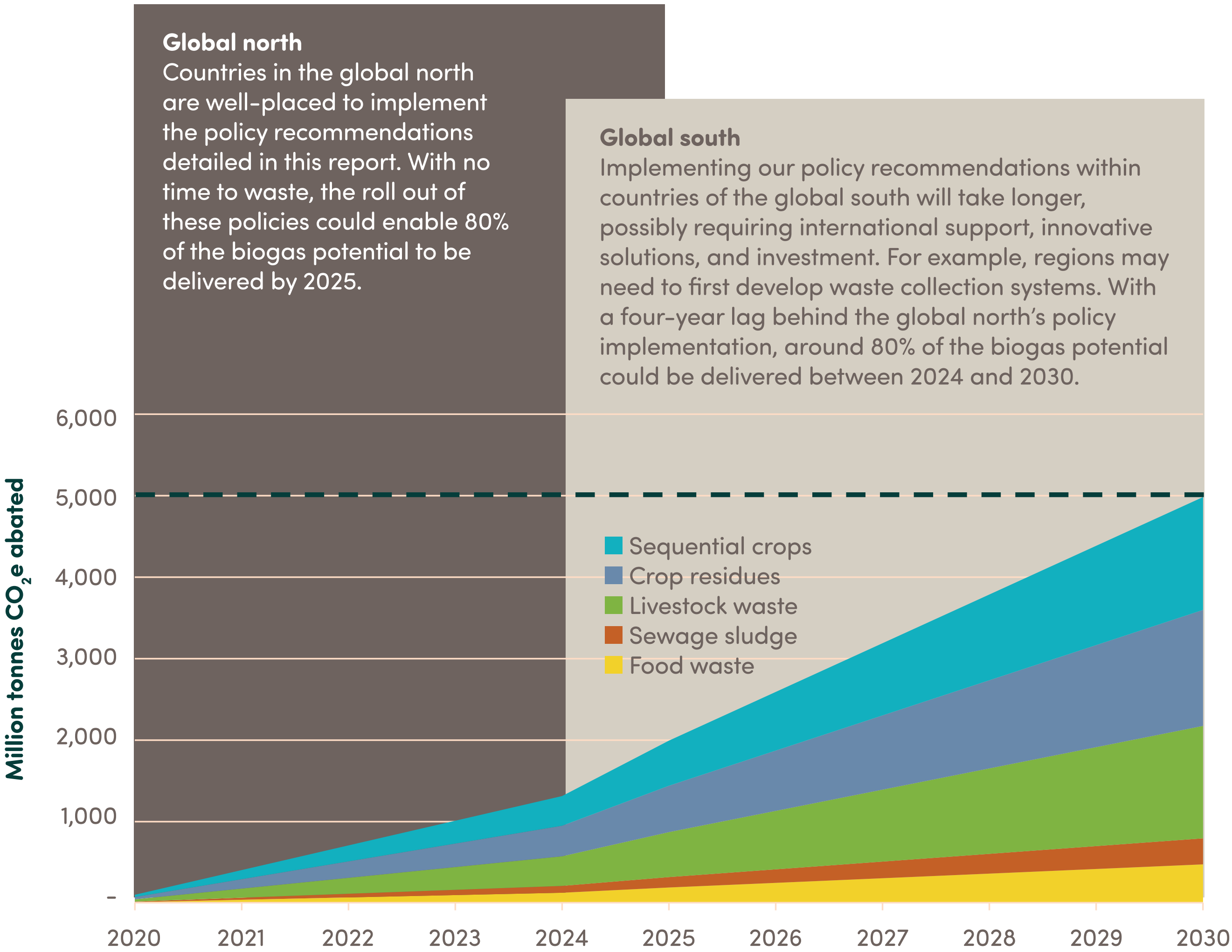


For example:

- By digesting 1,000,000 tonnes of food waste, the biogas produced would be composed of:
  - **115 million m³ of biomethane** – the energy equivalent of 650,000 barrels of oil
  - **76 million m³ of carbon dioxide** – with CCS technology, up to 140,000 tonnes of carbon dioxide could be sequestered
- CCS technology could additionally capture carbon when the biomethane is combusted, particularly if used to generate electricity.
- And AD's digestate returns organic carbon to soil, supporting short- and long-term carbon storage while restoring soil structure.

Pathway to 2030

The development of biogas is at a different stage within every country. Industry maturity may be affected by a country's spending on social and environmental issues, development of infrastructure and production/collection of organic wastes – to name a few. The World Biogas Association (WBA)'s modelling prioritises waste prevention in the first instance, where AD is used to treat all unavoidable wastes – for full model details see the previous WBA report *Global Potential of Biogas*. (see page 31)



Hydrogen

For decades now, oil and gas industries have promised that hydrogen systems will be ready 'within the next ten years', and when ready, they can solve the world's low carbon gas demand. In theory, it's the silver bullet capable of balancing the carbon budget; when combusted for energy, it simply produces water and oxygen. However, the technology is still not ready. It remains severely hampered by technological barriers: green hydrogen is difficult to produce at scale; blue hydrogen requires CCS technology which is not yet demonstrated at scale; hydrogen gas is costly to compress, distribute and store; and much of the world's natural gas infrastructure is not compatible with hydrogen gas (pipelines, vehicles and boilers etc).

We do not have time to wait until hydrogen is ready. Biomethane is a ready to use technology capable of delivering decarbonisation and defossilisation immediately. Moreover, AD and biomethane systems are highly compatible with hydrogen, such that when hydrogen systems are rolled out, AD can flexibly adapt to meet a society's energy needs, while still treating its organic wastes. The following highlights the interplay between biomethane and hydrogen.

The different colours of hydrogen

Green hydrogen

Hydrogen gas produced using renewable energy technologies. Renewable electricity can be used to split water (H_2O) into hydrogen (H_2) and oxygen (O_2), in a process known as electrolysis, or sustainable biomethane (CH_4) can be split into hydrogen (H_2) and carbon dioxide (CO_2), via steam reformation.

Blue hydrogen

Hydrogen gas produced from fossil natural gas via steam reformation (see above). Blue hydrogen may only be considered sustainable if integrated with carbon capture systems to prevent the emissions of GHGs.

Grey hydrogen

Produced in the same way as blue hydrogen except the carbon is not captured. Grey hydrogen is non-renewable and emits more carbon than simply using the natural gas.

Hydrogen to biomethane

When hydrogen gas is added to a digestion tank it binds with the bio-CO_2 to form more biomethane, in a process known as 'biomethanation'. This process can effectively increase AD's biomethane yield by up to 40%, creating a carbon-negative fuel. This process offers a country several key benefits:

- Balancing the energy network. As countries ramp up their renewable electricity capacities with intermittent generators, solar and wind, there will increasingly be periods of time in which electricity generation exceeds demand. As experienced during the summer periods in UK and Germany in the last couple of years, these conditions create negative energy prices – i.e., generators must pay to export their energy. Just a few days of negative energy prices can cost the system operator significantly and wastes valuable renewable electricity. Instead, this excess electricity could be used to create green hydrogen, via electrolysis, and stored in the gas grid as biomethane, via biomethanation; here it is ready to use when and where required.

- Using current infrastructure. Gas pipes, boilers, industries and vehicles will only change when people are confident of hydrogen availability. Therefore, as the hydrogen sector scales up, AD could provide the optimal route for hydrogen, converting it to biomethane compatible with all current systems.

Biomethane to Hydrogen

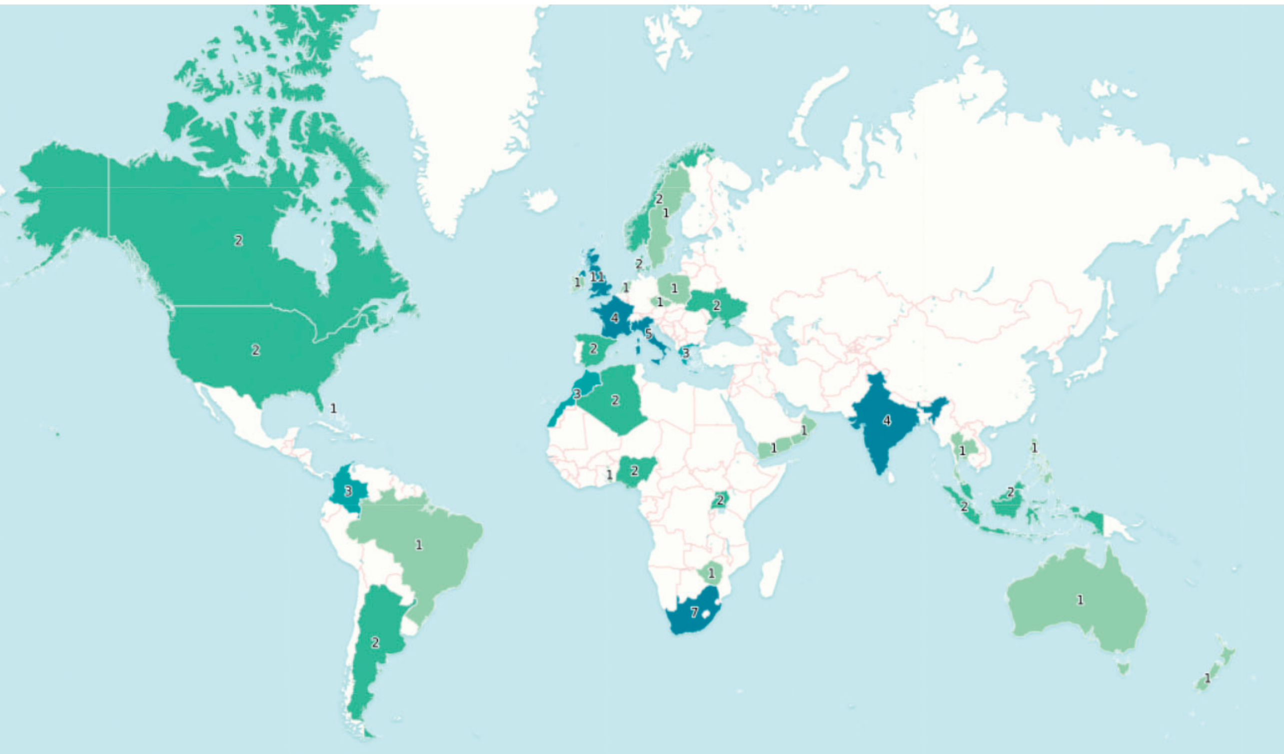
Currently, the most cost-efficient way to create hydrogen gas is through the steam reformation of methane. However, without CCS, this process releases CO_2 into the atmosphere and is no greener than simply burning the natural gas. Biomethane could therefore provide a source of low carbon methane to produce green hydrogen. Once CCS technologies are technologically and commercially viable, their additional integration within these systems would create carbon-negative green hydrogen – where carbon derived from the atmosphere is locked away permanently.

AD is a no-regrets option. Treat the organic wastes and create valuable bio-resources capable of adapting to meet a country's or community's needs.

1.4 Data collection

To help gather insight into global biogas markets, the WBA's Policy, Innovation and Technical Committee (PITC) launched an online survey, with questions attempting to better understand the value placed on AD's services and key barriers inhibiting industry growth in each country. The survey was completed by 83 respondents from 37 different countries across six continents (see map below).

Together these countries account for 45% of global emissions[21]. If these regions were to develop a comprehensive biogas industry, digesting all readily available wastes, annual emissions would be significantly reduced.

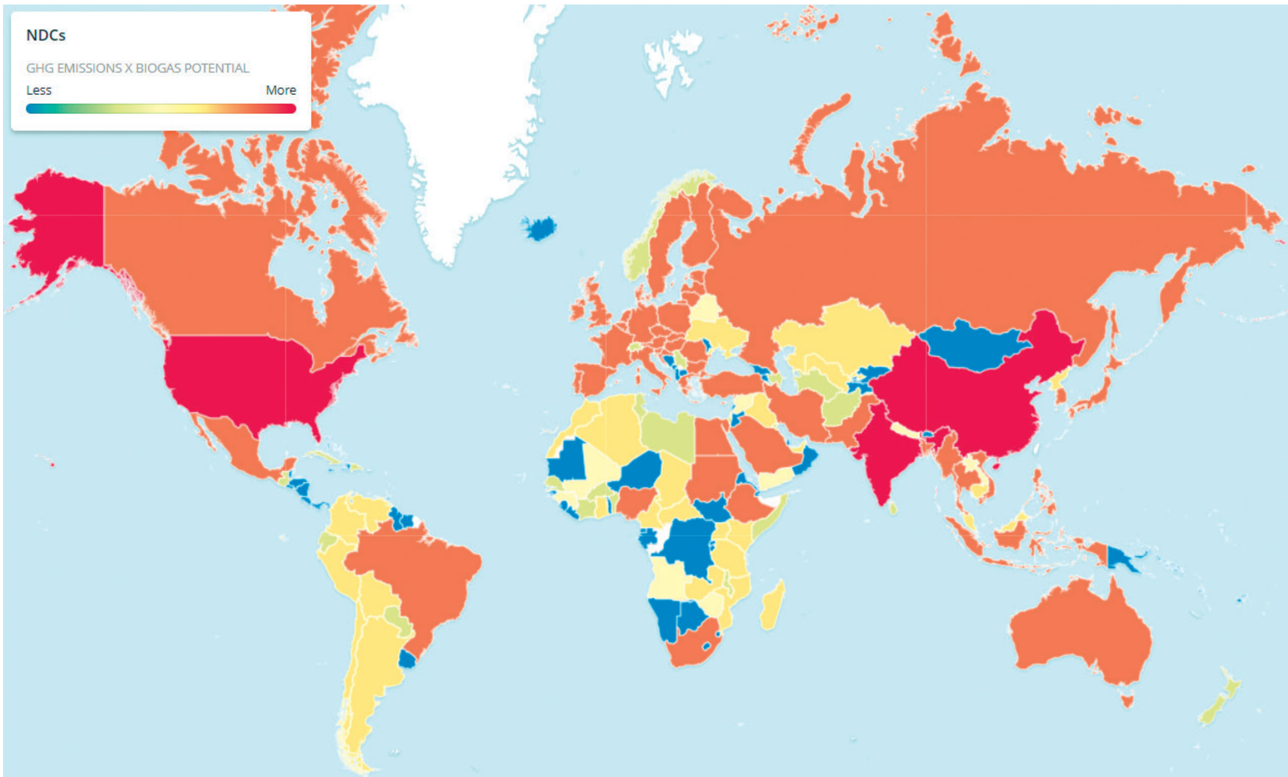


WBA survey responses
Number of completed survey from each country displayed

According to the survey the top two reasons for biogas plants failing to be built is (1st) financial cost and (2nd) unfavourable policies. The latter is in joint second place with the reason why established biogas plants fail prematurely. Around the globe biogas market experts cite policy as the most important factor that needs to improve to allow the biogas industry to thrive.

The following map (p27) highlights the countries in which biogas could deliver the greatest contribution to carbon reductions. Each country's approximate biogas potential (estimated per capita) is multiplied by the country's contribution to global emissions – thus creating an impact index. Note, countries within the EU are grouped together in line with the Paris Agreement's Nationally Determined Contribution (NDCs) – see Chapter 3 for more details.

[21] www.carbonbrief.org/paris-2015-tracking-country-climate-pledges



Top 10 priority countries for biogas:

Ranking	Country	Share of global GHG emissions	Approx. biogas potential (TWh)	Impact index+
1	China	24%	1,156	274
2	India	6%	1,108	63
3	USA	12%	266	32
4	EU*	9%	358	32
5	Brazil	6%	171	10
6	Russia	5%	117	6
7	Indonesia	1%	220	3
8	Japan	3%	102	3
9	Mexico	1%	104	1
10	Pakistan	1%	177	1

* EU includes 28 countries (inc. UK)
+ Impact index = Share of global GHG emissions x Approx. biogas potential [figures may not sum due to rounding]

1.5 Aims and objectives

This report is a **practical tool kit** – gathering insights from the world's biogas industry to help governments and stakeholders make well-informed decisions.

First, it details the multitude of advantages offered by a well-developed biogas industry (chapter 2), showcasing why all countries would benefit from recycling its organic wastes. AD delivers decarbonisation and so much more – from providing a clean burning fuel to rural communities to improving soil quality and productivity.

Chapters 3-6 focus on different aspects of the biogas system. They each explore how stakeholders at local, national, and international levels can best support biogas growth, identifying how they can unlock the full value of their valuable bioresources. The report highlights policies that have already been effectively implemented around the world and are helping the global industry grow today. This will enable policymakers to draw on a strong evidence base when designing new policies to support their biogas industry.

The following summarises the WBA's overarching policy asks:

1) Commitment to biogas in NDCs, backed by tariffs
Biogas should be incorporated into NDCs and backed up by effective national policies to incentivise growth in the industry, targeting the recovery of organic material and nutrients to return to soils; the generation of biogas for energy and transport; and CCS/CCUS from biogenic wastes. At the early stages of biogas industry development these support mechanisms, for use and/or generation of biogas, bio-CO_2 and digestate should take the form of direct financial support, most likely tariffs. It is vital that infrastructure to support the industry growth, such as collection of organic wastes, accompanies the development of the industry to ensure the methane that would otherwise be emitted from these wastes is prevented and there is sufficient feedstock available for AD plants.

2) Transition to more market-based policy support
As the industry grows and matures, policy can move away from direct subsidy to facilitate a market for the environmental benefit delivered by the biogas industry, while enabling the national biogas industries to become independent of direct subsidy. This should be accompanied by the removal of all direct support for the fossil industry, ensuring that there is a level playing field before any subsidies for biogas are removed. It will also be beneficial for governments to clearly set out their support for and backing of the biogas and organic waste recycling industry in a clear strategy to provide investor confidence as direct subsidies are tapered away.

3) Carbon pricing policies
Introduction of national, regional and finally global carbon trading mechanisms to create an effective market for the climate benefits delivered by the biogas industry, pricing in the value of the carbon saving delivered and enabling biogas projects to stack up financially, independent of national policy support is vital. The scope and methodology of carbon pricing mechanisms must be developed to effectively cover the biogas industry, e.g., they must cover GHG emissions, methane capture and carbon sequestration from agriculture and from organic wastes generated by human activity.

All policy asks are presented chronologically, to form a policy pathway.

However, since every country will be at a different stage of biogas development and have a different capacity for growth, it is impossible to set a universal timeline for policy adoption. While each policy recommendation can be implemented independently of each other, when reading the policy suggestions consider where your country is on the pathway – what has already been done? And what can be done?

For example, a country may have already identified a role for biogas in their NDC, but now must back their targets with action. Introducing policies to support demand for AD's products and accounting for carbon emissions in systems will inevitably stimulate biogas growth.

Chapter 2: The World in 2030 and The Pathways to Get There

This chapter presents a picture of the world with anaerobic digesters at the core of an extensive circular economy recycling societies' organic wastes. It identifies the key barriers inhibiting the collection of organic wastes and their recycling through anaerobic digestion (AD), which are preventing the AD industry from fulfilling its full potential to cut global GHG emissions. It explores how AD's sustainable products – biomethane, bio-CO_2, biofertiliser digestate and other valuable bio-products – can deliver a broad range of socio-economic and environmental benefits; mass employment, energy and food security and independence, agricultural productivity, clean air and more. This in turn will have a significant impact on the rural and urban landscape, in the way cities, farms, citizens' lives and governments function. We will explore the AD industry required to deliver the 10% global GHG emissions reduction target, while also estimating the investments required to meet this target.

2.1 The benefits on offer

Every day, every single person in the world produces organic wastes. This may be directly in the form of sewage or food waste, where the latter may be avoidable (good food thrown away) or unavoidable (banana skins, vegetable peelings, tea bags for example). Alternatively, waste may arise indirectly – manure and slurries from agricultural livestock, crop remains from arable farming, and organic residues produced during the manufacture of food and drink. Every time you drink a beer or eat some chips, a form of organic waste will have been created upstream on the farm or in the factory.

The following represents our best estimates for the organic wastes produced worldwide each and every year – where total organic waste production will invariably increase with population growth:

Food waste	1.3 billion tonnes
Sewage	69.1 billion tonnes
Livestock manures/slurry	33.3 billion tonnes
Crop residues	2.0 billion tonnes
TOTAL	**105.7 billion tonnes**

This vast quantity of waste produced every year is difficult to comprehend. First and foremost, society should seek to cut the amount of organic waste produced per person. However, many organic wastes are unavoidable and will forever be 'wasted'. AD is the most efficient technology available today to convert this material from a waste into a valuable resource, offering a broad range of socio-economic and environmental benefits – simply by treating and recycling the organic wastes we humans inevitably create each and every day.

Worldwide, organic wastes fall within a linear economy, where products serve their purpose before being buried or incinerated. It is an economy that fundamentally cannot run like this for much longer. Resources will deplete. The world will become uninhabitable. If we could build an economy that would re-use resources rather than use them up, we could build a future that really could work in the long term. A **circular economy** is based on the principles of recycling our waste, keeping products and materials in use and regenerating natural systems.

AD is the best technology available today for recycling organics. It enables the creation of a circular economy of organic wastes, where organic material that has already been used once can be reused to return nutrients and carbon to soils and to produce energy and other valuable bio-products. It is also recognised as a key education tool, stimulating circularity across all economies.

Wastes modelled to estimate global potential

- Global **food waste** alone can produce enough natural gas to satisfy the demand of Germany or electricity for 124 million people approximately.
- Global **livestock waste** could produce enough natural gas to satisfy the demand of both India and China or electricity for all agricultural demand globally.
- Global **crop residues** could produce enough natural gas to satisfy the demand of China and Japan or electricity production to cover 6% of global demand.
- Treating **sewage sludge** globally could produce enough natural gas to satisfy the demand of Ukraine or electricity for 33 million people.

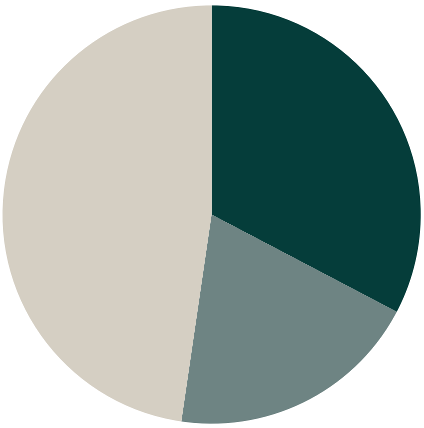
Additional organic feedstocks for AD not included in model

- **Garden waste**. From domestic gardens to municipal parks and sports centres, green waste can arise from numerous sources. While the digestion of woody biomass typically takes longer than most feedstocks, dry AD technology or the integration of aerobic decomposition (aka compost) post-AD can support its treatment, extracting biomethane and creating a high-value soil conditioner.

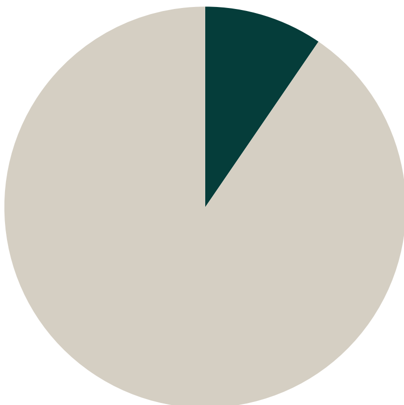
- **Algae**. These micro-organisms can act like a carbon sponge, drawing CO_2 out of the atmosphere. The resultant biomass can be digested to generate energy, and the digestate used to grow more algae. This closed system essentially converts sunlight into renewable gas.

- **Insect waste or "frass"**. Insects are often identified as a valuable source of protein and nutrients within both human and animal diets. With a relatively small footprint, their cultivation can help reduce the carbon intensity of food and improve food security worldwide. The organic by-products of insect farming can be readily collected and digested, to recycle waste material.

In 2019, the WBA published a ground-breaking report[22] which calculated, for the first time, the global potential of the biogas industry in terms of the energy and nutrients it could potentially produce and the GHG savings that could result from this. The modelling assumed achievable collection rates of organic wastes and realistic estimates for waste generation, for example, including a significant reduction in food waste generated. When diverted to AD plants, these vast quantities of bioresources could deliver the following:



Gas Demand
Biomethane could supply **33%** of the global gas demand, plus an additional **20%** with the integration of P2G



GHG emissions
AD could cut global emissions an estimated **10%** each year

[22] www.worldbiogasassociation.org/global-potential-of-biogas/

All organic wastes must be considered valuable bioresources. Only AD can fully unlock their intrinsic value. As a ready to use technology, AD can deliver a broad range of benefits.

1. **Produces green energy, biogas.** By digesting all readily available organic wastes, the global AD industry holds the potential to generate an estimated 12,000 TWh of energy every year. This is the equivalent of 33% of all gas or 28% of all coal used worldwide in 2017. Most importantly, AD produces this energy in the form of a renewable gas. Biogas (a mix of methane and bio-CO_2) can be 'upgraded' to biomethane by removing the bio-CO_2. This biomethane is chemically identical to fossil natural gas, such that it can directly replace fossil gas wherever used – from heating homes via gas boilers and fuelling vehicles, to refining into other products (plastics, lubricants etc). While there are plenty of technologies capable of generating renewable electricity, AD is a ready to use technology able to produce renewable gas.

AD's ability to produce renewable energy should not be understated. Yet, its benefits go far beyond energy generation. Governments often overlook its provision of numerous other social, environmental and economic services. The following outlines a selection of these key benefits which are not always recognised by governments and industry alike:

2. **Produces organic biofertiliser, digestate.** After the extraction of the energy during the AD process, the remaining solid/liquid residue retains all the nutrients and organic matter from the organic material originally fed into the digester. The nutrients and remaining organic matter can then be returned to the land to fertilise crops and restore soil health. Crucially, digestate also helps displace the need for artificial fertilisers, which are highly energy intensive to manufacture and generally involve the mining of finite mineral resources. Moreover, digestate typically contains high concentrations of organic carbon. Returning this to land improves soil structure, water retention and sequesters carbon in the ground.

   WBA's *Global Potential of Biogas* report analysed the amount of nutrients AD could recover from the organic feedstocks. Digestate, a by-product of the digestion process, is rich in nitrogen, phosphate and potassium (NPK) as well as a plethora of other key elements required for strong agricultural productivity. Consisting of up to 90% liquid, unprocessed digestate can further support agricultural systems in drier regions. We found that the potential for nutrient replacement is the equivalent of the amount that is used to fertilise an area equivalent to either Brazil and Indonesia or approximately 5-7% of all nutrients used globally.

3. **Delivers deep decarbonisation.** All AD prevents GHG emissions primarily in three key ways: (i) displacement of fossil fuels through its generation of biogas; (ii) displacement of artificial fertilisers through its production of digestate; and (iii) prevention of emissions from decomposing wastes. The UK government estimate for every tonne of food waste digested, 616 kg CO_2e emissions are prevented, compared to landfill. In 2020, the world produced an estimated 1.3 billion tonnes of food wasted post-farm-gate[23]. Had all this food waste been digested, around 801 million tonnes of CO_2e emissions could have been avoided – this is the equivalent of 2% of all global emissions.

   Of course, AD is not restricted to food waste; all organic material is suitable to varying degrees for digestion, from sewage, manures and slurries to industrial organic wastes and crop residues. The EU has identified AD as a keystone technology in tackling methane emissions from farms.

   Moreover, the AD process captures and concentrates CO_2 inside the digester thus, when integrated with innovative CCS technology, improves AD's ability to deliver negative carbon emissions – actively reversing global emissions.

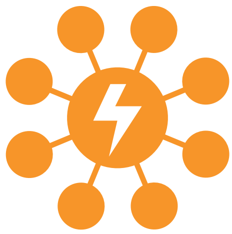
[23] https://en.reset.org/knowledge/global-food-waste-and-its-environmental-impact-09122018

4. **Creates green jobs.** For every MWe-e (megawatt electrical-equivalence) of capacity deployed within the AD sector, an estimated 14 temporary jobs are directly created to design, develop, and construct a plant, and 3 permanent jobs to operate and maintain them[24]. These figures may be doubled when expanded to include the indirect jobs created within the wider bioeconomy, such as those responsible for feedstock procurement and management. For example, jobs will be required to design, build and operate an extensive waste collection network.

   Crucially, as AD plant locations are typically located next to sources of organic waste/material, these green jobs are predominantly decentralised, providing often-neglected rural communities new opportunities for employment and training. Successful AD operation requires a range of skills. These skills may already be possessed by a local community (e.g., land management and farming), where other skills required may present opportunities to upskill a local workforce or retrain existing professionals within the oil and gas industry – many of these engineering-based skills are readily transferable to AD. When the AD industry is at full capacity, it is estimated that the industry will be **employing 10-15 million people** directly and indirectly. As the industry grows, additional jobs will also be created within the research and innovation sector, helping to optimise the operations of this increasingly important sector.

5. **Diversification of agricultural economies.** Farmers are under more pressure than ever before, attempting to eke out more value from their land and provide for a growing population. Intensification risks degrading land, yet customers increasingly expect cheap food. AD can help resolve both issues. Through its production of biogas and digestate, it can significantly cut the cost of importing energy from the grid and buying artificial fertilisers, even selling excess for additional revenue. As countries start to account for carbon emissions, AD stands to financially benefit from its ability to decarbonise and defossilise unsustainable systems. And the digestate spreading returns nutrients and organic matter, and stabilises soils, conducive to long-term agricultural sustainability.

6. **Cleaner air and cleaner water.** When organic wastes break down in the open air untreated, they not only produce harmful GHG emissions, but also NOx gases and toxic leachate. These chemicals present significant risks to all living organisms when breathed in or swallowed via contaminated water, respectively. Treating organic wastes effectively saves lives and protects biodiversity.



7. **Balance the energy network.** AD creates flexibility within the energy system – it can easily be stored and transported through the existing energy infrastructure, providing low carbon energy when and where demanded. Importantly, it can also be used to generate base load electricity and used to store excess renewable electricity via electrolysis and biomethanation. As wind and solar capacity has increased over the past decade, many countries are increasingly experiencing periodic negative energy pricing, whereby electricity generation exceeds demand. These conditions can cost the grid operators substantial amounts of money. In the UK, it was reported that system operators paid more than £6.6 million to balance the network on 26th May 2019 alone[25]. We cannot afford to waste renewable electricity, in any form. By using excess electricity to create green hydrogen, through the electrolysis of water, low carbon energy can be stored as a gas. Hydrogen can be subsequently fed directly into an AD plant, binding with CO_2 to form biomethane, increasing its yields by ~40% and utilising the CO_2 captured in the AD process. Again, this process transforms AD from a carbon neutral to a carbon negative technology.

[24] www.nnfcc.co.uk/publications/report-uk-jobs-bioenergy-sector-2020

[25] www.current-news.co.uk/news/uk-negative-power-pricing-record-smashed-and-balancing-costs-spike-during-extraordinary-weekend

8. **Exportable sector as a global leader.** The world is delivering just 2% of the global potential of AD[26]. As countries enact changes to meet their Nationally Determined Contributions (NDCs) in line with the Paris Agreement, AD is increasingly recognised for its ability to provide deep decarbonisation, while supporting local energy and food security, waste management and agricultural productivity. The race is on to develop a world-leading AD industry – the winner(s) will be identified as centres of knowledge and expertise, able to export their experience to any other country. In the UK alone, companies already export over £100 million worth of biogas-related expertise and equipment per year. Worldwide, to scale up the biogas industry to recycle the 105bn tonnes of unavoidable organic wastes would require an investment of ~US$100 trillion.

The Intergovernmental Panel on Climate Change (IPCC)[27] has predicted that 2030 is the tipping point for climate change, meaning that within the next decade every industry, including the biogas sector, needs to step up, set out a plan for their part in mitigating climate change and act upon it.

The data we analysed led us to the conclusion that harvesting these waste and crop resources (with a realistic measurement of potential that can effectively be harvested) for biogas can contribute a 10% reduction in GHG emissions worldwide. These GHG emissions reductions come from displacing fossil fuels with a perfecty compatible renewable fuel, reducing the transition costs. At the same time significant reductions in GHG emissions are achieved by improving current waste management procedures, capturing methane-emitting organic wastes for the production of biomethane. As a potent GHG, minimising methane emissions must be prioritised worldwide. Finally, a further GHG reduction comes from reducing the production of energy-intensive mineral fertilisers, as they are replaced with the nutrients recycled from the waste management.

In 2019, the WBA's principal industrial members pledged their commitment to support a >10% reduction to global emissions by 2030 via biogas. Members suggest that this target is achievable within the subsequent ten years if governments implement the right policies. This declaration was presented to the UNFCCC's COP25 on climate change in Madrid, December 2019[28].

Now we have to understand what policies need to be in place if the industry is to be able to deliver on this global target. The potential for investments and new employment opportunities in biogas are explored both relative to the global north and the global south taking into account technological and financial complexities and differences in waste streams and feedstocks.

In 2015, the United Nations (UN) formulated the sustainable develop goals (SDGs) in an effort to identify and address the world's most pressing issues. These goals encompass all aspects of life, to support people and protect the environment. In total, there are 17 goals[29]. An extensive biogas industry would make a significant contribution towards at least **nine** of these goals:

Goal 1: End poverty in all its forms everywhere

Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Rural and remote societies can feed into a community AD plant and convert their organic wastes into renewable fertiliser. Digestate also returns organic carbon to land, vital for soil structure and water retention, and can therefore stave off soil degradation and desertification. Healthy and stable soils are necessary to maintain agricultural productivity and support localised food security.

[26] www.worldbiogasassociation.org/global-potential-of-biogas/

[27] www.ipcc.ch/sr15/chapter/spm/

[28] www.worldbiogasassociation.org/wba-calls-for-decisive-policies-to-fulfill-global-decarbonisation-potential-of-biogas/

[29] https://sdgs.un.org/goals

Goal 3: Ensure healthy lives and promote well-being for all at all ages
Around 80% of sewage and wastewater worldwide flows directly into water systems untreated[30]. Drinking water is contaminated and water-borne disease spread rapidly. Sanitation is crucial for healthy lives and well-being. AD can treat these wastes and return value to its people. Moreover, AD supports better air quality, primarily through its ability to cut ammonia emissions from raw manure and its ability to generate a clean-burning fuel, biogas.

Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5: Achieve gender equality and empower all women and girls
In small communities, typically in the global south, the responsibility of gathering fuel wood and cooking falls on women. When wood is burnt inside, the fumes and particulate matter disproportionally damage women's lungs and eyesight. Establishing community biogas can negate the need to source wood, freeing up time, and when combusted, biogas does not adversely affect the users' health.

Goal 6: Ensure availability and sustainable management of water and sanitation for all
Also see goal 3. The majority of the world's organic wastes are left to rot and seep into freshwater supplies. AD can treat these wastes to ensure water quality is maintained and consequently support water security for all.

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all
AD helps unlock the energy held within organic compounds. Biogas is a renewable energy accessible to any individual, community, company and country producing organic waste. Moreover, it is a clean and flexible source of fuel – it can be used directly from heating or cooking, it can generate electricity through a CHP unit, or converted to biomethane it can be used to fuel a vehicle. It can also be stored and transported as required.

Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
The biogas industry is highly flexible. It can adapt to meet ever changing supply chain, from new types of organic waste, new uses for biogas and digestate, new agricultural techniques. The whole system encourages innovation to optimise the provision and value of products returned from organic wastes. Moreover, many skills required to effectively operate larger biogas plants are transferable from the fossil oil and gas sector; biogas can help retrain and employ these professionals as we move away from fossil resources.

Goal 10: Reduce inequality within and among countries

[30] www.unwater.org/water-facts/quality-and-wastewater-2/

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable
AD plants form the heart of a circular economy of organic wastes, at any scale. They offer decentralised employment opportunities, and new revenue streams from organic wastes which are already being created. Biogas plants support safer and more sustainable waste management systems.

Goal 12: Ensure sustainable consumption and production patterns

Goal 13: Take urgent action to combat climate change and its impacts
Biogas offers both decarbonisation and defossilisation. We can either leave waste to rot and pollute the environment or treat it through anaerobic digestion and return renewable energy, renewable fertiliser, bio-CO_2 and other valuable bio-products. It is a no-regrets option, particularly in terms of environmental conservation.

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Through the management of wastes, AD prevents land contamination and pollution of water. Through the provision of organic- and nutrient-rich digestate, AD helps restore soils and counter land degradation. Our organic 'wastes' must be recognised as organic 'resources' in the fight against environmental change.

Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development

AD's ability to contribute significantly towards these SDGs demonstrates that it is not just about renewable energy and decarbonisation. As important as climate change mitigation is, it is not necessary the top priority for all countries. Some countries' emissions may be negligible – the relative contribution to global GHG emissions from 50 countries with the lowest total emissions is <0.25% of worldwide emissions. Some countries may have extremely limited resources which are preferentially used to tackle immediately pressing health issues, such as hunger, drought, or disease.

By developing a circular economy via AD, countries can address multiple key issues affecting the health and well-being of their population. Therefore, AD's wider benefits are particularly relevant to those countries targeted by the SDGs – i.e., countries in the global south. Unlocking value from a community's or country's organic wastes builds resilience.

The use of firewood within rural communities is another excellent example of the benefits delivered by biogas. Firewood remains a primary source of fuel for cooking. Establishing small-scale biogas plants in rural communities can provide several tangible benefits. Studies in Nepal, India, Indonesia and Rwanda have found that biogas users use significantly less firewood, which in turn leads to a large reduction in the time spent collecting firewood, and the destruction of forests and the biodiversity they contain. Biogas burns cleaner than firewood, so families gain health benefits from cooking food in a cleaner environment. Having biogas on tap also provides opportunities for economic growth. Users of biogas are able to create and expand food-related businesses often led by women.

2.2 Current biogas industry

Of the 105 billion tonnes of organic waste produced each year, almost all of it remains untreated – left to rot, emitting methane into the atmosphere, and contaminating environments. Food waste is sent to landfill unsegregated from non-organic wastes, sewage flows into waterways, and agricultural wastes are simply spread to land. Organic wastes must be converted from a problem to a solution.

The WBA's *Global Potential of Biogas report*[31] estimated that the world is achieving just 2% of its full potential. That means almost all of these environmental and socio-economic benefits on offer from our organic wastes, or 'bioresources', are being wasted. At present, there are approximately 132,000 small, medium or large-scale digesters operating worldwide, with an additional 50 million micro-scale digesters serving homes/small communities.

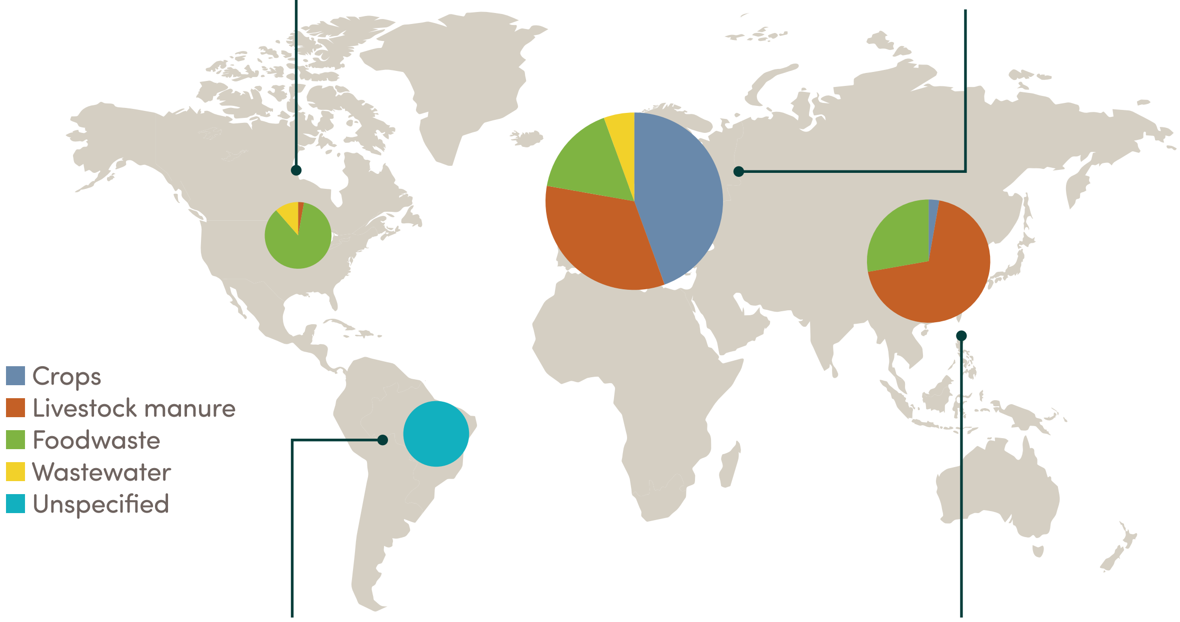
In 2018, approximately 407 TWh of biogas was produced worldwide. This represents a small fraction of the 8,490 TWh biomethane energy potential, as modelled by the IEA[32] – capable of supplying 20% of the worldwide gas demand. The following map displays the centres of biogas production by energy production – data from IEA.

USA 42 TWh

While much of today's biogas is derived from food waste within landfill, the biogas industry has developed rapidly within certain regions, owing to policy support. Most notably, in California, policy aimed at decarbonising transport fuels promoted the production of biomethane from manures. The framework recognised biomethane as the only sustainable fuel capable of delivering carbon negative life-cycle emissions.
Note, biogas/biomethane is commonly called Renewable Natural Gas (RNG) in USA.

Europe 209 TWh

Europe leads the global industry, driven primarily by large markets in Germany, Italy and the UK (in order of number of biogas plants; largest to smallest). **Agricultural feedstocks** fuel the industry. German subsidies stimulated the development of plants fed by bioenergy crops. Similarly, support schemes focusing on energy generation promoted the incorporation of bioenergy crops into UK feedstocks; although later regulation set limits of the proportion of gas derived from crops. Major biogas industries in France and Denmark have instead focused on the digestion of manures and slurries, recognising their potential to decarbonise agricultural practices.



Rest of the World 47 TWh

The biogas industry in the rest of the world is dominated by smaller, decentralised digesters. India and Thailand currently have the largest capacities, with much of the feedstocks comprising **food and agricultural wastes**. Brazil's biogas industry is growing relatively rapidly, with policy supporting the treatment of waste from its extensive cattle and soya bean farming sector.

China 84 TWh

China produces less than half of Europe's biogas output, despite having twice the population, yet it still represents the second largest individual market worldwide. Many of these biodigester are micro- or small-scale, serving small communities by treating locally sourced **agricultural and food wastes**. However, China have identified biogas in their industrial strategy and hope to rapidly develop capacity to decarbonise transport via biomethane.

[31] www.worldbiogasassociation.org/global-potential-of-biogas/

[32] www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth

The lack of organic waste management is a global issue, pervading all societies. These wastes must be managed to mitigate their impact on climate. Moreover, with all these untapped bioresources on offer, there are copious opportunities for growth – for example, over 12,000 TWh of untapped renewable gas. And, as a highly flexible technology, different biogas setups could target different social or environmental problems. Multiple small digesters could provide remote communities with a secure supply of clean-burning energy, or a large centralised plant could establish waste management systems and socialise investment costs.

Wastewater arguably represents the most underutilised feedstock globally, despite its supply being entirely predictable and consistent. And yet, digesting this bioresource worldwide could save lives by preventing the contamination of waterways and provide clean energy for communities of any size.

2.3 Estimating biogas potential

Governments and industry can estimate their own biogas potential. In the first instance, the availability and quantity of organic waste should be considered:

- **How many people live within a particular area?**
  All humans produce organic waste every day. More people, more wastewater. Sewage sludge can be easily estimated – for example, 47kg of faeces are roughly produced per person per year[33].

  More people also result in more food waste. While social and cultural factors may influence the amount of food wasted per person, food waste can arise from a range of different sources within a society: homes, shops, restaurants, schools, hospitals etc. Identifying waste streams within specific systems and regions will require local intelligence gathering from surveys and local expertise.

- **What are the key products and exports within a particular area?**
  The manufacture of countless food and drink products involves the production of organic wastes, from cheese making to breweries. Developing an on-site AD plant often creates a highly efficient system, treating wastes, returning energy to the factory and biofertiliser back to the fields to grow more food.

  Moreover, the bio-CO_2 from biogas can also be used in the manufacturing of products, such as carbonating drinks. Much of today's industrial-grade CO_2 comes from artificial fertiliser or biodiesel industries. If such a factory is not close to one of these production centres, CO_2 can be expensive. Co-locating an AD plant with a food/drink plant can present significant cost savings, while improving the company's green credentials and supporting access to green investment.

- **What do farms produce within a particular area?**
  Waste from cows, pigs, goats and chickens can all be digested to produce energy. The quantity of which can be estimated per head; for example, an adult cow can produce over 50kg of manure per day. Similarly, the quantity of crop residues, cover crops and sequential crops can also be predicted based on area covered. These organic wastes can be co-digested and the digestate used to fertilise the agricultural land.

  The agricultural structure may also influence how AD is developed. A larger centralised plant could be developed to treat the waste of multiple local farms, but more-remote communities might prefer smaller independent digesters.

With these questions in mind, the following can be used to estimate your biogas potential.

