Creating a Stink: How Manure Drives Pollution and Biodiversity Risk For Animal Protein Producers

A MEATY PROBLEM: ANIMAL PROTEIN PATHWAYS TO BIODIVERSITY LOSS

"The meat industry's failure to manage manure effectively is threatening both biodiversity and the bottom line for investors. Unbelievably, more waste is produced by animal farms each year, than the volume of plastic produced worldwide. The practice of dumping excessive amounts of manure and allowing nutrients to pollute waterways is killing off marine life and endangering public health. Investors are well aware of the regulatory risk for companies, having seen initial steps taken in the US and Netherlands. Moreover, companies are missing an opportunity to be part of a global solution by creating valuable fertilizer from waste, at a time when it has never been more expensive to procure."

Jeremy Coller
Chair and Founder of the FAIRR Initiative,
and Chief Investment Officer of Coller Capital

About this report
This report is the second in FAIRR's Animal Protein Pathways to Biodiversity Loss series, which explores protein producers' role in exacerbating the biodiversity crisis – and their potential role in mitigating it.

Contents

About this series

The variability of life on Earth is encompassed in the concept of biodiversity. Without biodiversity – or biological diversity – life and economic activities as we know them simply could not exist.

This is because biodiversity underpins nature's capacity to provide the ecosystem services on which humans, other species, societies and economies rely. These services can be divided into four broad categories: provisioning services (e.g. food, fruits, vegetables), regulating services (e.g. pollination, water purification, flood control, climate regulation), cultural services (e.g. non-material benefits that contribute to the cultural advancement of society) and supporting services (e.g. photosynthesis, nutrient cycling, creation of new soils).

In 2019 a major study by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services warned of "unprecedented" biodiversity loss, with a million species facing the threat of extinction and ecosystems "deteriorating more rapidly than ever"[1]. Animal agriculture – especially in its intensive, industrialised form – is a major contributor to this unfolding catastrophe.

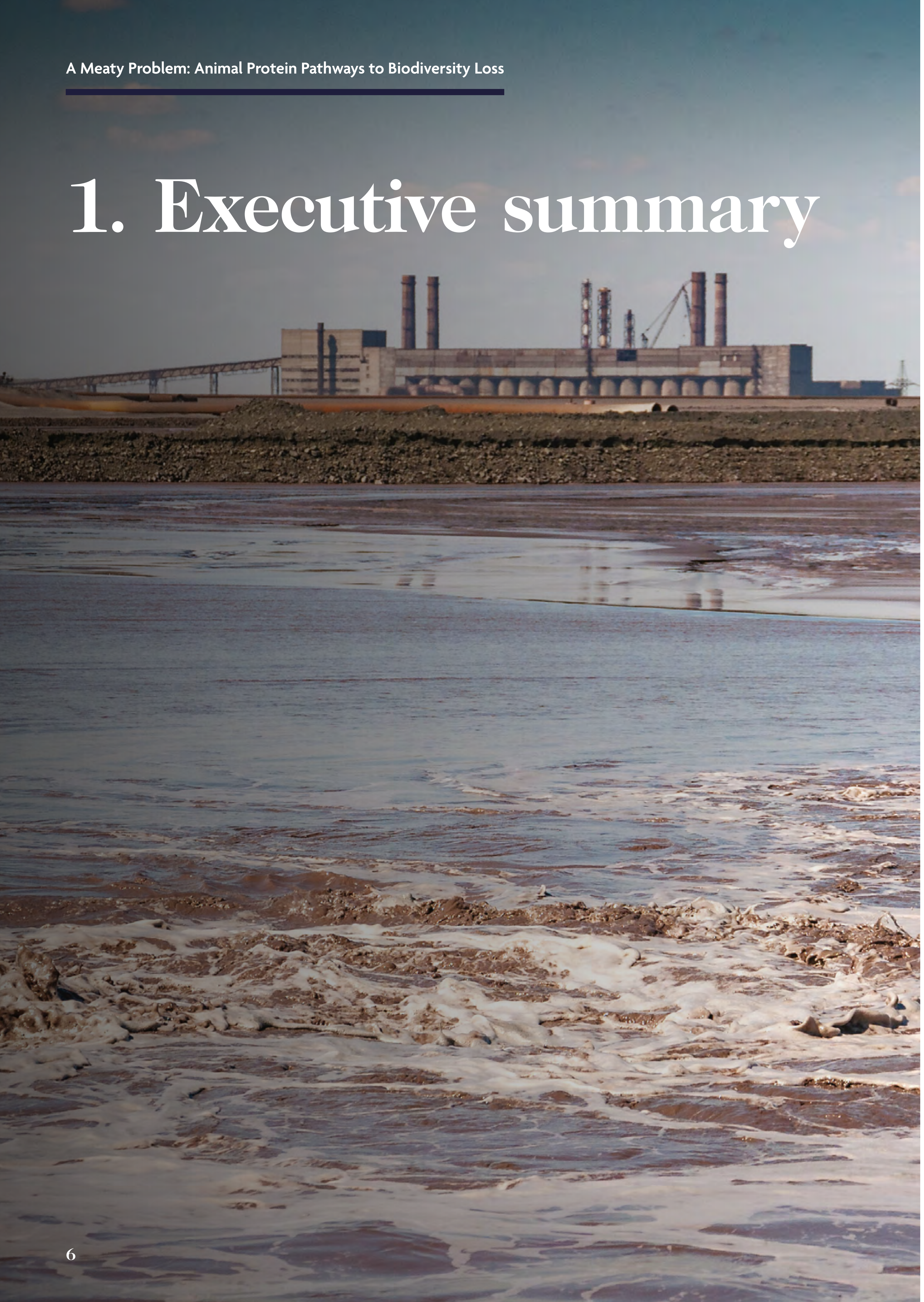
FAIRR's Animal Protein Pathways to Biodiversity Loss series explores protein producers' role in exacerbating the biodiversity crisis – and their potential role in mitigating it. The series comprises a dedicated policy briefing and three related papers:

- Biodiversity and Nature Risks: Implications for Investors and Policy
- Waste and Pollution
- Land and Resource Management
- Land Use Change

There are two fundamental dimensions to assessing biodiversity risk within individual companies and portfolios: first, locating and quantifying the exposure from a top-down perspective, and second, understanding the drivers of biodiversity loss so that they can be measured and addressed. **Protein Producers and Pathways to Biodiversity Loss** aims to assist investors and other stakeholders with the latter by shedding light on harmful practices; the risks that are emerging as a result; what is being done to tackle the issues; and, crucially, what could and should be done, and whether opportunities may arise from taking action. While this work aims to meaningfully contribute to the existing large-scale, top-down initiative such as the Task Force for Nature Related Financial Disclosure (TNFD), these papers will also guide FAIRR's engagement with companies. The goal is to help facilitate the shift toward sustainable strategies which reduce environmental and social harm, preserve cashflows and reinforce opportunities both for the industry and investors.