[33] www.tandfonline.com/doi/full/10.1080/10643389.2014.1000761

What is your country's biogas potential?

How many tonnes of food waste are produced each year?

__________ million tonnes

For each one million tonnes sent to AD:
- 1,008 GWh renewable energy available
- 826,000 tonnes of CO_2e abatement

Did you know?
Around 1.3 billion tonnes of food are wasted each year – a third of all food produced for human consumption! First and foremost, food waste must be reduced. The remaining, unavoidable material must be sent to AD. This requires infrastructure to collect separated organic waste.

How many tonnes of sewage sludge are produced each year?*

__________ million tonnes

*Around 47kg of sewage waste is produced per person per year.

For each one million tonnes sent to AD:
- 814 GWh renewable energy available
- 704,000 tonnes of CO_2e abatement

Did you know?
80% of wastewater produced is untreated, contaminating fresh water and damaging ecosystems.

How many tonnes of livestock waste are produced each year?

__________ million tonnes

For each one million tonnes sent to AD:
- 412 GWh renewable energy available
- 161,000 tonnes of CO_2e abatement

Did you know?
Over 33 billion tonnes of manure are produced by cows, pigs and chicken each year – and yet almost all this waste is spread back to farmland untreated.

How many tonnes of crop residues are produced each year?

__________ million tonnes

For each one million tonnes sent to AD:
- 2,378 GWh renewable energy available
- 450,000 tonnes of CO_2e abatement

Did you know?
80% of waste water produced is untreated, contaminating fresh water and damaging ecosystems.

How many tonnes of sequential crops are produced each year?*

__________ million tonnes

*15 tonnes of crops grown per hectare per year

For each one million tonnes sent to AD:
- 2,610 GWh renewable energy available
- 747,000 tonnes of CO_2e abatement

Did you know?
Modern, sustainable agricultural techniques can help farmers optimise the use of their land. For example, sequential cropping can protect land from erosion between food harvests and provide an energy-rich feedstock for AD.

Delivering this potential...

Smaller-scale biogas unit treating a community's organic waste

Feedstock = **Mixed food waste, agricultural waste, sequential crops and wastewater**
Tonnage = **10,000 tonnes per year**
Capacity = **1.0 MW**
Cost of energy production = **126 $/MWh**

Managing local waste provides a community with clean energy and biofertiliser, while supporting clean air and sanitation. Designing, building, and operating this plant would create ~5 jobs.

Larger-scale centralised biogas plant treating a city's or region's food waste

Feedstock = **Food waste (option to co-digest with agricultural waste or wastewater)**
Tonnage = **100,000 tonnes per year**
Capacity = **14.0 MW**
Cost of energy production = **62 $/MWh**

Revenue gained from managing waste, renewable energy generation, biofertiliser production, and source of biogenic carbon for use or storage. Designing, building, and operating this plant would create ~33 jobs.

Large-scale centralised biogas plant treating a city's or region's wastewater

Feedstock = **Wastewater (option to co-digest with food waste)**
Tonnage = **150,000 tonnes per year**
Capacity = **2.0 MW**
Cost of energy production = **90 $/MWh**

Revenue gained from managing this constant supply of waste, preventing environmental contamination, and supporting sanitation. Biogas can be used to power the whole treatment facility and biofertiliser can be sold to local farmers.

On-farm biogas unit treating its own waste

Feedstock = **Livestock waste, crop residues and sequential crops**
Tonnage = **20,000 tonnes per year**
Capacity = **2.0 MW**
Cost of energy production = **90 $/MWh**

Offsetting costs required to fuel farm vehicles, heat buildings, and fertilise crops. Digestate's nutrients can further improve soil health and structure, while sequestering atmospheric carbon.

Centralised biogas plant treating wastes from multiple farms

Feedstock = **Livestock waste, crop residues and sequential crops**
Tonnage = **350,000 tonnes per year**
Capacity = **22.0 MW**
Cost of energy production = **<62 $/MWh**

Highly efficient system reducing the need to build multiple plants, all farmers feeding into the plant receive a share of the energy, biofertiliser and even profits.

2.4 Barriers to growth

Biogas clearly offers a broad range of benefits at all scales, and yet the AD industry is operating at a fraction of its full potential – just 2%. Billions of tonnes of organic wastes remain either untreated or managed through inefficient technologies, such as landfill or incineration. This problem must be addressed. It is imperative we understand what is stopping people from unlocking the full potential of our world's valuable bioresources. In short, two barriers appear to predominately prevent the uptake of AD globally: **costs** and **competency**. The following will explore these barriers in detail and identify key aspects to consider when designing biogas policy.

2.4.1 Key barrier: Costs

An AD plant requires sizable capital expenditure (Capex) and on-going operational expenditure (Opex). A relatively small 1.0 MW capacity plant can cost an estimated US$ 8,600,000 to develop and US$ 500,000 each year to run. Too often, AD is compared directly with other technologies based on an individual service provided, for example:

- If **waste disposal** is the sole focus, landfill is cheaper. Up to 1.8 million tonnes of mixed waste could be thrown into landfill at a cost of US$8.5 million over a 10-year lifetime[34]. To treat a similar quantity of organic waste through AD would likely require around 20 large digesters, each costing upwards of US$30 million to deploy.

  ... Of course, you must also account for landfill's harmful environmental impacts: contamination of land and water by toxic leachate, methane emissions to the atmosphere, and poor air quality. Each of these impacts will result in knock-on costs, to treat the various adverse health, agricultural and other environmental impacts. Additionally, landfill requires vast areas of land which, once filled after several years, becomes largely unusable.

- If **energy** is the sole focus, at US$40-50/MWh, wind and solar can provide cheaper means of generating renewable energy, compared to AD's US$60-120/MWh.

  ... Of course, wind and solar also require large areas of land which might otherwise be utilised for agriculture and sustenance. These technologies serve only to generate renewable electricity. While they will eventually play a major role in decarbonising energy worldwide, other technologies are required to tackle harder to decarbonise sectors, such as heat and transport (especially heavier vehicles). AD is the only ready-to-use technology capable of generating a renewable gas, that can directly replace fossil natural gas.

- If **fertiliser production** is the sole focus, artificial fertilisers can be manufactured at scale using fossil gas and low-cost labour to mine non-renewable minerals. While they are not necessarily cheaper than digestate, regulation dictating strict nutrient spreading limits and existing agricultural equipment mean farmers often favour manufactured fertilisers over more variable organic fertilisers.

  ... Of course, you must also account for the greenhouse gas emissions released when creating these artificial fertilisers. The Haber-Bosch cycle used to fix nitrogen into a fertiliser requires vast quantities of natural gas, emitting significant amounts of CO_2 into the atmosphere. It is estimated the ammonia fertiliser industry uses 3-5% of the world's natural gas, requires 1-2% of the world's energy supply, and is responsible for up to 1% of total global emissions.

Anaerobic digestion is the only technology capable of delivering all these services – without depending on fossil resources, without contributing to global emissions, and without requiring vast swathes of land.

It is a low carbon waste management technology which generates a low carbon gas and a low carbon organic fertiliser. Altogether, waste AD plants can become carbon negative when compared to BAU.

Yet, carbon is not effectively costed within our current systems. Therefore, the true value of AD's services is not effectively accounted for within the economic model. By considering carbon emissions within the supply chain, the cost of AD makes sense – offering very good value for money.

[34] https://ec.europa.eu/environment/waste/studies/pdf/eucostwaste.pdf

The following table imagines a relatively large AD plant treating food waste and explores its current revenue streams and the barriers inhibiting economic feasibility.

Reference plant
Feedstock: Domestic and commercial food waste
Feedstock tonnage: 75,000 tonnes per year
Energy capacity: 10 MW biogas
Energy generation: >80 GWh per year
Capex: $30 million
Opex: $2 million per year

Potential revenue stream	Barrier to income	Future potential
Waste management	AD plants can charge a gate fee (US$ per tonne) for the treatment of organic wastes. However, the gate fees amount is primarily driven by two factors: availability of separated organic waste and cost of alternative waste pathways (such as landfill or incineration). If food waste collection and supply is limited, demand from AD plants increases and the gate fee decreases – undervaluing AD's role in waste management. If unsustainable waste technologies are cheaper, companies and government may opt to save money. **Current value = US$ 0 - 20 per tonne** **Reference plant = US$ 0 - 1.5 million per year**	AD should be adequately rewarded for treating waste in the most environmentally friendly way. Promoting separate food waste collection can ensure fairer gate fees. Taxing less efficient and unsustainable technologies can support the cost competitiveness of AD; the greater the value unlocked from the wastes, the lesser the tax. Ultimately, banning all organic waste diversion to landfill will also support the uptake and financial feasibility of AD. **Potential value = US$ 20 - 40 per tonne** **Reference plant = US$ 1.5 - 3.0 million per year**
Energy	Whether it's derived from renewable or non-renewable resources, the energy from methane holds value. In 2021, the price of natural gas is valued at $2.54 per MMBtu – which equates to: **Current value = US$ 8.7 per MWh** **Reference plant = US$ 0.7 million per year**	Biomethane is able to provide all the same energy services as natural gas, while also cutting GHG emissions from some of the trickiest sectors, such as heat and transport. Consequently, it should be worth more than natural gas. Based on the trade of biomethane certificates in the UK, the current value of biomethane as a renewable source is: **Potential value = US$ 10 - 12 per MWh** **+ energy value = US$ 8.7 per MWh** **Reference plant = US$ 1.5 - 1.7 million per year**

Potential revenue stream	Barrier to income	Future potential
Fertiliser	While AD produces an organic renewable fertiliser, the value of its environmental services is not always accounted for in the fertiliser market. Farmers may opt to use artificial fertilisers because of equipment compatibility or regulation compliance. Those that do spread digestate are savvy, recognising the need for AD plants to remove digestate, and therefore purchase nutrients at rock-bottom prices. **Current value = US$ 0 per tonne of digestate** **Reference plant = US$ 0 million per year**	The EU identifies the need to expand organic farming to promote sustainable food production. By stimulating market demand for organic fertilisers, such as digestate, the value of its nutrients will be better accounted for. AD could earn for the ability to recover nutrients and displace the need for energy- and carbon-intensive artificial fertilisers. **Potential value = US$ 25 per tonne of digestate** **Reference plant = US$ 1.8 million per year**
Bio-CO_2	Biogas is composed of 35-45% CO_2 which, when separated from the biomethane, can be used within a multitude of industries, such as carbonating drinks, boosting greenhouse productivity, and refilling fire extinguishers. Almost all the world's industrial CO_2 comes from either the production of ammonia (again, the Haber-Bosch cycle) or the formation of liquid biofuels. Increasingly, companies are recognising the financial benefits of co-locating AD with industries which require industrial CO_2 – these arrangements can save companies up to: **Current value = US$100 per tonne of CO_2** **Reference plant = US$1.0 million per year**	
Carbon emissions	For the most part, carbon is not accounted for in current systems – companies may be free to emit as much GHGs into atmosphere as they please. **Current value = US$ 0 per tonne of CO_2e** **Reference plant = US$ 0 per year**	AD should be effectively rewarded for its ability to cut annual emissions. Carbon is arguably the best proxy for all of AD's environmental services. Any policy which serves to financially account for carbon emissions will likely act to support the biogas industry. **Potential value = US$ 100 per tonne of CO_2e** **Reference plant = US$ 6.6 million per year**

AD is not just a waste disposal technology, nor a renewable energy generator, nor an organic fertiliser producer – it is all these things and more. Comparing these services directly with other technologies fails to tell the whole story. AD is a ready-to-use technology capable of turning organic waste from a problem into a solution.

Policies which act to account for carbon emissions within the supply chain act to promote the adoption of sustainable technologies, such as AD. If cutting carbon emissions becomes a national priority, AD can become a cost-effective means of decarbonisation, while providing key socio-economic products, such as biogas. Based on UK data, the following provides indicative estimates of the cost per tonne of CO_2e saved, based on average load factors and average cost per MWe capacity:

AD ≈ **US$ 1,500 per tonne of CO_2 saved**
Offshore wind ≈ **US$ 1,150 per tonne of CO_2 saved**
Solar PV ≈ **US$ 3,200 per tonne of CO_2 saved**

As the global biogas industry develops, the Capex and Opex will likely decrease, thus bringing the cost of decarbonisation down and enhancing the economic feasibility of AD within all sectors. Making the economic model of AD work is pivotal to its success. The following identifies opportunities to reduce costs and boost income – beyond accounting for the carbon savings delivered from its operators:

Reducing costs (Capex and Opex):

- **Reducing risk** Perceived risk increases insurance costs and interest rates levied on loans, negatively impacting the financial feasibility of AD plants. Moreover, a well-run plant will optimise the quantity and value of its products, while minimising any risk to human or environmental health. With clear government support and a long-term strategy, investors can feel confident investing in AD. With policy and regulation to instil best practice, insurance costs can be reduced. Internationalising schemes such as the Anaerobic Digestion Certification Scheme (ADCS) in the UK could demonstrate best practice, optimising the environmental and economic services delivered from plants.

- **Shared infrastructure.** Collaboration between communities and farms can negate the need to develop multiple AD plants or connections to grid – one large plant is typically cheaper than two (or more) smaller ones. In Denmark, large-scale centralised AD plants treat the waste from multiple local farms; construction and operational costs are shared within a collective, and all reap a share of the benefits. Similarly, in the UK, centralised gas injection sites can negate the need for each plant to develop a gas grid connection (see Portsdown Hill run by SGN). Known as the 'hub and spoke' model, this system optimises the use of money and resources. Shared infrastructure can save AD plants significant amounts of money.

- **Reducing residence time.** Research and innovation are continually improving the time required to digest feedstocks, from new pre-treatment techniques to improve biological communities. Time spent in the digester is known as the residence time, and by reducing the residences time' duration, the smaller the capacity of a digestion tank is required. This can greatly reduce the cost of construction and land. Innovation can potential make incremental improvements without adversely impacting biogas yields.

- **Standardisation of parts.** Equipment could become manufactured in factories at scale, greatly cutting the cost of bespoke plans and parts. Specialist parts and components could become cheaper for plants of all sizes. Moreover, micro-plants could become cheaper and more accessible for homes or communities worldwide.

Boosting revenue:

- **Optimising efficiency.** Much like 'reducing residence time', innovation can improve the quality, quantity and/or value of biogas and digestate. New technologies and practices continue to improve biogas yields, such as new biota communities, in-digester monitoring to maintain ideal digestion conditions and optimising feedstock mixes. For example, innovation from SGTech in Israel, is able to increase biogas yields from agricultural manure by up to 18%, while also recovering water from the feedstock and changing nitrogen and phosphorus concentrations in the digestate.

- **Creating higher-value products.** With digestate's environmental benefits as a fertiliser typically under-valued, innovative technologies have found ways of creating higher value products with the material. Digestate can be converted to a domestic gardening fertiliser, for nursery plant pots, or even used to grow algae, which may be used as a low carbon animal feed.

Research and innovation play an instrumental role in improving both the feasibility and benefits of AD. Specific funds can help tackle key barriers inhibiting the capacity and capability of the AD industry. The industry must seek to bring down costs wherever possible, albeit via new technologies or innovative approaches, to help make AD more accessible worldwide. Although cutting expenditure should never come at the cost of best practice.

2.4.2 Key barrier: Competency

The successful development and operation of an AD plant, of any size, requires professionals with a diverse set of skills and expertise. All stages of the supply chain will benefit from increased competency in AD, appreciating the complexities and their long-term operation (>20 years).

As an industry, we must ensure all AD plants are run in line with best practice. To address this, initiatives such as the Anaerobic Digestion Certification Scheme (ADCS) help demonstrate a plant's commitment to optimal operation – improving health and safety, boosting output and enhancing environmental services. Starting in the UK, ADCS establishes confidence in AD. A plant following industry best practice reduces all types of risk, thus reducing interest rates and insurance premiums, and inspires trust in the wider industry.

ANAEROBIC DIGESTION CERTIFICATION SCHEME

A growing biogas industry will create new green jobs. The following details some of the key roles needed within a well-run biogas industry:

- **Entrepreneurs / Developers / Operators.** To identify opportunities to obtain quantities of organic waste and benefit from their treatment. These professionals understand all of AD's socio-economic and environmental services to unlock their commercial value. They can negotiate with local farmers to utilise the resultant digestate and implement a circular economy. These roles have an appreciation of the entire supply chain of AD and work to optimise its output and efficiency at every stage.

- **Engineers.** To develop safe and efficient plants. Engineers understand the various complexities of AD and are therefore able to create bespoke solutions to barriers. Engineers with AD-specialism can help make AD accessible to all, from a remote community to a sprawling city. They can help bring the cost of AD down as new technologies and equipment are devised.

- **Farmers.** To recognise the value of its organic wastes, from crop residues to livestock manure, and the ability of digestate to fertilise crops and restore soil structure. Farmers can develop their own AD plants or work with developers to support sustainable agricultural systems. By integrating AD into agricultural practices, farmers must play a central role in the decarbonisation of food production worldwide.

- **Policy makers.** To promote best practice and set regulation to prevent unintended impacts. By understanding AD, its benefits, its risks, its opportunities, policy makers can introduce effective rules to stimulate growth and target key areas. Communications from government officials can provide investor certainty and enable industry to strategise – setting the ball rolling for industry growth.

- **Researchers / Innovators.** To continue improving AD, working to overcome barriers and push the industry potential. They can provide expertise and advise to the current sector and future developers.

- ...and more: **builders**, **feedstock brokers**, **vehicle manufacturers**, **waste managers**, **consultants**, **regulators**, etc.

Knowledge sharing is key. People have been anaerobically digesting wastes for hundreds of years – the industry has learnt from past mistakes and increasingly unlocked more value from organics. While the biogas industry will continually improve, expertise and experience can be shared worldwide. Many biogas companies have successfully expanded internationally (e.g., Suez) to apply their knowledge within new markets, adapting to meet different cultures and policy. Moreover, expertise holds a commercial value; governments may establish international initiatives to export experience and equipment to growing markets.

2.4.3 Key barrier: Other

While costs and competency are the most evident barriers inhibiting biogas growth worldwide, additional barriers can slow the uptake of technology. Policymakers and industry professional should be aware of these comparatively minor barriers and consider changing the system to help stimulate growth:

- **Feedstock availability.** As discussed above, an AD plant can be a long-term, expensive venture. Consequently, a plant requires plans to secure feedstock for multiple years; whether that is a contract with a city council to treat domestic food waste or a partnership with some local farms to digest cattle manure. Government policy can promote industry confidence and provide the long-term certainty necessary for investment.
  See Chapter 4: Sector policies for more detail.

- **Environmental legislation.** Most typically, digestate management. Rules governing the application of fertilisers are often created with the use of non-renewable artificial fertilisers in mind. While these rules may be subsequently adapted to account for digestate spreading, regulation is not always appropriate for digestate, failing to achieve their key objectives, such as avoiding eutrophication. Digestate spreading offers environmental benefits which artificial fertilisers cannot (e.g., carbon sequestration in soils). All governments have the opportunity to consider their priorities and introduce bespoke policy to encourage digestate utilisation – converting environmental legislation from a barrier to an incentive.
  See Chapter 5: Digestate policies for more detail.

- **Installed infrastructure.** While one of biomethane's key advantages is its compatibility with existing natural gas infrastructure, not all countries have national gas grids, gas vehicles or gas cookers – diminishing the perceived value of biogas. However, biogas is highly versatile and can help solve problems at all scales. If a country seeks to decarbonise domestic boilers, biomethane can substitute natural gas in the grid. If a city requires low carbon transport, biomethane could fuel buses, waste collection vehicles or lorries. If a town needs to slow deforestation and improve household air quality, biogas could provide a clean source of energy. Governments must identify their long-term priorities and invest. Industry can meet these needs and deliver the benefits desired.
  See Chapter 6: Biogas utilisation policies for more detail

Chapter 3: International and National Climate Policy

As the urgency of the climate crisis has risen up the agenda in the international community, the political will to cooperate and act together on this global challenge has allowed for international policies to be developed with greater weight behind them. Overarching climate agreements and supporting policies set the framework within which action is to be taken on carbon emissions, including the development of the biogas industry and domestic policies to support it. See Global Climate Policy Timeline, p47. In this chapter, we explore how the likes of the Paris Agreement and its accompanying Nationally Determined Contributions (NDCs), the UN's Green Climate Fund, the EU's Methane Strategy, and the various carbon pricing policies impact the biogas industry, as well as provide recommendations for how such frameworks can be improved to better incentivise the benefits delivered by the sector. We will also explore the role of removing subsidies for fossil fuel production and consumption, greenhouse gas reduction commitments, fossil fuel free targets, zero emissions targets, and air quality targets – to name a few. Overarching climate policies are in place at the global, regional and national level, and we will look at each in turn.

3.1 Global level

The climate crisis is a global issue that no single country can tackle alone. Cooperation is vital to deliver the objective of limiting warming to 2°C or below, and the Paris Agreement already commits many countries to working towards this together. The Climate Policy Initiative[35] has calculated the cost of transitioning to a sustainable global economy at US$3.8 trillion, or circa 5% of global GDP. While this cost is an investment in a future free from environmental devastation and its associated economic disruption, mobilising that amount of money requires global action. Policy mechanisms at the global level need to focus on financing this transition and supporting regional actors and national governments to urgently develop supportive policies in their own geographies. It is also critical that a joined-up approach is taken to ensure that emissions reductions made in one place are not just exported to a country or region with more lenient climate policies.

As we have seen in the Chapters 1 and 2, anaerobic digestion (AD) technologies have a critical role to play in achieving a green economy, both in terms of decarbonisation, through optimal waste management, and defossilisation, through the replacement of fossil fuels. The implementation of policies which stimulate the development of biogas to deliver this may also contribute towards the achievement of 9 of the 17 SDGs nations have committed to achieving by 2030.

It is how these global policies translate to regional and domestic markets that is of most interest while we are still some way away from seeing the shift needed in how the environmental impact of all industries are priced globally. Carbon pricing mechanisms are starting to develop at the national and regional level, but it is not until a comprehensive global carbon market is developed that the carbon saving delivered by a waste management and biogas industry will be fully factored into investment decisions, enabling growth without reliance on national and regional political wills. The price of carbon should adequately reflect the damage caused by carbon emissions through climate change. In the meantime, global climate initiatives are unlocking investment that can feed through to biogas, and spur local policy development that is critical to maturing domestic biogas sectors.

3.1.1 The Paris Agreement and Nationally Determined Contributions

The Paris climate treaty of 2015 committed the 196 signatories to enact policies at a national level consistent with the target of limiting global warming to well below 2°C, preferably 1.5°C, by 2100 compared to pre-industrial levels.

The United Nations Framework Convention on Climate Change (UNFCCC)[36] administers the Paris Agreement and hosts an annual Conference of Parties (COP). The latest, COP26[37], will be hosted by the United Kingdom in collaboration with Italy in November 2021, in Glasgow, Scotland.

[35] https://climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2019/

[36] https://unfccc.int/

[37] https://ukcop26.org/

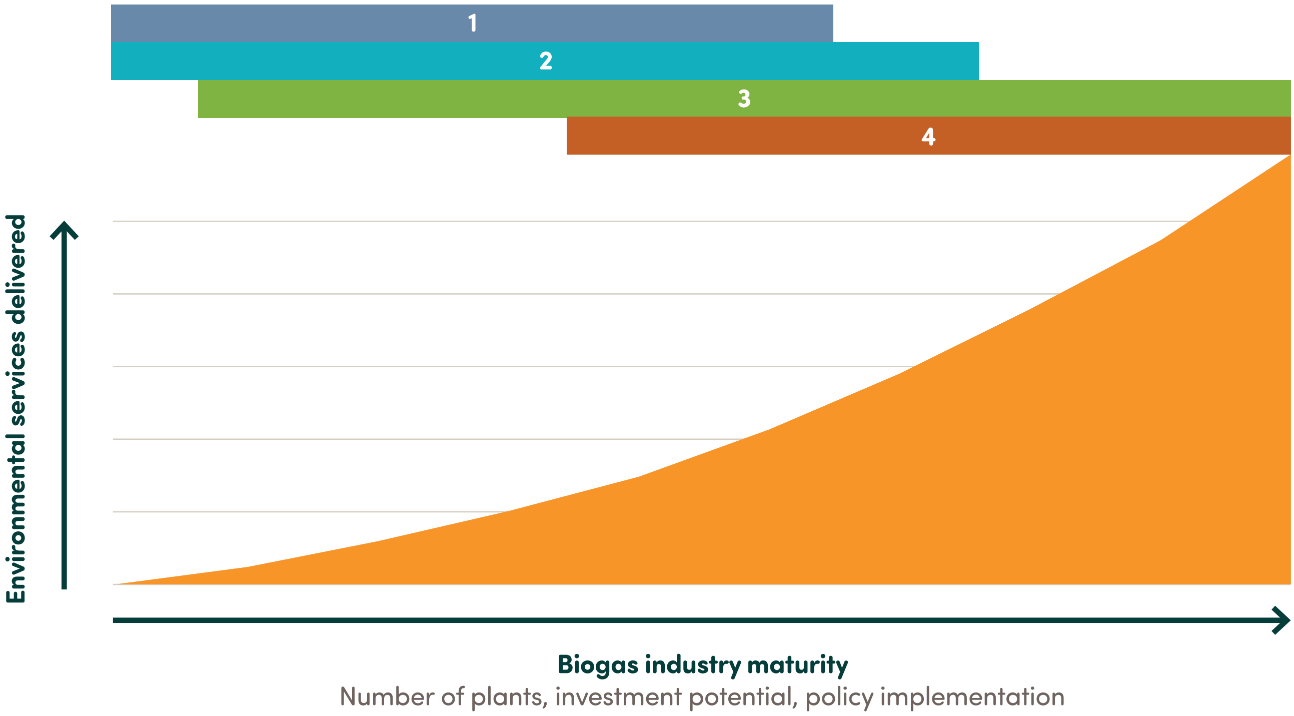
Global Climate Policy Timeline

(1) Set ambitious green targets
There is no doubt that the future is green – business as usual is no longer an option. By setting a suitably bold target, governments and companies can place themselves at the forefront of the transition. Green targets give stakeholders the confidence to plan ahead, stimulating green investment, the creation of new jobs and development of new services.

(2) Estimate the quantity of organic wastes produced and detail a management plant
Methane emissions from waste must be addressed. Strategically plan how these bioresources should be managed to decarbonise the sector. Due to the flexibility of biogas, most countries have the opportunity to identify its most desirable benefits and consequently develop complementary policy. Again, establishing a clear plan provides certainty necessary for investment and industry development. This includes incorporating biogas into every country's NDC.

(3) Divest from fossil industry and reallocate funds to green solutions
The fossil industry continues to be supported by public funds worldwide, particularly for the exploration of new resources. Fossil fuels need to remain in the ground. This money would be better spent funding green infrastructure and innovation, aiding the cost competitiveness and provision of future-proof solutions and supporting a just transition. Establishing green banks can help divert these key funds.

(4) Price carbon and natural capital within markets
By adequately accounting for the cost of the environmental damage incurred from GHG emissions, all sectors will be incentivised to decarbonise and integrate sustainable practices. Climate change is a global issue, where in many cases, the worst effects will not be felt by those countries/companies driving the change. Countries must protect their biodiversity, habitats and population from the impacts of climate change.



United Nations Framework Convention on Climate Change (UNFCCC)
A global treaty of 197 countries established to support a multinational response to climate change and its harmful impacts.

Paris Agreement
Developed as part of the UNFCCC, this agreement between member states establishes a global target to keep global warming below 2°C.

Nationally Determined Contributions (NDCs)
Member states are required to submit an NDC once every five years, detailing how they are reducing their GHG emissions to help deliver the Paris Agreement's central objective.

Conference of the Parties (COP)
An annual conference to discuss actions taken to cut emissions and mitigate the impacts of climate change. NDCs are presented during COPs.

The target commitments established by the UNFCCC as part of the Paris Agreement include a mechanism by which each nation declares how it will achieve emissions reductions consistent with maximum 2°C warming by 2100, known as the Nationally Determined Contributions (NDC)[38].

A selection of impacts of climate change – 1.5°C versus 2.0°C

Impact	+1.5°C	+2.0°C
Sea level rise by 2100	48cm	56cm
Annual flood damage losses from sea level rise	US$ 10.2 trillion	US$ 11.7 trillion
Probability of an ice-free Artic summer in any one year	3%	16%
Annual maximum daily temperature	+1.7°C	+2.6°C
Population facing at least one severe heatwave every 5 years	14%	37%
Frequency of rainfall extremes over land	+17%	+36%
Average drought length	2 months	4 months
Average crop yield change by 2100	Maize: -6% Wheat: -5%	Maize: -9% Wheat: -4
Suitability of drylands for malaria transmission	Drylands: +19% Humid lands: +6%	Drylands: +27% Humid lands: +8%

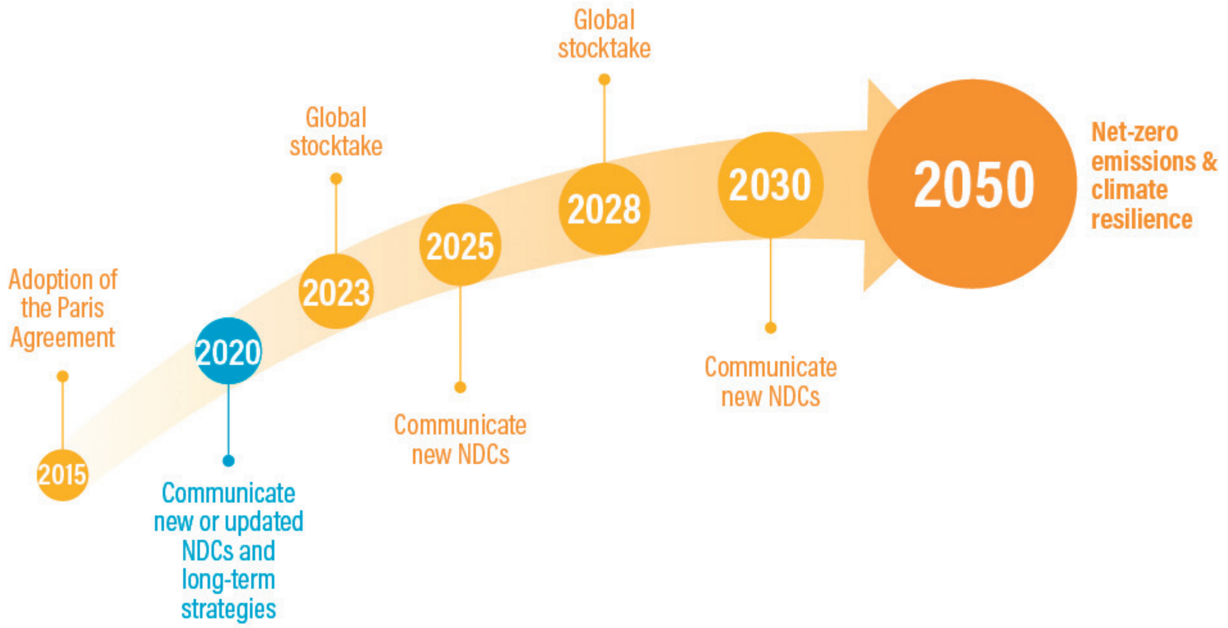
Data and more impacts from the Carbon Brief[39]

"The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions."[40]

[38] https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs

[39] https://interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two-degrees/

[40] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/nationally-determined-contributions-ndcs



Paris Agreement timeline (WRI)[41]

*Note, the 2020 deadline for new or updated NDCs (blue circle) was pushed back to 2021 due to Covid-19 and the postponed COP26.

At COP21, where the Paris Agreement was adopted, countries presented their "intended" NDCs (INDC). These varied considerably, with European Union nations adopting a collective target to reduce domestic GHG emissions by at least 40% by 2030, compared to 1990, and others such as Tanzania committing to "reduce GHG emissions economy wide between 10-20% by 2030 relative to the BAU scenario of 138 - 153 million tonnes of carbon dioxide equivalent ($MtCO_2e$)[42]. The disparity in how targets are presented shows the complexity inherent in the NDC process.

Within the NDCs, nations also set out the instruments that will be implemented to deliver their stated goals. Taking the EU's NDC as an example, a whole array of measures is foreseen across the economy. These include Energy, Industrial Processes and Product Use, Agriculture, Waste, Land Use and, for the purposes of our report, "Biological treatment of solid waste". Tanzania in its NDCs also proposes similar interventions across sectors including Energy, Transport, Waste and Forestry.

It is important that as nations incorporate the management of organic wastes and biogas into their NDCs, they clearly state the intended mechanisms to be used to support the industry.

As of February 2021, 190 nations have presented their first NDC to the UNFCCC and only eight nations have updated their NDCs with a second version, as required by the Paris Agreement. This second round of NDCs is critically important. Emissions remain far off-track for global climate goals[43].

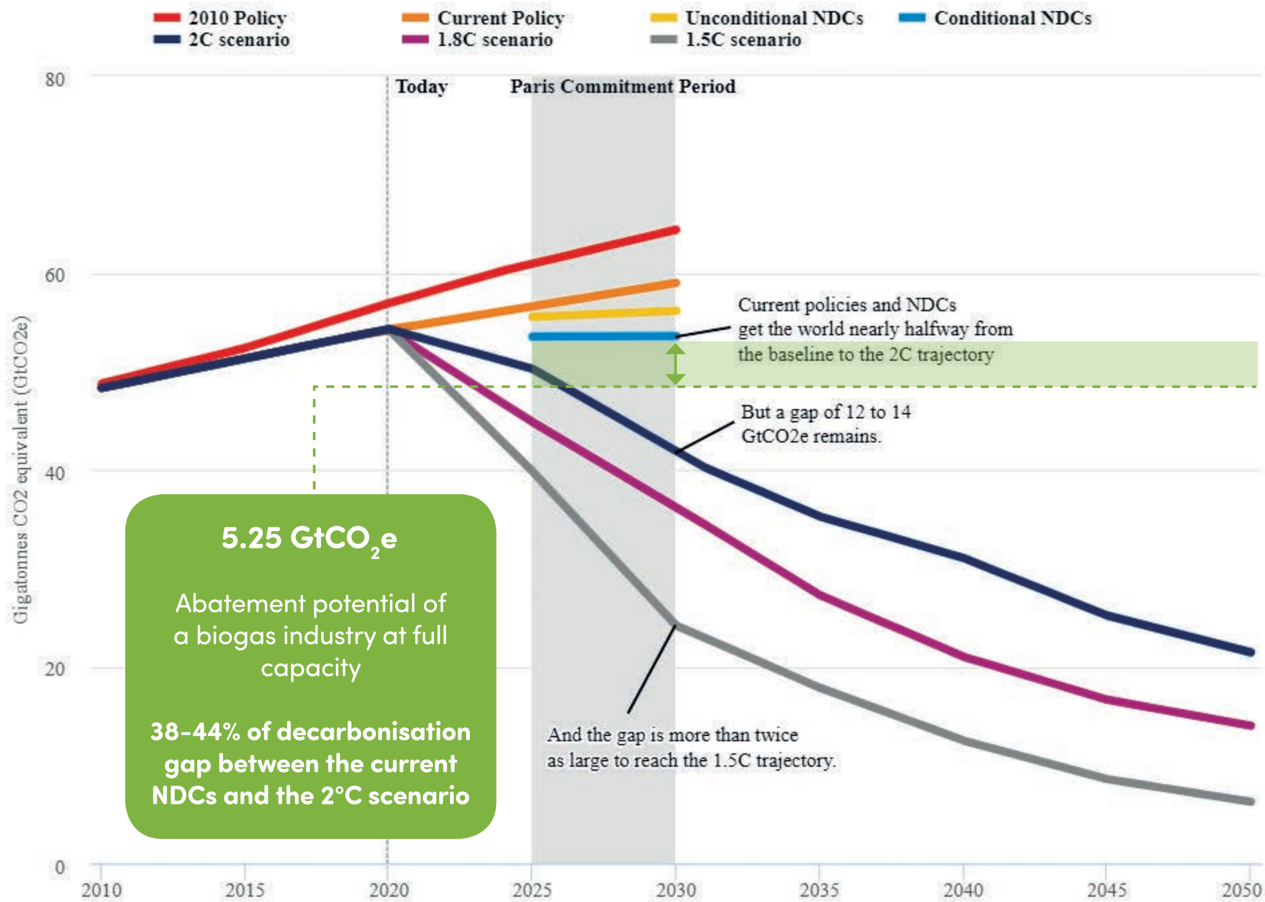
"Walking into a minefield blindfolded" – the UNFCCC describes countries' inadequate pledges to limit global warming to less than 2°C.

Waste management remains overlooked within nations' climate strategies. The wholesale adoption of biogas, through its ability to prevent methane emissions and mitigate further carbon emissions through its outputs, could put the world back on track to keep emissions below 2°C given that it is practically possible to achieve at least a 10% global reduction in GHG emissions by 2030 if the right policy mechanisms are put in place.

[41] www.wri.org/ndcs

[42] https://www4.unfccc.int/sites/ndcstaging/Pages/Party.aspx?party=TZA&prototype=1

[43] www.carbonbrief.org/unep-net-zero-pledges-provide-an-opening-to-close-growing-emissions-gap



NDCs are the mechanism through which commitments can be made by member nations to implement systems to manage organic wastes and subsequently develop the biogas industry, as part of their action to meet the Paris Agreement. It is vital that carbon savings secured through the collection and management of organic wastes (or bioresources), along with their treatment and recycling through AD, are recognised and incorporated into each country's NDC (Taken from Carbon Brief/edited by WBA).

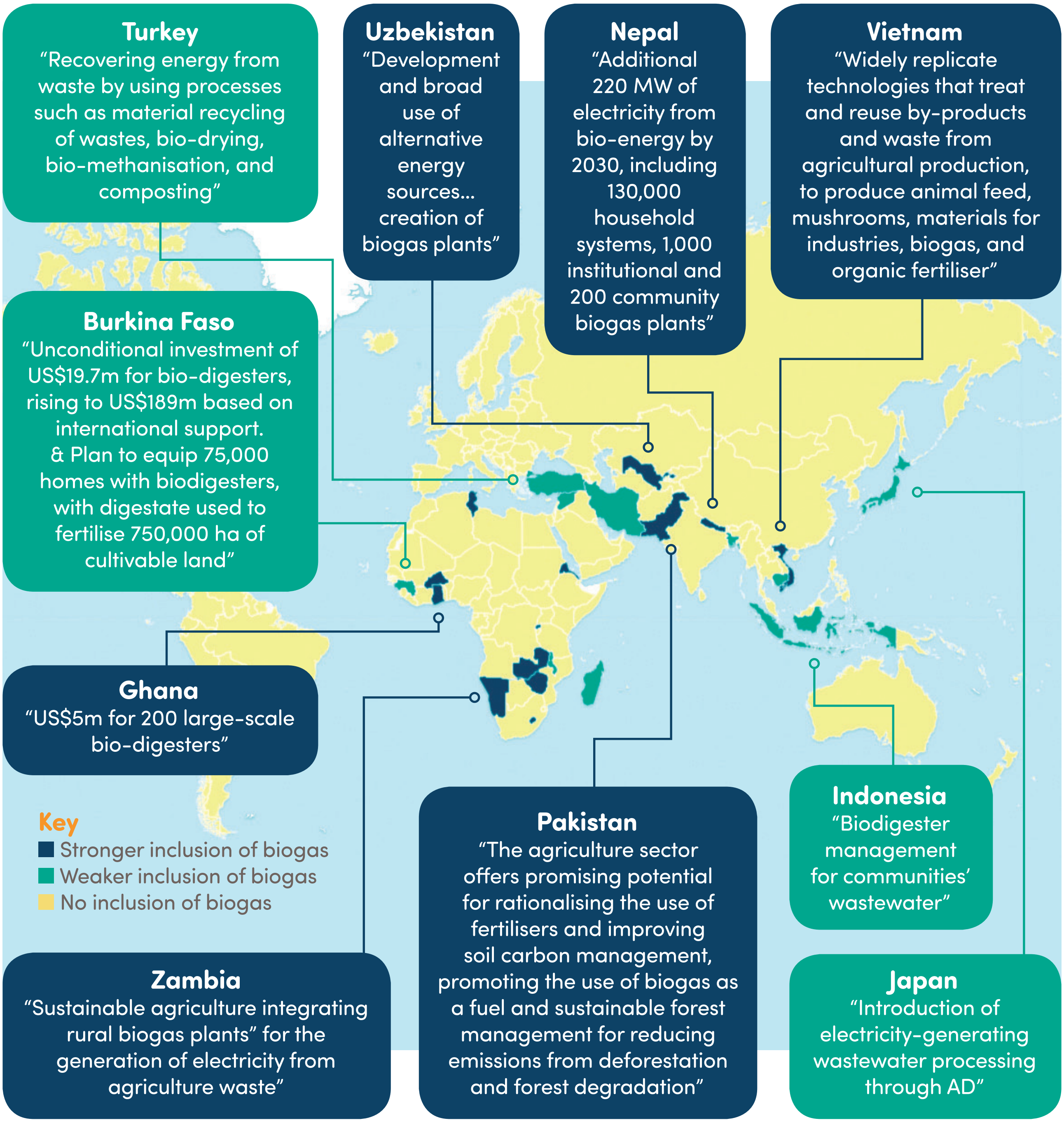
Recognition of AD/biogas within countries' first NDC

The following world map highlights those countries that included biogas within their first NDC, identifying its ability to cut GHG emissions. The two shades of blue distinguish between NDCs that simply mention biogas or related activity (light blue) and those which go into more detail, such as setting targets for investment, plant numbers or energy output (dark blue). Textboxes include biogas-related excerpts from these NDCs.

In total, 24 NDCs acknowledged AD or biogas. The combined emissions of these countries account for just 10% of global emissions. However, this group includes three countries identified in the top 10 priority regions for biogas: Japan, Indonesia, and Pakistan. These countries not only have a high potential for biogas, but also contribute significantly to total worldwide emissions.

While only these countries described a role for AD or biogas specifically, many more NDCs identified a role for bioenergy in a broader sense. In total, 52 NDCs discuss biogas, biofuels or biomass, recognising the need to decarbonise energy systems. Depending on the geography of a country, different uses for this renewable energy are prioritised. The combined emissions from these countries account for 65% of global emissions, owing largely to the inclusion of China, the EU, Brazil, and India.

All NDCs should include a section of wastes, estimating quantities produced, the emissions they cause, and how they will be managed in the future. Using the tools provided in this report (see Section 2.3 Estimating biogas potential), countries should estimate their decarbonisation potential available if organic wastes are effectively managed.



The Climate Action Tracker[44] assesses countries latest NDCs to determine whether their decarbonisation pathway is compatible with the Paris Agreement – i.e., whether or not a country would do its part in preventing global warming of more than 1.5°C. At present, the Tracker suggests only two countries' NDCs are sufficiently ambitious, while some of the largest global emitters (China, USA and EU) fail to deliver on the necessary targets. **Almost all countries' decarbonisation targets must be far more ambitious.**

[44] https://climateactiontracker.org/countries/

3.1.2 Climate finance mechanisms – creating a level playing field

Under the Paris Agreement, governments have agreed to hold global warming to well below 2°C and pursue efforts to limit warming to 1.5°C. In their NDCs, governments put forward their commitments to achieve this global goal. There is no mechanism or guideline to define what would be a 'fair level', reflecting a country's historic and current emissions. Rather countries agree to present NDCs that reflect 'the highest possible ambition' and 'common but differentiated responsibilities and respective capabilities, in the light of different national circumstances'.

This latter principle requires **developed country** Parties to provide financial resources to assist **developing country** Parties in implementing the objectives of the UNFCCC. To facilitate this, the Convention established a Financial Mechanism to provide climate finance to developing country Parties[45]. Climate finance refers to local, national or transnational financing - drawn from public, private and alternative sources of financing - that seeks to support mitigation and adaptation actions that will address climate change.

Transnational finance

The Global Environment Facility (GEF)[46] was formally established in 1994 as a "financial mechanism" to serve multiple international environment conventions, including the UNFCCC. It has funds held on account which amount to US$4.1 billion for the period 2018-2022, with funds replenished by the 40 GEF donor countries every four years. These are allocated to be spent not just on climate change mitigation and adaptation, but on other projects deemed beneficial to the environment – such as habitat and biodiversity protection. The GEF has been used to support biogas projects in a number of low-income countries.

The Clean Development Mechanism (CDM), established in 2006 as part of the Kyoto Protocol (the precursor to the Paris Agreement), works to direct funding from the global north to the global south. It allows developed countries to fund emissions reduction projects in developing countries and earn certified emissions reductions credits. These credits then count toward the developed country's own emissions reductions targets. While the CDM is seen as a trailblazer in many ways, the policy has been criticised for allowing developed countries to continue polluting. That said, the CDM has supported the development of several biogas projects in the global south, delivering industry growth in countries where domestic funding for AD is limited, and we would recommend continued use of the mechanism to support such projects.