Source: FAIRR
*Land is used generically for the purposes of this infographic, though FAIRR also includes wetlands and coastal ecosystems in its research.

1. Executive summary



The links between industrialised farming, the inadequate management of animal manure and the negative impacts of nutrient pollution on biodiversity and ecosystems are clear and concerning.

Research by FAIRR suggests leading protein producers' understanding and transparency of the multifaceted nature of this issue and the risks to which it gives rise remains limited.

It is estimated that 50% of freshwater biodiversity loss can be attributed to food systems.* The excessive or inappropriate use of livestock manure as fertiliser in concentrated areas of livestock production is a major source of nutrient pollution, which is a key driver of biodiversity loss in marine ecosystems at a large scale.

Current responses to the problem can be regarded as too narrow in focus, with some overly reliant on climate-related financial incentives that are well-intentioned on the surface, but ultimately fail to look at the issue of manure from a nature-wide perspective.

The mismanagement of animal waste is also responsible for a range of negative health and social impacts on communities that are in close proximity to intensive farming and processing facilities.

Protein producers need to:
A. Fully assess the biodiversity risk arising from the management of livestock manure including the upstream and downstream use as fertiliser for locations where they operate. Improved transparency with investors and other stakeholders being a key part of this.
B. Act accordingly to reduce the impacts on biodiversity from manure in their own facilities and implement circular solutions in order to avoid further environmental, economic, social and reputational impacts.

*See CBD, GSDR and ELD Initiative data aggregated by the WWF Living Planet Report, 2020.

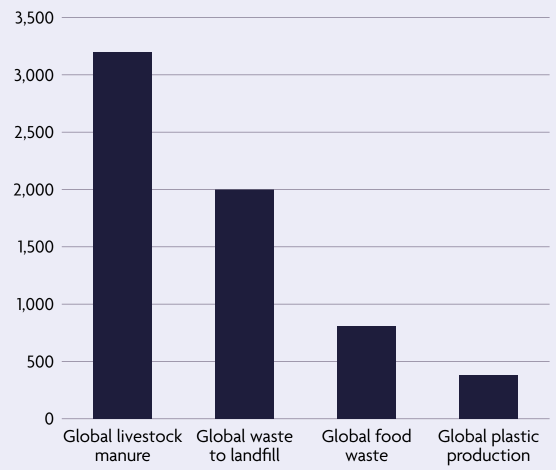
2. Introduction: Animal waste – the mess we're in

The 70 billion animals processed for the global food system each year generate an estimated 3.12 billion tonnes of waste[2] as manure[i]. By any standard, that is a lot of sewage to dispose of or deploy. In terms of sheer weight, as shown in the chart below, it easily exceeds the annual totals for human waste, food waste, waste sent to landfill and even the amount of plastic produced worldwide, yet it is scarcely acknowledged as a risk to biodiversity.

The scale of the problem

The amount of animal waste produced each year easily exceeds other major forms of waste. For example, FAIRR estimated that JBS produces as much sewage as the entire population of India.

The comparison below is measured in millions of tonnes. The quantity of human waste generated annually is around a fifth of its animal counterpart.



Source: Our World in Data, 2022; World Bank, 2022; kitco, 2022; IEA, 2022

> "The links between industrialised farming, the inadequate management of animal waste and the destruction of ecosystems are manifest and concerning."

The figure is set to rise further in the near future too. By 2030, because of population growth, coupled with increased consumption of meat per person[ii], the combined tonnage for both animal waste and human waste is expected to reach five billion, with livestock likely to account for around four-fifths overall[3].

What happens to animal waste presents a major threat to ecosystems. Unlike human waste, manure is not generally dealt with by efficient municipal systems that are often tightly regulated. By contrast, animal manure undergoes, varying levels of treatment and composting, and is then spread onto crop fields as fertiliser. If applied in incorrect quantities or within conditions prone to leaching (the loss of plant nutrients to water), it can pollute soil, water and air. The environmental, human and economic health of nearby communities is likely to suffer as a result. More broadly, biodiversity loss can be among the principal impacts of far-reaching ecosystem degradation. This problem ultimately creates a material risk to the biggest producers of animal protein given their highly industrialised processes.

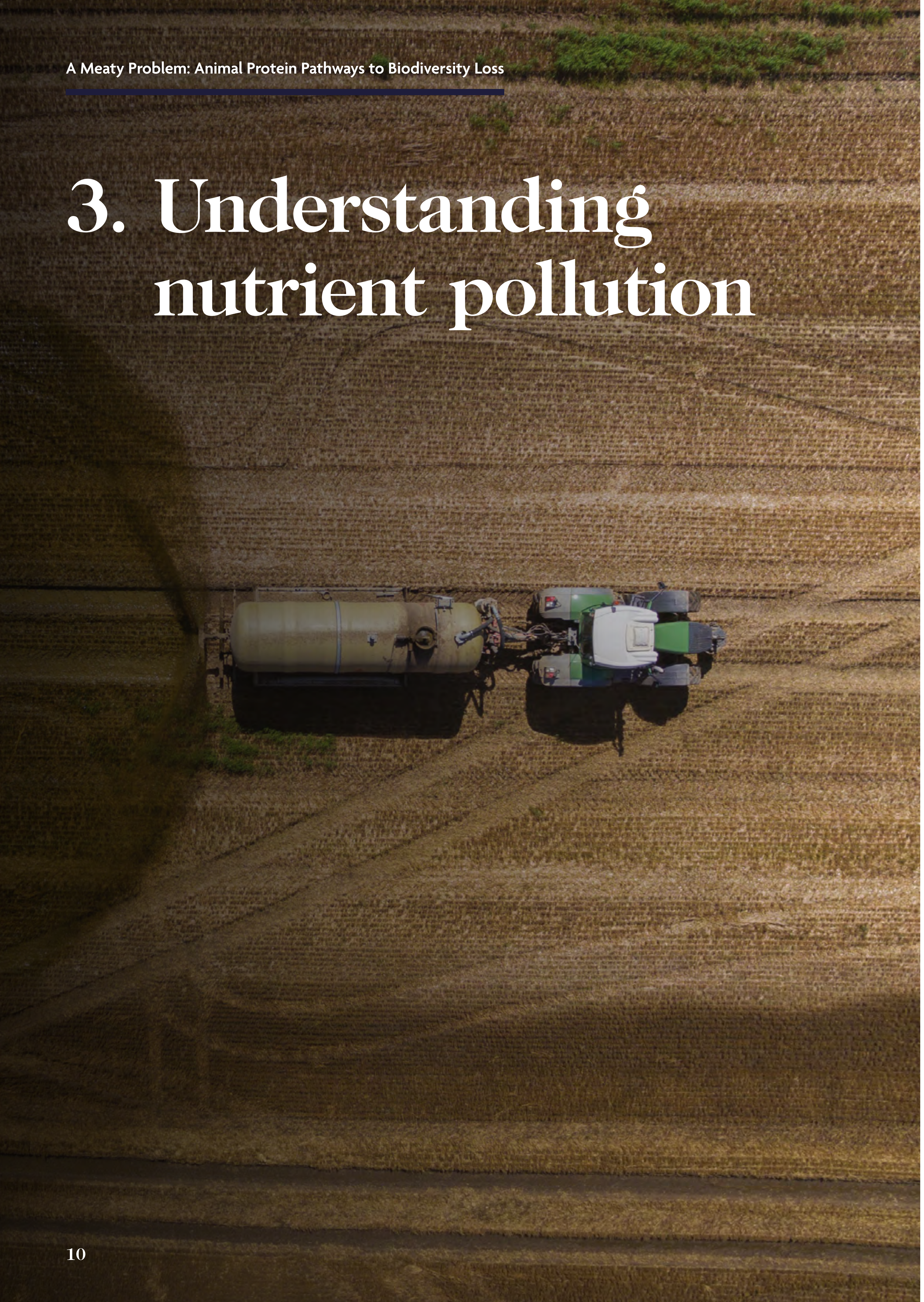
The links between industrialised farming, the inadequate management of animal waste and the destruction of ecosystems are manifest and concerning. This presents many agricultural businesses with a dilemma: they can either tackle the additional challenges of assessing the risks appropriately where they operate and improving practices accordingly, or cause ever more damage and await mounting regulator action.

This paper lays out how the inadequate management of manure waste and pollution from intensive animal agriculture leads to biodiversity and assesses how companies are addressing these risks now. It also covers what more could be done both in the immediate future and over the longer term by those companies to manage their exposure to this risk.

i Animal waste is commonly considered to be the excreted materials from live animals. In other words, it is manure. It may also include straw, hay, wood shavings and other sources of organic debris under certain production conditions, but in this report the terms "animal waste" and "manure" are treated as interchangeable; a third term, "slurry", which refers to manure with a high liquid content, may be found in referenced literature.

ii Each person globally is anticipated to eat 35.4kg of meat per year by 2030, up from 34.3kg in 2020, according to the OECD-FAO Agricultural Outlook for 2021-2030.

3. Understanding nutrient pollution



3.1. Too much of a good thing?

As shown in the table below, animal waste naturally contains nitrogen and phosphorus. Since these are two of the key nutrients most plants need to survive, there are reasonable grounds for expecting manure to support ecosystems rather than damage them. In theory, it should serve as a circular fertiliser[iii] and reduce crops' reliance on resource-intensive and carbon emission-intensive chemical nitrogen and mined phosphorus. A further benefit is that, as a commodity, manure is inexpensive. Unlike chemical fertilisers, whose prices are tied to energy costs, it is disconnected from the volatility of global markets[4,iv].

In reality, however, there are several impracticalities surrounding manure's use as fertiliser, turning a resource that should be beneficial to biodiversity and ecosystems into a detrimental one.

First, while manure itself may be inexpensive for crop growers, the associated costs to the livestock farmer can be significant. Storage, methane extraction and composting involve a material capital investment, and the cost of distribution in particular means manure is rarely transported more than a few kilometres before being spread onto crops[5].

Manure's use as fertiliser therefore tends to be concentrated in specific areas where large-scale livestock farming is prevalent. As a result, too much manure is distributed on too little land. Crops cannot absorb all the available nitrogen and phosphorus, which is instead likely to be washed off fields as "runoff". When this happens, as shown in the next section, potentially beneficial nutrients become potentially dangerous pollutants.

Nitrogen/phosphorus composition of animal waste by livestock type

Nitrogen and phosphorus values in manure are related to solids concentrations, or how much water is present. Generally, the higher the solids concentration, the higher the nutrient concentration. Manure from poultry contains the highest concentration of nitrogen and phosphorus, closely followed by pigs.

	Average weight (kg)	Total solids per day (g)	Nitrogen (g)	Nitrogen content (%)	Phosphorus (g)	Phosphorus content (%)
Broiler chicken	0.7	15	0.77	5.13	0.21	1.4
Laying hen	1.6	26	1.3	5	0.48	1.8
Pigs	52	570	27	4.73	9.4	1.6
Beef cattle	295	2,500	100	4	27	1.08
Dairy cattle	590	7,100	260	3.66	55	0.77

Source: FAIRR: FAIRR Protein Producer Index, 2021

iii Fertiliser can be thought of as circular if it reuses raw materials that have previously been disposed of as waste.
iv Issues such as Russia's invasion of Ukraine have recently helped drive the prices of chemical fertilisers to record highs.

3.2. Local impacts

Nutrient pollution's impacts on communities that are home to intensive animal farming are a reminder that biodiversity also encompasses the human race and that the consequences can be social as well as environmental.

In 2018, for instance, research concluded people living near North Carolina's 2,000 large-scale intensive pig farms faced an elevated risk of disease and death. While acknowledging that direct causality is difficult to establish, the study noted residents in close proximity to such facilities "are chronically exposed to contaminants from land-applied wastes and their overland flows… as well as airborne emissions"[6] even when adjusted for socioeconomic factors. Selected findings are illustrated in the chart below.

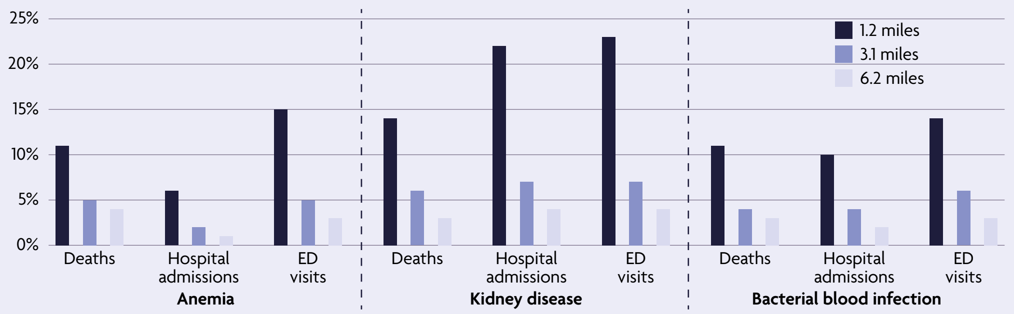
Communities with nitrogen-contaminated drinking-water supplies are likely to experience higher rates of colorectal cancer, thyroid disease, neural tube defects and "blue baby" syndrome[7]. Pollution from nutrients, as well as from heavy metals and antibiotic/anti-parasite drugs, also impacts communities that rely on wells and requires local authorities to use more elaborate treatments. In addition to those pollutants, manure contains ammonia, which breaks down into fine particulates that can cause strokes, heart attacks, respiratory diseases and cancer.