Building on the CDM, the UNFCCC set up the **Green Climate Fund (GCF)** in 2010, creating the world's largest dedicated fund to finance GHG emission reductions in the global south. This is the principal organ for funding climate adaptation and mitigation projects in the Global South, particularly societies that are highly vulnerable to the effects of climate change. Currently, parties have not met the ambition of financing the GCF to the target of US$100 billion. Indeed, at the time of writing, pledges and effective transfers to the GCF amount to US$10.3 billion[47], just over 10% of the target[48]. Developing nations access the GCF through local Nationally Designated Authorities (NDAs) of which there are now 147. One such successful application was made by the City of Karachi, Pakistan, to enable the use of fuel produced by biogas for the local city transport fleet, a perfect example of circular economy and resource efficiency[49]. Other examples financed by the GCF include a joint Kazakhstan-Egypt project on renewable energy, including biogas production, and support for the feed in tariff for renewable energy in Zambia[50].

Clearly at current funding levels the access to finance for low-income countries to invest in climate related projects is significantly below the levels agreed is required and therefore unlikely to be sufficient for them to make the needed investments to achieve the Paris targets. The UNEP Adaptation Gap Report 2020 finds that while nations have advanced in planning, huge gaps remain in finance for developing countries and bringing adaptation projects to the stage where they bring real protection against climate impacts such as droughts, floods and sea-level rise.

[45] https://unfccc.int/topics/climate-finance/the-big-picture/climate-finance-in-the-negotiations

[46] www.thegef.org/

[47] www.greenclimate.fund/about/resource-mobilisation

[48] www.greenclimate.fund/about/partners/nda

[49] www.greenclimate.fund/project/fp085

[50] www.greenclimate.fund/news/energy-transition-accelerates-with-gcf-support

The report says public and private finance for adaptation must be stepped up urgently, along with faster implementation. Nature-based solutions (NBS) – locally appropriate actions that address societal challenges, such as climate change, and provide human well-being and biodiversity benefits by protecting, sustainably managing and restoring natural or modified ecosystems – must also become a priority[51].

The definition of what is a NBS is broad, allowing for eco-systems approaches, such as afforestation and rewilding, and the development of green infrastructure compatible with circular economy principles, such as AD.

Consequently, 2021 is expected to be a pivotal year for climate action.

Ahead of COP26, which the UK hosts in November, PM Boris Johnson told the UN Security Council in February that climate change is as much a security issue as it is an environmental one. In his speech to the Council he said, "climate change is a geopolitical issue every bit as much as it is an environmental one. And if this Council is going to succeed in maintaining peace and security worldwide then it's got to galvanise the whole range of UN agencies and organisations into a swift and effective response."

"If we don't act now, when will we act? That's my question. When are we going to do something if we don't act now? When changing sea levels are affecting our navigation around our coasts? Or when, as Nisreen said, when huddled masses fleeing drought or wildfire, or conflict over resources arrive at our borders? Whether you like it or not, it is a matter of when, not if, your country and your people will have to deal with the security impacts of climate change."[52]

Mr Johnson also said the UK will place 'climate change firmly at the top of the agenda for our **G7** presidency as well'.

The World Economic Forum (WEF) in their annual Global Risks Report said that despite the inescapable fallout from Covid-19, it is climate-related matters that make up the bulk of this year's risk list, which it describes as "an existential threat to humanity." The WEF's vision is of a "great reset" across seven key themes: environmental sustainability; fairer economies; "tech for good"; the future of work and the need for reskilling; better business; healthy futures with fair access for all; and "beyond geopolitics" - national governments collaborating globally.

From the World Economic Forum's Global Risks Report. Risks' likelihood and impact colour coded such that economic (blue), environmental (green), geopolitical (orange), societal (red), and technological (purple).

[51] www.unep.org/resources/adaptation-gap-report-2020

[52] www.gov.uk/government/speeches/pm-boris-johnsons-address-to-the-un-security-council-on-climate-and-security-23-february-2021

To address these concerns the climate finance gap will have to be closed. Shortly before Christmas, the ***World Bank Group (WBG)*** announced a target for 35% of its financing to have climate co-benefits, on average, over the next five years. The bank will also seek to ensure that 50% of this financing supports adaptation and resilience.

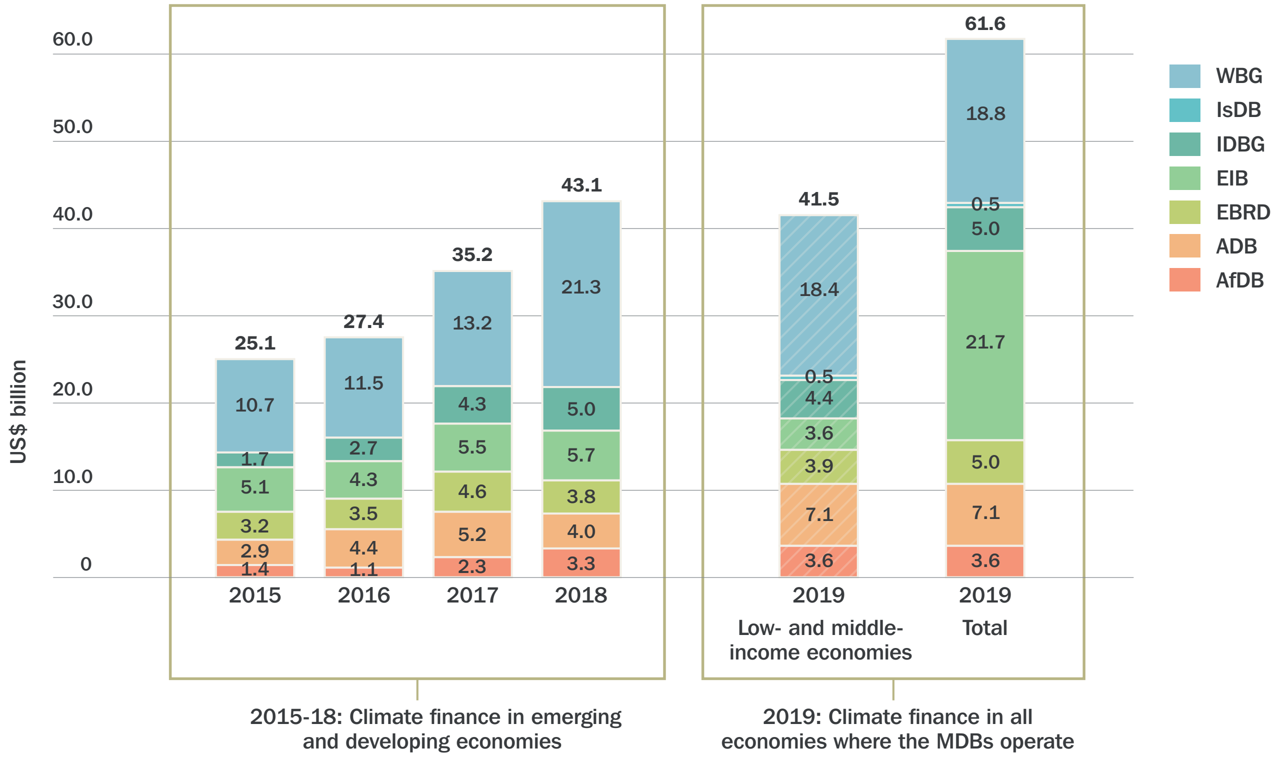
The WBG is already the biggest multilateral funder of climate investments in developing countries. The co-benefits target of 28% by 2020 was established as part of the Bank Group's First Climate Change Action Plan, covering 2016-2020. The new 35% average co-benefits target will be embedded in the Second Climate Change Action Plan, which will cover 2021-2025.

Between 2016 and 2020, WBG institutions – the World Bank, IFC, and MIGA – provided over US$83 billion in climate finance to developing countries. This translated into adding 34 GW of renewable energy and improving access to hydromet data and early warning systems for millions of people in over 50 countries. Last year also saw the largest amount of climate investments in WBG's history.

Through its programs, WBG says it is committed to helping countries meet their climate and development goals, including NDCs under the Paris Agreement, reduced reliance on coal, and a strong, green, climate-resilient recovery[53].

The **WBG** is one of a number of Multilateral Development Banks (MDBs), alongside the **Islamic Development Bank (IsDB)**, the **Inter-American Development Bank Group (IDBG)**, the **European Investment Bank (EIB)**, the **European Bank for Reconstruction and Development (EBRD)**, the **Asian Development Bank (ADB)**, and the **African Development Bank (AfDB)**. Taken from the MDBs Joint Report on Multilateral Development Banks' Climate Finance[54], the following graphs display the finance commitments from these bank groups, and how/where this money has been spent, between 2015 and 2019:

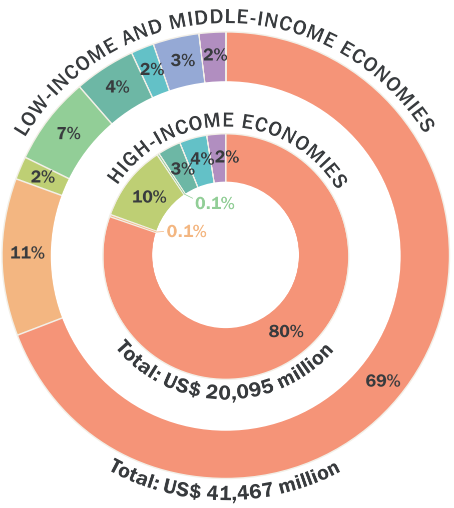
How much has been spent?



[53] www.worldbank.org/climate

[54] www.eib.org/attachments/press/1257-joint-report-on-mdbs-climate-finance-2019.pdf

How it has been spent?

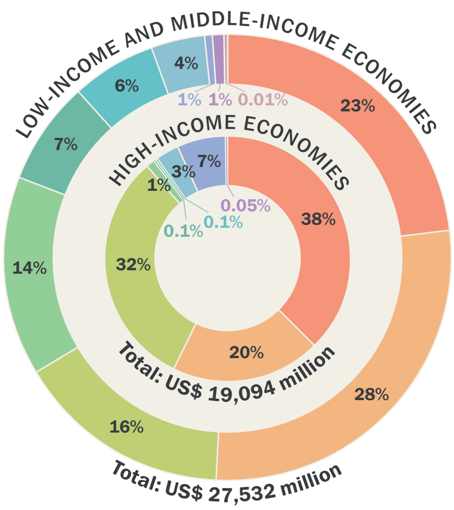


TOTAL CLIMATE FINANCE BY INSTRUMENT
US$ 61,562 million

- Investment loan **US$ 44,901 million**
- Policy-based financing **US$ 4,725 million**
- Line of credit **US$ 2,750 million**
- Grant **US$ 2,739 million**
- Guarantee **US$ 2,366 million**
- Equity **US$ 1,510 million**
- Results-based financing **US$ 1,367 million**
- Other instruments **US$ 1,204 million**

Where has it been spent?

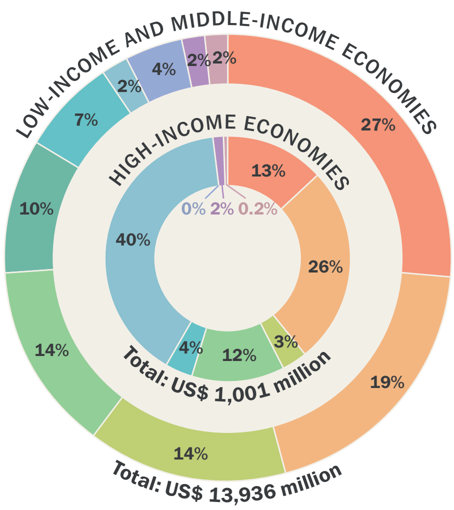
Climate **mitigation**



MITIGATION FINANCE BY SECTOR
US$ 46,625 million

- Transport **US$ 13,614 million**
- Renewable energy **US$ 11,380 million**
- Energy efficiency **US$ 10,299 million**
- Cross-cutting issues **US$ 4,193 million**
- Lower-carbon and efficient energy generation **US$ 2,024 million**
- Agriculture, aquaculture, forestry and land-use **US$ 1,742 million**
- Waste and wastewater **US$ 1,684 million**
- Low-carbon technologies **US$ 1,436 million**
- Non-energy GHG reductions **US$ 251 million**
- Miscellaneous **US$ 2 million**

Climate **adaptation**



ADAPTATION FINANCE BY SECTOR
US$ 14,937 million

- Energy, transport and other built environment and infrastructure **US$ 3,833 million**
- Water and wastewater systems **US$ 2,954 million**
- Institutional capacity support or technical assistance **US$ 2,049 million**
- Cross-cutting sectors **US$ 2,045 million**
- Other agricultural and ecological resources **US$ 1,325 million**
- Crop and food production **US$ 1,005 million**
- Coastal and riverine infrastructure **US$ 682 million**
- Financial services **US$ 576 million**
- Information and communications technology **US$ 237 million**
- Industry, manufacturing and trade **US$ 230 million**

These MDBs have since announced their climate action targets for **2025** – including:

- a collective commitment of climate finance of at least US$65 billion, with US$50 billion for low-income and middle-income countries
- an increase in adaptation finance to US$18 billion
- a co-financing of US$110 billion, including private direct mobilisation of US$40 billion

3.2 Regional level

Regional actors, such as the European Union (EU), the African Union (AU), and the Association of Southeast Asia Nations (ASEAN), also have a critical role to play in developing climate strategies and frameworks within which domestic biogas industries operate. This can range from mission statements, climate strategies, targets, and regional policy mechanisms such as the EU's Emissions Trading System (EU ETS), which developed the first multinational carbon market. Cooperation of this kind at the regional level can allow for greater ambition where challenges arise getting agreement at the global level. It can also see the development of policies and frameworks that can be tried and tested before being adopted on a larger scale.

3.2.1 The European Union

The Covid-19 pandemic and associated economic crisis have focused minds, requiring as the WEF say "a great reset". Nowhere is this need for 'systemic change' more evident than within the European Union, which has linked the pandemic recovery to the development of a 'sustainable Europe' – which had previously been targeted in the EU's Green Deal. These policies are now aligned to address sustainable growth across the economy.

The EU uses a combination of approaches to deliver coordinated action on climate change among member states. These include targets for the region, with connected targets for member states; strategy documents that outline action to be taken on specific topics; and policy mechanisms that drive change across the region.

AD technology has recently become increasingly evident in EU actions to tackle climate change. In October 2020, the EU released its Methane Strategy[55], that sets out the urgency of tackling these harmful emissions and the key role of AD in doing so across the agriculture and waste sectors. The focus of attention is on agriculture, which is by far the largest cause of methane emissions associated with human activity. The EU calculates it is responsible for 53% of the total, with the waste sector accounting for 26% and energy 19%.

The strategy says, "Non-recyclable human and agricultural waste (i.e., manure) and residue streams can be utilised in anaerobic digesters to produce biogas or in biorefineries to produce bio-materials and intermediate bio-chemicals. The biogas resulting from such feedstocks is a source of highly sustainable and useful renewable energy with multiple applications, while the material that remains after anaerobic digestion (digestate) can, after further processing, be used as a soil improver."

"This in turn reduces the requirement for alternative soil improving products, such as synthetic fertilisers of fossil origin. Moreover, in line with the waste hierarchy, the waste-based biodegradable input into biorefineries and biogas plants can count towards municipal waste recycling targets as set out in Directive 2018/98/EC. The role of sustainable biogas production in contributing to the EU's decarbonisation objectives has been recognised in the recently published EU strategies for energy-system integration and hydrogen."

The EU intends to use the Methane Strategy to set an international benchmark.

Furthermore, Agricultural Ministers of the EU27 agreed a revised **Common Agricultural Policy (CAP)** on 20th October[56], in which the role of organic carbon replenishment and storage in soils was underlined as a priority to ensure long-term soil quality[57]. Such a policy stimulates the market-place for the use of organic soil improvers, among them compost and digestate, produced by biogas plants. EU policy announcements are supported by funding which, over the four-year period to 2025, could reach US$ 1 trillion or more in loans, direct investments, grants, and subsidies.

[55] https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf (europa.eu)

[56] www.consilium.europa.eu/en/policies/cap-future-2020/

[57] www.europarl.europa.eu/news/en/headlines/society/20200109STO69927/europe-s-one-trillion-climate-finance-plan

Meanwhile an important policy mechanism is under review, the **European Union Emissions Trading Scheme (EU ETS)**, which developed the first multinational carbon market. We would argue it is vital that the key sectors that can gain significant carbon abatement from the use of biogas are included in the carbon market, namely agriculture and waste management.

Finally, the EU is developing a taxonomy, a classification system, establishing a list of environmentally sustainable economic activities. The **EU taxonomy** is an important enabler to scale up sustainable investment and to implement the European Green Deal. It will determine such things as whether energy from waste (EfW) can be considered recycling; Zero Waste Europe is lobbying hard for EfW to be omitted from the taxonomy to drive finance toward AD, which it says meets the definition of recycling . A new Platform on Sustainable Finance will drive the inclusion of biodiversity, circular economy, water systems and pollution prevention and control into the taxonomy, likely at the end of this year (2021). In addition, the Sustainable Finance Disclosure Regulation (SFDR) to be implemented in phases from 10th March 2021 will eventually require financial market participants to access and disclose sustainability risks across all asset classes or explain why they have not been considered, under the EU Action Plan.

3.2.2 The African Union

The African Union's Department of Rural Economy & Agriculture (DREA) leads on the promotion of sustainable management of the environment and natural resources. This work has focused on advancing Africa's Climate Change Agenda, strengthening its position in global climate negotiations and facilitating coordination around the African Common Position on Climate Change, and the development of an African Climate Change Strategy[59].

The DREA also works to enhance the capacities of Member States to access quality environmental and climate information to inform policy decision making, as well as make best use of available funding from Multilateral Environmental Agreements. It has also supported the implementation of the Great Green Wall for the Sahara and Sahel Initiative, to combat land degradation and desertification. The DREA is also focused on advancing the African Water and Sanitation agenda, which ties in closely to the role AD can play in sustainable wastewater treatment. **There are a number of ways that AD and biogas projects can deliver against the climate objectives of the African Union and we recommend greater coordination of support for the industry to unlock these benefits.**

In the 2019 Joint Report on Multilateral Development Banks' Climate Finance, Dr Anthony Nyong, Director of Climate Change and Green Growth at the African Development Bank, noted, "Our investments that contribute to the goals of the Paris Agreement continue to grow. The climate finance provided by the Bank increased from US$3.2 in 2018 to US$3.5 billion in 2019 – representing 35% of total project approvals worth US$10.2 billion." The largest climate finance investments were made in the energy, agriculture and transport sectors[60].

The Bank exceeded its target of achieving parity between adaptation and mitigation finance by allocating 55% of its climate finance resources to adaptation and 45% to mitigation, whereas globally more than 70% of climate finance is allocated to mitigation. More global efforts are needed to build climate change resilience and adaptation in Africa.

"As African economies face the devastating impacts of the Covid-19 pandemic, slacking action or redirecting financial resources from climate change will further compound these impacts in a diverse and complex manner," Dr Nyong cautioned.

[58] www.cewep.eu/waste-to-energy-in-eu-taxonomy

[59] https://au.int/en/directorates/environment-climate-change-water-land-and-natural-resources

[60] www.afdb.org/en/documents/2019-joint-report-multilateral-development-banks-climate-finance

3.2.3 The Association of South East Asian Nations

Collectively ASEAN countries have been long-standing and vociferous campaigners for global action on climate change. The organisation is engaged with the UNFCCC in developing a monitoring and reporting system to allow the region to take advantage of carbon markets. An ASEAN Working Group on Climate Change (AWGCC) has been established to coordinate regional initiatives to support ASEAN Member States in implementing mitigation and adaptation measures.

ASEAN set and exceeded its energy efficiency target for 2020, reducing energy intensity by more than 21.9% compared to 2005 levels. The next target is to reduce energy intensity by 30% by 2025.

Additionally, ASEAN also set a target to increase the component of renewable energy mix by 23% by 2025. On land transport, ASEAN aims to reduce the average fuel consumption per 100 kilometres of new light-duty vehicles sold in ASEAN by 26% between 2015 and 2025. Climate change initiatives are being undertaken by various relevant ASEAN sectoral bodies linked to the environment, forestry, agriculture, energy, transport, and disaster management. Increasing adaptive capacity now through development planning ASEAN projects the annual benefit (from avoided damage) is likely to exceed the annual cost by 2060 and by 2100; benefits could reach 1.9% of GDP, compared to the cost at 0.2% of GDP.

3.3 National level

While global and regional initiatives play an instrumental role in setting targets, recommending strategies and providing robust research, it generally falls on individual countries and their governments to implement the laws required to drive change. As nations look to recover from the impact of the coronavirus, there are positive signs that many countries are focused on delivering a green recovery, amid a chorus of warnings that the climate crisis will destabilise the global economy to a magnitude far greater than experienced during the pandemic.

In May 2020, two of the world's leading economists Joseph Stiglitz and Nicholas Stern issued a working paper calling for a green recovery from the Covid-19 pandemic. Ahead of publication, the authors surveyed 231 finance chiefs from 53 countries, including all G20 nations, to ascertain their perspectives on Covid-19 fiscal recovery packages.

The results were in favour of a green recovery. The report states, 'Our results suggest that, in many cases, experts think that climate-positive policies also offer superior economic characteristics.'

The paper says that pound for pound, investment in green energy technology delivers three times as many jobs than would be created by investment in fossil fuels and makes five policy recommendations (plus one item specific to low to middle income countries (LMICs)) that it says are well-placed to contribute to achieving economic and climate goals. These are:

- clean physical infrastructure investment
- building efficiency retrofits
- investment in education and training to address immediate unemployment from Covid-19 and structural unemployment from decarbonisation
- natural capital investment for ecosystem resilience and regeneration
- clean R&D investment

For LMICs, rural support spending is another high-value policy item.

The paper was the first to coin the phrase 'build back better', which has become shorthand for systemic change the world over – a new social contract aligned to greater respect for nature and the environment.

At its full potential, the AD industry can create between 10-15 million skilled jobs around the globe and address the ambitions set out in the Paris Agreement and the UN SDGs as well as meet the desire to 'build back better' environmentally and socially from the Covid-19 pandemic.

The positive response to the Stiglitz/Stern analysis provides hope that overarching climate policy at the national level will accelerate, particularly with NDCs being reviewed and refreshed in advance of the next COP26 due to be held in Glasgow in 2021.

The World Resources Institute's Climate Watch reports that 25 countries and the EU are currently working toward some sort of net-zero commitment (in many cases by 2050, though some countries such as Denmark and Finland have earlier deadlines). This year several Asian economic powers made net-zero commitments, including South Korea and Japan (by 2050) and China — the world's largest emitter — by 2060.

83 **countries**, representing 46.1% of global emissions, **have stated their intention to enhance ambition or action in new or updated NDCs**

73 **countries (including the 27 EU countries)**, representing 28.4% of global emissions, **have submitted a new or updated NDC**[61]

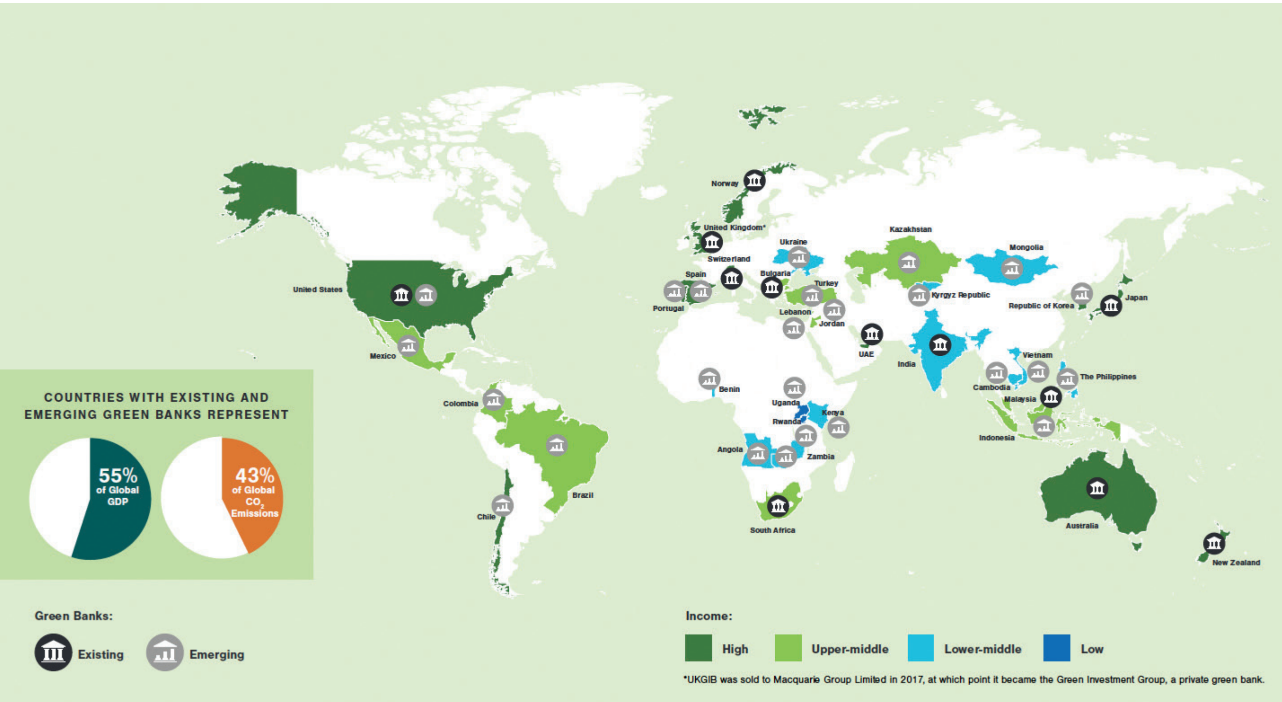
However, all these goals are purely aspirational if they are not reflected in ambitious and actual actions that countries begin to take now, including their economic recovery plans from Covid-19 and their NDCs for the period out to 2030. As of 31st December 2020, 75 Parties had communicated new or updated NDCs, countries cumulatively representing approximately 30% of global GHG emissions. Ensuring that they – and those that have not made any commitments - follow through by COP26 will be critical to get global climate action on track.

We recommend as a key policy priority the adoption of binding GHG emission targets within the framework of all government departments, to be supported by robust policies, and oversight of these commitments by an independent review body.

An effective means of driving sustainable development at a national level is through the creation of **National Green Banks**. A study by the Rocky Mountain Institute found that where Green Banks exist, they have a leverage ratio of 2:3, i.e., against US$24.5bn of their own capital, $45.5bn private capital was leveraged. Where Green Banks exist, they generally have a mandate to invest in low carbon, climate resilient projects. Green Banks also have a symbiotic relationship with the aims of Multilateral Development Banks, opening a potential pathway for leveraging sustainable development.

[61] www.climatewatchdata.org/2020-ndc-tracker

Multilateral Development Banks need to:		Green Banks help by:
Align portfolio with Paris Agreement	→	Having a Mandate to Invest in Low-Carbon, Climate-Resilient Projects
Maintain Credit Rating	→	De-Risking Projects
Leverage Private Capital	→	Incentivizing Co-Investors by Addressing Risk
Identify Projects	→	Raising Profile of and Building Existing Pipeline of Low-Carbon Projects
Build Local Financial Capacity	→	Staffing with Experts in Low-Carbon and Climate-Resilient Technologies and Transactions and Who Have Local Market Knowledge



3.3.1 Renewable Finance

Finance is shifting in favour of sustainable solutions, both institutionally and within an emerging asset management class associated with the transition to a green economy, in the form of renewable infrastructure funds. The London Stock Exchange (LSE) report:

- Over 20 green funds, worth more than $10bn, are currently listed
- With over 200% increase in market capitalisation over the last 5 years, the LSE's green funds are experiencing particularly strong demand as existing funds typically trade on a weighted average premium to NAV.
- More than $6bn has been raised in further capital by green funds since their listing.

Investors are increasingly concerned about the sustainability of investments so a methodology to measure the Environmental, Social and Governance (ESG) performance of listed companies has been established. In 'Your Guide to ESG Reporting' the LSE states, "Once upon a time, environmental, social and governance factors were a niche interest among asset owners, asset managers, banks, brokers and investment consultants. No longer. Investors now routinely analyse information on ESG performance alongside other financial and strategic information in order to gain a better understanding of companies' future prospects."

Examples of the FTSE Green Revenues Definitions, FTSE Green Revenues Classification System:

Energy Generation (EG) Waste to Energy
Companies generating power through the use of domestic, agricultural and commercial refuse as fuel for both thermal and non-thermal energy creation where the reduction of greenhouse gas emissions is a significant function of the power generation process either on a life-cycle analysis basis or at the point of generation.

Energy Equipment Bio Fuels
Companies providing goods, products and services including components, specialist materials, bespoke manufacturing and maintenance processes, design and operational support capabilities that enable the generation of power through the use of crops, plants and other organic materials as fuels where the reduction of greenhouse gas emissions is a significant function of the power generation process either on a life-cycle analysis basis or at the point of generation.

Energy Equipment Waste to Energy
Companies providing goods, products and services including components, specialist materials, bespoke manufacturing and maintenance processes, design and operational support capabilities that enable the generation of power through the use of domestic, agricultural and commercial refuse as fuel for both thermal and non-thermal energy creation.

The increasing influence of ESG reporting is evidenced by the actions multinationals are taking to address their GHG emissions from production (Scope 1) and down the supply chain (Scope 3). So, we see the likes of Nestlé investing in AD at its production facilities, but also offering 0% finance to its raw materials' suppliers, to green the company's supply chain. Similarly, Unilever, which aims to halve its global carbon footprint by 2030, has entered into a Farm Powered Strategic Alliance (FPSA) with Vanguard Renewables. Underpinning the FPSA is a long-term feedstock supply and output purchase guarantee. Members such as Unilever commit to sending their endemic (unavoidable) waste to a Vanguard Renewables AD facility and to purchase the resulting renewable natural gas (RNG aka biomethane) to lower the company's dependence on fossil fuels. Arla Foods, which aims to become carbon net zero by 2050, has deployed biogas at two of its production facilities, reducing their carbon footprint by 30%.

Other noteworthy initiatives contributing to this shift in capital towards greening the economy include:

1. **The GHG Protocol** – the most widely used accounting and reporting standard for GHG emissions inventory through a partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).

2. **Compact of Mayors** – a coalition of city officials who use the GHG protocol to report their reduction in GHG emissions in line with targets (**globalcovenantofmayors.org**).

3. **Carbon Disclosure Project (CDP)** – a not-for-profit charity that houses a global disclosure system of environmental impacts for investors and businesses; 92% of Fortune 500 companies respond using the GHG Protocol directly or indirectly.

4. **Science Based Targets Initiative (SBTi)** – a partnership between CDP, the United Nations Global Compact (UNGC), WRI and the World Wide Fund for Nature (WWF), working with +1,000 companies to reduce emissions in line with their Paris Agreement goals.

5. **Financial Stability Board's Task Force on Climate-Related Financial Disclosures (TCFD)** – established voluntary recommendations on climate related financial risk disclosure for large companies and financial institutions to adopt, which is gradually becoming mandatory.

6. **Task Force for Nature-related Financial Disclosures (TNFD)** – 62 entities in an informal working group led by Global Canopy and WWF, supported by the UN Development Program (UNDP) and the UN Environment Program Finance Initiative (UNEPFI), are working to issue a set of guidelines for nature and biodiversity related disclosure late next year (2022).

3.3.2 Carbon pricing/trading and accounting for externalities [62]

Meanwhile, many companies are running a 'shadow carbon price'. According to the Carbon Disclosure Project (CDP) there are more than 1,000 companies reporting that they price carbon internally or plan to do so in the next one to two years.

A shadow price on carbon creates a theoretical or assumed cost per ton of carbon emissions. It serves to reveal the risk of carbon being priced to a planned or existing business. When emissions bear a cost in profit-and-loss statements, it helps to uncover inefficiencies and incentivise low carbon innovation within departments, cutting a company´s energy use and carbon pollution.

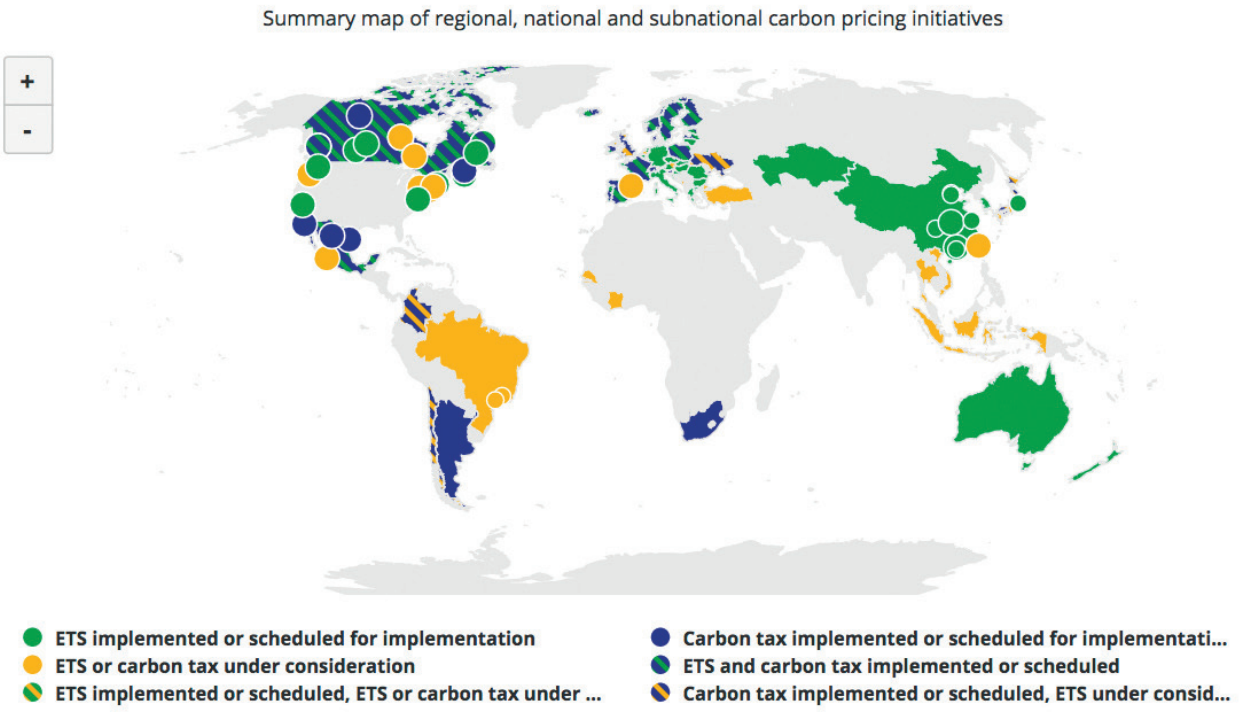
Policies designed to limit climate emissions are all essentially trying to address this problem; that the environmental cost of carbon emissions is not considered when market decisions are made. Because of this, high volumes of GHG emissions are released into the atmosphere despite the significant impact we know this is having on our planet. The policy looked to as the gold standard to correct for this is the development of a carbon market, whereby the true cost of carbon is revealed by a market mechanism, generally a trading system, and emitters must pay the price. The introduction of a carbon tax can also be used in a similar way to put a price on carbon emissions and ensure the environmental cost is factored into private sector decision making.

In the case of an Emission Trading System, a market for emission allowances is created that producers can exchange and this exchange creates a market price. A cap on total emissions of a sector is created to ensure a pre-allocated budget within which trading occurs. The World Bank is among entities in the Carbon Pricing Leadership Coalition calling for strengthened global carbon pricing policies[63].

Carbon pricing of some sort is currently applied to a wide range of geographies and with a wide variation in values. The following map helps illustrate this:

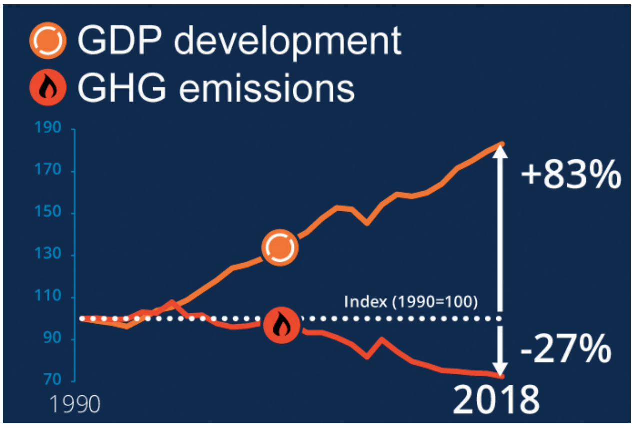
[62] See also in the annexes "Emissions trading systems" by Liron Friedman, Ph.D. dated October 2020.

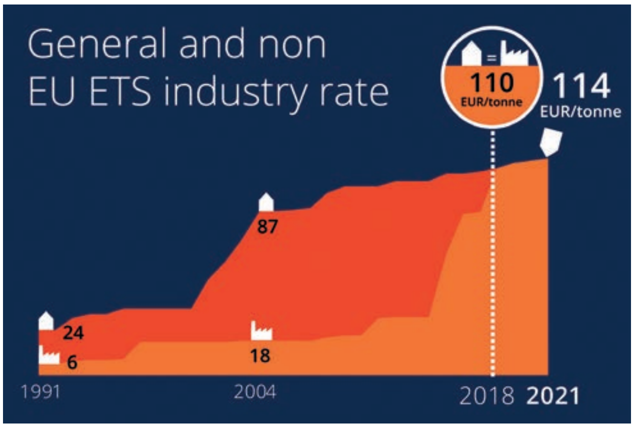
[63] **www.carbonpricingleadership.org**



The World Bank's Carbon Pricing Dashboard[64]. In total, there are 64 carbon pricing initiatives implemented or scheduled for implementation worldwide. In 2020, these initiatives would cover 12,000 $MtCO_2e$, representing 22.3% of global GHG emissions.

Almost one quarter of global carbon emissions are currently covered by some form of carbon pricing. As the map shows, most of Africa, Russia, the whole of the Middle East and southern Asia, and large swathes of Latin America and the USA have no carbon pricing mechanisms. **Sweden has the highest carbon price currently applied at US$ 126 per ton of CO_2**. The Swedish economy has continued to grow despite the high cost of fossil fuel energy and the reduction of emissions, as the graphs below illustrate, with growth accelerating as the economy has integrated the cost of the carbon tax[65].



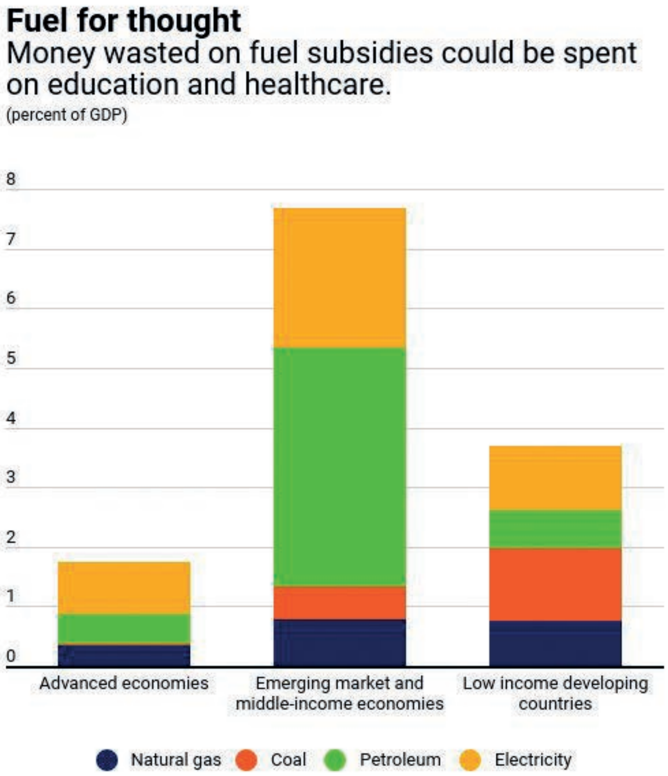


Expansion of carbon markets, both across geographies and sectors (primarily to cover agriculture and waste management) will support the growth of the biogas industry as the carbon saving delivered will be properly accounted for in investment decisions. The development of national carbon pricing mechanisms can significantly reduce the need for direct subsidy policies for the sector as the financial model for projects will improve dramatically.

[64] https://carbonpricingdashboard.worldbank.org/

[65] www.government.se/government-policy/taxes-and-tariffs/swedens-carbon-tax/

The elephant in the room - fossil fuel subsidies



Source: IMF Working Paper, *Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates*

A broad coalition of international actors has for some time called for an end to subsidies supporting the extraction, production and consumption of fossil fuel energy. Among leaders of this campaign[66] are the International Monetary Fund (IMF), G20 countries,[67] and a range of multinational corporations. Despite these calls over the last decade, fossil fuel subsidies at production and consumption phases still amounted to an astonishing US$5.2 trillion in 2017 or 6.3% of global GDP[68]. Comparing this to the 5% of global GDP required to fund the transition to a climate compatible future, it is clear the subsidy regime needs to be tipped in favour of renewables instead of continued support for fossil fuels. The largest subsidies were paid in the EU, China, USA, Russia and India, all of whom are signatories to the Paris treaty. 85% of those subsidies go to the coal and oil industries. Whilst declining overall, the subsidies are still enormous[69].

Energy subsidies and externalities cause many misconceptions about the costs of the energy transition. In 2016, subsidies to fossil fuels exceeded those to renewables by a factor of between two (not counting externalities) to thirty-eight (including externalities) (Coady et al., 2015; IEA, 2017)[70].

There are two different types of subsidies currently used to support the fossil fuel industry. The first is an incentive, tax break, tax holiday, tax write off, or (for example) VAT exemption for the exploration, production and distribution of fossil fuels. These amount to between US$300 billion and US$500 billion a year. The second is a subsidy for the consumption of fossil fuels and is by far the larger and therefore the most difficult to reform. This amounts to between US$4.5 trillion and US$5 trillion a year.

[66] www.weforum.org/agenda/2020/06/end-fossil-fuel-subsidies-economy-imf-georgieva-great-reset-climate/

[67] www.iisd.org/gsi/subsidy-watch-blog/stop-fossil-fuel-subsidies-campaign

[68] www.imf.org/en/Publications/WP/Issues/2019/05/02/Global-Fossil-Fuel-Subsidies-Remain-Large-An-Update-Based-on-Country-Level-Estimates-46509

[69] www.iea.org/topics/energy-subsidies

[70] Quoted in www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf

By artificially lowering the cost of production, or the price of consumption, Governments make access to fossil fuel energies cheaper. At the same time, they use considerable amounts of their fiscal resources to stimulate demand for those energies. Both have the effect of making the transition to a green economy more costly whilst reducing fiscal resources available for investments in that very transition nations have signed up to under the Paris treaty.

Conversely, the subsidies for consumption have the effect of lowering the cost of fuels for poorer communities and are therefore considered a social benefit in many countries. Whilst aimed at helping poorer communities access energy at lower prices, the World Bank made the analysis that subsidies are in fact regressive and create a barrier to investments in other, cleaner energy sources[71]. Lower energy prices represent a higher subsidy in favour of larger and wealthier households as they use more energy and are enjoying a disproportionately higher tax subsidy that they don't need.

While complicated it is clear that energy subsidies need to be restructured in favour of green fuels to be compatible with the Paris accord, support the transition to a low-carbon economy and mitigate the worst impacts of climate change. This must be an urgent priority for all national governments to stop incentivising an increase in greenhouse gas emissions. As fossil fuel subsidies are removed, funding should be utilised to support alternative energy solutions, namely biogas. IRENA's report from 2018[72] lays down a roadmap to 2050 for the contribution of renewable energy to the transition to a net zero global economy. The additional costs of investments in renewable energy are estimated at US$1.7 trillion per annum until 2050- approximately one third of the subsidies given to the fossil fuel sector currently – or circa 2% of global GDP. Whilst subsidies in the short term may be needed to stimulate and de-risk renewable energy investments, these will rapidly decline as both the cost of those energy sources decline and as the scale of deployment increases. We explore this in more detail in chapter 6, looking at specific policies to support the production and use of biogas.

Key policy recommendations - International and national climate policy

1. **Set ambitious green targets.** There is no doubt that the future is green – business as usual is no longer an option. By setting a suitably bold target, governments and companies can place themselves at the forefront of the transition. Green targets give stakeholders the confidence to plan ahead, stimulating green investment, the creation of new jobs and development of new services.

2. **Estimate the quantity of organic wastes produced and detail a management plant.** Methane emissions from waste must be addressed. Strategically plan how these bioresources should be managed to decarbonise the sector. Due to the flexibility of biogas, most countries have the opportunity to identify its most desirable benefits and consequently develop complementary policy. Again, establishing a clear plan provides certainty necessary for investment and industry development. This includes incorporating the management of organic wastes and materials and biogas into every country's NDC.

3. **Divest in fossil industry and reallocate funds to green solutions.** The fossil industry continues to be supported by public funds worldwide, particularly for the exploration of new resources. Fossil fuels need to remain in the ground. This money would be better spent funding green infrastructure and innovation, aiding the cost competitiveness and provision of future-proof solutions and supporting a just transition. Establishing green banks can help divert these key funds.

4. **Price carbon and natural capital within markets.** By adequately accounting for the cost of the environmental damage incurred from GHG emissions, all sectors will be incentivised to decarbonise and integrate sustainable practices. Climate change is a global issue, where in many cases, the worst effects will not be felt by those countries/companies responsible for the change.

[71] www.worldbank.org/en/news/feature/2012/05/09/real-costs-fossil-fuel-subsidies?hc_location=ufi

[72] www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf

Chapter 4: Feedstock Management Policy

Methane accounts for 20% of all man-made greenhouse gas (GHG) emissions globally. An estimated 25% of these arise from the rotting of untreated organic wastes. If we are going to limit global warming to less than 2°C, these methane emissions must be tackled immediately. With over 100 billion tonnes of organic wastes being produced each year, the most effective means of achieving this is primarily through **waste prevention**. An average of 2.5 tonnes of CO_2e emissions, primarily in the form of methane, are released per tonne of food wasted[73].

When good food is wasted, all of the land, energy, water, and nutrients used to produce it are also wasted. Approximately one third of all food produced is wasted, an estimated 1.3 billion tonnes worldwide. Halving this waste production could cut global emissions by 1,650 million tonnes of CO_2e – or **3%** of total emissions. Wherever possible, societies must seek to reduce the production of all wastes.

Of the wastes which cannot be avoided – from vegetable peels to sewage sludge – governments must develop a comprehensive strategy to treat these wastes. By treating societies' unavoidable organic wastes, preventing these methane emissions, global GHG emissions would be cut by **5%** each year.

By placing AD at the heart of a circular economy of organic wastes, these organic 'wastes' are converted into valuable 'bioresources' – namely biomethane, bio-CO2, and biofertilisers. These products can help displace the need and use of traditional fossil-based alternatives – natural gas, fossil-derived CO_2 and energy-intensive artificial fertiliser. Using AD's sustainable products can cut global emissions by a further **5%**.

Total global GHG savings (%):

Halving food waste **3%** + [Avoiding methane emissions by treating unavoidable waste **5%** + Displacing fossil-based products with biomethane and digestate **5%** — *Delivered through AD = 10%*] = Total GHG savings from effective waste management **13%**

Untreated organic wastes are a problem. AD not only solves this problem, but also delivers the greatest value from these bioresources. See Feedstock Management Policy Timeline, p67.

Organic wastes arise from a huge variety of sources: sewage sludge, breweries, slaughterhouses, bakeries, farms, dairy processors, restaurants, canteens, shops, bars, households and so on. However, they are commonly categorised into three key categories, discussed here:

1. **Food waste**
2. **Wastewater**
3. **Agricultural feedstocks**

Each of these bioresources will have a different biogas potential, a different nutrient content, and different decarbonisation capability when treated through AD. Nevertheless, all organics will release harmful GHGs and pollute the environment, when poorly managed.

[73] www.fao.org/3/i3347e/i3347e.pdf

Feedstock Management Policy Timeline

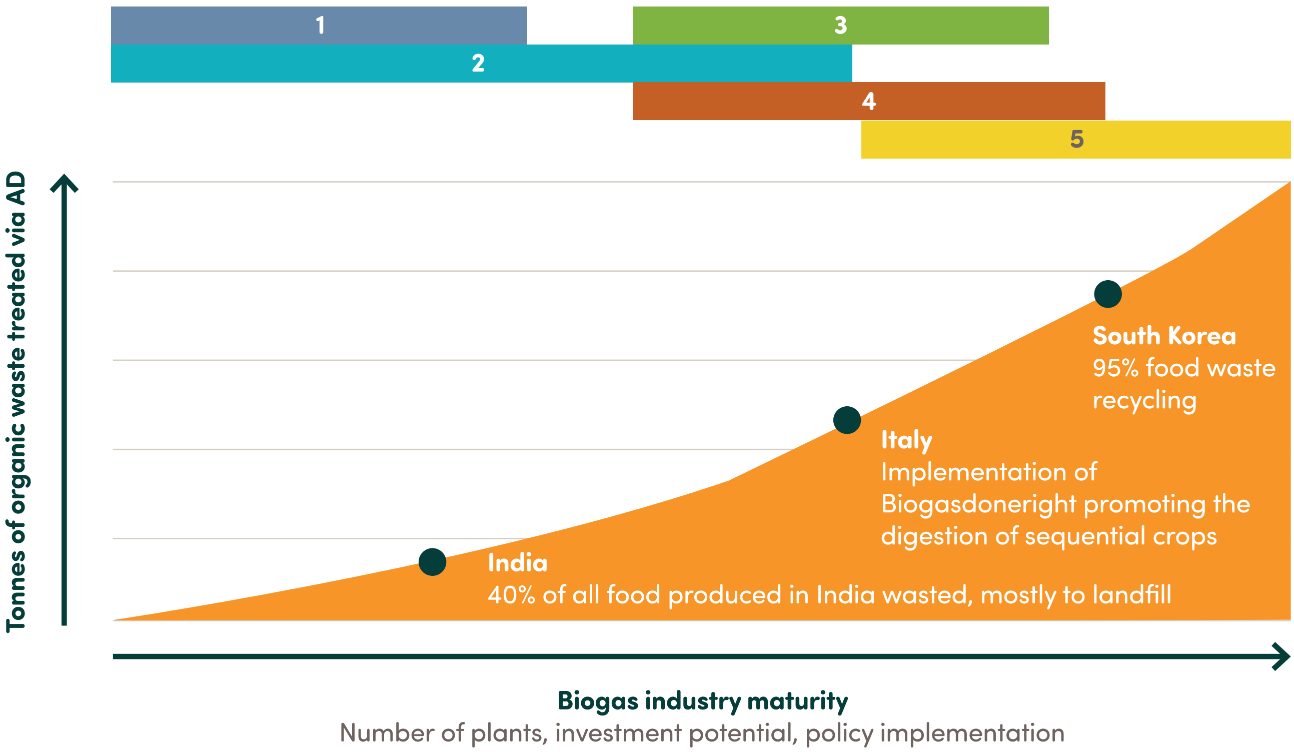
(1) Sanitation infrastructure must be developed worldwide to hygienically treat wastewater. AD facilities on-site must be used to turn this waste into valuable energy and recycle the nutrients and organic matter. Where sanitation infrastructure is already in place but without AD, biogas generation should be built to ensure this energy intensive process goes green and that the organic resources are being utilised in the most efficient manner.

(2) Organic material hierarchies should be established in national law as guidance for local waste management and should be underpinned by policy to enforce it, such as landfill bans and the introduction of a tiered tax system to encourage wastes to be diverted to the most resource efficient use, e.g., away from incineration and towards AD.

(3) Introduce separate food waste collection and treatment through AD across the global north, including in rural areas, and in urban areas of the global south. It is vital that these collections are accompanied by effective communications campaigns to secure high quality waste streams that are not contaminated with plastics or other contaminants that should not be returned to soils.

(4) Funding should be provided for the development of micro-AD plants in rural areas of the global south to capture local food, garden and farm waste as well as provide sanitation solutions for wastewater. Funding should also be provided to support the development of small-scale AD in the global north to provide the same function in rural off-grid communities. In the global south this should be financed through the Global Climate Fund or similar initiatives and be paid out as a grant to support the initial capital investment required.

(5) Incentives should be put in place to reward sustainable agriculture. In areas of the world where agriculture is heavily dependent on subsidy systems, these payments should be overhauled to incentivise sustainable agricultural practices, particularly cutting carbon emissions. Such payment systems to reward sustainable agriculture must include the collection of farm wastes – particularly manures and slurries that emit high quantities of methane – and their treatment through AD.



Wet and Dry AD

AD is a flexible technology. Different setups can be established to suit the type of waste treated. Broadly speaking, AD can be wet or dry:

- **Wet AD** is most common in the global north, treating wastes with a relatively low dry matter content, including food waste, manures, slurries and wastewater.

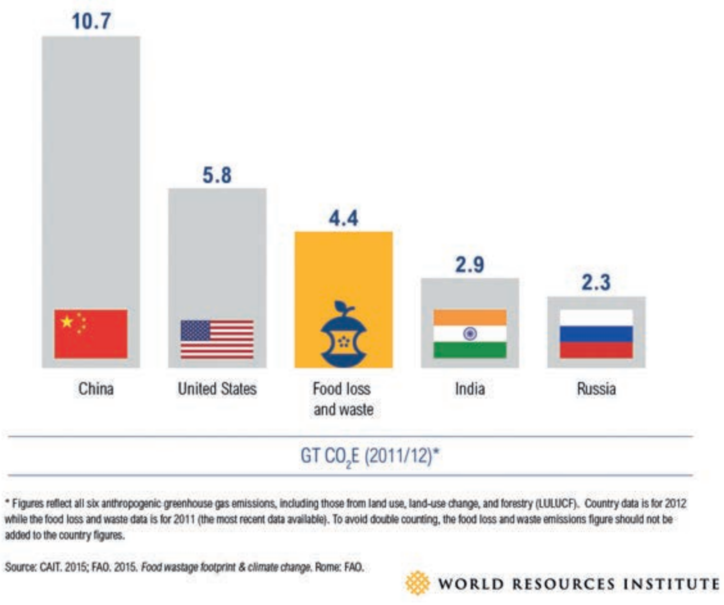
- **Dry AD** is best for treating woody waste, such as that from gardens or parks or agriculture straws (i.e., waste with a high lignin content).

Technically speaking, any organic wastes can be treated by either wet or dry AD. However, the length of time and energy required to effectively digest these feedstocks can vary significantly. Developers should consider which setup would best suit the feedstock processed.

4.1 Food waste

Food waste represents a key bioresource. An estimated one third of all food grown is wasted – around 1.3 billion tonnes per year[74]. The majority of this waste is sent to landfill, mixed in with all types of other wastes. Here, they rot, releasing significant quantities of methane into the atmosphere, a potent greenhouse gas (GHG). For every tonne of food waste sent to landfill, an estimated 0.6 tonnes CO_2e of methane is released[75]. When additionally accounting for all the energy, nutrients and water required throughout the supply chain, emissions per tonne of food waste increases to 2.5 tonnes CO_2e per tonne[76]. Moreover, as the waste rots, toxic chemicals leach into the environment, polluting land and causing eutrophication of freshwater bodies, harming biodiversity and reducing fish populations.

If food waste were a country it would be the 3rd largest emitter of GHGs, behind China and USA – with an estimated 4.4 million tonnes of CO_2e per year.[77]



First and foremost, societies must seek to reduce the amount of food waste produced. Growing food and transporting it around the world requires vast amounts of land, energy, water and nutrients. All of these valuable resources are truly wasted when good food is thrown away. Minimising food waste is the best means of cutting GHG emissions.

[74] www.fao.org/platform-food-loss-waste/en/

[75] www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020

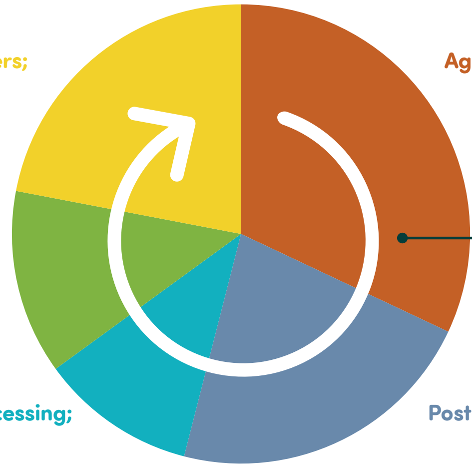
[76] www.fao.org/3/i3347e/i3347e.pdf

[77] www.e-education.psu.edu/geog438w/node/560

Beyond GHG emissions, to produce the 1.3 billion tonnes of food waste requires:

- **Around 1.4 billion hectares of land used to produce wasted food**[78] - almost 30% of the worlds agricultural land.
- **A minimum of 256 trillion litres of water.** This estimate is based on the water demand of sugar crops, a crop with a comparatively low water demand. Cereals and beef require substantially more water per kg of food produced, upwards of 8x and 78x more, respectively[79].

1.3 billion tonnes of food waste - where does it come from?



Governments and industry must take an active role to help minimise food waste production throughout the entire supply chain – from farm to fork. The following highlights a selection of actions that can be taken to address food waste production:

1. **Balance food production and demand.** The world already produces more than enough food to feed everyone. However, it needs to be better managed and distributed. Countries should shift focus away from ever increasing agricultural productivity, towards improving the existing food system and its management of resources.

2. **Enhance food storage infrastructure**. As food is transported and stored around the world, inadequate infrastructure can result in food spoiling before it reaches its consumer; food may not be appropriately refrigerated/frozen or damaged from poor practices. Again, countries should support the development of infrastructure and training to optimise the management of food.

3. **Limit production surplus.** Countries in the global north and multinational food companies have a vested interest in maintaining over-production – they can keep the cost of ingredients down and minimise risk of supply disruption. However, by its nature, production surplus results in vast quantities of waste. Establishing long term contracts with farmers/cooperatives can help avoid over production by ensuring a consistent level of supply that more closely meets demand.

4. **Promote seasonal, locally grown produce.** Supermarkets in the global north often import food from around the world to maintain customer choice year-round. For example, summer berries may be grown in the opposing hemisphere and shipped thousands of kilometres to a supermarket in winter, simply to offer consumers the option when shopping. Waste arises at every stage of a supply chain. Shorter chains mean less waste. Moreover, less energy would be required to grow and transport food that is local and seasonal. Consequently, this food waste will have a lesser environmental impact per kg, compared to food transported around the world.

[78] https://moveforhunger.org/the-environmental-impact-of-food-waste

[79] https://waterfootprint.org/en/water-footprint/product-water-footprint/water-footprint-crop-and-animal-products/

5. **Remove 'best before' dates.** People will dispose of good food if the best before date has passed. These dates attempt to cover the food manufacturer from people eating mouldy food, but early dates result in food being thrown away long before they actually go off.

6. **Support use of 'ugly' food.** Fruit and vegetables with visual imperfections are often thrown away before they even leave the farm. Countries can help ensure this edible-but-ugly food is not wasted. In line with the food waste hierarchy (see below for more detail), this food could be used in food processing (e.g. to makes soups or preserves), feed the hungry, sent to animal feed, or recycled using AD.

And central to our report...

7. **Mandate separate food waste collection.** Evidence suggests that homes which separate their food waste, produce less food waste - an average reduction of 16.1 kg per household per year[80]. Governments can implement compulsory food waste separation by homes and business, and collection by local councils and municipalities. Waste production is not only reduced, but separated ready for recycling.

   The IEA recognise AD as a key education tool to teach people about the values of a circular economy. It says, "Circular economy is a broad concept, which can be hard to comprehend. The biogas plant is a concept which could also be used for education purposes to give children concrete examples of a circular economy concept. People can start to understand the need to reduce and recycle food waste. Showrooms in farms have been used to show "where the food comes from" to school groups. These same concepts could be used more widely to explain how separate collection of food waste in homes can be used to produce green energy or fertiliser."[81]

   With greater public participation, the cost of obtaining source segregated waste is significantly reduced, creating a virtuous circle. It also serves to embed circular thinking across the consumer economy, which distinguishes between technical and biological cycles. Consumption happens only in biological cycles, where food and biologically-based materials (such as cotton or wood) are designed to feed back into the system through processes like composting and anaerobic digestion. These cycles regenerate living systems, such as soil, which provide renewable resources for the economy. Technical cycles recover and restore products, components, and materials through strategies like reuse, repair, remanufacture or (in the last resort) recycling[82].

   Without separation, mixed waste is far more likely to be sent to unsustainable technologies such as incineration (also known as energy-from-waste, EfW), or worse, landfill.

Case study: Food waste recycling in South Korea

With 95% of all food waste being recycled, South Korea is leading the world in food waste management. This rate has been achieved through the implementation of policy and regulation throughout the supply chain.

In 2005, disposing food waste to landfill was banned, stimulating the development of more sustainable technologies such as AD and composting. In 2013, the government introduced compulsory disposal of separated food waste into special biodegradable bags. Citizens are required to purchase these bags, thus incentivising the reduction of waste production and uptake of domestic composting; a 4-person household might expect to pay around US$6 per month for these bags. Monies raised support the cost of running the scheme.

[80] https://resource.co/article/report-shows-link-between-food-waste-collections-and-food-waste-arisings

[81] www.ieabioenergy.com/blog/publications/the-role-of-anaerobic-digestion-and-biogas-in-the-circular-economy/

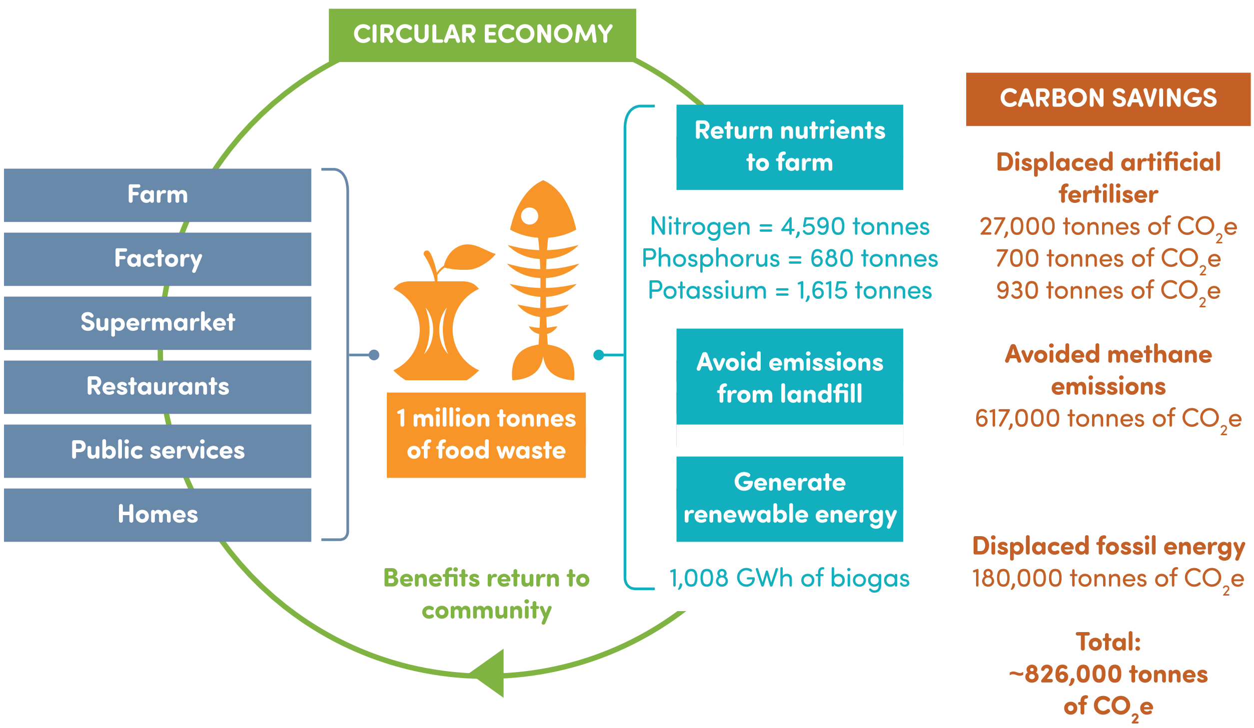
[82] www.ellenmacarthurfoundation.org/circular-economy/concept

In Seoul, smart bins were also installed, where people can “pay-as-you-recycle”. By scanning an ID card and inserting the food waste, the smart bin weighs the waste and charges the person’s account. Again, this system promotes waste reduction. The city’s annual production of food waste has been cut by an estimated 47,000 tonnes since smart bins were introduced. Moreover, being composed of 80% water, residents have also started removing the moisture from food waste, to reduce the weight and save money. The city benefit from this too, saving money by transporting a more concentrated feedstock. In Songpa District alone, smart bins have saved around US$ 8.4 million in logistical expenses[83].

From here, this chapter will focus solely on **unavoidable food waste**, materials such as used tea bags, banana skins and vegetable peels, and wastes from the manufacture of food and drink products, such as brewery draff and dairy effluent from the cheese-making process. WBA’s modelling optimistically assumes that total food waste production can be cut by 50% and of this remaining waste, 69% is suitable for collection and diversion to AD[84].

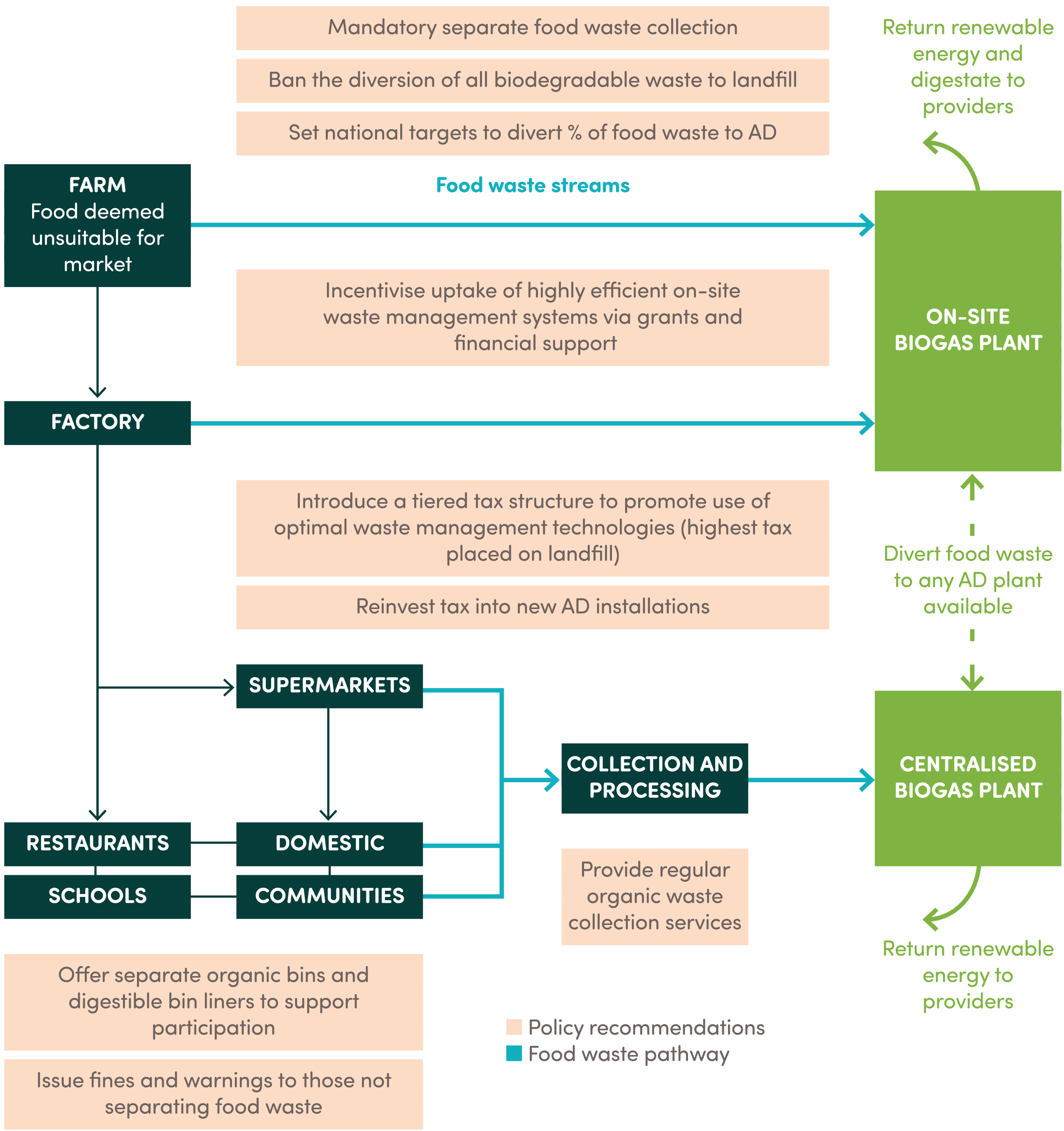
	Proportion of global emissions
Halving food waste production, primarily leaving only the unavoidable food waste, could cut emissions by 1,650 million tonnes CO_2e	**-3%**
Treating 69% of this **remaining waste via AD** and utilising its sustainable products could cut emissions by further 470 million tonnes CO_2e	**-1%**
Total	**-4%**

AD helps convert food waste from being a major problem into a climate solution. It captures the methane for use as a renewable fuel and recovers the nutrients in the form of digestate. The following highlights the decarbonisation potential of recycling food waste via AD per million tonnes:



[83] www.weforum.org/agenda/2019/04/south-korea-recycling-food-waste/
[84] www.worldbiogasassociation.org/global-potential-of-biogas/

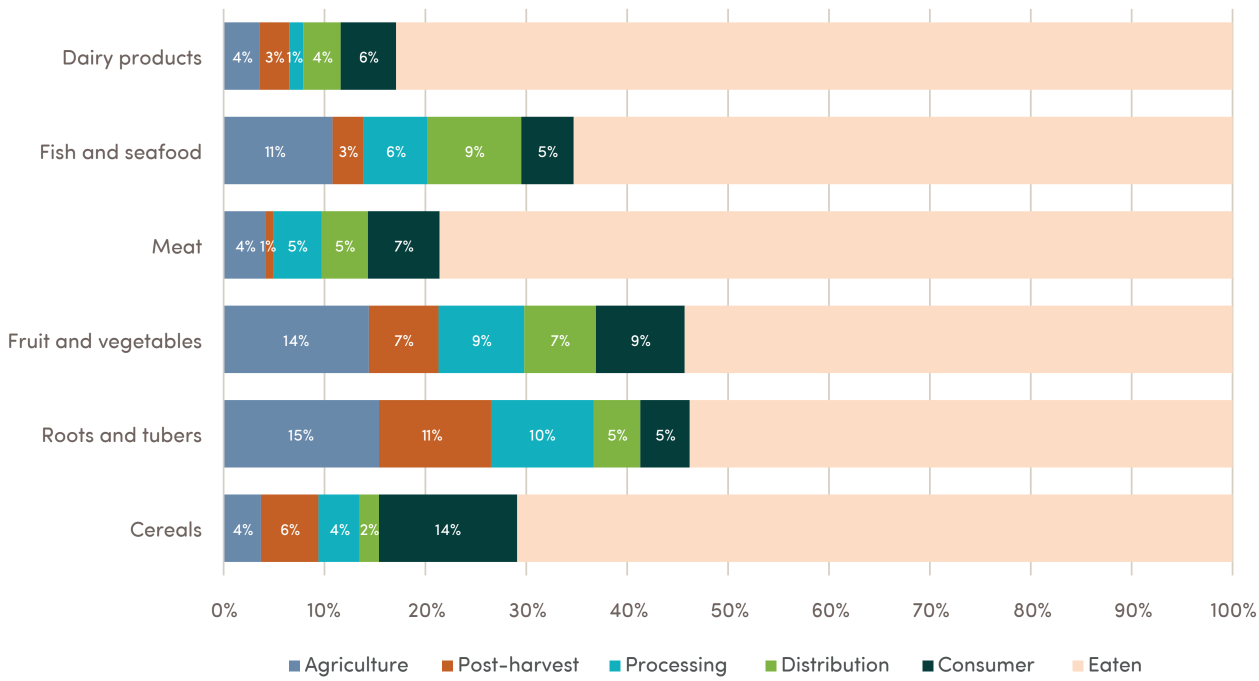
Policy and regulation must be enacted throughout the entire supply chain to support the development of technologies to enable the recovery of these valuable resources. Organic wastes from homes and businesses require separation, collection and diversion to AD. Complementary policy must disincentivise its diversion to poor waste management technologies, namely landfill and incineration (also known as EfW). As mentioned in Chapter 3, EfW has been removed from the EU's taxonomy of sustainable economic activities – i.e., it is no longer considered a recycling technology suitable for food waste management by the EU. The following conceptualises this supply chain and suggests suitable policies and regulations to promote the best utilisation of these organic wastes:



Food waste can arise from a number of sources from farm to fork, where there are more opportunities for waste to arise within longer supply chains. For example, within the supply chain of a supermarket selling apples to customers, food waste could arise:

- On farm, where apples do not meet quality standards
- During transit, where poorly packed containers result in damaged produce
- In processing plants, where sub-optimal conditions may affect food quality (e.g. inadequate refrigeration)
- Within distribution centres, where produce can spoil if poorly managed
- At the supermarket, where produce is not purchased before starting to rot
- At home, where the produce may rot before being consumed

Food waste through the food chain worldwide



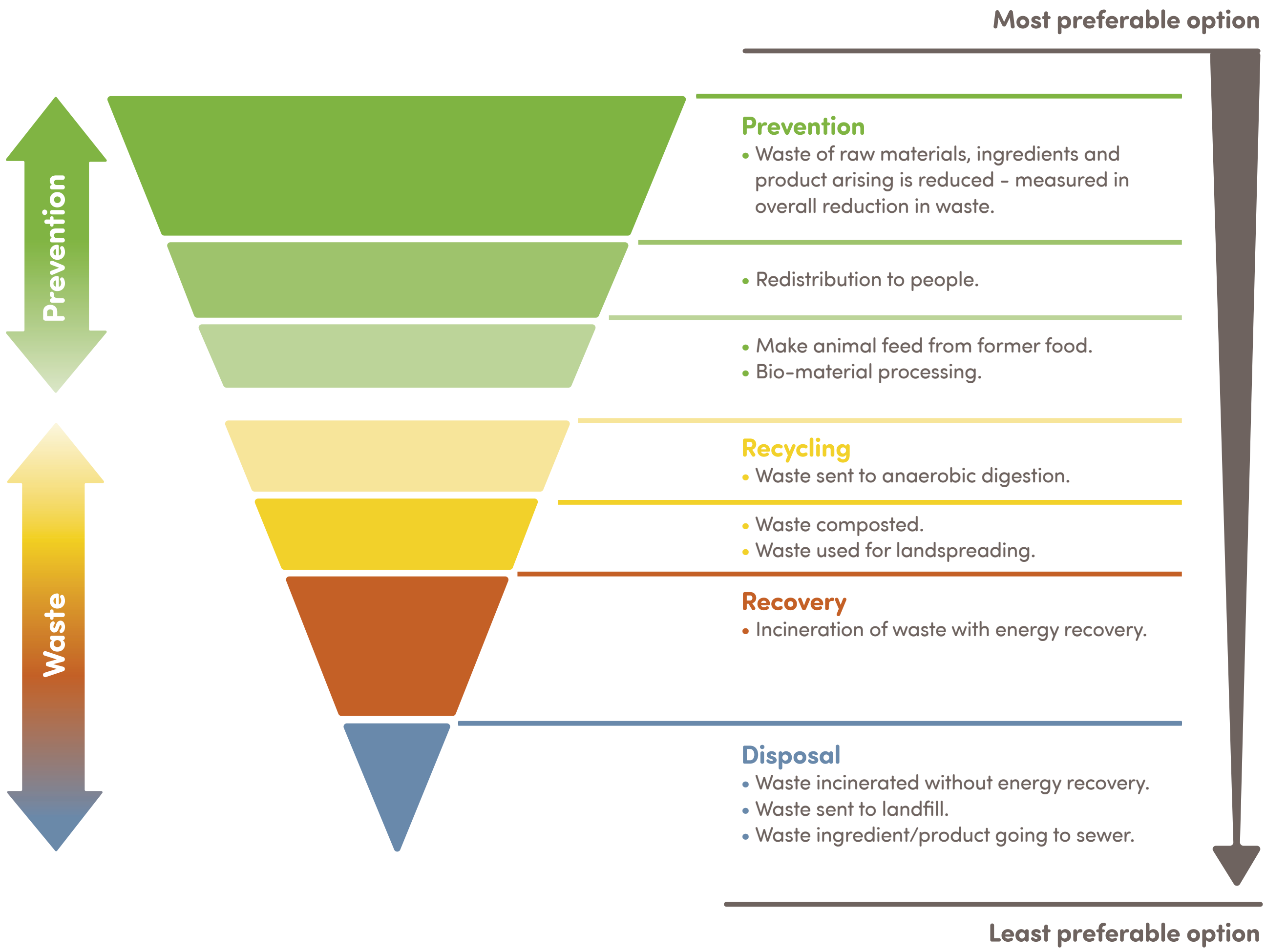
Source: FAO[85]

It is crucial to work with the full supply chain to identify sources of food waste and implement systems to first reduce and then recycle these bioresources. This will help develop the collective awareness to tackle the issue from the root.

[85] www.fao.org/food-loss-and-food-waste/flw-data

Both countries and companies should set ambitious waste reduction and recycling targets. They should look to implement a comprehensive waste management hierarchy, detailing the order of preference for waste reduction and management technologies. The following hierarchy, developed by WRAP, currently guides waste management policy in the UK:

Food and drink material hierarchy



The hierarchy emphasises that food waste should be preferentially prevented or redistributed to people or animals. For unavoidable food waste, AD is identified as the optimal recycling technology. At bottom is landfill and incineration – the last choice for food waste management.

Separating organic waste from other wastes is the first, and often the most vital, step in moving food waste up the hierarchy and recycling it using optimal technologies. Public and private participation in separating organic wastes overcome the primary costs associated with material-specific recycling. While waste can be separated post collection, it is not always 100% effective and separation costs fall on the council/government. Most importantly, developing a consistent stream of food-only waste encourages the construction of recycling infrastructure, such as AD plants. It would not make sense to collect separate food waste, only for it be sent to landfill or incineration.

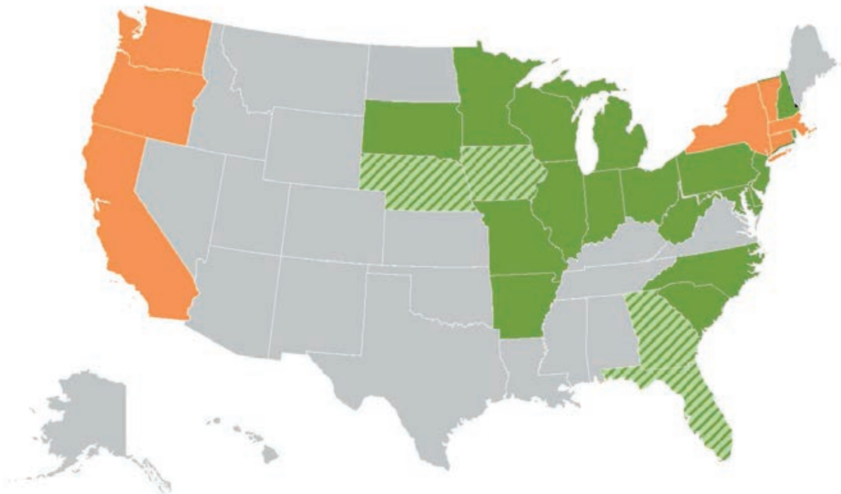
To facilitate this waste segregation, infrastructure often requires upgrading – from the provision of bins within homes, business and in public spaces, to new waste collection vehicles and processing sites. Within the home, research suggests caddy liners can encourage public participation by increasing perceptions of hygiene when handling rotting wastes[86]. Complimentary policy can also help push people to separate wastes. For example, in Scotland, businesses producing more than 5kg of food waste per week can face a £300 (US$415) on-the-spot fine if they are caught disposing food waste unseparated.

[86] https://wrap.org.uk/resources/guide/household-food-waste-collections-guide/section-4

Once separated, policy can support the development of food waste collection services. In the EU and UK, it has been mandated that all local authorities must collect separated food waste from homes by 2023. This forward planning has also stimulated discussions across governments and industry about how best to treat and recycle this waste. AD developers can be assured that consistent feedstock streams will be in place, necessary for plant investment. The EU has targeted a ban on all organic wastes sent to landfill by 2030, and the UK by 2025.

Again, policy can ensure food waste that has been separated and collected is treated by the optimal technology. Several states in the USA have also banned the practice of sending biodegradable waste to landfill, forcing it to be treated using technology higher up the waste hierarchy. While this does not prevent incineration, it goes a long way to prevent the methane emissions from rotting waste.

State Organics Legislation - December, 2019



Yard debris bans: Arkansas, Delaware, Illinois, Indiana, Maryland, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota, West Virginia, Wisconsin

Yard debris bans with exemptions for landfills with gas collection systems: Florida, Georgia, Iowa, Nebraska

Food scrap collection mandates or aggressive legislation for keeping out of landfills: California, Connecticut, Massachusetts, Oregon, Vermont, Washington

Several US states have already introduced bans for food waste and garden waste disposal to landfill[87]

An additional tiered tax system could help move waste further up the hierarchy. For example, food waste sent to incineration would be subject to the greatest tax, and the amount of tax incurred would be reduced through the use of better technology. If sent to AD, the optimal technology, waste management would not incur this additional tax. Funds raised could be used to improve waste infrastructure nationwide.

The success of any separate organic collection system depends strongly on public participation, be it householders or employees at commercial retail establishments. It is important that citizens are aware of the benefits of recycling, how segregating their food waste contributes to a better environment and how important it is to do it correctly. Communication campaigns and face to face engagement with the community are key to any successful recycling programme. It is also very important that the communications are clear and consistent, informing what can and cannot be put in the waste caddies and which liners can be used. In general, information leads to action: the more citizens hear about and see ways to reduce food waste the less food is thrown away. Good practice guidance is available from WRAP Global providing material and case studies to support any food waste reduction roadmap. AD has been recognised for its ability to educate the public about circular economies and the benefits they deliver.

[87] www.compostingcouncil.org/page/landfill-organics-bans

Again, total management costs can be diminished with supportive policy to reduce waste generation in the first instance; less waste to collect, transport and manage.

Case study: Montreal city aims to become a leader in biogas

SUEZ in 2019 won a contract to design, build, operate and maintain an 'organic waste treatment centre' in the City of Montreal. The new plant will convert organic material into biomethane, producing enough renewable gas to power around 3,600 households.

When it is commissioned in 2021, the plant will be able to process 60,000 tonnes of organic material annually, recovering organic waste produced by nearly 1.5 million inhabitants of the east side and the city centre and producing biomethane and carbon rich soil improver.

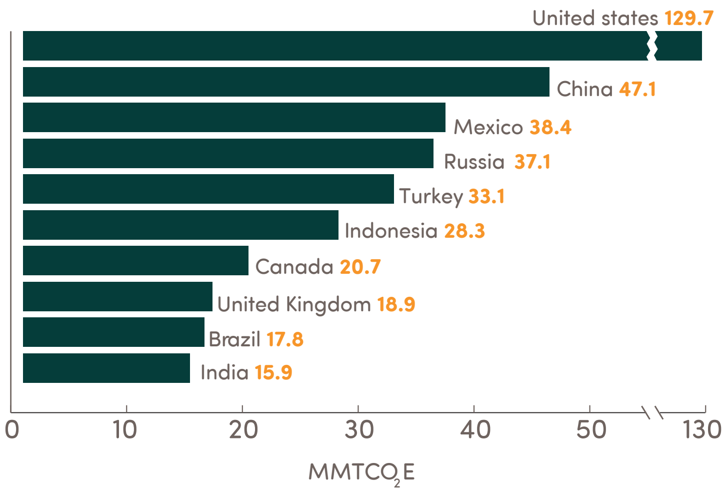
The plant has been commissioned as part of the City of Montreal's efforts to reduce greenhouse gas emissions. Aside from delivering non-polluting, locally produced renewable energy, the development will significantly reduce 'waste miles', with organic material currently being taken to a facility around 50km (31 miles) northeast of Montreal. This facility is the second organic waste treatment centre planned by the City, to recover and divert its organic waste away from landfills by 2020.

"Our concern for the environment is a major reason why the City of Montreal wants to become a leader in the use of biogas. Biogas plants significantly curb the greenhouse effect by capturing this harmful gas and using it as fuel. Biogas generation helps cut reliance on the use of fossil fuels, such as oil and coal. Recovering household waste into new resources is as much an economic issue as an environmental one: it helps preserve natural resources, curb greenhouse gas emissions and reduce the volumes of waste stored."
Valérie Plante, Mayor of Montreal

"Cities like Montreal are now playing a key role in the circular economy by creating local recovery cycles. SUEZ is proud to support the City of Montreal in its transition towards a new local, sustainable, and low-carbon energy model."
Bertrand Camus, CEO of SUEZ

Upgrading landfill infrastructure

Globally, landfills are the third largest anthropogenic source of methane, accounting for approximately 11% of estimated global methane emissions or nearly 800 $MtCO_2e$ in 2010. These methane emissions arise from organic wastes, typically food waste, mixed in with all other wastes. The following graph displays the top 10 countries with the greatest GHG emissions from landfill in 2010[88]:



These methane emissions are not only a concern for the climate. They can also cause landfill explosions, release odours, contaminate local waterways with toxic leachate and, once filled up, render the land largely unusable.

[88] www.globalmethane.org/documents/landfill_fs_eng.pdf

The liability of landfill gas (LFG) can be turned into an asset. Landfill sites can be retrofitted with methane collection infrastructure. Many countries regularly capture LFG as a strategy to improve landfill safety, generate electricity, reduce greenhouse gas emissions and to earn carbon emission reduction credits. Many projects in developing countries are taking advantage of the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) to earn carbon credits by capturing and combusting methane (e.g., the Sudokwon Landfill in Republic of South Korea, the Bandeirantes Landfill in Brazil and the Nanjing Tianjingwa Landfill in the People's Republic of China). These Landfill Gas-to-Energy (LFGE) projects provide a valuable service to the environment and a potentially profitable business venture, bringing benefits to local and regional communities.

While this technology can mitigate methane emissions from existing landfill sites, it is not a future solution. Landfill should be a last resort for waste management – at the very bottom of the waste hierarchy. Preventing food waste being sent to landfill will prevent methane emissions from landfill.

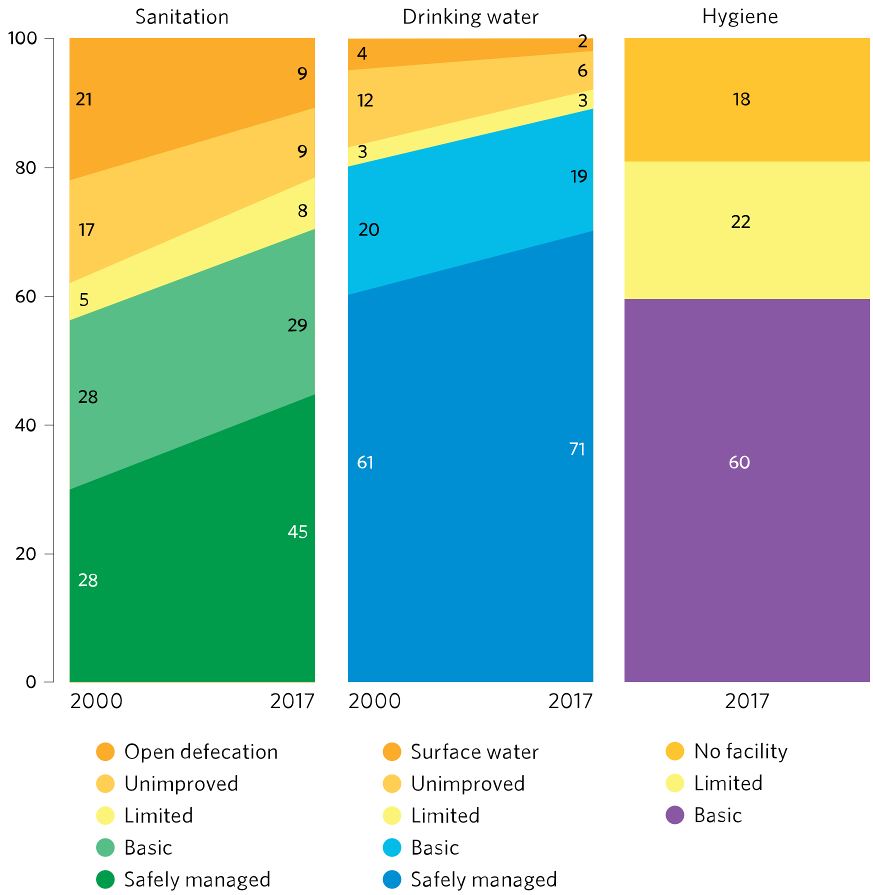
Food waste specific policy recommendations:

- Implement zero food waste to landfill, together with a delivery plan that ensures the organic waste is being recycled via AD.
- Implement a target for maximum allowance of food waste in the residue waste so it is treated higher up the waste hierarchy.
- Develop comprehensive waste collection infrastructure to deliver separated food waste to optimal waste treatment technologies, such as AD.
- Incentivise GHG mitigation, including savings from reduced volumes of waste needing disposal.