In 2015 it was estimated around a fifth of the 3.3 million deaths resulting from air pollution each year could be attributed to ammonia emissions from agriculture. Ammonia "entering the atmosphere as a result of the use of fertilisers and intensive livestock farming" was identified as a leading cause of air pollution in Europe, Russia, Turkey, Japan and the eastern US[8].

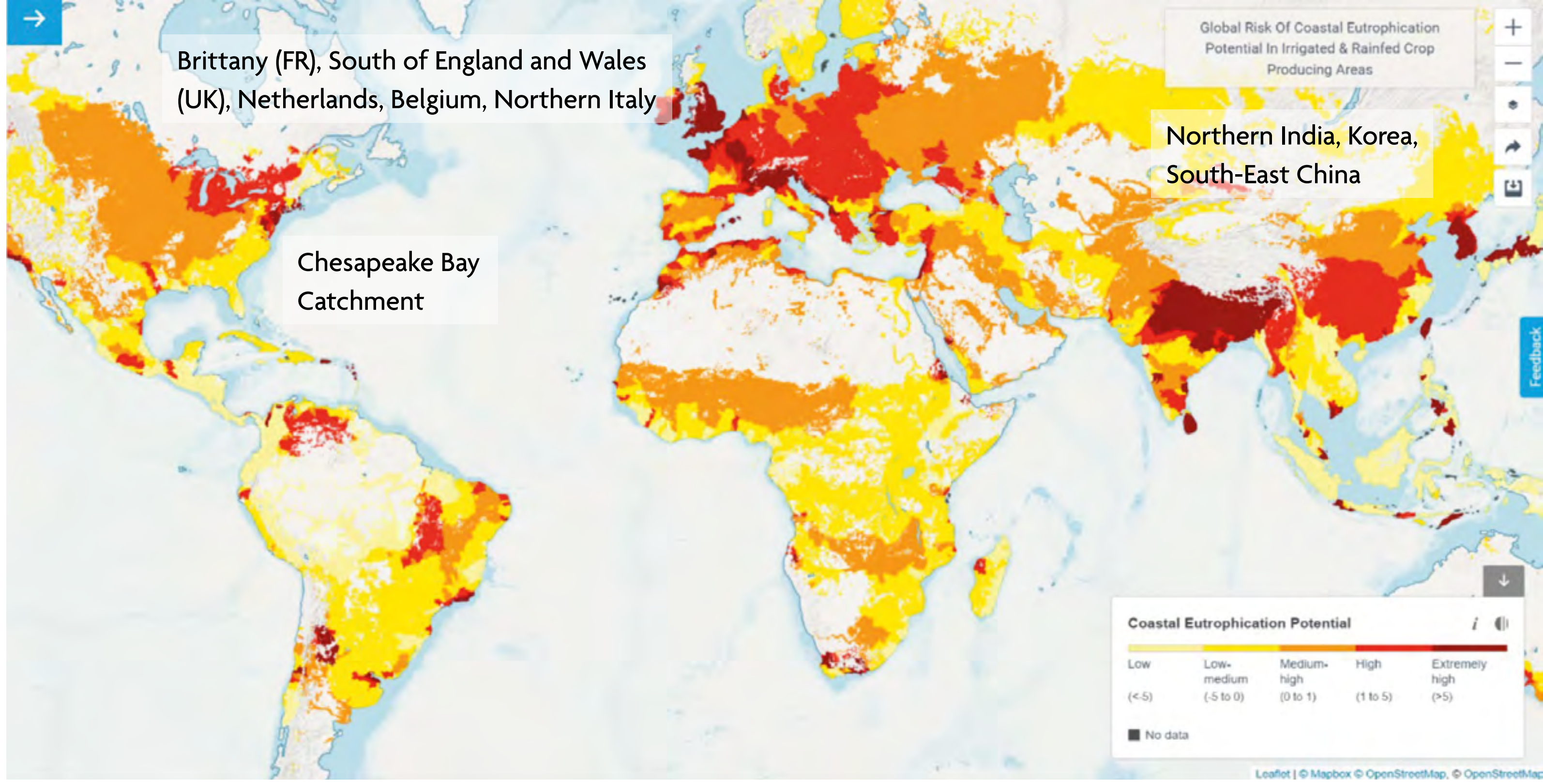
Amid growing evidence of the deleterious effects of intensive livestock farming on the communities in which they operate[9], many livestock producers including Tyson Foods, JBS USA, Smithfield (now WH Group), and others have faced substantive lawsuits in recent years. Even in less litigious jurisdictions producers are facing mounting opposition to both existing and new facilities. Numerous projects, particularly in the UK and the US, but also in other markets including Mexico, have recently been shelved[10]. Nonetheless, enormous damage is already being done – and not just locally.

The perils of proximity?

A 2018 study by Duke University School of Medicine found people living near pig farms in North Carolina faced an increased risk of disease and death. The findings were based on data for disease-specific hospital emissions, emergency department (ED) visits and deaths from 2007 to 2013.



Source: Kravchenko, J, at el: Mortality and Health Outcomes in North Carolina Communities Located in Close Proximity to Hog Concentrated Animal Feeding Operations, 2018



Source: World Resource Institute – Water Risk Aqueduct: using cutting-edge data to evaluate water risks around the world", 2022.

3.3. Further-reaching impacts

In 2009, under the aegis of the Stockholm Resilience Centre, scientists identified nine planetary boundaries within which humanity can continue to develop and thrive[11]. These limits mark the likely tipping points for the stability and resilience of the Earth system. According to ongoing research, three boundaries have so far been exceeded "beyond uncertainty" – meaning a high risk to the environment and all forms of life[12]. The first is the integrity of the biosphere; the second is the extent of "novel entities"[v] such as plastics[13]; and the third is the level of biogeochemical flows of nitrogen and phosphorus.