4.2 Wastewater

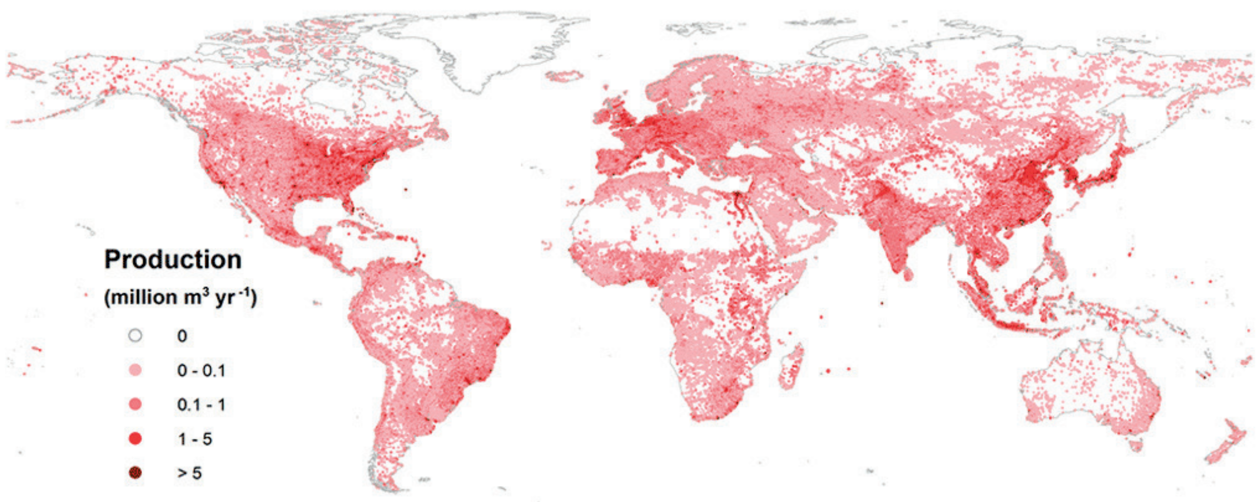
Water is crucial in determining whether the world will achieve the SDGs' deadline of 2030. Sanitation and potable water are critical to human dignity, bringing an end to chronic and fatal health conditions, and are key drivers of economic development and growth. Hence there is a global movement to end water, sanitation and hygiene (WASH) inequality.

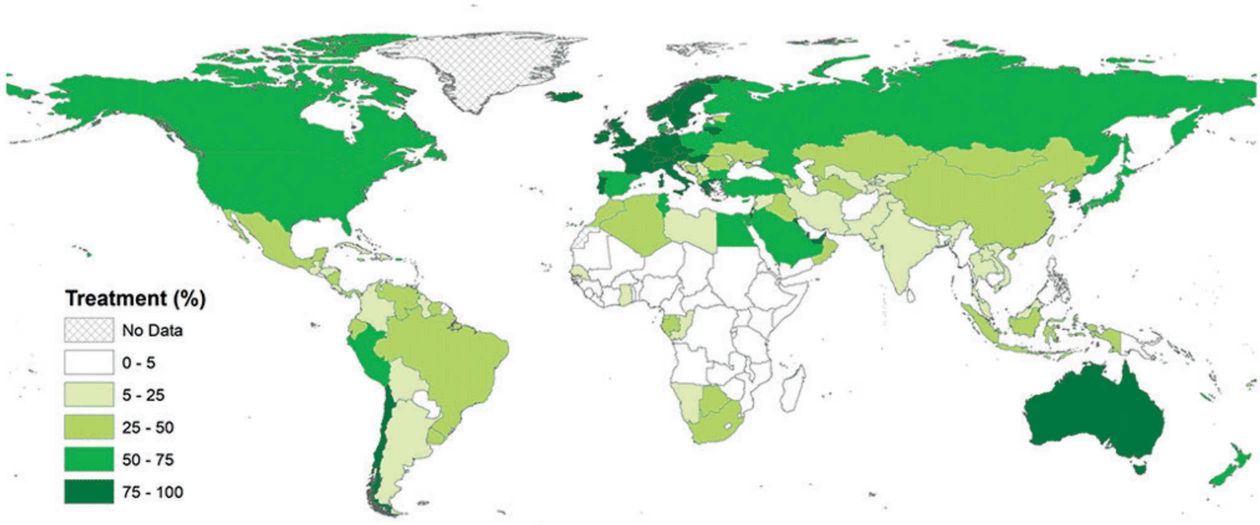
Globally, 2.3 billion people live without access to a basic sanitation service: almost 892 million of these people practice open defecation. Today, only 68% of the world's population has access to basic sanitation, and only 39% of people have access to safely managed sanitation (which includes containment, through safe collection and conveyance, to treatment and end use/disposal)[89].



[89] https://unstats.un.org/sdgs/report/2019/goal-06/

Wastewater is broadly defined as "used" water that has been contaminated as a result of human activities; return flows from domestic and manufacturing sources (henceforth "wastewater") that can be collected in infrastructure including piped systems (sewerage) or on-site sanitation systems (septic tanks and pit latrines)[90].





Up to 80% of wastewater produced globally each year is released into the environment with little or no treatment[91]. The maps above show global wastewater production and treatment. This pollution is extremely damaging to both human health and the environment. Contaminated waterways spread lethal diseases, such as cholera and typhoid, responsible for the death of nearly 300,000 children under five years old every year. It is worth noting that lack of access to clean water hampered the global response to Covid-19; 3 billion people worldwide lack basic handwashing facilities at home, the most effective method for Covid-19 prevention[92].

The nitrogen and potassium content of the waste can lead to eutrophication in lakes and rivers, killing fish and reducing biodiversity. This in turn can have an adverse impact on food security for communities which rely on fishing for sustenance or income. And the rotting of waste results in the release of GHGs to the atmosphere, driving climate change – an estimated 199 million tonnes CO_2e are released each year from untreated wastewater[93].

[90] https://essd.copernicus.org/articles/13/237/2021/

[91] www.unwater.org/water-facts/quality-and-wastewater-2/

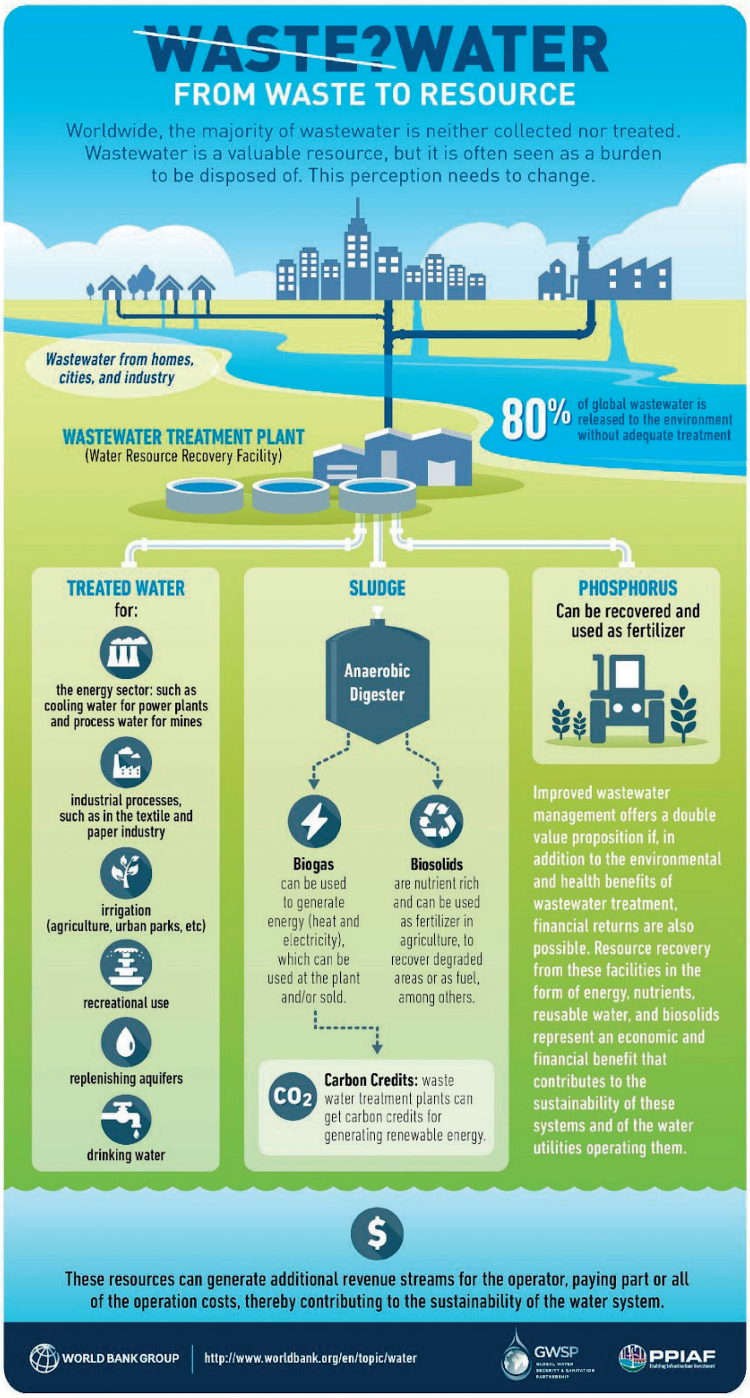
[92] www.un.org/sustainabledevelopment/water-and-sanitation/

[93] www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-globalreport-56ppa4_digital-Sept-2019.pdf

A lack of sanitation also holds back economic growth. Poor sanitation costs billions to some countries, amounting to the equivalent of 6.3% of GDP in Bangladesh (2007), 6.4% of GDP in India (2006), 7.2% of GDP in Cambodia (2005), 2.4% of GDP in Niger (2012), and 3.9% of GDP in Pakistan (2006)[94].

The economic losses are mainly driven by premature deaths, the cost of health care treatment, lost time and productivity seeking treatment, and lost time and productivity finding access to sanitation facilities. The World Bank has quantified the impacts, saying the lack of adequate sanitation is costing US$260 billion annually.

However, the World Bank also says that wastewater remains an "untapped" and "undervalued" resource; fecal sludge and wastewater can provide valuable resources - water, nutrients, soil conditioner, briquettes and energy - and economic opportunities, especially in urban areas and in water-scarce environments. It says AD is the key to unlocking the optimal solution, calling wastewater facilities integrated with AD a 'double value proposition'. It says AD enables "resource recovery from these facilities in the form of energy and nutrients, reusable water and biosolids, representing economic and financial benefits that contributes to the sustainability of these systems and water utilities operating them."



This of course speaks to the possibilities open to cities and towns, to either upgrade wastewater treatment centres or from the outset integrate AD into any new facility because it makes economic sense. Treating wastewater is an energy intensive process. Typically, water and wastewater-treatment processes can account for between 25% and 40% of a municipality's electricity bill – energy that can be saved and money that can be freed up and put to better use elsewhere.

However, there are countless examples of AD making wastewater treatment (WWT) centres carbon neutral, energy self-sufficient and increasingly producing a surplus to 'sell'.

The International Water Association has produced a roadmap for WWT facilities to achieve carbon neutrality. Speaking in 2018 Corinne Trommsdorff, IWA-WaCCliM Project Director, and co-author of the The Roadmap to a Low-Carbon Urban Water Utility, said, "If the urban water sector were to become carbon neutral, it could contribute the equivalent of 20% of the sum of committed reductions by all countries in the Paris Agreement (the Nationally Determined Contributions)".

[94] www.wsp.org/content/economic-impacts-sanitation

The report draws on an approach that has been successfully piloted in utilities in Jordan, Mexico, Peru, and Thailand that participated in the WaCCliM (Water and Wastewater Companies for Climate Mitigation) project, with drastic reductions in greenhouse gas emissions[95].

Wastewater can be treated using physical, chemical and biological processes. Wastewater may be separated into different components by allowing it to settle or using filters (physical); it can be mixed with chemicals to kill dangerous microbes (chemical); and it can also be digested under anaerobic conditions to break down organic material and capture biogas (biological). Modern treatment plants will typically draw upon all three of these processes to treat the waste completely. This full treatment is relatively energy intensive. However, the biogas produced can contain more than enough energy to power the entire process. Any excess energy can be exported to the local gas or electricity grid.

Scottish Water in 2019 announced that its Galafoot Waste Water Treatment Plant in Galashiels now generates more energy than it uses. Imported sludge is mixed with the on-site, indigenous sludge. This feeds a digester which produces biomethane and fuels a 124 kW capacity CHP. Currently the suite is powering its own operations and 204 local homes. The company aims to achieve carbon neutrality across its operations by 2040[96].

Source: IWA

[95] https://iwa-network.org/press/the-urban-water-utility-of-the-future-the-roadmap-to-a-low-carbon-urban-water-utility/

[96] https://wwtonline.co.uk/news/scottish-water-wwtw-celebrates-green-efficiency-milestone

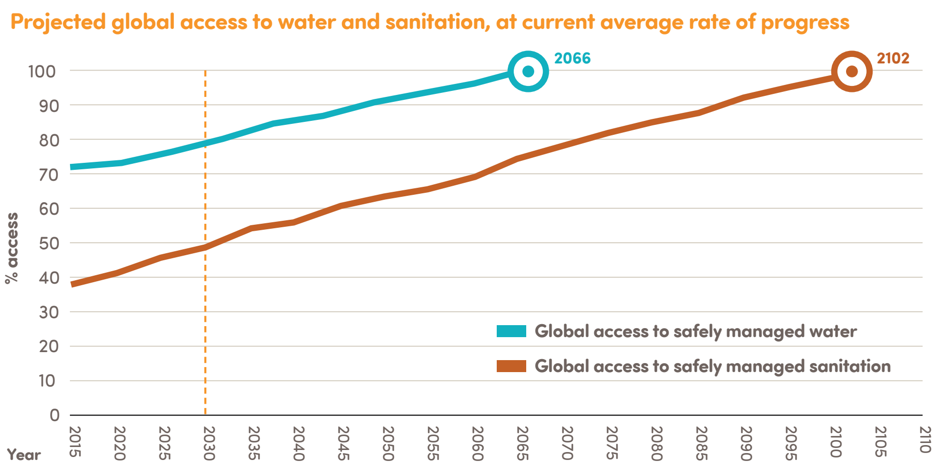
WWT facilities across Europe are following a similar path. Marselisborg Wastewater Treatment Plant Aarhus Vand, in Denmark, produce +50% more energy than is used. By implementing energy efficient solutions and producing biogas from the sludge, the utility is almost able to cover the energy consumption for the whole water cycle from groundwater extraction, to pump stations, water distribution and wastewater treatment.

It must be noted that soon after the adoption of the UN's SDGs in 2015, Danish wastewater utilities started investigating how the SDGs could be used to improve their performance towards sustainability. A commonly overlooked fact is that the SDGs are to be implemented globally and are not directed towards developing countries only[97]. The Danish Water and Wastewater Association created the following assessment:

DANVA's grouping of the SDGs most relevant to water (© DANVA)

As the world continues to urbanise, cities and small towns will increasingly bear the burden of poor sanitation. The UN forecast that 68% of the global population will live in cities by 2050, and that an estimated 57% of urban dwellers will lack access to toilets that provide a full sanitation service, 16% access to basic sanitation services, and almost 100 million will practice open defecation.

However, of the two billion people that currently lack basic sanitation, 72% live in rural areas. At current rates of progress, universal access to safely managed sanitation will not be realised until after 2100[98].



Source: WashMatters[99]

[97] www.thesourcemagazine.org/denmarks-water-utility-sdg-agenda-for-change/

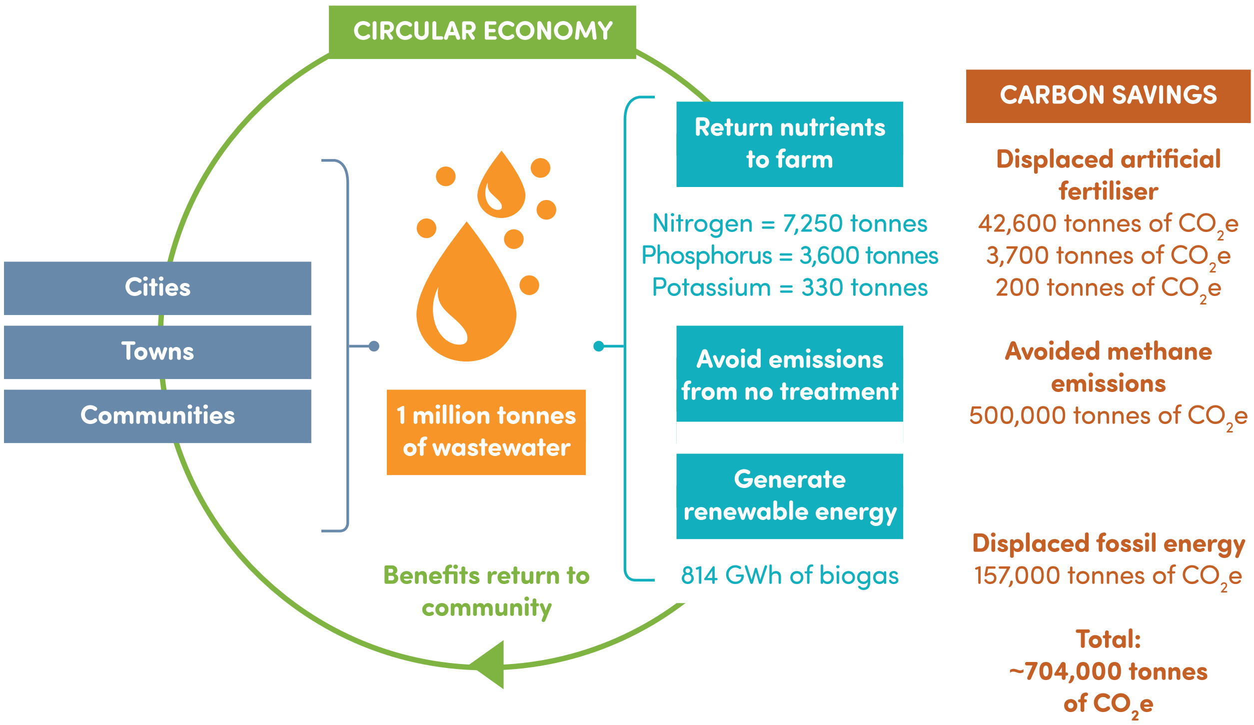
[98] https://washmatters.wateraid.org/publications/delivering-rural-sanitation-programs-at-scale-equity-sustainability-call-to-action

[99] https://washmatters.wateraid.org/publications/how-to-reach-everyone-with-safe-water-and-sanitation-by-2030

Developing infrastructure will be crucial to improve sanitation and unlock the potential of wastewater. This includes the collection and transportation of waste to centralised treatment plants. In urban areas, this may involve publicly funded sewage works running underground; in rural areas, it could relate to community cesspits and waste management solutions. Companies such as Loowatt are at the forefront of delivering an AD-based solution for rural sanitation – toilets with a wrap system operating as waterless flush, allowing fecal matter to be collected and treated in an AD facility. Toilets vary in scale from a single home toilet to a hub, to service larger events or communities. The more sophisticated models digitally alert the service company when the toilets are nearly full[100].

Fortunately, waste production is relatively predictable and reliable both in terms of production and content. The waste diagram below enables policymakers to estimate the biogas potential from communities of any size, facilitating the development of a comprehensive strategy to develop wastewater infrastructure and sanitation.

Around 47kg of sewage waste is produced per person per year. For example, a city with a population of 1 million people will produce around 47,000 tonnes of sewage per year. Additional organic waste will arise from the disposal of other organic wastes (e.g. drinks) down drainage systems.



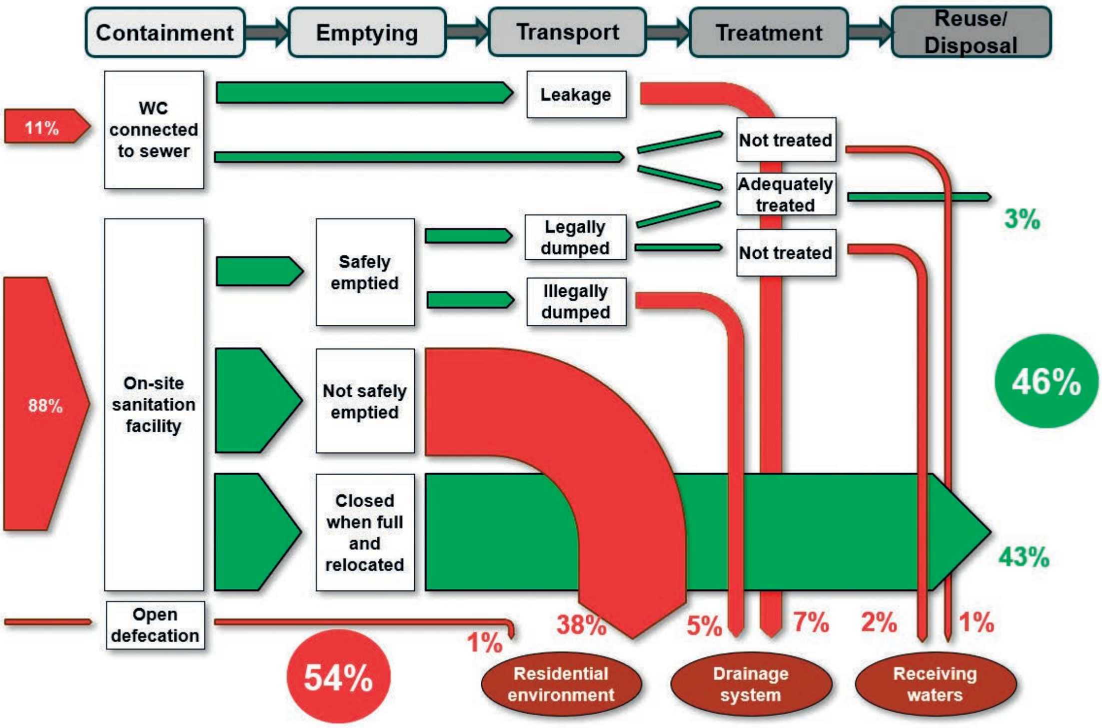
Another planning tool is what is commonly called a Shit Flow Diagram (SFD). An SFD, or formally excreta flow diagram, is a tool to help municipal leaders to readily understand and communicate how excreta physically flows through a city or town[101].

In the example on the next page, green arrows represent the proportions of excreta that are 'safely managed' along the whole sanitation chain: from the toilet, through a pit or septic tank, via sewers or sludge tankers, to treatment stations and eventual disposal or reuse. The red arrows show what is not happening as it should be: leaking sewers, non-functional treatment plants, illegal emptiers discharging sludge in rivers, full pits that are contaminating groundwater because high fees mean they are never emptied, and waste from people who do not even have a decent toilet[102].

[100] www.loowatt.com/

[101] https://sfd.susana.org/

[102] https://washmatters.wateraid.org/blog/three-things-we-have-learned-by-creating-shit-flow-diagrams



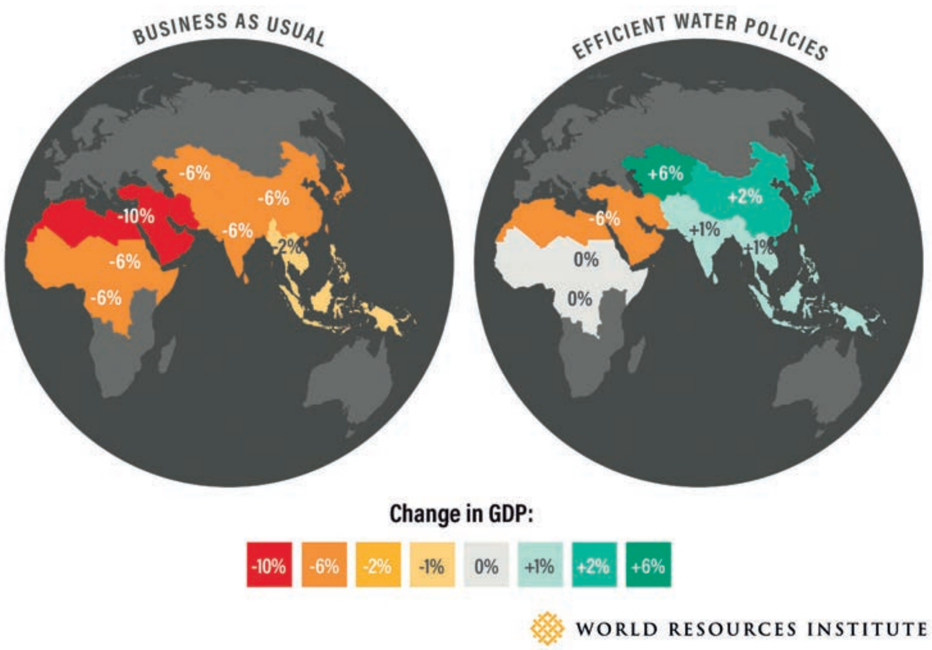
Note: this diagram is indicative only. (© Peter Hawkins)

Through visualizing the challenges facing a city, they serve to enable a multi-stakeholder and coordinated dialogue among stakeholders and potential partners about excreta management.

Research for the World Resources Institute found that securing water for our societies by 2030 could cost just over 1% of global GDP. Global GDP is ~US$87.5 trillion, and 1% is around US$875 billion, about 29 cents per person per day from 2015-2030.

And the economic benefits outweigh the costs. Every dollar invested in water access and sanitation yields an average $6.80 in returns. The World Bank found that failing to implement better water management policies could result in regional GDP losses from 2-10% by 2050.

Estimated change in 2050 GDP due to water scarcity



Source: Global Commission on Adaption 2019, World Bank 2016

The study concludes

"the solutions to the world's water crises are readily available; what's missing is the money (from public and private sectors) and political will needed to implement them. It's time that water solutions be seen not as a burden, but as an opportunity. Resolving the world's shared water challenges improves the lives and livelihoods for billions, benefits the ecosystems around us, and can yield significant returns on investment"[103].

Wastewater specific policy recommendations:

- Set a strategy to capture wastewater
- Set a strategy for all wastewater companies to focus improvements on energy consumption, energy production and becoming clean energy positive.
- Ensure that there is clear regulatory regime governing the outputs of co-digestion providing general protection of any receptor.

4.3 Agricultural feedstocks

Agriculture lies at the heart of many fundamental global challenges faced by humanity, including food security, economic development, environmental degradation and climate change. It is the world's largest driver of species loss and habitat conversion and is a major contributor to toxic and nutrient pollution, soil degradation and invasive species introductions. These adverse impacts will only continue to grow as global population and income levels rise.

Global agricultural production has nearly tripled over the last 50 years and is likely to increase by a further 50% or more in the first half of the 21st century as the global population reaches 9.0 billion (up from 7.8 billion in 2020). The agricultural sector is also a major contributor to GHG emissions. Most studies attribute ~10% of all global GHG emissions to the production of food, feed, and biofuels, including emissions from agriculture-driven land use change. The figure rises to ~23% when deforestation for agriculture is included[104].

Many of the sources of these emissions can be mitigated by the deployment of AD, as has been recognised in the EU's Methane Strategy[105], which advocates the very real and positive impacts biogas production represents as a cost-effective way to address methane emissions.

The strategy says:

"Non-recyclable human and agricultural waste (i.e., manure) and residue streams can be utilised in anaerobic digesters to produce biogas or in biorefineries to produce bio-materials and intermediate bio-chemicals. The biogas resulting from such feedstocks is a source of highly sustainable and useful renewable energy with multiple applications, while the material that remains after anaerobic digestion (digestate) can, after further processing, be used as a soil improver.

"The collection and use of high methane emitting organic wastes or residues from farming as biogas substrates should be further incentivised. This can be achieved, for example, through identifying best practices for collection and/or harvesting of sustainable wastes and residues or by incentivising the use of digestate as a sustainable soil improver in lieu of mined fertilisers. Sequential cropping can also be used in combination with manure as feedstock for sustainable biogas production, while contributing to sustainable farming practices, and as such could also be further incentivised."

The EU's strategy calls for the promotion of opportunities to reduce emissions with support from the Common Agricultural Policy.

[103] www.wri.org/publication/achieving-abundance

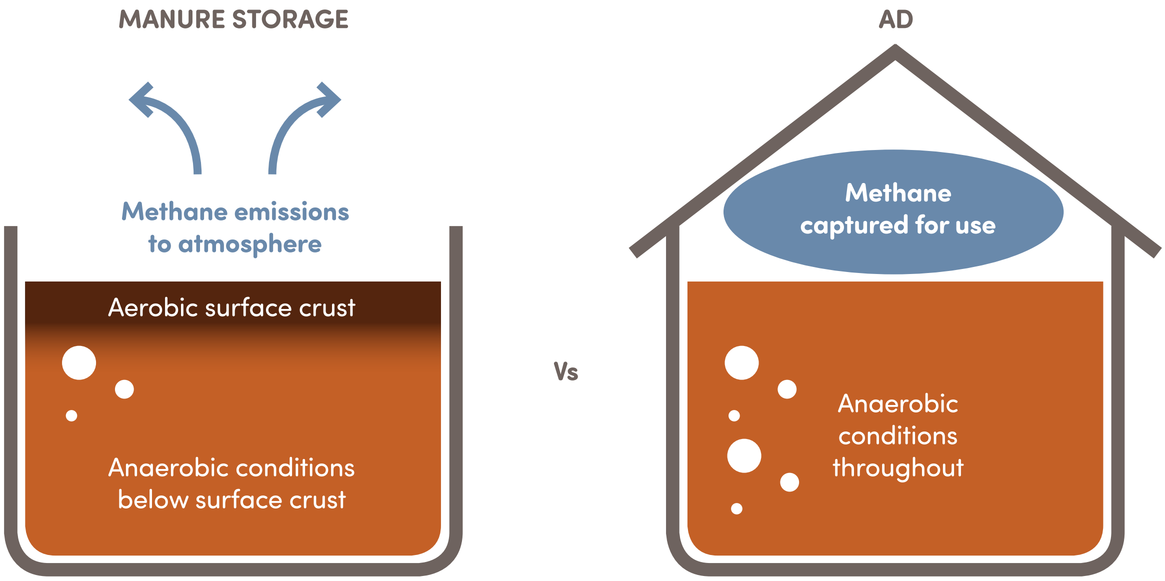
[104] www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

[105] https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf

4.3.1 Manures and slurries

Cows, pigs and chickens produce over 33 billion tonnes of waste per year. Manure management is responsible for the release of 403 million tonnes CO_2e each year.

Depending on the time these animals spend in housing, between 50% and 90% of this waste is readily collected and stored; various factors determine housing time, from the milking frequency/duration and weather conditions to the intensity of farming practices. Assuming just 70% of this collected manure is treated through AD, over 1,650 million tonnes CO_2e emissions may be abated – more than the total annual emissions of Japan, the world's 6th largest emitter of GHGs[106]. The modelling of AD's emissions savings account for the avoided direct-to-atmosphere methane emissions, the displacement of fossil fuels with biomethane, and the replacement of artificial fertilisers with digestate.



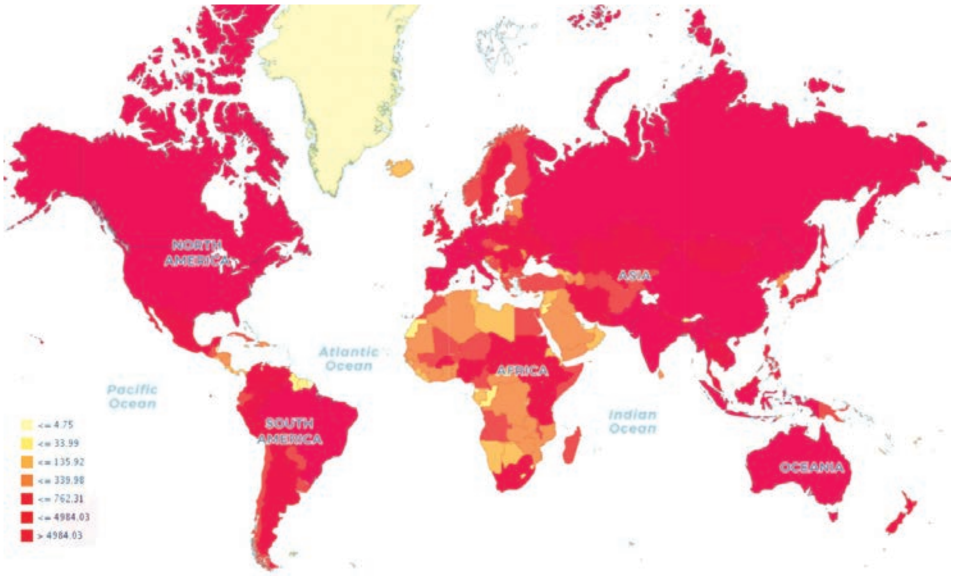
Manure may be stored for several months before being spread to land. During this time, a surface crust will form where the waste is exposed to air. The manure below then decomposes in anaerobic conditions (i.e., no oxygen present). This process creates methane, which is subsequently released into the atmosphere.

Alternatively, manure can be fed directly into an AD tank, with minimal storage. This closed system captures all the methane, not only preventing GHG emissions, but forms the valuable fuel biogas. It's a win-win.

At present, almost all the manure collected worldwide is stored for several months and spread to land untreated. During this time, methane is being released into the atmosphere, contributing significantly to global emissions. By digesting this waste, emissions are minimised, and biogas is created. Moreover, all of the nutrients held within manure are retained – recycling valuable and finite minerals and trace elements back to land through the spreading of digestate (see Chapter 5).

[106] https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE?most_recent_value_desc=true

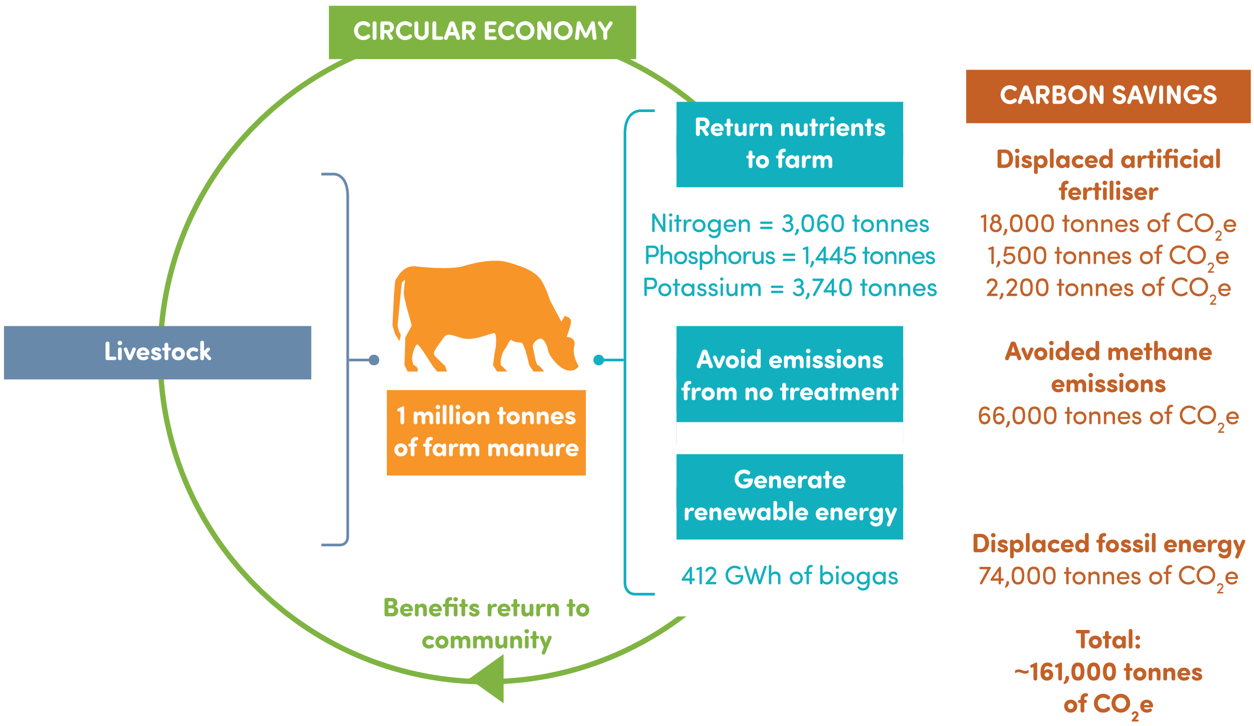
The following map displays the average annual emissions from manure management (all animals) by country between 2008-2018[107]. Countries within Asia are responsible for the greatest proportion of these emissions (44%), specifically China, India and Russia. Europe and the Americas are second (25%) and third (22%) respectively. Moreover, these total emissions have risen consistently during this 10-year period, intensifying the need to address this global issue.



Annual GHG emissions (CO_2e) from manure management 2008-2018

In terms of animals, manure from cows contribute the most to these global emissions – 44% of total manure-based GHG emissions each year. Pigs are second with 34% and chickens are third with 8%. The remainder arises from other farmed animals, such as buffalo, camels, turkeys, horses, goats and donkeys (to name a few).

While manures and slurries have a lower biogas yield compared to other feedstocks, owing to the fact that it has already been digested by the animal, the total amount of waste could generate a significant amount of green energy – nearly 4,000 TWh per year. Again, this assumes that 70% of manures currently collected are digested.



107 http://www.fao.org/faostat/en/#data/GM/visualize

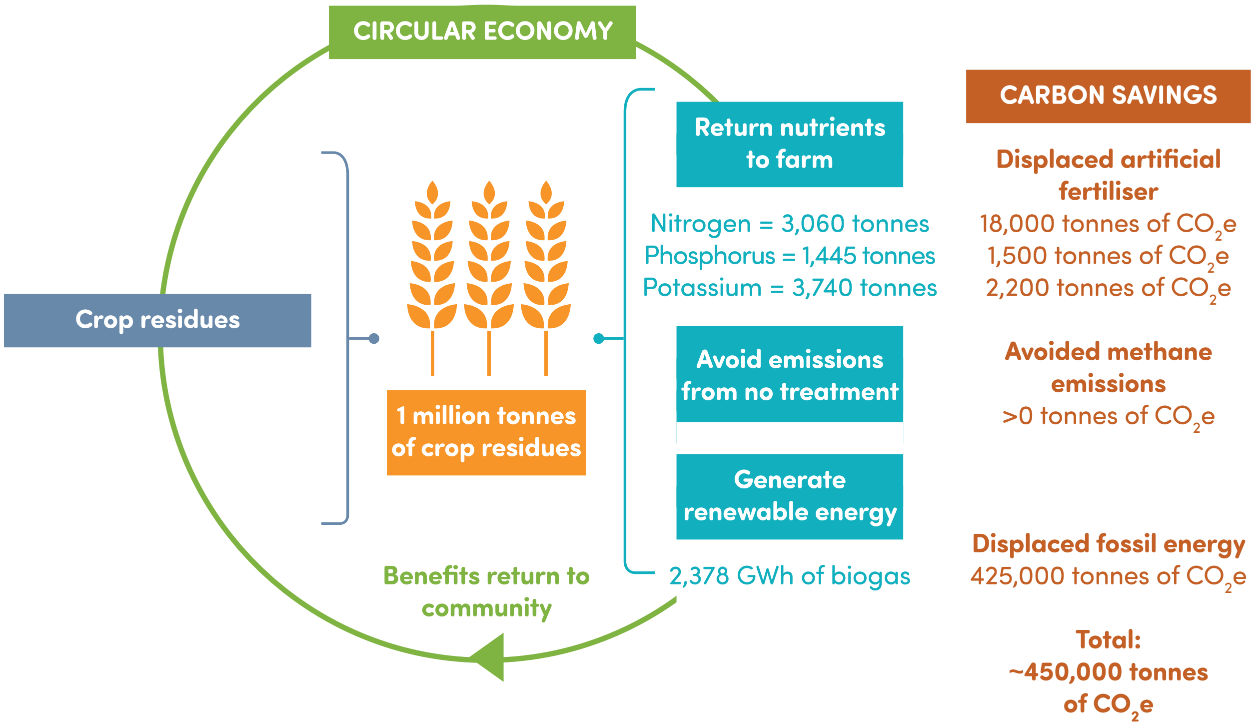
4.3.2 Crop residues

An estimated 2.5 billion tonnes of crop residues are produced each year. Crop residues refer to the non-edible plant material left from harvesting and processing food crops (rice, wheat, maize, rye etc.). This organic material is typically ploughed back into soil untreated or burnt, expelling particulate matter into the atmosphere, adversely impacting air quality.

However, the full value of these bioresources is not being realised. Crop residues typically have a high biogas potential. If 80% of this material is collected and digested, over 4,700 TWh of biogas could be generated. This energy could help power farms and provide fuel for these rural, often remote, communities.

The burning of crop residues is another major source of air pollution, particularly in India and China. In India, the two regions most impacted by this are the Punjab and Haryana where an estimated 35 million tonnes of stubble from rice are burnt in the autumn months to accelerate the planting of winter crops[108]. The smoke from burning drifts across major urban areas and the air quality of New Delhi is notoriously impacted with major repercussions in terms of respiratory illnesses. Despite government announcements restricting such practices, including making burning illegal, the situation seems far from being resolved as alternative treatments cost farmers more than their incomes allow and no incentives to cover the additional cost is currently available.

Similarly, in China there has been widespread burning of agricultural residues where approximately 20% of all stubble is burnt[109]. However, the Chinese Government has introduced incentives against burning, in order to spur farmers to plough residues into the soil, use them for biogas production and other uses. This subsidy, or incentive, is applicable if a minimum 70% of the feedstock is crop straw, husk and or corn crop and pays 0.75CNY/kWh (US$0.12/kWh) including tax[110]. While much still must be done, some 80% of straw residues are now either reused, ploughed in, or consumed in other ways[111]. Sending these residues to AD would not only improve air quality but provide local farms with clean energy and organic fertiliser – improving health and supporting energy and food security.



[108] www.theguardian.com/world/2019/nov/08/indian-farmers-have-no-choice-but-to-burn-stubble-and-break-the-law

[109] www.sciencedirect.com/science/article/abs/pii/S0048969719301676

[110] www.mdpi.com/2071-1050/12/4/1490

[111] www.mdpi.com/2071-1050/11/6/1762/pdf.

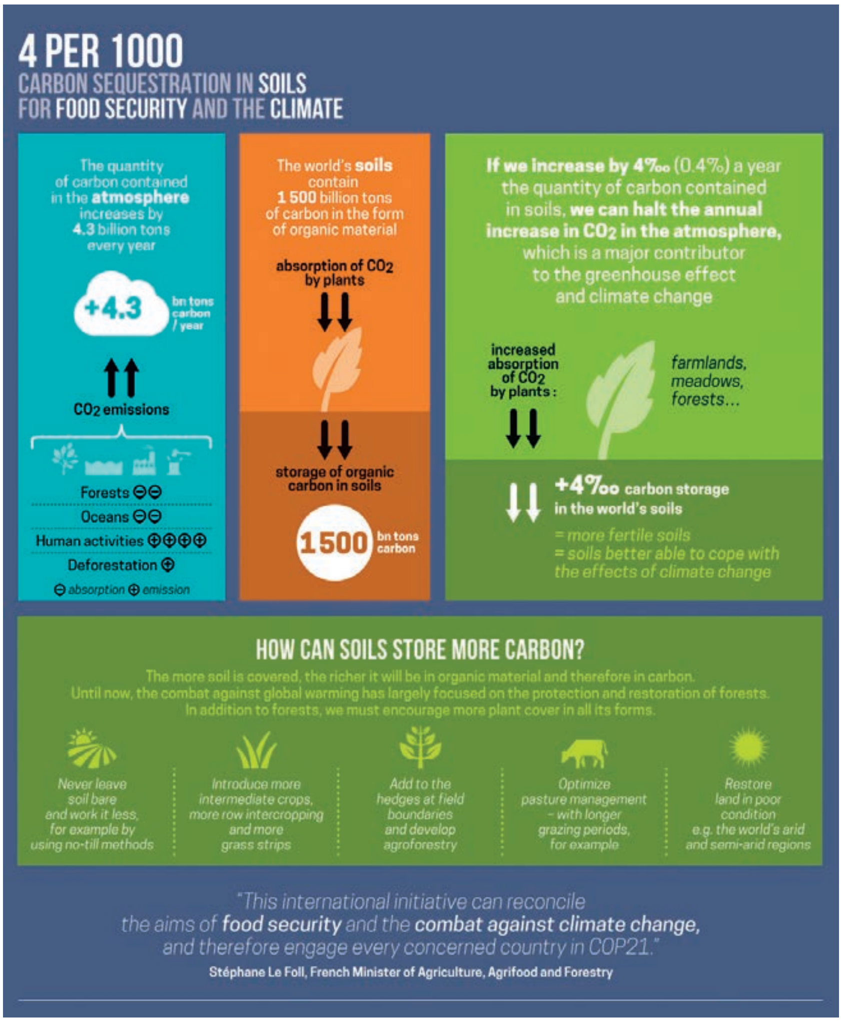
The International Energy Agency (IEA) say crop residues provide around half the global biogas potential today, particularly across Asia and Central South America. The sustainable feedstock in Africa is smaller but would nonetheless be sufficient to meet the needs of the 600 million people in sub-Saharan Africa who remain without access to electricity. **Over 2.6 billion people lack access to clean fuels for cooking; four million people die a year as a result of current practices using wood or kerosene.** Furthermore, the IEA estimate that by 2040, the agricultural sector will remain the largest contributor to global biogas supply potential, with crop residues accounting for over 40% and animal manure for 35% of the total. Availability of animal manure as a feedstock is projected to increase by around 2.5% on average each year, double the rate of increase for crop residues.

Manures, crop residues, animal waste and agricultural by-products form part of a large variety of agricultural feedstock for biogas with little or no other commercial value. Hence, at farmer scale, the most usual way of handling animal waste is direct spreading to soil, which produces significant atmospheric emissions of GHG.

4.3.3 Sequential Cropping

Photosynthesis is nature's way of storing carbon. Globally plant life – trees, hedgerows, grasses, crops – fix around 100 billion tonnes of CO_2 annually, >15% of the total in the atmosphere. The more of the planet that is covered in vegetation the greater the levels of CO_2 will be drawn down. This simple principle underpins many of the actions called for in the IPCC's latest assessment report.

Thanks to the organic matter they contain (from plants and microorganisms), soils store two- to three-times more carbon than the atmosphere. Increasing the annual carbon stock in agricultural soils by 0.4% (or 4 per 1000) in the top 40 centimetres of soil would, in theory, be equivalent to the increase of annual carbon emissions caused by human activity (4,900 million tonnes); i.e. it would make human activity carbon neutral.



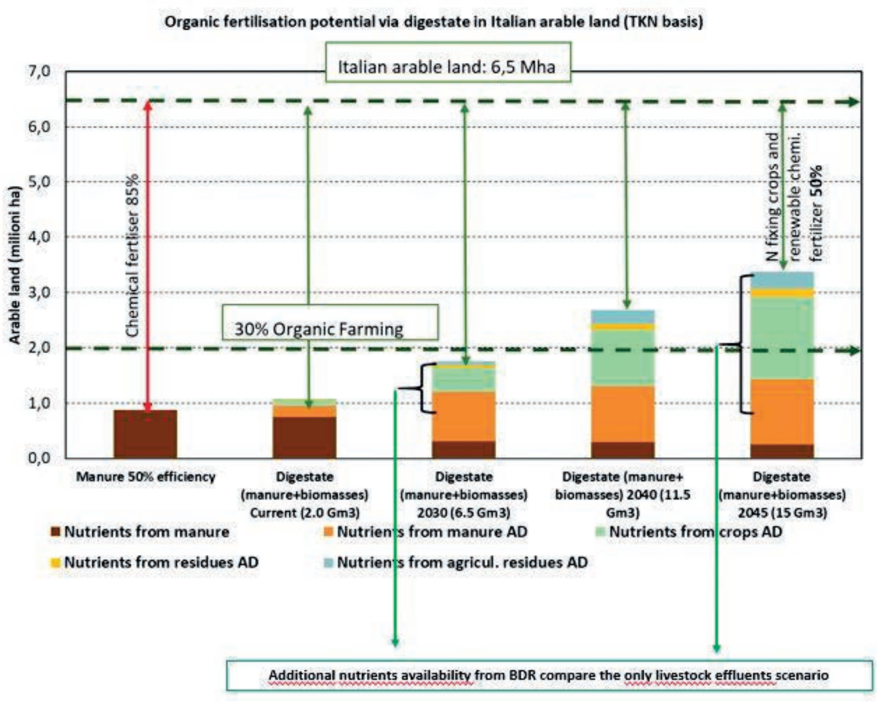
A recent study on how to achieve this undertaken by INRA, France's new National Research Institute for Agriculture, Food and Environment, highlighted three key actions as the most effective means of increasing the carbon content of soils: double cropping, minimum tillage and the use of new organic resources such as digestate and biochar.

These are the three key pillars of the **Biogasdoneright™ model**. Widely practiced in Italy, this farming system is based on a model developed for biofuels production by Professor Bruce E Dale of Michigan State University. This Biofuels Done Right study set out to show how using less than 30% of total US cropland, pasture and range, 400 billion litres of ethanol could be produced annually **without decreasing domestic food production or agricultural exports**. "This approach also reduces US greenhouse gas emissions by 670 $MtCO_2e$ per year, or over 10% of total US annual emissions, while increasing soil fertility and promoting biodiversity. Thus, we can replace a large fraction of US petroleum consumption without indirect land use change."

This was the blueprint that inspired CIB, the Italian Biogas Consortium. The model incorporates the principles of conservation farming, which in southern Italy helps to retain humidity in the soils during the seeding season. Conservation farming is defined by the UN Food and Agriculture Organisation as "a farming system that promotes the minimum soil disturbance, maintenance of a permanent soil cover and diversification of plant species".

One of CIB's founding fathers Stefano Bozzetto says, "In farming we not only have to decarbonise, we are called on to **recarbonise** our systems. We need farming to produce more by using resources in a more efficient way, using less land and producing more per drop of water, per unit of energy and per unit of carbon, per unit of input."

Under the Biogasdoneright system no livestock effluent is disposed of, as it is a valuable digester feedstock. Bozzetto's land is now covered for at least 11 out of 12 months, with winter and summer silage cover crops sown after the main crop for feed or market. "This is now possible as there is local demand for it from an AD plant." Organic fertilisation is up to 80-90% from 1-3%. Mineral fertilisers are only used when digestate is not available and occasionally during seed planting – nitrogen, potassium and micro-nutrients. The farm has adopted a system of precision farming, using digital GPS, the Internet of Things (IoT) and drones to monitor and map the land and soil health and dribble bar spreaders. The farm uses strip tilling as much as possible, which is an evident and natural consequence of double cropping. "Precision farming is helping us to maximise outputs from inputs," Bozzetto says. "Soil carbon and biological fertility and soil compaction are not a freak issue anymore but well understood."



The EU aims to switch 30% of farms to organic production by 2030, which will require an increase in the availability of natural fertiliser. The above graphic shows how the Biogasdoneright model enables Italy to achieve this.

In the US, a US$10m study is underway into a similar model to Biogasdoneright, known as C-CHANGE – the Consortium for Cultivating Human and Natural reGenerative Enterprise – the five-year programme will seek to create new value chains on US farms, with emphasis on the generation of renewable natural gas (RNG) from 'cover crops' and the sowing of prairie grasses on marginal land. Meanwhile, the Agricultural Resilience Act before Congress seeks to embed RNG production in agricultural systems to build rural economies and farm resilience.

Reward environmental services

In rare instances the environmental services provided by AD have been recognised. Denmark is famed for its bacon. In the 1980s pigs notoriously outnumbered people 5 to 1; the human population being around five million. Farmers routinely spread the pig manure to the land, causing nitrification, or let the slurry run off directly into the waterways, causing eutrophication, adversely impacting the farming and fishing industries respectively.

A raft of environmental regulations was introduced as a consequence. A requirement to have enough slurry storage for 6-9 months of the year and nitrogen limits on spreading to land meant farmers had to rethink their manure management strategies. On the back of this, the Danish Energy Association, Environmental Protection Agency and Ministry of Agriculture joined forces to develop the Biogas Action Plan (1988) (BAP). Grants of up to 40% were made available for biogas development.

In 2015, experiencing similar adverse environmental impacts from a nutrient overload to Denmark, China launched its first five-year plan to protect its waterways, with biogas being a cornerstone mitigation.

Also in 2015, France introduced a tariff rate of €220 per MWh for units below 80kW with more than 60% animal manure by volume as feedstock. It is nearly three times the rate being offered to domestic waste facilities above 2MWh, €81.2. The French tariff was introduced in recognition of the myriad environmental services AD delivers, targeting farms with herds of up to 200 cows, or between 200 to 5,000 tonnes of organic waste per year. It aims to enable small farms to reduce GHGs related to livestock manure and energy consumption; reduce the strong odours associated with the use of untreated manure as fertiliser; minimise the need to transport the organic inputs for treatment; and benefit from the advantages of digestate, which it details as being easier to spread, with fewer weeds, less need for pesticides and petro-chemical fertiliser.

These initiatives, however, are the exception rather than the rule. Nutrient management plans, sustainability criteria for crop feedstocks, crop residue management, use of manures, are all important for the development of rural biogas where the potential for building small to medium sized plants remains largely untapped.

Rural development of biogas is especially relevant to delivering certain SDGs, especially in regard to gender equality, farm yields, drought and desertification mitigation, and reducing deforestation. AD can provide multiple business and positive environmental and social outcomes to farmers around the world. It presents an opportunity to diversify the business and generate renewable energy, helps manure management and provides a platform for improved soil management techniques and nutrient management plans through the use of digestate.

Deploying on farm AD facilities will require governmental support and will be paramount to achieve net zero across agricultural production and land use. One way of helping in this transition is by developing forms of carbon accounting, benefiting from the provision of negative emissions via carbon capture alongside climate-friendly agricultural production.

4.4 Overview of policy recommendations

Support for wastewater treatment infrastructure

Management of wastewater is not only a climate priority but an essential for human health to deliver hygienic sanitation systems. Developing sanitation infrastructure, which also anaerobically digests the collected wastewater, should be a priority for any national government. In parts of the world where sanitation systems are still rudimentary, integrated infrastructure can be developed that incorporates AD in the sewage treatment process, generating the energy requirements of the intensive treatment process on-site, using biogas. These sanitation solutions can be large scale or community systems depending on the political will and project funding available.

Projects looking to develop low-carbon sanitation infrastructure should be granted finance from funds such as the UNFCCC's Green Climate Fund or alternative funds to support progress towards the Sustainable Development Goals, which must be met by 2030. In countries and localities that already have established sanitation systems, the infrastructure should be developed to incorporate AD into the treatment process to use the wastewater to generate energy, which again can be used in a circular way to power the energy-intensive treatment process.

Organic material management hierarchy

Across all organic wastes being generated by human activities, there should be clear guidelines for the most resource efficient way for these materials to be treated. The FAO provide a food and drink materials hierarchy in their guidance on food waste prevention and reduction, setting out that this organic material should first be avoided and redistributed where possible, if not it should be recycled, primarily through AD, and if this is not possible then as a last resort it should go to incineration or landfill.

While this is valuable guidance it needs to be adopted more widely and the scope expanded to cover all organic materials. It is also not sufficient on its own to deliver the desired outcome. The guidance needs to be accompanied by enforcement policies, such as a ban on all organic wastes going to landfill, a supportive tax structure that makes the most environmentally friendly treatment method, namely AD, also the most cost effective for businesses such as food manufacturing companies.

Food waste collection and treatment

Currently around one-third of all food grown for human consumption is thrown away . As an urgent priority, countries worldwide must reduce food waste production. While some of this waste can be redistributed to humans or animals, and should be, it is vital that the unavoidable food waste is treated as the valuable resource that it is. The introduction of separate food waste collections is another key policy that must be implemented to deliver a more climate compatible waste management system. Many countries such as Wales, South Korea and Sweden already have separate food waste collections and there are plans in place to introduce separate food waste collection across the EU by 2023. In much of the global north separate food waste collection should be implemented within the first half of this decade, across both urban and rural areas.

In the global south, separate food waste collections should be a policy priority for urban areas, particularly as these will be the most densely populated areas where the majority of a country's food waste is generated. In more rural areas, policies should be introduced to develop small-scale community AD projects that can capture local food waste, along with any farm waste and combined with local sanitation solutions. This should be developed as a community grant scheme to support the initial capital investment requirement. If government funding is not available, industry can seek finance from UNFCCC's Green Climate Fund and other green development funds (see Chapter 3).

[112] www.unenvironment.org/thinkeatsave/get-informed/worldwide-food-waste

Sustainable agriculture payment scheme for farm waste treatment

Agriculture is the largest single source of human caused methane emissions[113], responsible for over two-fifths globally, with livestock rearing and rice cultivation the two largest contributors. To tackle GHG emissions there must be a radical shift in how we grow our food. Methane emissions from both livestock rearing and rice cultivation can be significantly reduced if the wastes generated from their production, i.e., manures, slurries and rice straw, are treated through AD. Other organic farm wastes can be diverted to AD to prevent potential GHG emissions being released if they are not managed sustainably, which will further contribute to carbon emission savings from the agricultural sector.

Policy to support a transition to more sustainable domestic agricultural systems is therefore vital to limiting global warming to 2°C or below. Strategic frameworks to mitigate methane emissions, following the example of the EU's Methane Strategy, must include treatment of farm wastes through AD to cut agricultural emissions with robust domestic policies to support this. Sustainable agriculture schemes should be developed that reward farmers for environmental farming practices, and these must include payments for the treatment of methane emitting farm wastes through AD. In addition, countries that already have agricultural support systems in place that make payments according to size of land cultivated, such as the EU, need to overhaul these and replace them with payment systems based on environmental services delivered.

[113] www.climatewatchdata.org/data-explorer/historical-emissions?historical-emissions-data-sources=cait&historical-emissions-gases=all-ghg&historical-emissions-regions=All&historical-emissions-sectors=total-including-lucf&page=1

Chapter 5: Digestate Policy

By volume, digestate is the greatest output from anaerobic digestion (AD). "Digestate" describes the feedstock after it has been degassed. Scientists generally add the suffix 'ate' to indicate the consequence of an action; the by-product of anaerobic *digestion* is therefore digest – ate, the consequence of digestion. For every tonne of feedstock degassed within a digester, ~50-85% by weight emerges as digestate.

Digestate is a natural fertiliser, recovering and recycling nutrients from treated feedstocks. From a life cycle perspective, AD recovers nutrients that otherwise would have been lost to landfills or water bodies. All of the nutrients held within organic wastes are retained within digestate. As such, digestate is also referred to by several other names worldwide, including biofertiliser and organic/natural fertiliser.

The nutrient value of digestate makes it a ready replacement for fossil-heavy mineral fertiliser and its use should be encouraged in the drive to decarbonise agriculture. See Digestate Policy Timeline, p94.

AD can be visualised as a spectrum, running from wet to dry. The technology can be configured to operate at any point in between. In Italy, for instance, you will hear some operators refer to their AD plant being medium dry – referring to both the feedstock input and digestate output. Dry AD treats materials with higher lignin content – such as agricultural straws, or green waste from parks and gardens. Wet AD treats feedstock with a higher liquid content, such as manures, slurries and food wastes. What goes in determines both the consistency and nutrient content of the digestate.

Generally, digestate typically comes in three forms:

a. Whole Similar in appearance to livestock slurry, often with less than 5% dry matter (DM), this material comes straight out of the digester

AD plants may choose to then separate digestate into its two component parts:

b. Liquor A liquid biofertiliser where most of the dry matter has been separated out
c. Fibre A solid biofertiliser composed of the remaining separated dry matter.

5.1 Fertiliser markets

In this chapter, all references relating to fertilisers are in terms of the three primary plant nutrients: nitrogen (N), phosphorus (P), and potassium (K). When these nutrients are discussed together, they are often referred to as NPK. The following details the typical nutrient content of digestate derived from food- and farm-based feedstocks:

Nitrogen, along with phosphorus, is one of the key building blocks of life; all organisms require nitrogen to live and grow. Although the majority of the air we breathe is N_2, most of the nitrogen in the atmosphere is unavailable for use by organisms. This is because of its complex 'unreactive' structure.

Plants need reactive nitrogen to thrive, which they traditionally derived from the centuries old organic wastes contained in soils, which delivered nitrate from the stored organic matter as it migrated closer to the surface. Microbial activity and environmental conditions (soil moisture and oxygen levels, for example) convert nitrogen into this reactive state, suitable for plant absorption.

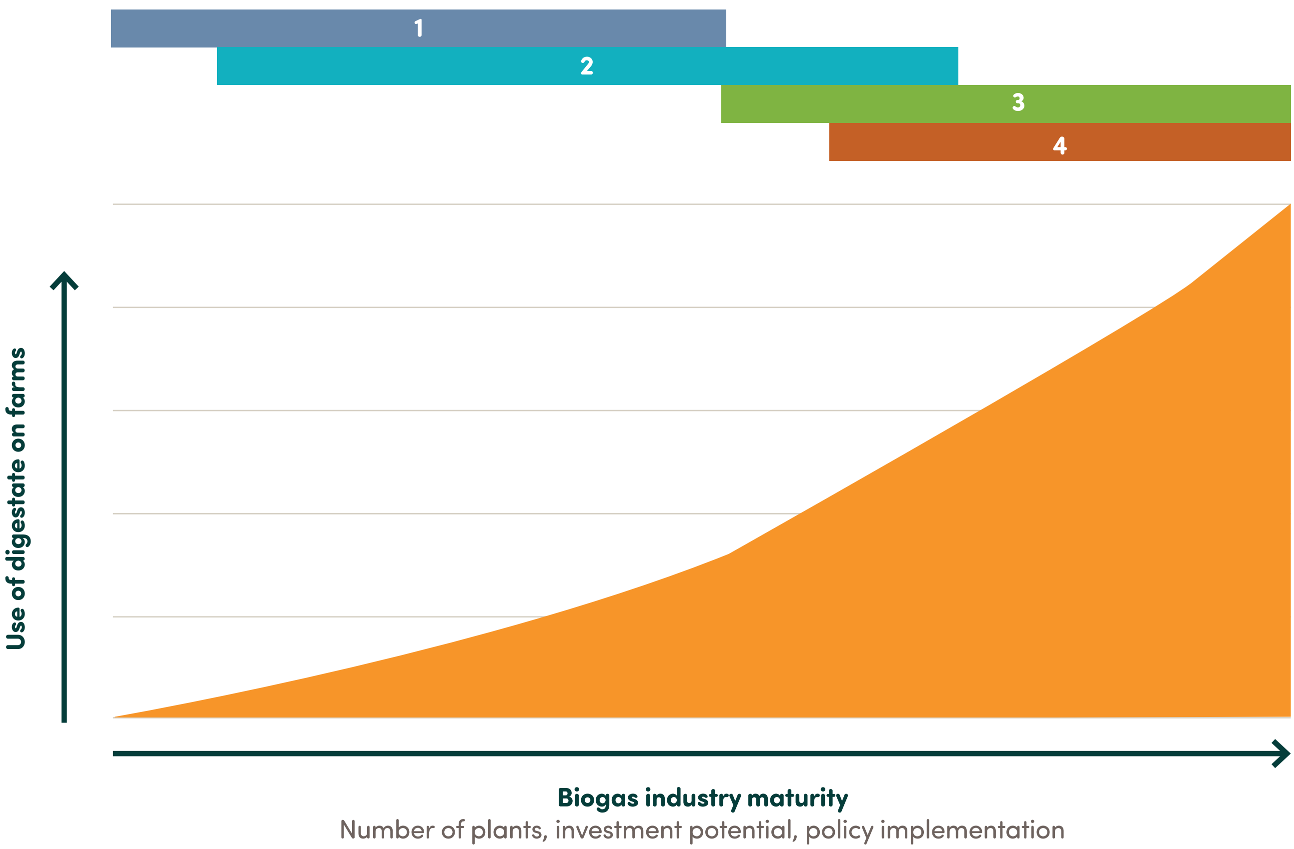
Digestate Policy Timeline

(1) Effective regulation and guidance should be put in place to support farmers to use digestate as a renewable fertiliser instead of fossil-heavy mineral fertilisers. This should cover best practice spreading techniques, nutrient management plans, and optimal timings for spreading to deliver greatest value back to the soil and support crop yield. The regulations should also support mitigation of environmental risk as with all fertiliser use. This should aim to minimise ammonia emissions from digestate storage and spreading.

(2) Regulation must be developed to ensure food waste sent to AD plants is of a high quality and is not contaminated with plastic such as food packaging or other contaminants. While these can be removed as part of the AD process, fragments will remain and the cleaner the waste received by the plant the less risk there is of contaminants being spread to soil. The regulations should set limits on contamination levels allowable in feedstock received and place the responsibility on the producer of the waste to prevent contamination.

(3) Incentives should be put in place to reward sustainable agriculture. In areas of the world where agriculture is heavily dependent on subsidy systems, these payments should be overhauled to incentivise sustainable agricultural practices, particularly cutting carbon emissions. Such payment systems to reward sustainable agriculture must include the utilisation of digestate in place of fossil-heavy mineral fertilisers when spread in line with best practice techniques. This should be accompanied by targets for the level of renewable fertilisers in use.

(4) Innovation funding should be provided for the development of new technologies to prevent fugitive ammonia emissions from the spreading and storage of digestate to further mitigate the environmental risk associated with this. Grant funding should be available for development and commercialisation as well as the adoption of novel technologies.



The following tables present the typical nutrient content of digestate from food-based and farm-based digestate via wet AD. Note, that digestate from dry AD has much higher dry matter content, with a consistency and nutrient concentrations closer to compost. Discussed in more detail later in the chapter, wet-AD digestate can act as a valuable fertiliser, whereas dry-AD digestate and compost are better suited as a soil improver, supporting soil structure. Both soil fertilisers and improvers can play a vital role in improving agricultural productivity.

Nutrient values of digestate

Typical total nutrient contents for food-based digestate

Type	Dry matter %	Total N	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
	kg/m³ or kg/t					
Whole	4.1	4.8[a,b]	1.1	2.4	0.2	0.7
Separated liquor	3.8	4.5[a,b]	1.0	2.8	0.2	1.0
Separated fibre	27.0	8.9[c]	10.2	3.0	2.2	4.1

Typical total nutrient contents for farm-sourced digestate

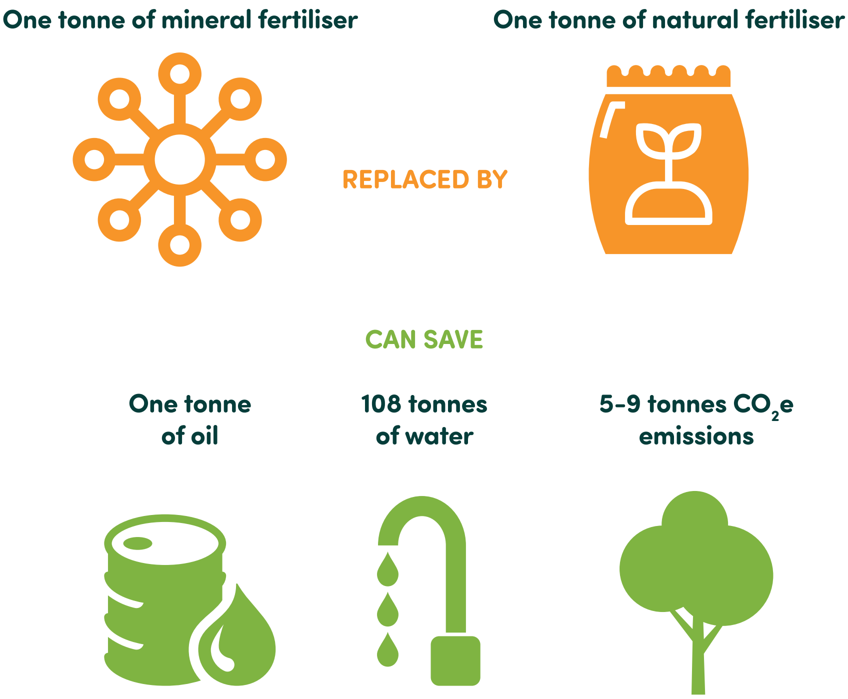
Type	Dry matter %	Total N	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
	kg/m³ or kg/t					
Whole	5.5	3.6[a,b]	1.7	4.4	0.6	0.8
Separated liquor	3.0	1.9[a,b]	0.6	2.5	0.4	<0.1
Separated fibre	24.0	5.6[c]	4.7	6.0	1.8	2.1

© Nutrient Management Guide (RB209)

In 1960-70, the Green Revolution introduced the new age of agriculture, where artificial fertilisers, pesticides and new industrial equipment significantly increased agricultural productivity worldwide. Subsequently, agriculture's reliance on mineral fertilisers has increased year on year.

Mineral fertilisers are fertilisers manufactured using artificial processes, fixing chemicals into usable forms. By far, the most common process is the Haber Bosch, which combines nitrogen gas (N_2) from the atmosphere with hydrogen from fossil natural gas (CH_4) to form liquid ammonium (NH_4). This process requires vast quantities of natural gas and energy. According to multiple studies, this uses 3-5% of the world's natural gas production – around 1-2% of the world's annual energy supply – to produce around 450 million tonnes of nitrogen fertiliser a year.

Natural fertiliser avoids all this. Digestate can help displace the demand for mineral fertilisers, providing nutrients recovered from organic wastes. Digestate consequently cuts our reliance on fossil natural gas, the need to transport these fertilisers worldwide, and all the emissions incurred from this supply chain.

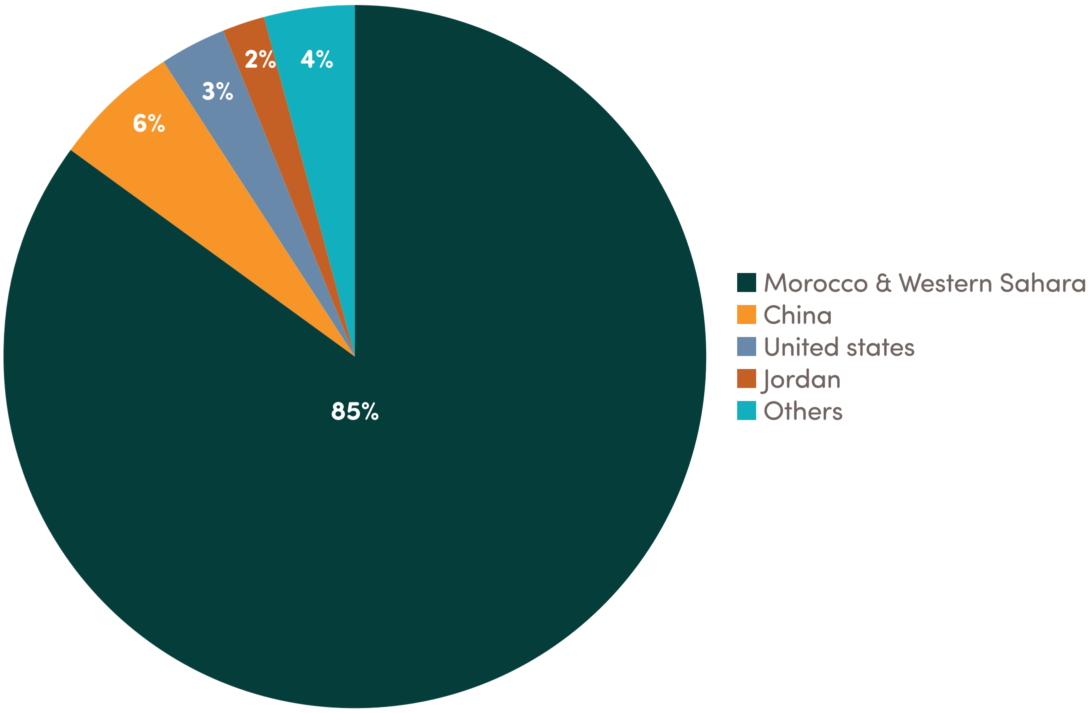


Since the Green Revolution farmers have relied on applying reactive nitrogen, primarily in the form of nitrates (NO_3) – ammonium nitrate being among the most popular - to increase yields. However, reactive nitrogen also allows the microbes that convert unreactive nitrogen to NO_3 to thrive. This serves to weaken soil structure and ultimately causes the release of ammonia and nitrous oxide (N_2O). This degradation is accelerated by repeated compaction and ploughing.

Furthermore, if too much NO_3 is applied, leaching occurs, from both the nitrate applied and the nitrate converted from stored organic matter. The critical issue here is that while the release of such gases is statistically small compared to CO_2, they are much more harmful pollutants: N_2O is 300 times more potent than CO_2 as a GHG, and ammonia reduces air quality and drives eutrophication and aquatic ecosystems. The cost of the overall N_2O damage is £60-80 billion a year, a sum more than double the extra income gained from using nitrogen fertilisers in European agriculture[114].

The cycle of manufactured nitrogen is unsustainable. When applied to crops only about ~30-40% goes to the food chain, with the remainder being lost to the atmosphere or waterways. On top of this, 12.5% of the food chain nitrogen is excreted by humans and sent to wastewater treatment plants to be returned to atmospheric nitrogen through aeration, using again two litres of fossil fuel to produce one kilogram of nitrogen.

"Using such quantities of fossil fuel energy to take from and then return nitrogen to the atmosphere is simply not sustainable," says Professor Willy Verstraete of Ghent University[115].



The global distribution of phosphate reserves

Phosphorus is also critical for food production, requiring 3kg per person per year. 85% of the world's phosphate rock is located and mined in Morocco. The Global Phosphorus Research Initiative, led by Swedish and Australian scientists, estimates that the world's readily available phosphorus supplies will be inadequate to meet agricultural demand within 30 to 40 years. Others predict shortages sooner rather than later. Estimates for world reserves and resources of phosphate rock vary widely and can change with different assumptions about economic viability, technologies for access and extraction and with new exploration data. IFA (International Fertiliser Association) data indicates ~270 million tonnes of phosphate rock are sold annuallyy[116].

[114] www.tsnf.org.uk

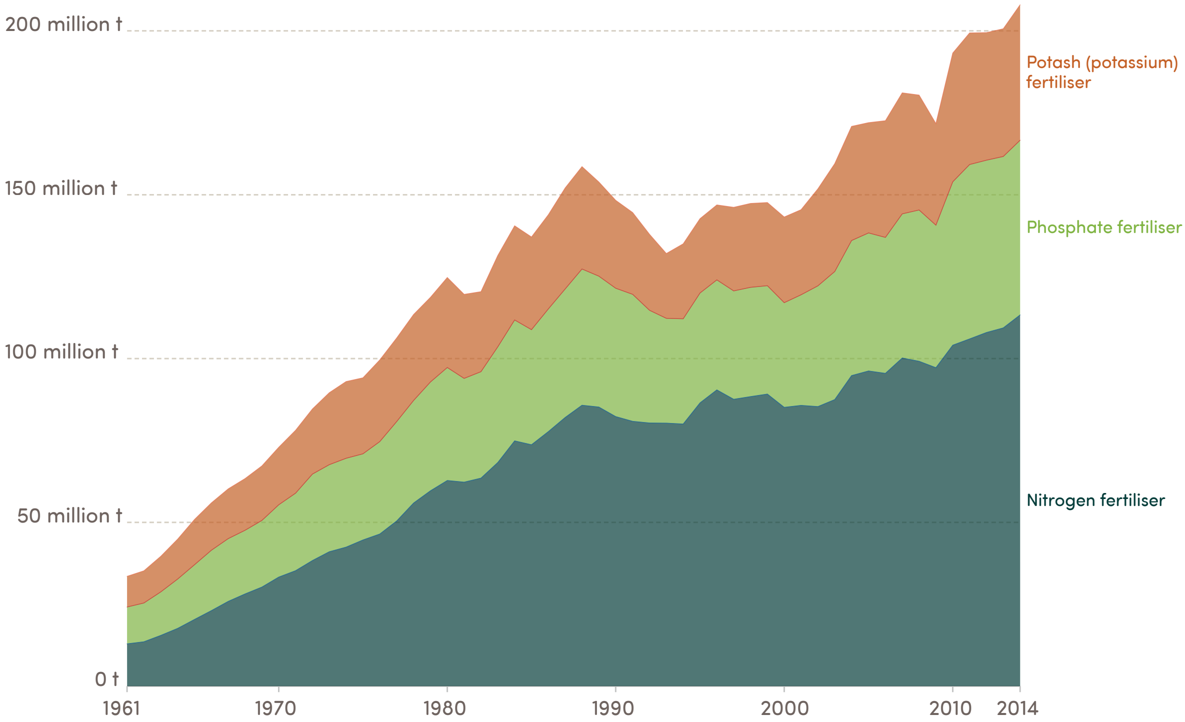
[115] https://adbioresources.org/newsroom/ad-bioresources-news-issue-43-spring-2019/

[116] www.phosphorusplatform.eu/home2

Today, the world can produce almost three-times as much cereal from a given area of land as it did in 1961, principally as a result of intensive farming methods with a reliance on mineral fertiliser.

Total fertiliser production by nutrient, World, 1961 to 2014

Total fertiliser production by nutrient type (nitrogen, phosphate and potash/potassium), measured in tonnes per year.

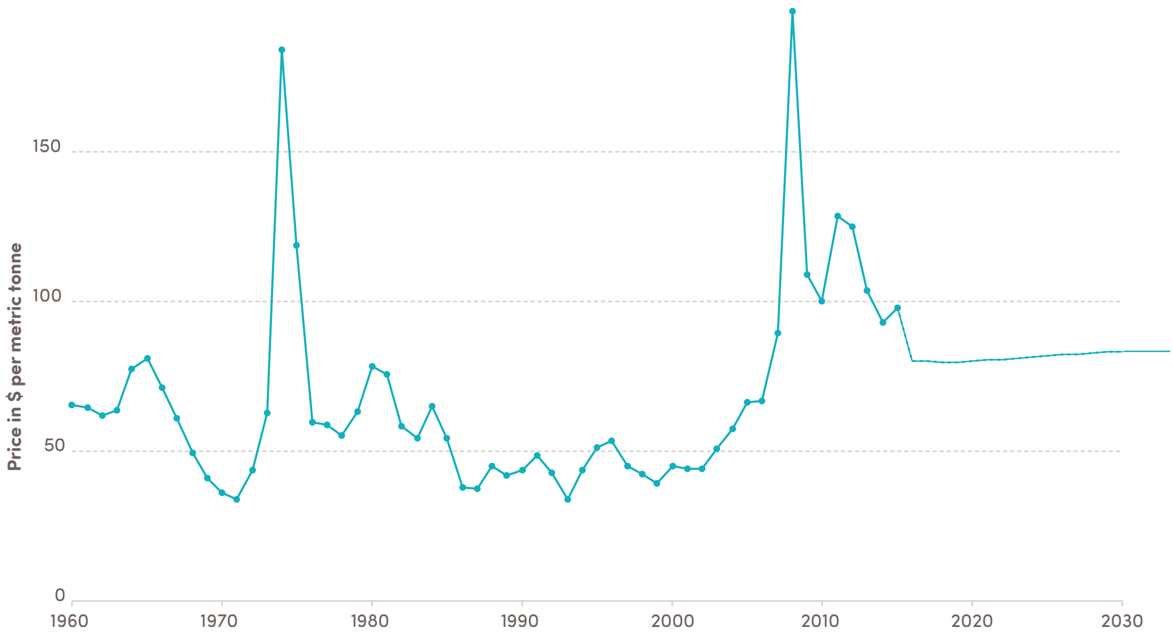


Source: UN Food and Agricultural Organisation (FAO)

The price of mineral fertiliser is forecast to increase over the remainder of the decade (see chart below). Note also the sensitivity to geo-political events – the 1970s oil crisis and 2008 crash.

Fertiliser Price Index, World, 1960 to 2030

Global fertiliser price index, measured relative to real prices in 2010 (where 2010 = 100). Also shown are World Bank projections of fertiliser prices to 2030.



Source: World Bank (2017)

Mineral fertilisers deliver no organic matter to the soil. Consequently, mineral fertiliser use is affected by the law of diminishing returns – more needs to be applied to maintain yields to compensate for the damage to soil. Fertiliser consumption varies widely worldwide[117]:

- **Brazil**, ~186 kg per hectare of arable land
- **China**, ~503 kg per hectare of arable land
- **Democratic Republic of Congo**, 3 kg per hectare of arable land
- **India**, ~165 kg per hectare of arable land
- **Indonesia**, ~231 kg per hectare of arable land
- **Ireland**, >1,240 kg per hectare of arable land
- **Morocco**, ~71 kg per hectare of arable land
- **South Africa**, 59 kg per hectare of arable land
- **USA**, ~138 kg per hectare of arable land
- **UK**, ~253 kg per hectare of arable land

5.2 Soil organic carbon

All soil is composed of four fundamental components: minerals, water, air, and organic matter. It can take many hundreds of years to form but can be destroyed very quickly (sometimes within decades) through poor land management practices. While organic matter represents the smallest fraction by volume in most soils (typically <5%), its presence often determines the soil's health and productivity. Soil organic matter (SOM) crucially supports soil structure and its ability to retain nutrients and water necessary for plant growth. Increasing organic matter content results in increased crop yields, particularly in soils with less than 2% SOM[118].

Moreover, SOM is carbon rich. Around 560,000 million tonnes of carbon are stored in SOM – this is the equivalent to 70% of all carbon in the atmosphere[119]. Therefore, soil is one of the largest carbon sinks in the world, locking away significant quantities of carbon and preventing it from contributing to GHG emissions. And yet, global levels of SOM are in decline, posing concerning risks to agricultural productivity and global warming.

Haney: *"We know that over the past 50 years the levels of organic matter — it is kind of a standard test for soil in terms of its health and fertility — have been going way down. That's alarming. We see organic matter levels in some fields of 1% or less. Whereas, you can go to a pasture sitting right next to it where organics levels are 5-6%. So that is how drastically we have altered these systems. We are destroying the organic matter in the soil, and we've got to bring that back to sustain life on this planet. The good news is that soil will come back if you give it a chance. It is very robust and resilient. It's not like we have destroyed it to the point where it can't be fixed. The soil health movement is trying to bring those organic levels back up and get soil to a higher functioning state."*

What has caused this decline in soil quality?

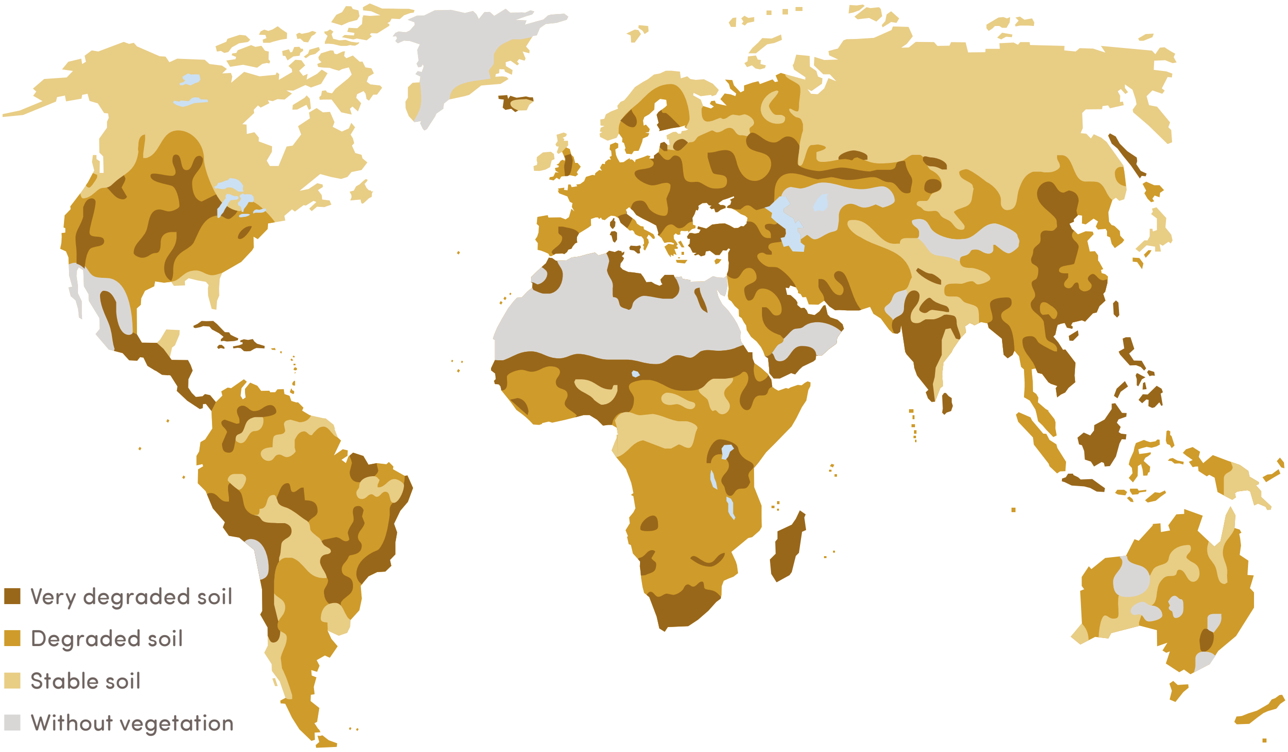
Haney: *"We see that when there is a lot of tillage, no cover crops, a system of high intensity [chemical-dependent] farming, that the soil just doesn't function properly. The biology is not doing much. It's not performing as we need it to. We are essentially destroying the functionality of soil, so that you have to feed it more and more synthetic fertilizers just to keep growing this crop."*
USDA Researcher Rick Haney speaking to Yale e360[120]

[117] https://data.worldbank.org/indicator/AG.CON.FERT.ZS?end=2016&start=2002

[118] https://environment.yale.edu/news/article/commonly-held-premise-on-link-between-soil-carbon-and-crop-yield-is-valid-to-a-point/

[119] www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/

[120] https://e360.yale.edu/features/why-its-time-to-stop-punishing-our-soils-with-fertilizers-and-chemicals



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Over the last 40 years about 30% of the world's cropland has become unproductive, with an estimated 10 million hectares of agricultural land being lost through soil erosion every year[121]. The United Nations' Food and Agriculture Organization (FAO) reported in 2015 that global soils were degrading so quickly that there may only be 60 harvests left[122].

Mineral fertilisers do not contain organic matter. Therefore, each year the soil's natural organic matter is eroded away by farming equipment and weather, and not replaced.

In a briefing note to the IPCC, scientists from the University of Sheffield's Grantham Centre for Sustainable Futures warned that erosion rates from ploughed fields averages 10-100 times greater than rates of soil formation and leads to preferential removal of organic matter and clay, removing nutrients and releasing CO_2.

"Soil is becoming a hydroponic system: a physical substrate to support plants but providing little else. In particular, deep ploughing has caused a decline of soil organic carbon, reducing soil's abilities to retain water and supply nutrients, and a loss of structure that allows rapid soil erosion[123]."

To futureproof agriculture, the report called for a radical shift in farming practice, from the current intensive farming model to what it called "a model for sustainable intensive farming", incorporating natural (organic) fertiliser application, including the recycling of nutrients from sewage, crop rotation, reduced ploughing and crop development to build up natural resilience and wean crops off their reliance on manufactured fertiliser.

It describes a whole-systems approach similar to the Biogasdoneright model (see Chapter 4.3 Agricultural feedstocks). In a study undertaken for the Society of Chemical Industry, Professor Bruce E Dale of Michigan State University concluded "soil carbon levels are further enhanced by the double-crop, primarily by decomposing roots from the double-crop".

[121] www.iswa.org/media/publications/iswa-soils-project/

[122] www.fao.org/soils-2015/events/detail/en/c/338738/

[123] http://grantham.sheffield.ac.uk/soil-loss-an-unfolding-global-disaster/

He continued, "Thus the double-crop also increases soil organic matter and soil fertility. Long-term digestate administration to the fields can lead to higher organic matter content of the soils. This practice enables long-term soil carbon sequestration. Thus, the fertility of the farm increases over time by applying digester solid residues and the farm becomes more capable of food production, not less so." Other benefits of double cropping he said were reduced soil erosion, further protecting soils, and more efficient capture of mobile soil nutrients for recycling on farm, which served to protect water supplies. Dale said, "The overall system therefore functions as a biological carbon capture and sequestration (BECCS) process[124]."

A further report into the system, *Biogasdoneright: Soil Carbon Sequestration and Efficiency in Agriculture*, by Bezzi, Maggioni and Pieroni, concluded that "the continuous application of digestate had a significant effect on the content of soil organic matter content, which increased by **0.5%, from 2.2% to 2.7% in seven years**. This confirms the positive effect of continuous input of organic matter on the increase of soil carbon stocks".

A UK study undertaken by Future Biogas delivered similar results.

Increasing soil organic matter with digestate

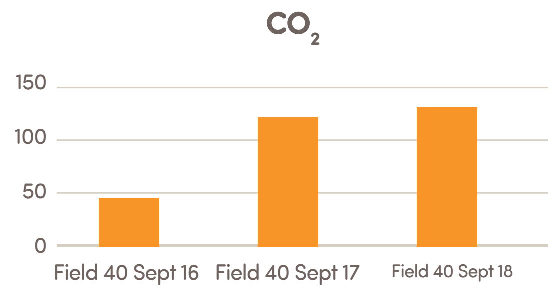
Jon Myhill, Technical Feedstock Manager with Future Biogas, reports similar findings from a study looking at the interaction of liquid digestate on a light Norfolk soil in the UK. The trial found that repeated applications of digestate increased microbial biomass and organic matter, therefore improving the health of the soil, and resulting in improved yields.

From the study he concluded, "Potential increases in both organic matter and microbial biomass levels are possible with the use of energy crops and the use of the resulting digestate. Light, overworked soils are particularly prone to erosion without the increases in soil life we are demonstrating with applications of digestate."