Even in the European Union, which introduced regulation around the issue under its Nitrates Directive more than 30 years ago[14], more than a third of surface-water bodies have been classified as under significant pressure from "diffuse sources" of nutrient pollution. Runoff from agricultural land is foremost among these[15].

Excessive flows of these nutrients alter freshwater, marine and soil ecosystems by favouring fast-growing plants or algae. These then dominate more sensitive species; they also deplete oxygen levels when they die and decompose, creating what are known as eutrophic zones – also referred to as dead zones. There are more than 400 severely eutrophic zones worldwide[16], with most located near the confluences of major rivers. Together, they indicate that the improper use of fertiliser, including manure, be largely concentrated in certain areas, but the devastating effects can be felt far away.

As the map above shows, this is in many ways a global problem that demands a global response. But it is also a problem that is tightly linked to regions that have heavily industrialised livestock production as shown by World Resources Institute's Aqueduct's mapping tool.

The worldwide threat of eutrophication

The World Resources Institute's Aqueduct suite of tools can help livestock producers gauge the risks attached to the locations of existing or proposed facilities. The map above offers a snapshot of the global risk of eutrophication.

v This boundary refers to environmental pollutants such as plastics, chemicals and "other new types of engineered materials or organisms not previously known to the Earth system".

3.4. Global evidence of ecosystem degradation and biodiversity loss

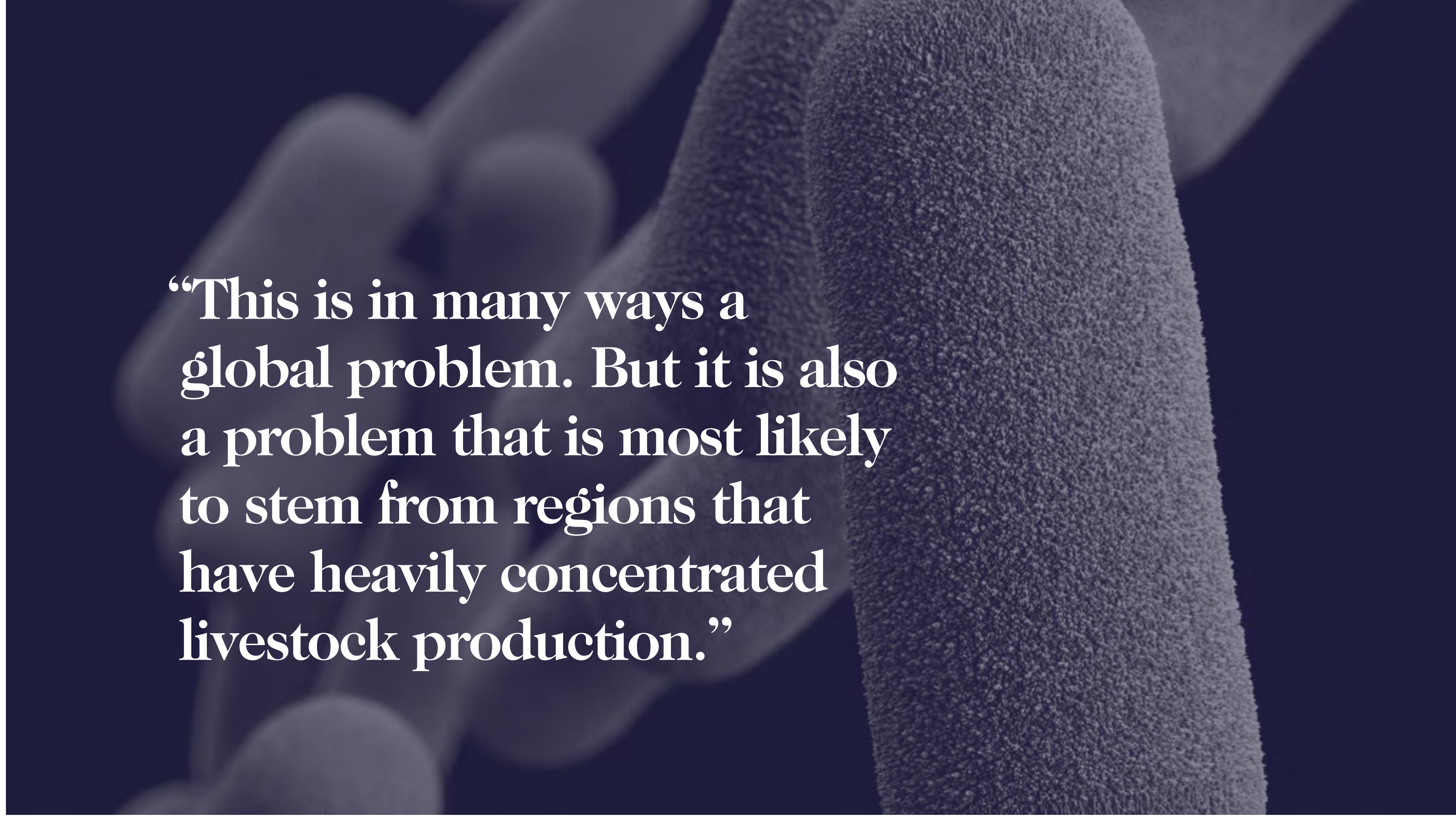
Studies around the world have tied intensive animal farming both to nutrient pollution in local freshwater sources and, crucially, to ecosystem degradation and biodiversity loss up to hundreds of miles away. The issue has come to affect virtually every coastal nation[17].

In China, an analysis published in 2022 argued around 10 billion farm animals should be relocated within the country to limit exposure to nitrogen pollution for 90% of its population. A near-perfect 0.87 correlation between nitrogen losses to water and livestock density was found by the researchers[18].

Similarly to the Chinese study above, a 2020 study of North Carolina's Cape Fear river basin found nitrogen concentration to be positively correlated with the proximity of intensive farms and with the manure-spreading season. The report suggested nitrogen originating from livestock is a more significant source of pollution than fertilisers from traditional row crop agriculture[19]. The huge eutrophic zone in the Gulf of Mexico, as illustrated below, offers a compelling example of nutrient pollution's reach.

Covering 5,380 square miles, it is roughly the size of the state of Massachusetts. It is caused largely by nutrient pollution in the Mississippi river basin, whose watersheds drain much of the US – including the farming heartlands of Arkansas, Illinois, Iowa, Louisiana, Minnesota, Missouri, Tennessee, Wisconsin and Mississippi itself[20].

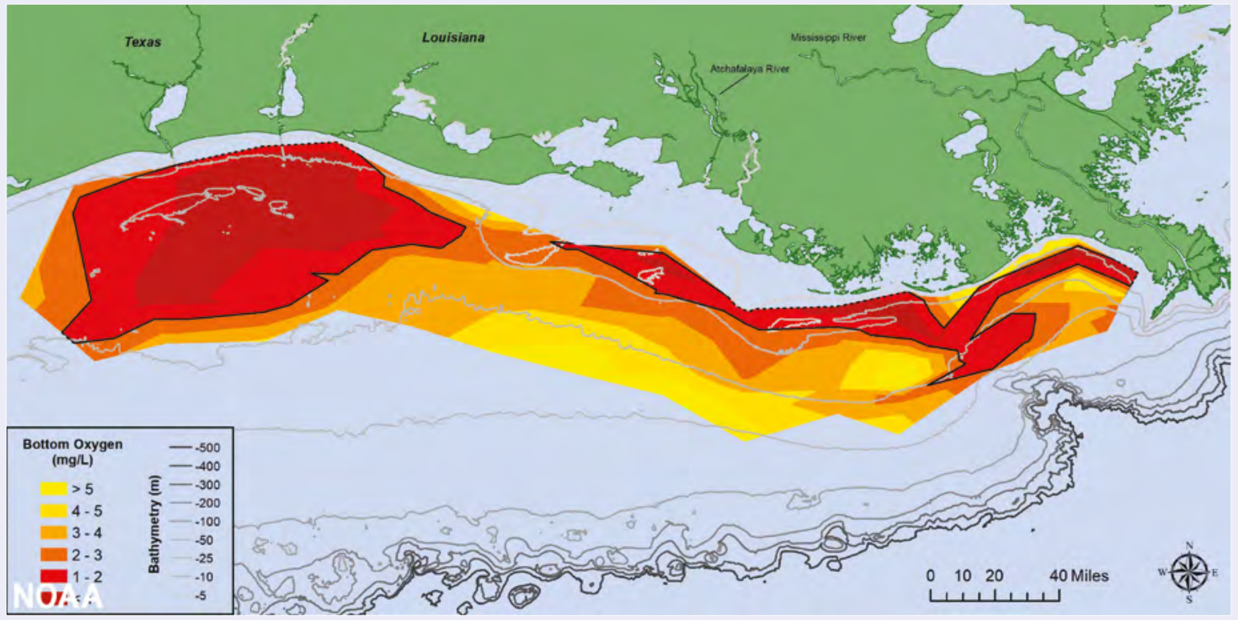
In 2021 algal blooms killed more than 6,000 tonnes of farmed salmon in Chile, also affecting the Southern Pacific marine biodiversity. The incident was attributed to a high concentration of nutrients – caused by intensive salmon farming – combined with sewage from nearby towns and persistent drought conditions[21]. Salmones Camanchaca was the worst-hit salmon producer, losing 3,700 tonnes of fish – nearly 10% of its annual production – across six farms. Despite the company being insured against such an event, the financial impact amounted to around $15 million – leading to a $13 million operating loss[22].



"This is in many ways a global problem. But it is also a problem that is most likely to stem from regions that have heavily concentrated livestock production."

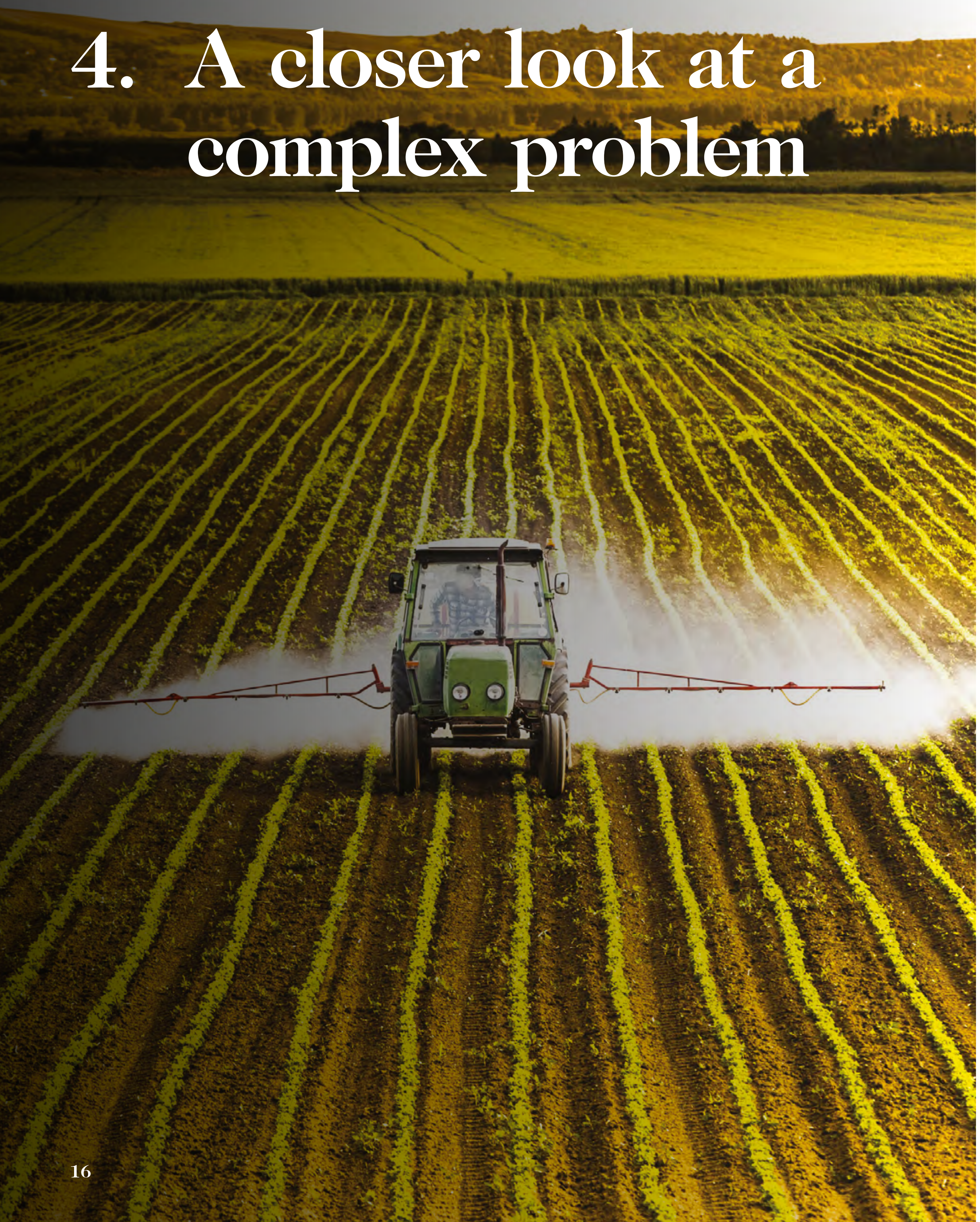
Downstream to the dead zone

The enormous eutrophic zone in the Gulf of Mexico has been largely attributed to nutrient pollution originating on farmland many hundreds of miles north. Runoff from manure-based fertilisers is at the heart of the problem.