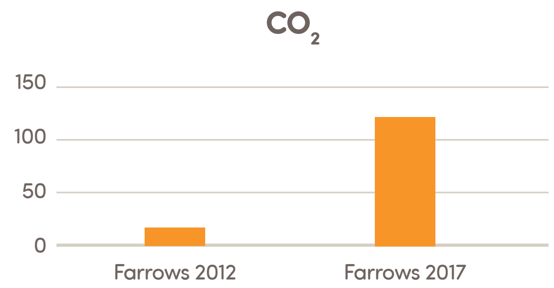
Other key findings from the Future Biogas trial were:

- **Sugar beet yields:** In 2017, a large Estate in north Norfolk concluded that they achieved 11% more yield where solid digestate was used as part of the fertiliser programme for sugar beet, compared to untreated fields. This was conducted on 100ha. The main benefit was the slow release of the available nutrients, especially nitrogen in this case

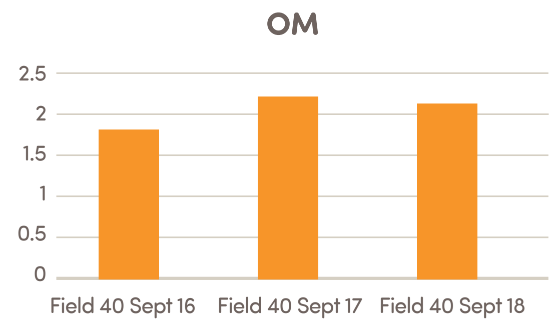
- **Rotations:** The use of energy crops allowed the farmers to extend their crop rotations, coupled with adding extra organic matter back into the soil; using digestate did boost the fertility of their soil and their farm's overall profitability. These farmers are experiencing improved yields in crops like cereals, potatoes and sugar beet.



Soils becoming "healthier"; CO_2 burst, measuring the microbial biomass indicator species. Multiple applications of digestate on an annual basis have increased the level of micro biological soil life.



Different location of a long term monitored field: this field has been receiving regular applications of digestate since 2012, showing a 12-fold increase in microbial biomass

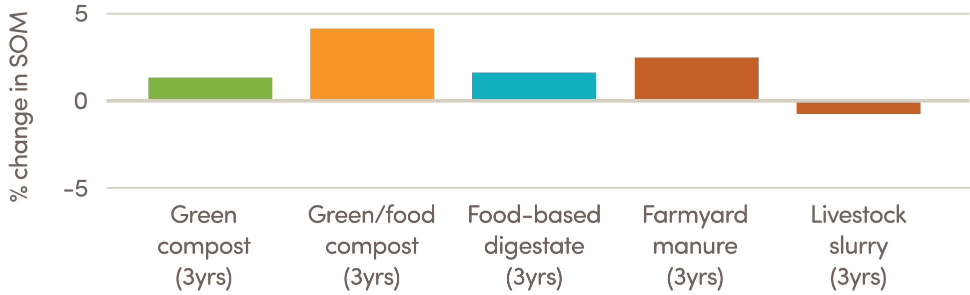


Organic matter, showing an increase on 2016 initial start – 11% increase from the base level; 1% organic matter will hold 75,000 litres of water per hectare. Therefore, the soil is more resilient to drought. The above trial also looked at how the maize yields where were impacted: Year 1 (before digestate application) the fields were 24% behind the average yields. Year 3 (after repeated digestate application) the fields were 3% behind average. Not only did the soil become more fertile and healthier, the farmer saw a financial benefit from improved yields.

[124] www.researchgate.net/publication/305371248_Biogasdoneright_An_innovative_new_system_is_commercialized_in_Italy

The benchmark study on the use of natural fertilisers in the UK was undertaken by DC Agri on behalf of WRAP. The study looked at the impacts of digestate (household and farm wastes), slurries, farmyard manures (FYM), and compost over a five-year period. It also found digestate was beneficial in delivering both readily available nutrients (NPK) and organic matter.

Digestate's capabilities as a soil improver have often been overlooked as it compares unfavourably to compost, in containing more readily-available nutrients (RAN) for plant uptake and less 'effective organic matter' (EOM) which is required to improve soil organic matter (hummus).



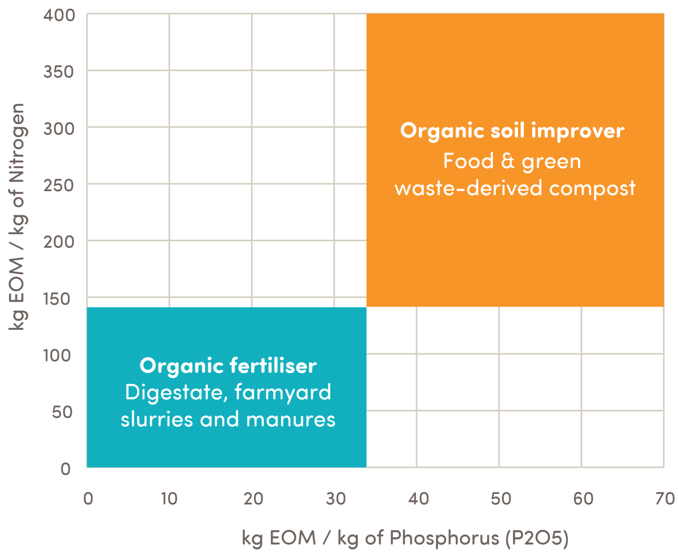
Soil organic matter content can be improved through the application of organic fertilisers over time. Results are expressed as a percentage difference from the control treatment (bagged fertiliser only). Digestate not only supports increased organic matter content akin to compost, but also provide all the key nutrients required for enhancing plant productivity.

The chart below reflects the findings of a study into the respective benefits of digestate and compost[125]. It suggests that:

- An organic soil improver should contain a high level of EOM to contribute to soil organic matter and should be low in nutrients as it is not a fertiliser
- For an organic fertiliser it is the other way around: high in nutrients and low in EOM.

On the basis of this classification, and for the purposes of quantifying soil benefits:

- Composts can be classified as an organic soil improver
- Digestates can be classified as an organic fertiliser.



Re-drawn from Veeken et al. 2017

As addressed earlier in this chapter, the consistency of digestate will be determined by the feedstock and process. Essentially, the higher the lignin content of the feedstock the greater the levels of EOM in the resulting digestate. The practice of separating digestate also assists in this, with the solid DM delivering more EOM and commonly spread prior to planting and the liquid fraction being used as crop fertiliser in the run up to harvest.

In Italy, the two processes work in tandem. Agricultural digestate is generally directly applied as a fertiliser. Food and green waste compost, however, is separated into solid and liquid fractions. The solid fraction is composted and then used as soil improver, while the liquid fraction is either recirculated in the plant or treated in wastewater treatment plants[126].

In Europe, many existing compost sites are upgrading to dry AD, to capitalise on the net energy balance and conversely interest in Dry AD is increasing as the EU has a target to have 25% of agricultural land under organic farming by 2025, "to produce food using natural substances and processes, leading to an agricultural method with limited environmental impact. It encourages the use of farm-derived renewable resources, the enhancement of biological cycles within the farming system, the maintenance of biodiversity, the preservation of regional ecological balances, the maintenance and increase of soil fertility, and the responsible use and proper care of water[127]."

Digestate, from both wet and dry-AD, and compost are the only means of enabling delivery of these benefits – organic farming requires organic fertilisers and soil improvers.

[125] www.iswa.org/media/publications/iswa-soils-project/

[126] https://ec.europa.eu/environment/chemicals/reach/publications_en.htm

[127] https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1548

5.3 Regulating digestate use

The benefits of digestate are clear – it can provide a sustainable source of NPK nutrients while restoring soil structure and displacing the use of energy-intensify fossil-derived mineral fertilisers. However, like the use of any fertilisers, regulations must be put in place to promote best practice.

The spreading of any fertilisers – including fossil-derived mineral fertilisers, raw manures, or digestate – can cause environmental impacts if poorly managed. The following details these risks, and specifically identifies how regulation on digestate can mitigate against them:

a. **Eutrophication of freshwater.** The term eutrophication is used to describe the process in which a waterbody, such as a lake or river, becomes enriched with nutrients – primarily nitrogen and phosphorus. Increased nutrient concentrations can result in algal blooms – periods in which rapid algae growth covers the entire surface of the water. Under these conditions, the algae deplete oxygen levels in the water, resulting in "dead zones" in which fish and microorganisms cannot survive. Some species of algae also produce harmful toxins, capable of rendering freshwater undrinkable.

   Eutrophication affects lakes and rivers worldwide. In the USA, eutrophication is considered the primary cause of freshwater impairment, costing an estimated US$ 2.2 billion each year[128].

   Agriculture is one of the leading causes of eutrophication worldwide. When fertilisers are spread to land, their nutrients can be washed out of the soil by rainfall or irrigation and accumulate in freshwater waterbodies. Again, this process can occur following the spreading of any type of fertiliser.

   To tackle this issue and mitigate this risk, the EU adopted the Nitrates Directive[129] in 1991. This aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. The following details the policies implemented to meet these goals:

   - **Measure the nitrate concentration within rivers and lakes**, particularly those used for drinking water. Water with nitrate levels greater than 50 mg/l are deemed 'at risk'.

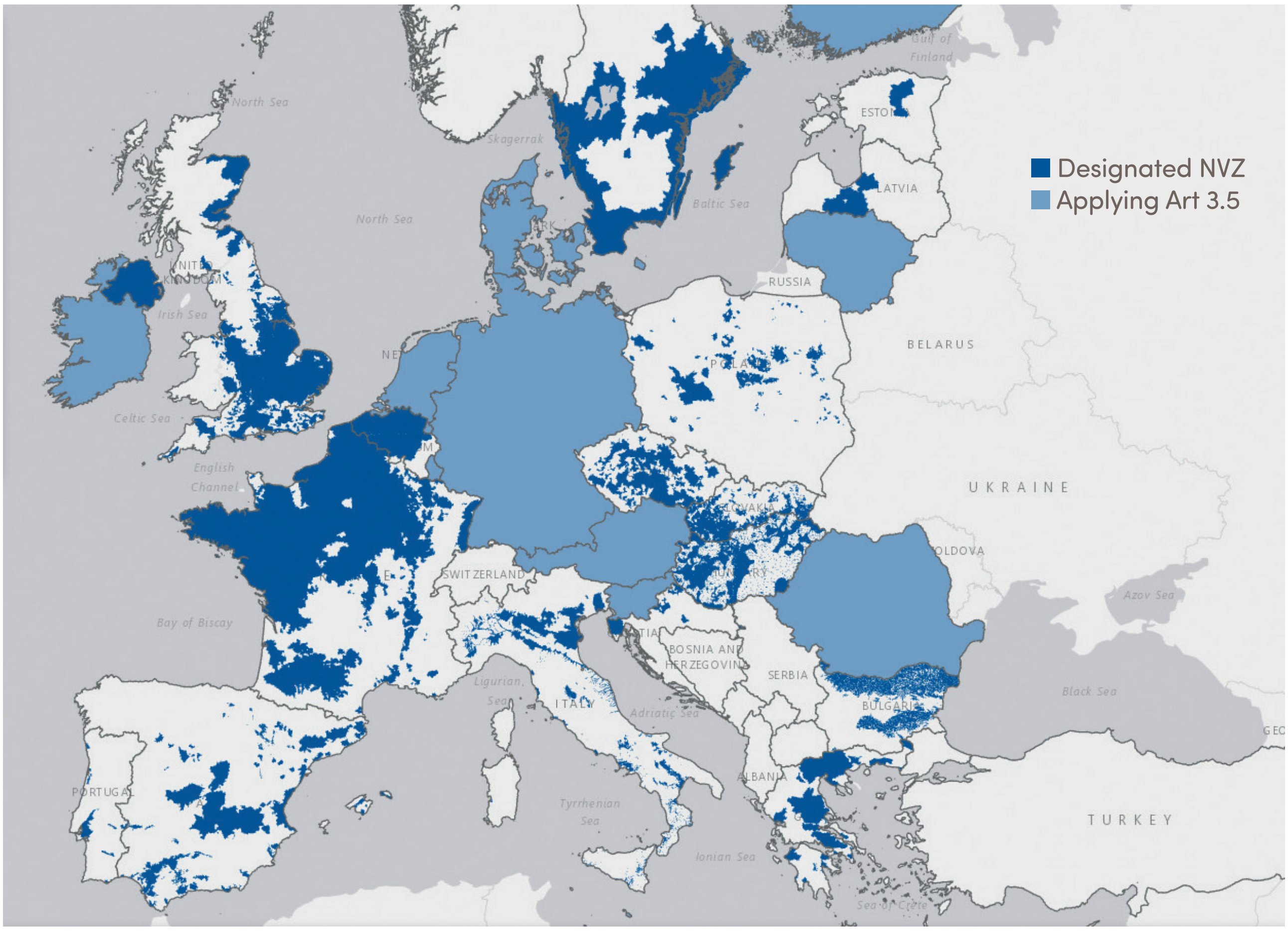
   - **Designate Nitrate Vulnerable Zones (NVZs)** to identify areas of land which drain into these 'at risk' waterways. Note, rather than identify specific regions, some European countries opted to regulate nitrate concentrations across all agricultural land – applying article 3.5 of the Nitrate Directive (see map p104).

   - **Establish a Code of Good Agricultural Practice.** Introduce rules to place limits on quantity of nitrogen applied to land within a year. These limits are determined by the crop grown, such that nitrogen demand better meets supply, thus preventing over fertilisation and run off of excess nutrients. For example, to grow spring barley, a maximum of 150kg of nitrogen may be spread per hectare. Rules also prevent spreading on land directly next to water and restrict application during conditions which increase runoff rates (e.g., when the ground is frozen). Under the Directive, rules were first introduced on a voluntary basis before becoming mandatory, to smooth the transition to new rules.

   - **Require monitoring and reporting.** EU member states are required to report on nitrate concentrations, NVZ designations and water quality every 4 years.

[128] https://pubs.acs.org/doi/abs/10.1021/es801217q

[129] https://ec.europa.eu/environment/water/water-nitrates/index_en.html



Source: EU's Joint Research Centre (JRC)[130]

As a result of the Nitrate Directive, nitrate pollution levels declined between 1992 and 2018, on average by 0.02% per year, yet reductions have slowed in recent years. The recent trend suggests that these rules may not be stringent enough, with many waterways in Europe remaining 'at risk'. Nevertheless, the most polluted rivers have seen the greatest improvements in water quality.

Regulations worldwide can play a vital role in preserving water quality. Fertiliser use should match the crop demand, not only reducing the risk of eutrophication, but also preventing the wasteful use of resources. By focusing on nitrogen limits and environmental conservation, governments can remain technology neutral, meaning digestate is not disproportionately impacted by restrictive legislation.

Farmers will seek to use fertilisers with high concentrations of readily available nitrogen, to optimise the nutrients delivered to crops while remaining within the total application limits. Here, digestate's high levels of readily available nitrogen can improve its desirability.

b. Ammonia emissions. All nitrogen fertilisers emit ammonia when stored in open containers and spread to land. These fertilisers all deliver nitrogen to soils in the form of ammonium (NH_4), a highly volatile liquid. This chemical is readily converted to ammonia gas (NH_3), where the rate of transformation can depend on a range of factors, from soil pH, to temperature and humidity. Ammonia emissions can cause acid rain, exacerbate eutrophication and harm public health. In the case of the latter, it can bind with other air pollutants to form particulate matter (PM10) which contribute to respiratory diseases when inhaled.

According to the European Nitrogen Assessment[131], the damage of ammonia emissions to public health and ecosystems can be valued at € 10-25 per kg NH_3. It is estimated that a 50% reduction to agricultural ammonia emissions could prevent more than 200,000 deaths per year.

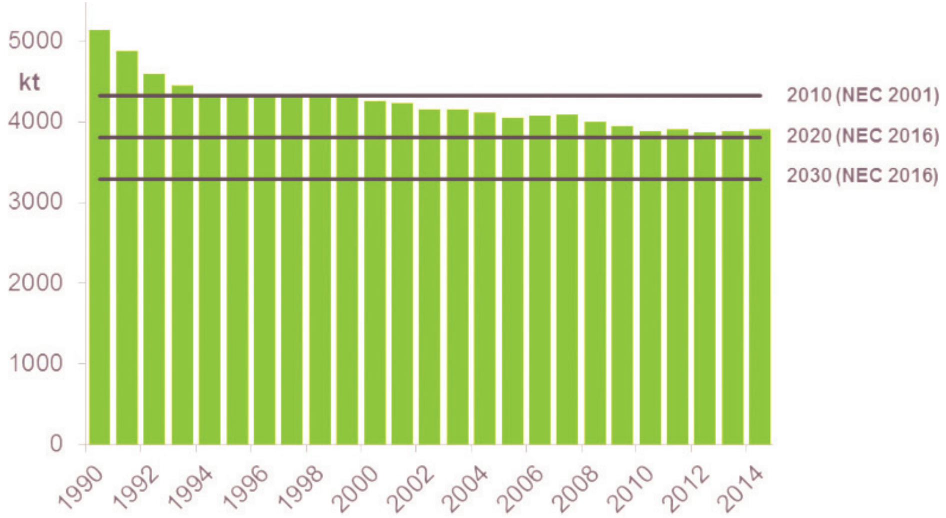
[130] https://water.jrc.ec.europa.eu/portal/apps/webappviewer/index.html?id=d651ecd9f5774080aad738958906b51b

[131] https://unece.org/fileadmin/DAM/env/documents/2019/AIR/EMEP_WGE_Joint_Session/Assessment_Report_on_Ammonia_20190827.pdf

Worldwide, 80-90% of total ammonia emissions arise from agricultural practices - of which, 75% comes from livestock manure and 22% comes from mineral fertilisers[132]. From the latter, it is estimated that mineral fertilisers are responsible for the loss of between 1.9 and 16.7 million tonnes of nitrogen to the atmosphere via ammonia volatilisation[133].

Crucially, ammonia emissions represent a loss of nitrogen within the agricultural system. Nitrogen which, if better managed, could be used to grow plants. Wasting nitrogen within agricultural systems serves only to increase nitrogen demand, suiting the energy-intensive manufacture of artificial fertilisers.

To tackle this issue, the EU introduced the National Emission Ceiling (NEC) directive, setting limits on emissions per country every 10 years. The following shows how these limits have helped curb ammonia emissions across the EU and sets the future target for 2030:



To reach these targets, the UK is developing The Clean Air Strategy. Learning from experiences gained from the Netherlands, this strategy focuses on two of the key sources of agricultural ammonia emissions:

- **All stores of manure, slurry and digestate must be covered by 2027.** Covering these organic fertilisers inhibits the volatilisation of ammonia, thus reducing emissions. This legislation aims to also reduce fugitive methane emissions from organic stores, as they continue to degas during storage. Research suggests that the widespread adoption of better manure storage in the EU – using concrete, corrugated iron or polyester caps on stores of organic fertiliser – could cut regional ammonia emissions by up to 80%[134].

- **Low emission spreading equipment must be used by 2025.** All slurry and digestate must be applied to land using equipment which minimises ammonia volatilisation, such as trailing hose, trailing shoe, or injection. It therefore seeks to ban the use of surface broadcast techniques, such as the splash plate, which results in high ammonia emissions. The UK's Code of Good Agricultural Practice further dictates that fertiliser should be incorporated fully into the soil within 12 hours of spreading; again, to mitigate emissions.

Many countries globally, including the USA and China, have very little regulation on fertiliser management regarding ammonia emissions. However, in Colorado, USA, live weather updates provide an early warning system to regional farms about incoming weather systems. Focusing on fertiliser management, this app provides farmers with advice to when best to spread organic fertilisers to minimise ammonia emissions (and eutrophication). However, following this advice is voluntary and unregulated.

Moreover, in the global south, many farms do not have the resources available to fully install equipment to properly store and spread organic fertilisers. Development funds should not overlook the environmental and health damage caused by ammonia when investing agricultural upgrades globally.

[132] www.yara.co.uk/crop-nutrition/agronomy-advice/reducing-ammonia-emissions-from-agriculture/

[133] https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.14499

[134] https://ensia.com/features/ammonia/

c. **Plastic contamination.** Depending on the source of organic feedstocks for AD, the resultant digestate may contain varying levels of unwanted contaminants – most prominently from plastics. Plastic contamination is most commonly derived from food waste originating from the latter stages of the supply chain, such as homes and supermarkets. The public may not sufficiently separate food waste from the packaging and supermarkets may not adequately de-package unsold food. In the first instance, educating the public about the value of removing all plastic from separated food waste could help minimise the risk of spreading plastic-contaminated digestate to land; while incidentally also serving to curb the levels of food being wasted.

AD plants treating waste with potential plastic contamination should remove all plastic prior to digestion. In Scotland, to spread food waste derived digestate to land, digestate must comply with an 'End of Waste' specification – i.e., it is no longer considered a waste and therefore no longer regulated by waste disposal laws. To meet this specification, there are strict limits of plastic concentrations; if the limit is exceeded, digestate cannot be spread to land until plastic limits are met.

In the long term, biodegradable and/or digestible food packaging could provide a potential solution. This would not only help remove the dependence on fossil-based resources but ensure that any contamination is compatible with the waste management process. Waste processing costs could be reduced, and environmental pollution would be minimised.

5.4 Overview of policy recommendations

Environmental regulation

At initial stages of AD industry development, it is critical that a regulatory framework is in place to support the use of digestate, setting out best practice guidance for farmers and managing quality standards; e.g., limits on allowable contamination in the food waste recycling process for the digestate to be granted product status. Guidance for farmers should provide information on how to develop nutrient management plans aligned to local conditions, such as weather patterns and soil and crop requirements, store and spread digestate in the most environmentally sustainable way, to minimise ammonia emissions. Regulation of digestate at this stage should also cover mitigation of environmental risk as with the spreading of manures and slurries to land, and the use of artificial fertilisers. This is of particular importance in geographies that drain into waters polluted by nitrates, for example those designated 'Nitrate Vulnerable Zones' (NVZs) in the EU. This regulation should be supported by effective monitoring capabilities to ensure that digestate is being used in line with the rules and guidance.

Regulation to ensure high quality digestate is also vital to support the adoption of digestate and continued use by farmers, as they will not be willing to switch from manufactured fertilisers if the digestate is not a consistent, quality product. Food waste and wastewater must be regulated to prevent contaminants, such as microplastics from food packaging, from entering the recycling process and potentially being returned to soils. This regulation should set contamination limits that must be met for the wastes to obtain 'end of waste' status, indicating that it is no longer a waste but has become a product again in line with circular economy principles. The stricter these limits the greater confidence farmers will have in the quality of the digestate as a valuable biofertiliser, increasing uptake. Most importantly the risk of contaminants being returned to soil will be mitigated.

While AD plants manage contamination levels in the food waste feedstock received, by pre-digestion depackaging and post-digestion treatment of digestate, it is also important that those generating the food waste are held responsible for ensuring that contamination levels are reduced upstream. Regulation should also ensure penalties are in place for producers of food waste that send it to AD plants for treatment with high levels of contamination. It is important that the level of penalty is considered alongside the cost of alternative, less environmentally sound forms of treatment to ensure the food waste is not inadvertently diverted to incineration or landfill.

Sustainable agriculture payment scheme for digestate use

As discussed above, our agricultural system is responsible for significant emissions and is second only to the energy sector in terms of total GHG emissions.

Fertiliser manufacture and use is a major contributor to these emissions and so switching to renewable biofertiliser, especially one that is generated from the essential activity of treating our organic wastes, is a vital part of moving to a more sustainable, low-carbon agricultural system.

Policy to support a shift to an agricultural system that is compatible with our urgent need to prevent climate change must include incentives for farmers to transition from artificial fertilisers to renewable biofertilisers such as digestate. A system of agricultural subsidies should be developed that rewards farmers for the environmental services they deliver, including cutting emissions by moving away from carbon-heavy fertilisers. Payments should be made for the use of digestate in place of artificial fertiliser, provided it is used in line with environmental standards to limit ammonia emissions or nitrate pollution (as should be done with any nitrogen-based fertiliser). This policy should be accompanied by a legally binding target to reduce the amount of carbon-intensive artificial fertilisers used in place of renewable biofertilisers, such as digestate, or organic growing practices that reduce the fertiliser requirements in the cultivation process.

Innovation funding for digestate enhancement

Finally, to maximise the benefit delivered by digestate and mitigate any potential environmental risks from mismanagement, innovation funding should be made available to develop and commercialise novel technologies to enhance digestate, including technologies to reduce potential ammonia emissions from its storage and use. Innovations should also be targeted at improving the economic value of digestate. Developing higher value, easier to administer fertilisers from digestate will increase the market value and so the revenue that can be generated from this co-product of the AD process. This will support the financial performance of AD plants, moving them closer to independent viability and facilitating greater industry growth with less financial support from national governments.

Chapter 6: Biogas Utilisation Policy

Composed of around 60% biomethane and 40% bio-CO_2, biogas is often seen as AD's most desirable product. As a highly versatile gas, it can be used to generate electricity and heat or fuel local gas cookers and machinery. Or it can be 'upgraded' by splitting the biogas into its component parts; biomethane can heat homes or fuel vehicles, and bio-CO_2 can be stored or used within various industries. Moreover, as biomethane is chemically identical to natural gas, it too can be refined and processed to create all manner of currently fossil-derived products, from plastics to lubricants. Biomethane can help remove supply chains' dependence on non-renewable resources.

Biomethane is also highly compatible with hydrogen – again, enabling AD to meet the different energy demands of the future. Using existing technology (steam methane reformation), biomethane can be converted into green hydrogen. The integration carbon capture and storage (CCS) technology can further reduce the carbon intensity of this hydrogen – i.e., greener hydrogen. Alternatively, hydrogen can be converted to biomethane. Fed into an AD tank, it binds with the bio-CO_2 to upgrade biogas into additional biomethane. This energy pathway can further enhance AD's ability to deliver carbon negative biomethane.

Its versatility enables governments to explore how best to use biogas in their countries. See Biogas Utilisation Policy Timeline, p109. For example, colder regions may favour biogas-to-heat, while a country lacking a national gas grid may favour localised biogas cookers and electricity generation. Biogas can meet the needs of the user. In terms of environmental benefit, the best use of biogas is generally determined by the plant size and surrounding infrastructure available.

When developing an AD infrastructure, a key consideration will be how the biogas is to be used. Typically, biogas represents the most highly valued product of AD (at least in current markets). Policies designed to support AD development have commonly focused on renewable energy generation. While many government-support schemes for biogas initially focused on its ability to generate renewable electricity (e.g., Germany and UK), most now favour the production of biomethane for heat or transport (e.g., USA and France), recognising AD's ability to generate a **renewable gas**. While there are multiple technologies which can produce renewable electricity, AD is the only ready to use technology capable of decarbonising gas networks.

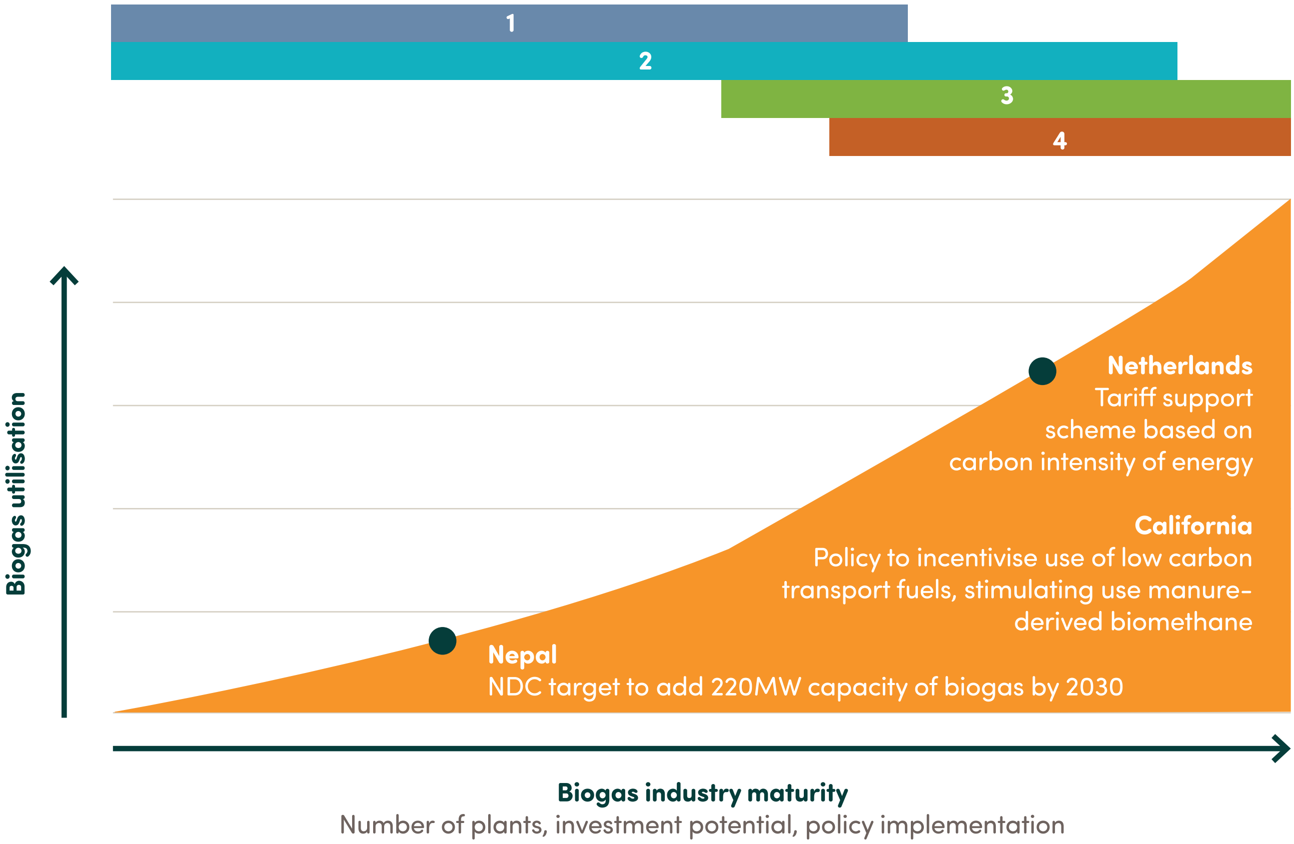
Biogas Utilisation Policy Timeline

(1) While the biogas industry is maturing, the generation of biogas for CHP, biomethane for grid injection and biomethane for transport should be **supported with direct government payments in the form of a tariff**. This is to correct for the fact that the significant environmental benefits delivered by AD are not priced into the market and so the industry cannot deliver this benefit without initial support. Tariff based policies also deliver the investor confidence required to support project development.

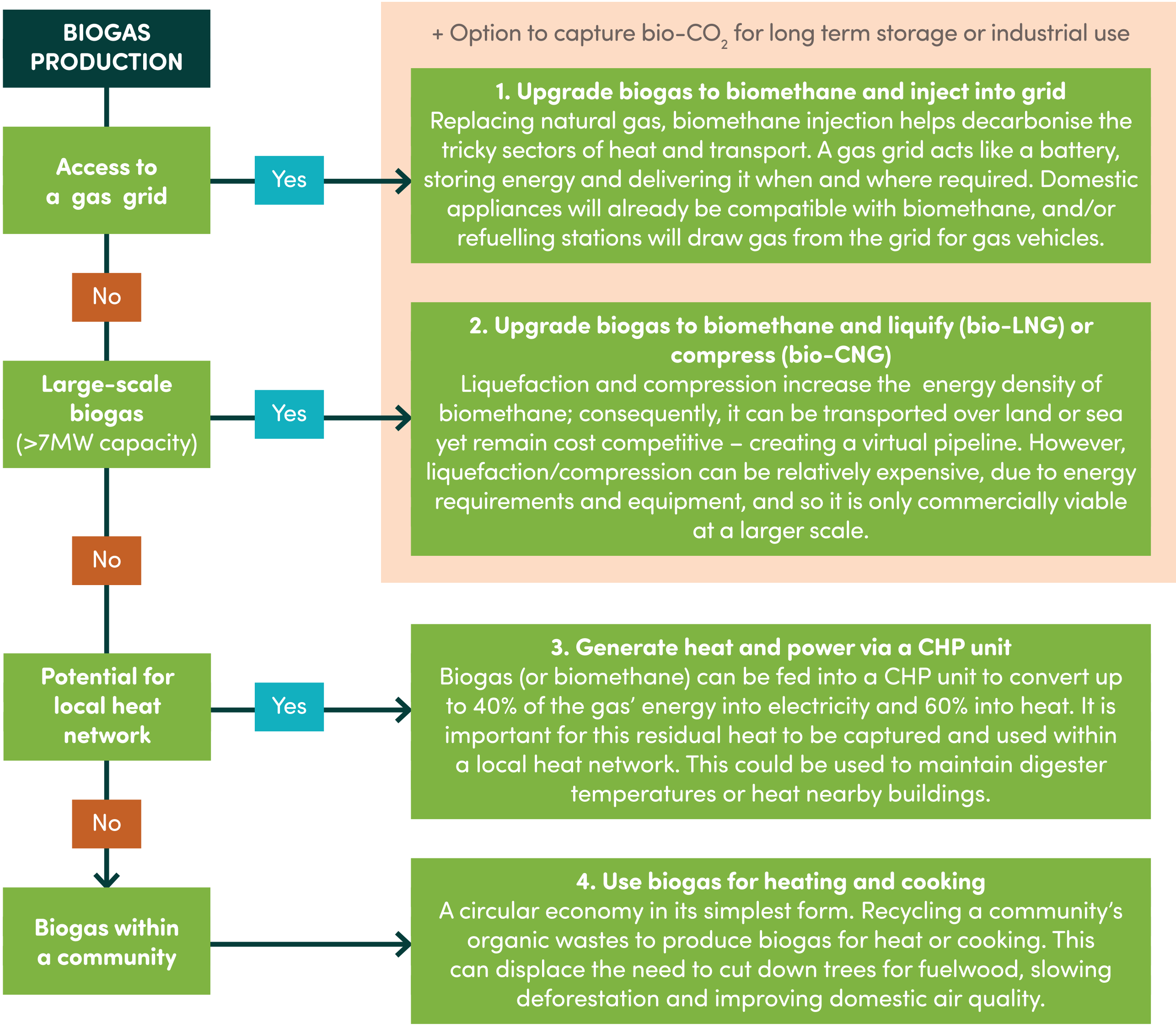
(2) Targeted innovation funding should be directed towards increasing biogas yield, as well as biomethane yield within biogas; bringing down the cost of project development, for example through the modularisation of plants; and capturing the bio-CO_2 separated from biomethane in the upgrading process for use and storage, to bring the technology from carbon neutral to carbon negative. Innovation will support the reduction of costs and increased revenue of AD projects, making plants more viable independent of subsidy.

(3) Grant funding should be made available for the development of carbon capture, utilisation and storage (CCUS) technology on new and existing biomethane plants. Ongoing support should be provided in the form of a tariff for the use and storage of bio-CO_2 captured by AD plants, to incentivise continued CCUS as part of the AD process. As the hydrogen market develops and more biomethane is used to generate green hydrogen, CCUS should be incentivised within this process as well.

(4) As the biogas industry matures and innovation improves the financial model, tariff support can be tapered away in place of more **market-based mechanisms to support the growing AD industry**. A 'renewable obligation' placed on energy suppliers to source an increasing proportion of their energy from renewable sources. Connected to certification of the renewable fuel, is an effective policy to create a market for the green element of the biogas and ensure producers of biogas are still paid for the environmental service they deliver.



The following indicative decision tree helps identify some of the key factors which may govern biogas' best outcome:



6.1 Biomethane

Biogas is composed of a mixture of ~60% biomethane and ~40% bio-CO_2. 'Upgrading' biogas involves splitting these two components to produce separate and purer gases, thus creating two new, often higher-value, products: biomethane and bio-CO_2.

i. **Biomethane** is a highly combustible and valuable gas, chemically identical to fossil natural gas (also methane). Note that biomethane has several different names worldwide, for example: renewable natural gas (RNG), sustainable natural gas (SNG), bio-natural gas (BNG), and depending on how it is stored, bio-compressed and bio-liquified natural gas (bio-CNG and bio-LNG). For the purposes of this report, we will use the term biomethane.

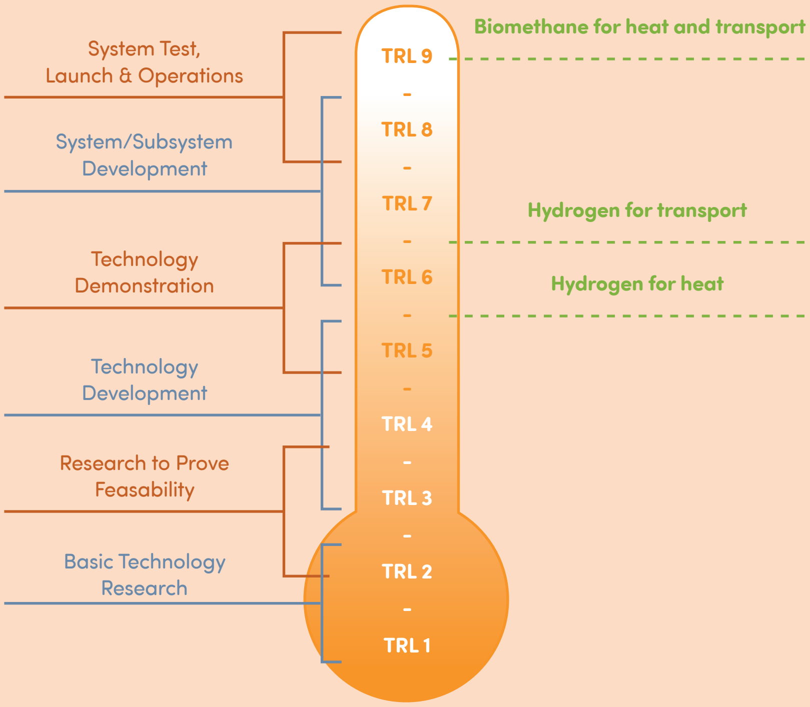
   Upgrading biogas to biomethane significantly increases its versatility as a fuel. As there are very few technologies able to produce low carbon gaseous fuel – even fewer that are ready to use and proven at scale – decarbonising gas networks is particularly difficult. Biomethane can be used interchangeably within any system currently using fossil gas – that includes a country's extensive gas grid, industrial boilers and machinery, and any products derived from natural gas refining. This means that, where existing infrastructure is in place, biomethane enables governments and industry to start decarbonising the gas grid now by scaling up biomethane production rather than restructuring the entire energy network.

While the emissions from the burning of natural gas and biomethane are practically identical, it is the origin of the carbon that it is critical to consider. Burning fossil fuels introduces additional carbon into the atmosphere and biosphere, whereas biomethane recycles existing carbon - drawn from the atmosphere and fixed into organic matter via photosynthesis, which as feedstock for AD becomes biomethane, recycling carbon back to the atmosphere but not adding to existing levels. Through the use of biomethane countries will improve domestic fuel security, cut costs importing energy, and mitigate GHG emissions.

ii. **Bio-CO_2** can either be used in numerous industrial processes or permanently stored. AD can help ensure that any process that requires CO_2, e.g., the carbonation of drinks, utilises carbon sourced from the atmosphere – not fossil sources. Both utilisation and storage can improve the decarbonisation potential of AD, supporting its ability to deliver carbon negative emissions.

Technology Readiness Levels

Technology Readiness Levels (TRL) is a measurement system designed by NASA to assess the maturity level of technology. Technologies are evaluated against the parameters for each technology level and assigned a TRL rating based on the projects progress. There are 9 technology readiness levels from TRL 1, the lowest, to TRL 9 the highest.



6.1.1 Injection into a gas grid

Biomethane injection leverages the existing energy infrastructure to supply renewable energy to wherever it generates the most value. Biomethane and natural gas are chemically identical – they are both methane gas (CH_4) – but natural gas' carbon is from a fossil source and biomethane's carbon is from the atmosphere. Once injected into an existing gas grid, biomethane can be transported and used wherever gas is consumed, but without adding to emissions. It is limited only by the extent of the existing infrastructure. This key benefit enables biomethane to decarbonise the trickiest sectors, typically heat and transport.

The existing gas infrastructure can also store vast quantities of energy for long periods of time. Much like a battery, the grid's energy can be delivered when and where required as, unlike energy supply from intermittent generators wind and solar, it is not dependent on external conditions. In fact, biomethane can be converted to electricity to cover periods when these other renewable technologies are not able to meet demand. While wind and solar generation is weather dependent, biomethane can provide flexible, baseload generation 24 hours a day. Moreover, as biomethane production is decentralised, with many AD plants generating biomethane, the supply from any one producer is less critical. This averages out the risk of failures and improves the resilience of the energy system.

Biomethane-to-grid (BtG) is most appropriate where a gas grid already exists. As alluded to above, gas networks are difficult to decarbonise. AD is one of few technologies capable of producing a renewable gas which is compatible with the existing infrastructure. Arguably, it is the only technology with the maturity necessary to scale up immediately and deliver a significant proportion of global gas demand. With the potential to deliver an estimated 12,500 TWh per year, biomethane is the largest contributor to low-carbon gas supply in the next 10 years, as modelled by the World Energy Outlook (WEO) Scenarios[135].

Drawing on this existing infrastructure, biomethane can be anywhere where natural gas is currently used. The following lists the three key uses that rely on gas grids:

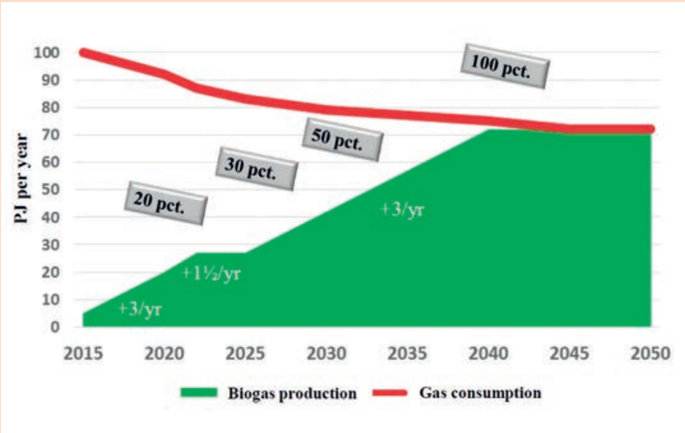
1) Heat

In the global north, most homes and buildings are connected to a national gas grid. Gas may be used in boilers for hot water or central heating, or for cooking. Increasingly, these countries are seeking to decarbonise heat through the installation of low carbon technologies, such as solar heat, ground-source heat pumps, and electric boilers/cookers. However, the vast majority of homes required for the next 100 years have already been built; converting these homes from gas to these other technologies will be exceptionally expensive and disruptive. To decarbonise heat, countries must use every renewable, low carbon technology available. Gas heating will be near impossible to remove altogether. Engineers would be required to visit every gas-fuelled home and business to replace the heating system installed, where some buildings are not suitable for low carbon alternatives. Biomethane must therefore play a critical role.

Examples of countries incentivising biomethane injection

- **UK** In 2020, the government established a target of tripling biomethane in the national gas grid by 2030. To help deliver this, the UK's first AD-only incentive will open in Autumn 2021, the Green Gas Support Scheme (GGSS). The GGSS will pay a fixed tariff rate (p/kWh) over a 10- to 20-year period for all biomethane injected. This scheme will be funded by a countrywide levy placed on all gas used, known as the Green Gas Levy (GGL).

- **Denmark** There is a target to eliminate natural gas from their gas grids by 2040 and replace it with biomethane. This has encouraged existing AD plants to upgrade biogas to biomethane and supported the development of new plants, so that this target can be reached. The graph (right) displays the Danish Biogas Association's modelling of how the industry will scale up over the next 20-30 years to ensure biomethane supply can meet total gas demand.



- **Malaysia** The government expressed a desire to source 20% of their energy from renewable sources by 2025. They recognised the need to address the disposal of organic waste from palm oil production into sewage systems, causing blockages and disrupting wastewater treatment. This has led to a new law requiring any palm oil plant wishing to expand to build a biogas plant (the EPP5 program). As of 2019, 35% of Malaysia's palm oil plants have built biogas plants.

[135] www.iea.org/reports/world-energy-outlook-2020

Biomethane certificates, such as those offered by Green Gas Trading (GGT) in Europe, offer an additional revenue stream for AD plants sending their biomethane to heat. Certificates crucially track biomethane within a gas grid currently filled with natural gas. As energy consumers increasingly demand greener energy, energy suppliers are introducing new green tariffs to their customers. To verify that green energy is provided, suppliers can purchase these certificates from AD plants. This increasing consumer demand for green energy has resulted in an increase in demand for these certificates. As a result, biomethane certificate prices have increased year-on-year over the past five years, from less than £2/MWh to around £9/MWh (US$12.50/MWh) today. A relatively large 8MW biomethane plant could therefore gain an additional £560,000 (US$ 780,000) per year by injecting gas and earning biomethane certificates.

2) Transport

Wherever there are gas grids extensive pipelines exist, connecting cities and towns to points of production. Much of any given network, as a matter of engineering efficiency, will run alongside roads. Therefore, by installing refuelling stations across the gas grid, a region can develop a transport network capable of delivering biomethane to vehicles when and where needed.

While electric vehicles (EVs) will play a major role in cutting transport emissions, they cannot decarbonise transport on their own. Many vehicle types are not currently suitable for electric power, such as long-range heavy goods vehicles (HGVs). Long charging times and low range delivered from batteries remain some of the key technological barriers inhibiting the viability of electric HGVs. Renewable gases, such as biomethane and green hydrogen, are therefore essential to decarbonise these heavier vehicles.