Source: National Oceanic and Atmospheric Administration: "Larger-than-average Gulf of Mexico 'dead zone' measured", 3 August 2021

4. A closer look at a complex problem



4.1. A foundation for engagement and positive change

As previously discussed, prevailing practices around animal waste invite an array of negative consequences. These range from biodiversity loss and other forms of environmental damage to social, health and economic consequences. Given these impacts, businesses involved in intensive livestock farming could be expected to thoroughly assess the risks associated with the inadequate management of animal waste. Unfortunately, as shown in the table below, all currently appear to have only a limited grasp of the issues at hand.

According to FAIRR's analysis of publicly available documents, the leading livestock producers do not fully recognise the location-specific dimensions of nutrient pollution. Relatedly, while 47 out of 48 display a basic understanding of the upstream implications of nutrient pollution and discuss nutrient management plans in feed farming to some extent, very few do so for downstream use of their animal waste.

There is also little evidence that the companies appreciate how the two main nutrients can have different detrimental effects. Nor do they disclose how their approaches to storage and treatment might influence such considerations. With these shortcomings in mind, this chapter takes a closer look at the science and challenges behind some of the impacts discussed so far. The intention is not to bewilder or overwhelm. Rather, the aim is to underline that this is a complex problem that demands serious attention – and to help lay a foundation for meaningful engagement with livestock producers that are committed to positive change.

Risk recognition remains limited

FAIRR's Protein Producer Index assesses the performance of 48 companies involved in intensive farming of dairy, beef, pork or poultry. They are scored in relation to a range of key performance indicators (KPIs) linked to 10 overarching environmental, social and governance (ESG) considerations. The overall average score on KPIs related to waste and pollution in the 2021 Index was just 12% – the second-lowest score across all categories[vi].

KPI	Average score	Companies scoring >70%	Companies scoring <20%
Facilities wastewater	21.7%	3/48	29/48
Manure management in animal farming	11.9%	0/49	38/49
Nutrient management in feed farming	3.3%	0/48	47/48

Source: FAIRR: FAIRR Protein Producer Index, 2021

vi These scores exclude aquaculture producers. While other kinds of producers obviously contribute to the issues discussed, this paper will focus on pork and poultry because of their high level of industrialised production globally. It has been estimated that up to 79% of all pork and poultry worldwide is farmed using intensive methods.

4.2. Components and consequences

Livestock manure is a source of both organic waste and other pollutants. As illustrated in the diagram below, these are not only a potential cause of nutrient pollution and biodiversity loss, they also contribute to climate change. This underscores that the inadequate management of animal waste is a multifaceted issue with wide-ranging implications. Businesses involved in intensive animal farming therefore must understand the different consequences each of the components shown below can bring.

As discussed in the preceding chapter, **nitrogen** and **phosphorus** are nutrients that favour the growth of various plants and algae. They are responsible for biogeochemical flows, whose balance is crucial to the health – or decline – of ecosystems.

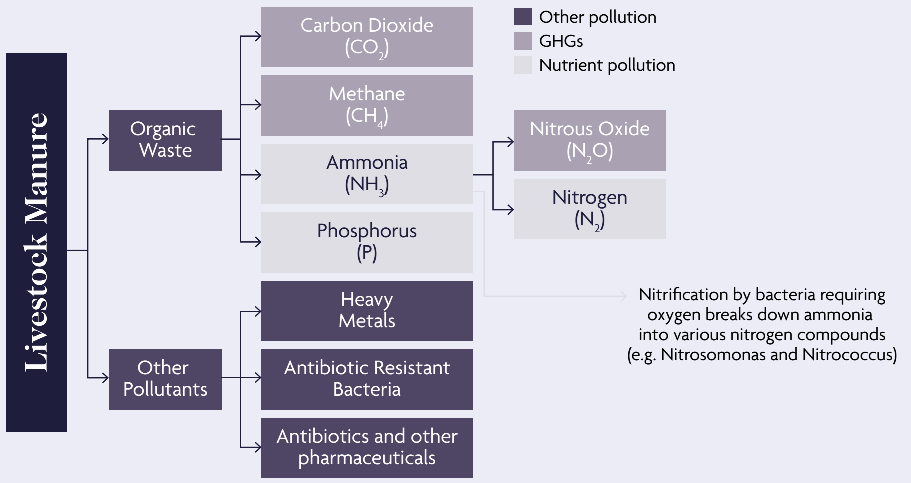
Ammonia pollutes air through nitrous oxide (N_2O) and pollutes water through nitrogen. The US Environmental Protection Agency (EPA) estimates 30% of the nitrogen produced by a pig farm is lost to ammonia volatilisation into N_2O, a particulate air pollutant that is 273 times more potent a greenhouse gas (GHG) than carbon dioxide (CO_2) over a 100-year timeframe[23].

Methane is formed by the decomposition of undigested organic matter. It is 27 times more potent as a GHG than CO_2 over a 100-year timeframe[24]. Livestock is responsible for around 44% of anthropogenic methane emissions[25]; just 5% of cattle methane comes from manure, but the figure for pigs and chickens is closer to 85-90%[26].

It is also important to understand the role of **antibiotics** as a pollutant arising from the inadequate management of animal waste, and this topic is addressed in more detail later in this chapter.

Pathways to pollution

The damaging effects stemming from the inadequate management of animal waste can be arrived at via various routes, depending on the organic waste and other pollutants produced.

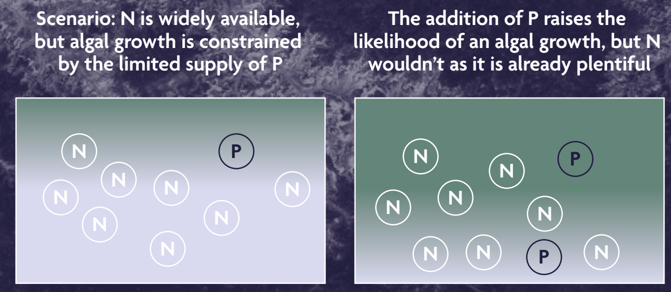


Source: FAIRR

Upsetting the balance of nature

As detailed above, large-scale eutrophication isn't always caused by the same inputs. In an ecosystem where the nutrient balance is weighted toward nitrogen, phosphorus will be the nutrient to promote algal growth if input into the ecosystem.