Replacing a diesel-HGV (Euro VI) with a biomethane-HGV cuts emissions by around 80% per km driven[136]. As identified in trials, biomethane can be easily blended with natural gas within the national gas grid and/or via gas compression, and still deliver significant carbon savings. A fossil-biomethane mix containing just 25% biomethane (B25) still offers Well-to-Wheel (WTW) emission savings of 17%. Therefore, once an HGV has been fitted with gaseous fuel systems, the fuel mix can smoothly transition from fossil- to AD-derived sources while delivering emission savings from day one.

Not only can gas vehicles facilitate the sector's decarbonisation, but they can also offer significant cost savings to freight and logistics companies. Despite higher capital investment and maintenance costs, a report published by Cenex, a low emission vehicle research and consultancy company, suggests that gas vehicles can pay back within two years, with an HGV driving 160,000 km/year. Therefore, government support would not be required to fund a transition to gas vehicles; in many cases, it already makes commercial sense for logistics companies to switch to gas. Moreover, reports from HGV drivers all noted that gas vehicles were typically more comfortable to drive and improved vehicle performance, most notably by enhanced engine braking. Additionally, refuelling a gas HGV with compressed natural gas (CNG) from the national grid only takes approximately six minutes, providing enough fuel to drive 500 miles.

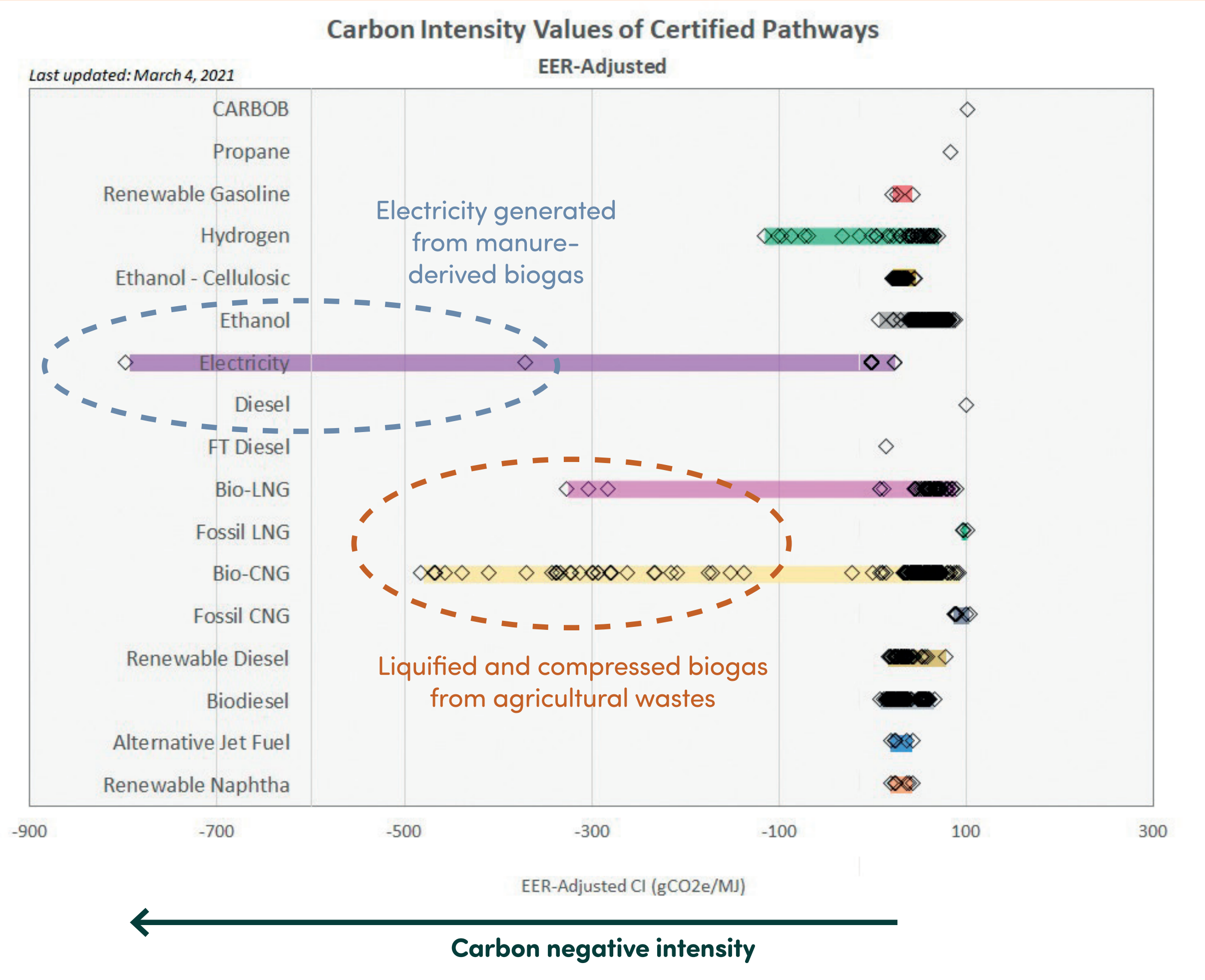
[136] www.cenex.co.uk/app/uploads/2019/11/Dedicated-to-Gas-Assessing-the-Viability-of-Gas-Vehicles.pdf

Case study: California, USA

California introduced the Low Carbon Fuel Standard (LCFS) to measure the carbon intensify of transport fuels – it quantifies emissions through a fuel's entire life cycle. In a market-based system, fuel suppliers can purchase different fuels to meet these emissions targets. The scheme recognises that **biogas derived from organic wastes delivers carbon negative emissions.** As one of the only fuels to do so, it is a highly valuable fuel and has stimulated the development of agricultural AD across the state. Now, biomethane fuels around 90% of all gas vehicles in the programme.

By 2024, it is estimated that Californian biomethane for transportation will have an average energy-weighted carbon intensity of -101.7 gCO_2e/MJ[137].

With this carbon negative intensity, an average biomethane-powered gas vehicle will completely offset the GHG emissions of two diesel trucks.



Consequently, the use of biomethane as a transport fuel has been increasing in many countries. Biomethane burns extremely cleanly and reduces dependence on diesel for heavy vehicles and can also substitute (in the future) marine and aviation fuels. However, we need to look at what this means in terms of support for an industry competing with abundant gas and an average crude petroleum price of US$40/barrel in 2020. Biomethane-for-transport can support the development of circular economy in cities. For example, urban food waste can create biomethane to fuel vehicles collecting that waste – this model is already a reality in some cities.

[137] www.gladstein.org/gna_whitepapers/an-assessment-californias-in-state-rng-supply-for-transportation-2020-2024/

Case study: Biogas-fuelled refuse trucks in New Jersey, USA

New Jersey has invested in 550 new trucks to collect waste across the state – all fuelled by compressed biomethane (bio-CNG, or 'compressed RNG' as typically referred to in the USA). This gaseous vehicle fleet now serves around 76% of New Jersey's counties and is significantly cutting the emissions from the regular collection of waste from households and businesses. Already, this green transition has stimulated the investment of US$200 million to decarbonise this mode of transport and improve local air quality[138]. Crucially, biogas was identified as the most cost-effective and ready to use solution:

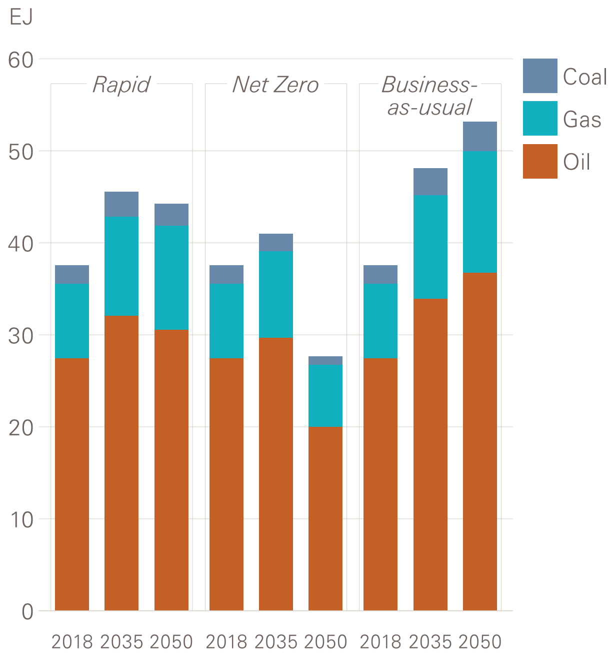
CNG Refuse Truck		Battery Electric Refuse Truck	
Total Cost Payload	$335,000 10 tons, Comparable to Diesel	Total Cost Payload	$650,000* Up to 5 tons, 50% less than Diesel
Cost per ton of NOx reduced	$24,842 LFG**	Cost per ton of NOx reduced	$360,575
Cost per ton of GHGs reduced	$33 LFG**	Cost per ton of GHGs reduced	$381
Sector Wide* Transition Incremental Cost**	**$350 million**	**Sector Wide*** Transition Incremental Cost**	**$3.5-4.2 billion**

*Note that costly battery electric refuse trucks are still in development. Those currently in service are for demonstration purposes only. Alternatively, CNG refuse trucks are deployable, scalable, and affordable now.
**LFG = RNG produced from landfill gas
*** Incremental vehicle costs only (over diesel incumbent) to convert entire state fleet of 10,000 refuse trucks.

3) Non-energy uses

Fossil fuels are used to create a broad range of products worldwide, such as plastics, lubricants and chemicals. Consequently, this production is unsustainable, as fossil resources diminish and become more expensive to extract. Renewable alternatives can help fill the gap and ensure these often vital products continue to be developed. While natural gas (methane) is not the most utilised platform chemical, it is possible for methane to be converted into a range of fine chemicals and materials for a broad spectrum of uses, using well established technologies (e.g. Fischer-Tropsch synthesis). As the global economy moves towards a fully decarbonised future, biomethane can displace fossil gas as the feedstock input.

According to BP's global energy outlook, in 2018, the use of fossil fuel products in non-energy processes accounted for approximately 10 million barrels of oil equivalent (mboe) per day – equivalent to 17 TWh of energy[139]. BP examined how demand for coal, gas, and oil for non-energy purposes may change over the next 30 years, across three scenarios: Rapid assumes policies drive a 70% reduction in GHG emissions by 2050; Net Zero assumes 95% reduction by 2050; and BAU assumes GHG reductions are consistent with recent changes. The graph displays fossil demand forecasts under the three scenarios:



Non-combusted demand by fuel

[138] www.ngvamerica.org/wp-content/uploads/2020/11/NGVAmerica-NJ-RNG-Refuse-Impact.pdf

[139] www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-sector/non-combusted.html

By 2050, demand for natural gas for non-energy purposes will likely range between 7 exajoules, EJ (2,000 TWh) and 14 EJ (4,000 TWh) each year, depending on the scenario. In fact, demand could increase from 2018's level in both the BAU and Rapid scenarios. While many products require hydrocarbons, found in fossil resources, their formation does not necessarily result in significant GHG emissions; e.g., plastics lock carbon away within their structures, rather than release it directly into the atmosphere. Consequently, policies introduced to better account for carbon emissions, as modelled by BP, may not drastically affect the non-energy market for fossil resources.

Plastic pollution must be addressed in tandem with climate change. The availability of cheap fossil resources facilitate the extremely cheap production of plastics, such that they can become single-use and disposable. By reallocating all subsidies for the exploration and extraction of fossil fuels towards sustainable alternatives, the cost difference between natural gas and biomethane will be reduced. While the cost of new plastic may increase, people around the world can start to value plastic better, reducing demand and incentivising the recycling and reuse of the material. It can also stimulate the production of bioplastics.

Bioplastics could play an increasingly important role within the circular economy, reducing a country's need to extract or import fossil fuels. Some bioplastics in production are digestible. Their use could be integrated with the roll out of AD, whereby food packaging and food waste lines become digestible, reducing the risk of non-degradable plastic contamination.

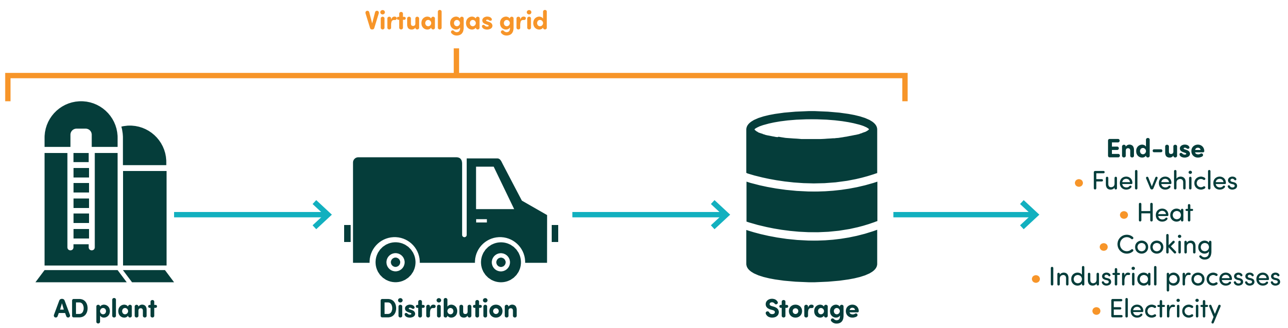
6.1.2 Liquify biomethane

If there is no gas grid available, an AD plant can liquify biomethane to a highly energy-dense fuel. Optimising the energy density of biomethane supports the economic feasibility of transporting the fuel – the more energy transported, the fewer trucks and journeys required. As liquid, this valuable green fuel can be transported over land or by sea to wherever required. Again, that might include heat, transport and/or non-energy use.

Liquifying biomethane, however, is energy intensive and requires expensive equipment. Consequently, it is only financially viable for the largest plants, benefitting from the economies of scale. Based at today's pricing, we suggest that this operational model is only an option for biomethane plants with a capacity greater than 7MW.

Liquefaction of biomethane (bio-LNG) presents an opportunity to create a virtual gas grid or pipeline. Much like a grid, gas can be delivered whenever and wherever required, drawing on the existing transport infrastructure (roads, ports, etc).

Biomethane can also be compressed (bio-CNG) and delivered via these virtual pipelines. Compared to bio-LNG, it takes less energy to compress biomethane but it also has a lower energy density. When establishing an AD plant, it is important to assess both transport distances required and the end user; in the case of the latter, bio-CNG may be better suited for smaller-scale heating and cooking, for example.



Global potential of biogas = 12,500 TWh

This biogas would also contain: **1,560 million tonnes of bio-CO_2** – enough to satisfy the current demand CO_2 gas nearly seven times over.

Current uses for industrial CO_2:

- 130 $MtCO_2e$ per year to manufacture urea
- 70-80 $MtCO_2e$ per year to enhance fossil oil extraction
- 14 $MtCO_2e$ per year in the food and drinks industry

Data from IEA

Where this bio-CO_2 has been used it has generally been fed into local greenhouses where both the heat and extra CO_2 can stimulate plant growth. Technological advances have increased the potential number of uses for bio-CO_2. They allow bio-CO_2 to be refined to such a purity that it can be used in the manufacture of food and drinks, where CO_2 attracts a premium price. The market for bio-CO_2 is growing as industries and governments alike recognise its ability to further decarbonise supply chains. The utilisation or storage of this gas can present new commercial and environmental opportunities to its users.

Commercial opportunities

CO_2 gas is used in numerous industries: manufacture of foods and drinks; increasing greenhouse productivity; filling of fire extinguishers; medical procedures; production of materials; and increasingly used in mobile refrigeration solutions[140].

Much of this industrial-grade gas is currently sourced from the manufacture of artificial fertilisers (nitrogen fixing via the Haber Bosch cycle). As ammonia production is very centralised, CO_2 must be liquified and transported. Consequently, the cost of this industrial gas is largely dependent on the user's proximity to these production centres. Prices exceeding $100 per tonne of CO_2 gas are not uncommon in the global north.

Co-locating an AD plant next to a user of CO_2 can therefore become mutually beneficial for both parties. An AD plant gains a reliable revenue stream from one of its products, and the industry user gains a cheaper supply of CO_2. Benefits can be extended further through the supply of biomethane and/or digestate, if required. With an eye on energy efficiencies and a hydrogen future, many such symbiotic clusters are being developed, such as GreenLab in Denmark.

Environmental opportunities

CO_2 gas produced from the manufacture of artificial fertilisers is derived from fossil resources. This process requires vast amounts of energy and natural gas to fix nitrogen from air into a useable fertiliser. On application to land this industrial CO_2 is simply released to the atmosphere, contributing to GHG emissions. Use of bio-CO_2, however, is carbon neutral as its carbon is originally derived from the atmosphere.

Moreover, as economies increasingly account for emissions, Carbon Capture and Storage (CCS) technologies could lock the carbon within bio-CO_2 away from the atmosphere – actively reversing GHG emissions. As detailed in Chapter 2, AD plants could become a carbon hub, whereby atmospheric carbon is concentrated within a digester ready to be permanently stored within materials or underground. At full potential, the global industry would produce over 12,500TWh of biogas, containing 1,560 million tonnes of CO_2e. If this carbon were permanently stored using CCS technology, the global biogas industry could negate the total annual emissions from all of Russia (~1,700 MtCO_2e), the world's 4th largest emitter of GHGs.

At present, the most important barrier to CO_2 storage, regardless of the origin of the carbon, is the lack of development of CO_2 storage solutions. Only very few facilities are operational and, in some cases, the national regulations do not recognise the storage of bio-CO_2 as a carbon negative system. Permanent storage solutions might include the injection of CO_2 into underground aquifers or natural gas cavities, or through the mineralisation of CO_2 to a solid carbonate that can be used as an aggregate or soil additive.

(Future) Opportunities

Bio-CO_2 can either be mixed with hydrogen gas to form methane, or biogas can be upgraded to grid-ready hydrogen by feeding hydrogen directly into the digester tank. The conversion of CO_2 is set to become another major opportunity in the future energy supply through innovative power-to-X (P2X) applications, especially as it complements the growth in the hydrogen economy. Catalytic conversion of CO_2 can be expected to become a relevant technology relatively quickly as the production costs of sustainable CO_2 from large biomethane production facilities are already competitive against some other commercially available CO_2 value streams.

[140] www.iea.org/reports/putting-co2-to-use

P2X can help balance the energy network. Wind and solar are intermittent generators of renewable electricity – i.e., they only produce energy when it is windy or sunny. Consequently, this power generation does not link to energy demand. In the summer, countries are increasingly experiencing periods in which electricity generation exceeds demand, resulting in negative energy pricing. Without storage capacity in the network, energy suppliers must pay significant sums of money to waste this valuable green energy. For example, in February 2020, Germany's negative electricity price caused an estimated €50 million in losses to offshore wind projects[141].

Instead of being wasted, excess renewable energy from intermittent sources could be used to generate green hydrogen through electrolysis. In turn, this hydrogen could be fed into an AD plant, binding with the bio-CO_2 to form biomethane – an example of P2X systems. Biomethane is easier to store than electricity and hydrogen, particularly if the plant is connected to the gas grid. Again, this green gas can be transported across regions and used when and where required; this includes the conversion back to hydrogen or electricity if needed.

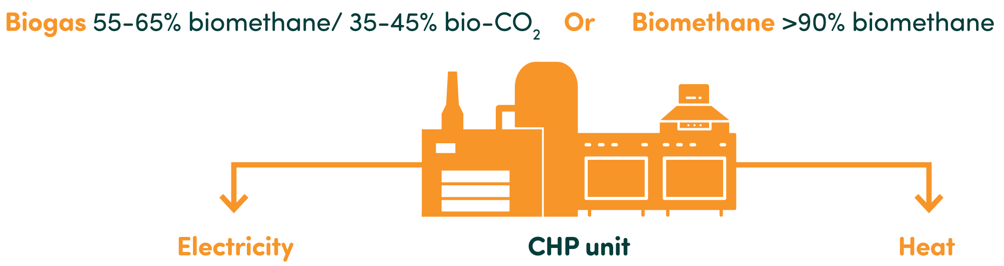
P2X pathways can also refer to non-energy pathways for biogas. Green hydrogen created using excess renewable electricity can also be processed with biogas' components, bio-CO_2 and biomethane, to form a host of platform chemicals – for example, syngas, a mix of carbon monoxide and hydrogen. As previously discussed, these chemicals are typically created from fossil resources and used to manufacture a range of products, such as plastics and lubricants. Biogas could help provide a renewable source of these compounds, thus decarbonising sectors beyond energy.

One of the biggest barriers to the use of bio-CO_2 from biomethane facilities is delivery costs from the existing stock of biomethane facilities, compared to the fossil alternatives and their established supply chains. The financial challenges of this revolves around at least three distinct issues. One is the quality requirements (typically food quality) which means that a significant investment will have to be made to document and deliver the adequate purity required. While this may be viable for the larger plants, equipment costs may be prohibitive to the smaller ones. Distribution of the recovered CO_2 is then either via pipeline or tanker – both can have significant costs. The other challenge is that the market for CO_2 is limited and currently mostly being served from fossil fuels.

6.2 Combined heat and power (CHP)

Combined Heat and Power (CHP) engines compress and combust flammable gases, fuelling a generator to produce electricity. However, a CHP engine may only convert 37-42% of biogas' energy into electricity, the rest generates residual heat. This heat can be recovered and transported to a heat consumer via a local heat network.

When biogas CHPs are co-located adjacent to a suitably large commercial consumer of heat and electricity, they can deliver highly efficient decarbonisation, in an economical manner. The main economic driver for this is the ability to export directly to the end consumer in a "behind the meter" arrangement, avoiding expensive electrical transmission fees levied by the electricity network. Moreover, if the industrial process creates organic waste, a co-located AD plant can also minimise waste management fees and transport distance, further improving the financial and environmental benefits to a company while establishing a local circular economy.



Electricity can be supplied at Low Voltage (LV) or High Voltage (HV). Whilst LV is more efficient due to minimal system losses, in order to export the electricity to a national grid, a transformer is used to convert to HV.

Recovered heat is usually supplied as hot water, around 90-100°C. However, in specialist applications can be supplied as pressurised steam for industrial use, albeit with steam generation the CHP thermal efficiency will typically be reduced.

[141] www.districtenergy.org/blogs/district-energy/2020/05/01/germanys-negative-price-rules-bring-negative-conse

Biogas combustion within CHP engines has been the predominant end-use over the last 20-30 years. The main drivers for use of CHPs are a combination of:

- **Government subsidies** for renewable electricity production have been historically very high in specific countries – for example, through the UK's Feed in Tariff (FiT) rates of >£150/MWh of electricity generated could be secured over a 20-year period at the scheme's inception. This incentive encourages the displacement of coal-heavy generation assets.

- Electricity from biogas was initially **cost-competitive** relative to other green technologies, solar, wind etc. However, in recent years, the price of intermittent renewables has fallen drastically and they are now substantially cheaper than any other form of electricity production.

- CHP gas engines are **readily available, proven technology** derived from the natural gas industry.

- **Minimal infrastructure** required as the CHP can be grid connected or in "island mode", reducing utilities connection costs. Remote communities with little/no access to electrical or gas grids can install a CHP to provide local heat and power.

- **Operationally simple**, with several CHP manufacturers offering complete Operation and Maintenance (O&M) packages.

Where the CHP is co-located with an appropriate consumer of both the electricity and heat produced, the overall efficiency can be between 80-90%, with minimal pre-clean-up costs to the AD plant. However, if the residual thermal energy is not utilised, the system efficiency will equal that of the electrical efficiency – i.e. up to 42% from the best-in-class engine.

Due to the limited electrical efficiency of a CHP engine, they are not recommended without an end-user of the thermal energy. If the CHP's heat is not used, most of the biogas' energy is wasted.

Where generation of biogas is not co-located with industrial consumers, the biogas could be upgraded to biomethane and then transported to industrial users via a suitable gas network, or via road transportation (a virtual pipeline) in multi-element gas containers (MEGCs). After transportation of the biomethane, it can then be utilised within CHPs at strategically important industrial clusters.

To support additional deployment of CHPs in the best strategic locations, governments worldwide should tailor economic incentives to the overall decarbonisation delivered, rather than paying per unit of renewable energy produced. This can be in the form of a support price per tonne of CO_2e abated (relative to a baseline scenario), which would incentivise the highest efficiency CHPs to be used in both electricity and heat applications.

Finally, use of biogas for electricity generation presents a very significant opportunity to displace the current electricity "baseload" which is predominantly provided by fossil fuels such as coal or natural gas. Most developed countries utilise natural gas and coal-based plants to buffer out "peaking" in electricity demand; typically during the morning and early evening as consumer demand soars. As more and more intermittent renewable generation from solar and wind is brought online, additional flexible generation capacity will be needed to balance the electrical grid. Due to biogas' "on-demand" nature, generators have the ability to increase or decrease electrical output as necessary, whilst allowing the excess biogas to be upgraded and used for transport, heat or storage in the gas grid.

6.3 Localised domestic use

Biogas is a highly flexible technology. It is accessible to all. Cheaper, low-tech systems can serve remote, poorer communities. At its simplest, organic waste can be fed into a pit dug into the ground, where a lid prevents oxygen from entering and a plastic liner captures the biogas. This setup can be easily scaled up to meet the waste production.

The benefits of micro-scale biogas units are well known across countries in the global south. Millions of low-tech biogas solutions are already serving small rural communities. Using manure from animals, human sewage and food scraps, micro-scale digesters produce biogas that can be directly connected to a cooker or light unit inside the building. The scale and cost of these allows widespread roll out across low-income countries and modular units are now marketed for ease of installation[142,143]. Cheap and simple to use, in line with the UN's SDGs (see Chapter 2), micro-AD can:

- Improve food security by recovering nutrients from waste. Digestate fertilises crops and returns organic carbon to soil, enhancing water retention and minimising soil degradation. **[Goals 2, 11, 15]**
- Enhance sanitation by treating waste and prevent the contamination of freshwater. **[Goals 3, 6, 15]**
- Improve air quality (and reduce deaths from air pollution) by providing a clean burning gas, displacing the need for fuel wood. **[Goals 3, 7]**
- Support gender equality by freeing up women's time by reducing the need to cut fuel wood. Women are also disproportionally affected by eye and lung damage caused by burning fuel wood. **[Goals 3, 5]**
- Improve energy security by delivering biogas **[Goal 7, 11]**
- Provide jobs and be used as a tool to educate communities about the benefits of a circular economy. **[Goal 9]**
- Deliver decarbonisation by converting organic wastes from an emitter of GHGs into a tool to cut emissions. **[Goals 11, 13]**

Poor air quality is a major cause of premature deaths. From burning wood in rural homes to traffic pollution in cities, some 7 million people a year die from diseases caused by breathing polluted air. Indeed, 90% of the global population breathes air with pollution levels above those recommended by the World Health Organisation (WHO) and the worst impacts are in low-income countries[144]. Air pollution is both inside and outside the home/buildings: inside through the burning of fuels whose emissions are inhaled directly and outside from emissions caused by traffic, industrial activities, heating, burning of crop residues, ammonia emissions from farms, and many other sources.

The use of biogas technologies can substantially reduce those emissions. Aid programmes and policies have been developed to promote the use of small-scale biogas units; already, they have successfully supported the development of millions of such installations. The Clean Cooking Alliance[145] and SNV[146] of the Netherlands are among the major donors and promoters of small-scale biogas.

Developed countries can put such installations at the heart of rural development aid in low-income countries. Few other practices have the capacity to change the quality of life of rural households that do not enjoy access to energy grids or natural gas supplies.

Countries in the global south can promote the use of small-scale biogas installations across remote areas to provide energy independence to rural communities, with the benefits listed above. Promotion can include exempting the materials needed for such installations from sales or import taxes; providing technical assistance for installation; education on biogas use; and promoting the use of domestically produced fertilisers versus synthetic, mineral fertilisers.

[142] www.homebiogas.com/

[143] www.researchgate.net/figure/Typical-operational-biodigester-at-the-small-scale-farm-in-Muldersdrift-Johannesburg_fig2_318163175

[144] www.who.int/health-topics/air-pollution#tab=tab_1

[145] www.cleancookingalliance.org/home/index.html

[146] https://snv.org/update/snv-shares-lessons-learnt-major-latin-american-biodigester-event

6.4 Beyond 2050

Post-2050, climate scenarios often identify hydrogen as a key low-carbon fuel. However, its current use remains hampered by several technological barriers – specifically, it is difficult to compress and store hydrogen, and carbon capture and storage (CCS; necessary to produce low-carbon blue hydrogen at-scale) is not yet cost-effective. Governments cannot wait for innovation to solve these issues and must utilise ready-to-use technologies, such as biomethane, capable of delivering immediate decarbonisation.

Biomethane offers flexibility within the long-term pathway to net zero. If, in 30 years, hydrogen emerges as the best solution for heat or transport, AD's biomethane can be converted to green hydrogen via steam reformation, a technology already available. However, unlike the generation of blue hydrogen through the steam reformation of natural gas, biomethane's conversion to hydrogen does not require CCS for the process to become carbon neutral. If integrated, the biomethane and CCS technologies would produce carbon-negative hydrogen, thus actively reversing sector emissions.

It is likely to be over a decade before hydrogen is ready and capable of fuelling any mode of transport at scale to decarbonise the sector. Increasingly new developments and funds (e.g., the £900 million HyNet Low Carbon Hydrogen Plant in the UK) aim to increase the production of low carbon hydrogen and overcome technological barriers, and yet few sectors are ready to utilise this valuable resource today.

6.4.1 Reversing Climate Change

It is clear that in order to limit global warming to 2°C, ideally 1.5°C, in line with the Paris Agreement commitments, all sectors need to deliver much quicker and deeper decarbonisation than is currently being achieved. Indeed, in the UK (the first nation in the world to legislate for net-zero), the independent Climate Change Committee (CCC) recently reported to Government1 that the UK was failing on 14 of 21 progress indicators on the route to net-zero. Many other nations have struggled to make headway with their initial NDC targets. As such, global efforts to limit global warming to <1.5°C is firmly off track. In this scenario, the world will have to drive deep negative emission technologies in the latter half of the century, to reverse the impacts of climate change.

Again, if wastes are treated, AD can already act as a carbon negative technology – actively reversing GHG emissions. This capability can be enhanced through the integration of carbon capture and storage (CCS) technology. The carbon within bio-CO_2 is derived from the atmosphere, AD can facilitate the permanent removal of carbon, currently driving climate change.

Other technologies can also achieve negative emissions, including biomass with post-combustion CCS, as well as novel gasification and direct-air capture (DAC) of CO_2. However, none of these pathways use currently available technology and all of them require significant capital and operational expenditure. To capture and store atmospheric CO_2 via DAC, it would cost an estimated US$134-342 per tonne[147]. Since CO_2 concentrations are over 1000 times greater within an anaerobic digester, the cost to capture this carbon is significantly reduced, compared to DAC. Integrating CCS with AD technology could bring the cost of carbon removal to US$52-78 per tonne of CO_2[148].

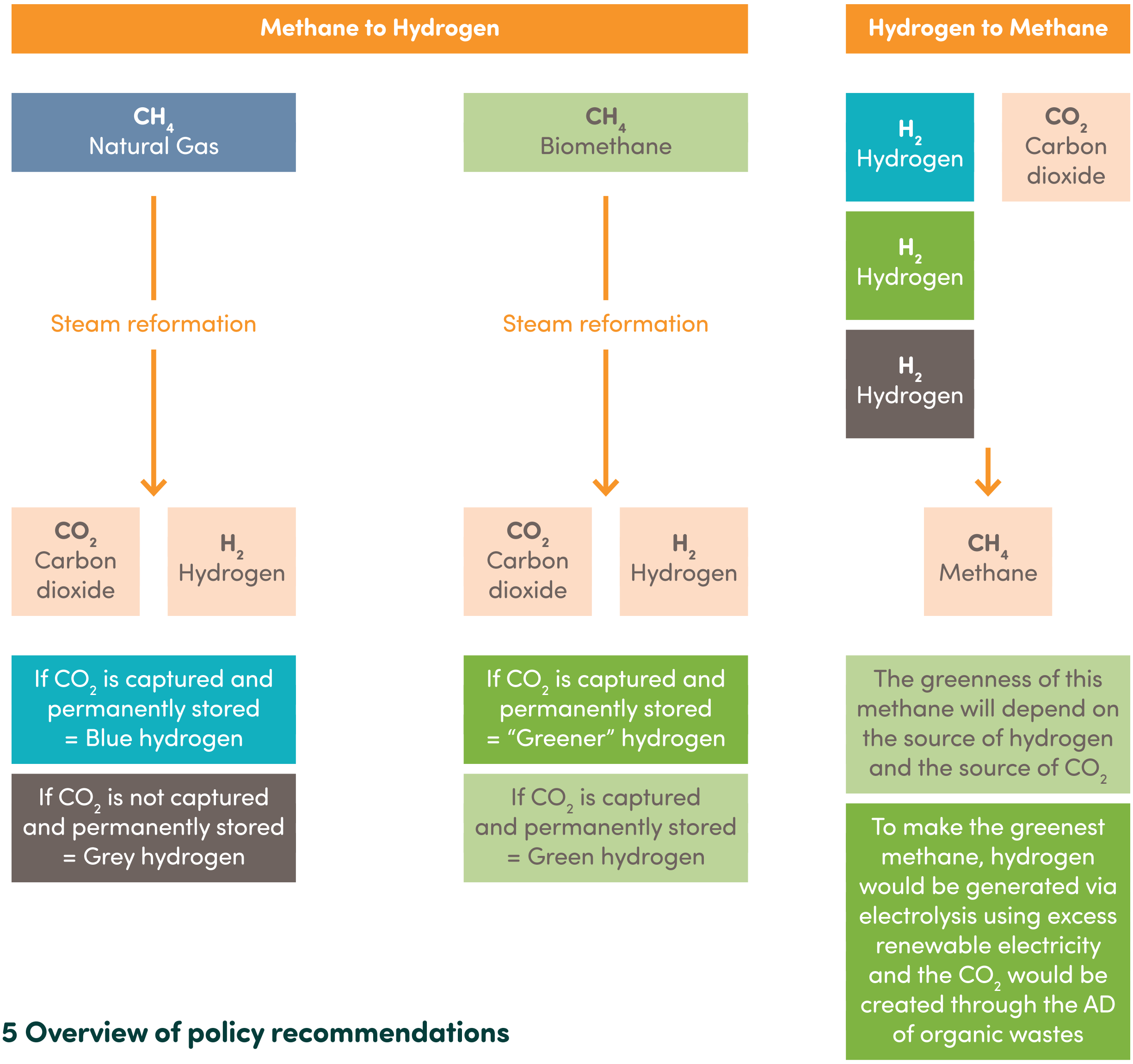
6.4.2 "Greener" Hydrogen

Methane reformation of fossil natural gas has been conducted on an industrial scale for decades and is the main source of hydrogen globally at present (referred to as "grey" hydrogen). Without CCS, this process emits fossil CO_2 into the atmosphere, contributing to global warming. Whilst carbon capture is not as widespread, it has also been demonstrated on an industrial scale. With CCS, this process is carbon neutral "blue" hydrogen.

Methane reformation of biomethane can deliver carbon neutral-negative hydrogen with or without CCS – referred to as "green" hydrogen. Green hydrogen can also be created though the electrolysis of water using renewable electricity. However, by combining AD and CCS technologies, biomethane can be one of the most commercially viable, carbon negative emission technologies available, delivering hydrogen that is significantly more decarbonising than the current "green" hydrogen, produced by electrolysis.

[147] www.iea.org/commentaries/is-carbon-capture-too-expensive

[148] https://pubs.acs.org/doi/10.1021/acs.est.0c02816



6.5 Overview of policy recommendations

1) Tariff payment for biogas generation

The value of the carbon saved from the use of biogas instead of fossil energy is not priced into the market so when investment decisions are being made on biogas developments, the financials struggle to stack up on their own. To correct for the fact that the environmental services delivered are not priced by the market, policy needs to be designed to ensure projects will receive a revenue for this and the full environmental benefit is factored into investment decisions. In countries where the domestic biogas industry is still in the earlier stages of development, the sector will struggle to grow without direct government support. Investors need assurance that this revenue will accrue for the lifespan of the project. The policy that has had the greatest impact at growing biogas industries across the globe has been tariff based support, where plants are provided with government payments for the biomethane, or biogas power generated. This has generally consisted of ongoing tariff payments usually for between 10-20 years with some variations on how the policy functions – e.g., fixed rate tariffs; a top-up tariff with government paying the difference between a set level and the wholesale energy price; sustainability criteria to manage feedstock sourced from waste versus bioenergy crops; and a premium tariff for certain feedstocks such as manures and slurries.

We recommend that, as methodologies are developing for carbon accounting, new tariff-based policies should be designed to make payments based on the carbon intensity of the biogas or biomethane generated, such that the greater the carbon saving generated the higher the tariff rate. Carbon accounting should factor in emissions savings from the entire life cycle of AD, including savings offered from waste management and digestate (see Chapters 4 and 5). This would ensure that government money is being spent in the most effective way to cut carbon emissions. It would result in the greatest carbon reduction from AD plants. Operators would be incentivised to utilise the bio-CO_2 generated and integrate CCS or CCUS technology, consolidating AD's ability to deliver carbon negative biomethane.

2) Innovation funding for improved biogas generation

The most effective way to help grow a biogas industry is to support it to become independently viable, moving away from reliance on direct government subsidy. While the fact that carbon emissions are not properly priced in the market is the major inhibiting factor for the financial model of AD plants, there are a number of areas of AD plant development and operation that could be improved to reduce costs and increase revenues.

Targeting innovation towards these areas, such as biogas yield, biomethane content, standardisation and modularisation, integration of CCUS technology and improvements to associated processes such as grid injection, can help improve the financial model and move projects closer to independent viability. Innovation in these areas can also improve the carbon savings delivered if, for example, more biomethane can be generated to replace fossil natural gas. Innovation should be provided both to support research and development as well as commercialisation and practical adoption of novel technologies. As innovation reduces the cost of projects in the future the level of tariff required to make projects viable will fall, saving government money.

3) Support for CCUS at AD plants

While the development of solutions to integrate CCUS into AD projects should be included in innovation funding, direct support should be provided for implementation of these technologies. Currently, for many of biomethane upgrading projects, it does not make economic sense to utilise or store the bio-CO_2. Meanwhile, significant amounts of capital are being invested in developing Direct Air Capture technology despite the AD industry already capturing bio-CO_2 from the atmosphere as a by-product of the organic waste recycling process. It is imperative this is not wasted: it must either be used to replace CO_2 in industrial processes, such as drinks manufacture, or stored, using novel techniques such as mineralisation or other technologies to permanently lock in the carbon. Another alternative use, as the technology develops, is to integrate AD with power to gas technologies, using hydrogen generated from excess wind and solar power to upgrade the bio-CO_2 to more biomethane. Grant funding for the adoption of CCUS on AD plants and/or continued support for the use and storage of the bio-CO_2 captured on-site should be implemented to incentivise this.

4) Renewable Obligation on suppliers

As the biogas industry in any given country matures and innovation improves the financials of project development, investor confidence should strengthen, particularly as their operational knowledge and expertise increases . As mentioned above, this can open the door to a transition away from direct government subsidy reducing the financial burden on governments. As tariff-based policies begin to be tapered away, alternative market-based policies can be introduced that create an effective market for the environmental benefits, e.g., the carbon saving delivered by the AD plant. One form of market-based policy that has proved effective is the introduction of renewable obligations on fuel suppliers, whether for transport fuel, electricity, or gas. The obligation sets growing proportions of fuel that must be derived from renewable sources, with suppliers having to purchase certification of their fuel's renewable origin. It is the market for the tradeable 'renewable certificates' that provides a revenue to generators of renewable fuel and power, such as biogas electricity and biomethane, for the 'green element' of the energy, in place of a tariff-based policy.

It is important to note that the primary difference between the two types of policy from a practical perspective for the project developer is that the price received from the sale of certificates is determined by market forces and so is variable. Investors will no longer have a guaranteed revenue and so there is greater risk attached to the project. It is critical the transition to this form of market-based policy is not done too early or it can stall industry growth and lead to loss of domestic knowledge and expertise as well as green investment looking for opportunities overseas. It can be advantageous to support the move to a market-based policy with a clear government strategy for the AD industry going forward, such that investors still have confidence that the government is committed to seeing growth in the sector.

A renewable obligation plays a similar role to the development of carbon markets, but on a much smaller, sector specific scale. As carbon markets are developed at the national, regional and eventually global scale, the value of the carbon impact should be factored into AD projects, superseding the need for sector specific policy.

Chapter 7: Conclusion

Organic wastes are a global problem. Over 105 billion tonnes are produced each year. Yet only 2% of these organics are currently being recycled. Without effective management, these rotting wastes pollute our planet. They contaminate drinking water; they reduce air quality; and they emit methane directly into the atmosphere – a greenhouse gas (GHG) far more potent than carbon dioxide. Untreated organic wastes left to rot account for 5% of annual emissions worldwide. For too long organic wastes have been ignored.

Reducing organic waste production is, by far, the most effective means of mitigating against all these harmful impacts. With less waste arising, GHG emissions are avoided, and less energy is required to manage the remaining material.

However, not all wastes can be prevented; for example, not all food waste is edible, and humans and livestock will continue to defecate. Governments and societies should seek to treat these organic waste streams using the optimal technology, AD, which turns them into valuable resources.

This report seeks to ensure that no policy maker will be able to say, "I didn't know", as they consider how the collection and recycling of organic wastes through AD can be adopted into their own climate change policies, specifically their Nationally Determined Contributions to maintain climate warming well below 2°C.

At full potential, where AD is digesting all readily available and unavoidable organic wastes, annual global emissions could be cut by at least 10%, on top of the 3% reduction that can be achieved from halving food waste. Recycling organic wastes is a win-win.

Total global GHG savings (%):

Halving food waste **3%**

\+

Avoiding methane emissions by treating unavoidable waste **5%**

\+

Displacing fossil-based products with biomethane and digestate **5%**

Delivered through AD = 10%

=

Total GHG savings from effective waste management **13%**

AD unlocks the greatest value from organic wastes. If harvested through AD, these organic wastes will provide sources of renewable energy, green CO_2, natural fertilisers and other valuable bioproducts, playing a multifaceted role at the heart of the circular economy. It extracts the greatest value out of organic wastes and turns them into the most valuable array of renewable resources, which is reflected in the technology's versatility.

AD can be installed on a micro level to recycle a household's organic wastes, delivering on 9 of the 17 SDGs. In cities, large scale merchant facilities can recycle 500,000 million tonnes annually and be a nexus of waste management and energy production, connected to local heat networks and delivering transport fuel. Or AD can be the hub of industrial clusters, where CO_2, process heat and energy is required. Biogas can also produce heat, electricity and fuel all off-grid and depending upon the geography of installations, one or the other uses may be more beneficial.

AD can handle wet or dry wastes, or a mix of both, and can be used in conjunction with composting, depending on the soil requirements in a given geographical area. Moreover, the production of biogas is continuous (baseload) and does not suffer from the fluctuation of wind, solar and hydro sources, making biogas a perfect integrator to these.

The biofertiliser produced from recycling nutrients improves both the health and carbon capture capability of soils and improves biodiversity by mitigating the use of mineral fertilisers and pesticides.

Investment in AD also has long-term security. Furthermore, biogas is compatible with a hydrogen future. Low carbon biomethane can be converted into green hydrogen, or hydrogen can be converted to biomethane when mixed with biogas' CO_2. In this way biogas is future-proofed, adapting to the energy needs of tomorrow.

At its full potential, the AD industry could replace 33% of the demand for fossil natural gas, with renewable biomethane; this proportion could be increased to 53% through the integration of power-to-gas technology, converting AD's bio-CO_2 into additional biomethane.

Scaling up the biogas industry to recycle the 105 billion tonnes of unavoidable organic wastes would require an estimated investment of US$100 trillion, while creating 10-15 million new green jobs in AD development and operation.

Waste not, want not. Each Government when reviewing its NDC under the Paris Climate Treaty should include the collection and recycling of organic wastes among its target instruments. The collection of urban food wastes, the reduction of uncontrolled burning of stubbles and harvesting of animal manures are all part of the policy landscapes which bring us greater sustainability and better-quality air, water and soil outcomes.

Governments should therefore not simply measure biogas in terms of the cost of the kilowatt hour or megajoule of heat, but in the overall beneficial outcomes biogas produces through the whole range of its environmental services and wider benefits to humanity.

Carbon is the best way of accounting for all the environmental benefits presented by AD. As policy begins to account for emissions – albeit through carbon trading schemes, carbon tax, or emissions limits – carbon will gain value.

Consequently, it will make economic sense to decarbonise, adopting new practices and installing new technologies. Organic wastes will be recognised as valuable bioresources; from an expenditure if left to rot to a revenue stream if effectively managed.

Experience shows that any policy introduced to tackle decarbonisation will positively support the development of AD, and the development of AD will positively deliver decarbonisation.

WORLD BIOGAS
ASSOCIATION

The World Biogas Association

The WBA is a non-profit association dedicated to the development of biogas globally. We are available to offer services to countries, cities and industries wanting to know more about biogas, its technologies, the policies and incentives needed to ensure biogas is made a core solution to resolving global challenges around sustainable development, climate change and public health.

The future of biogas is now
Join us in realising our mission

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