The opposite will be true of a ratio weighted toward phosphorus, where nitrogen input will be what promotes algal growth.[vii]



Source: FAIRR; McDowell, R, et al: Global Mapping of Freshwater Nutrient Enrichment and Periphyton Growth Potential, 2020

4.3. The importance of limiting nutrients

Plants and algae require various nutrients for growth, and those are not interchangeable, meaning the rarity of one nutrient cannot be overcome by the plentifulness of another. What sets a limiting nutrient apart is that growth is constrained by its relative absence: in effect, it acts as the key to **unlocking** plant or algal growth.

Imagine, for example, that a particular biological organism requires three nutrients – X, Y and Z – in order to grow. If all three are available in abundance then the organism is more likely to grow out of control, whereas growth will be checked if the supply of Z is restricted regardless of whether the availability of the other two increases. Z thus serves as the limiting nutrient. As such, it preserves the delicate balance of the ecosystem in its current state. If supplies of Z were to increase – as might happen in the context of nutrient pollution – this can alter the nutrient balance in the ecosystem, potentially resulting in biodiversity loss.

In many regions around the world there is already a surplus of nitrogen in waters and soils as a result of agriculture, allowing for phosphorus to become the limiting nutrient; phosphorus the more problematic of the two with respect to its potential to trigger algal blooms. As shown in the illustrated example above, in such cases, it is the addition of phosphorus that upsets the balance of an ecosystem more dramatically – fuelling the algal growth that leads to eutrophication.

In considering the consequences of nutrient pollution, companies should be aware that the likelihood and seriousness of algal growth are by no means uniform. They can vary in light of original nutrient concentrations and the subsequent quantities and types of the nutrients that flow into a body of water. It is therefore useful to understand the nutrient ratios of bodies of water located near intensive animal farming facilities relative to their production of both nitrogen and phosphorus through manure. As discussed in more detail in the next chapter, such insights can be vital to a thorough assessment of the risks surrounding the inadequate management of animal waste.

vii Typically, a nutrient ratio above or below seven parts nitrogen to one part phosphorus dictates which nutrient will be the limiting factor.

Just one protein producer assessed is engaged in maintaining this delicate balance

Cranswick is the only company among the twelve pork and chicken producers assessed by FAIRR that considers phosphorus pollution from manure in addition to nitrogen which is more widely acknowledged in publicly available filings. In the company's 2021 CDP responses it cites the use of buffer zones, cover crops and sediment traps to reduce nutrient runoff and leaching from its outdoor hog facilities. Although this transparency is welcome, it covers only a portion of the company's production, leaving out indoor facilities and finishing units. The company also states that over a third of its UK pork is sourced from its own farms affording it "a greater level of control"[27] in all aspects of production, including waste.

4.4. Antibiotics as a key pollutant

As well as being affected by nutrient pollution, many of the world's waterways contain dangerous levels of antibiotics. Antibiotic residues were identified at around two-thirds of the sites tested across 72 countries for landmark research published in 2019[28].

The highest concentration level – 300 times above the recommended limit – was found in Bangladesh. Excess levels of antibiotics were most common in Africa, as shown in the chart on page 21, with some rivers sufficiently polluted to suffer a "total population crash"[29]. Pollution is the result of inadequate treatment of sewage and antibiotic manufacturing effluent, as well as animal waste, although the latter is less discussed despite more than two thirds of all antibiotics produced globally being used in livestock agriculture[30].

The metabolism of antibiotics by animals (and humans) varies greatly, with some compounds metabolised at only around 10% and others at around 90% in the gut. The remaining fraction is excreted as an active compound, alongside resistant bacteria formed in the microbiome. While some municipal water treatment facilities are equipped to at least partially remove these pharmaceutical products from the water, this rarely applies to livestock manure (which as a reminder makes up 80% of global faeces produced).

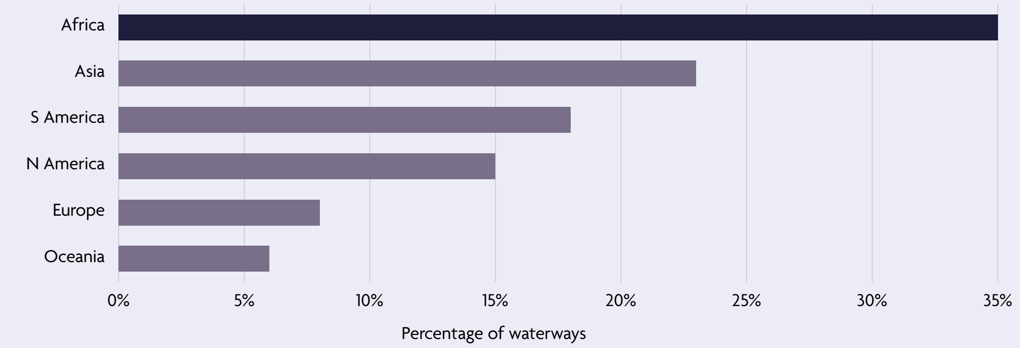
This is further compounded when livestock manure is applied as fertiliser. Antibiotic residues and resistant bacteria add to the global antimicrobial resistance (AMR) burden. Once released into the environment, resistant bacteria and antibiotic residues are widely dispersed through dust, air and surface runoff.

Moreover, antibiotic residues lead to biodiversity loss by impacting plant growth and development, for instance, by delaying seed germination and shortening primary root length. In addition, the presence of antibiotics can alter bacterial communities and result in the loss of microbes that fill critical ecological roles within soil, including the cycling of nitrogen and carbon, which can disrupt ecosystem services[31].

Further, antibiotic pollution in aquatic environments can reduce microbial diversity and carbon cycling. It can also lead to greater abundance of pathogens and alien species, as seen in the increasing frequency of toxic Cyanobacteria (also known as blue-green algae) in freshwater environments resulting in eutrophication and posing health risks to animals and humans[32].

Antibiotics: from animal waste to the world's waterways

A global study of the presence of antibiotics in waterways found 35% of sites tested in Africa exceeded safe levels. The problem was identified to varying extents in every region, with both human and animal waste cited as causes.



Source: Guardian: "World's rivers 'awash with dangerous levels of antibiotics'", 27 May 2019, data by Alistair Boxall and John Wilkinson

4.5. Wastewater: a closely related issue

Potentially dangerous wastewater is often used to irrigate farmland globally. Much of it comes from slaughterhouses and is only partially treated, with local government control of the treatment quality often constrained alongside those of the environmental agency budgets.

The World Business Council for Sustainable Development has reported that wastewater is used on an estimated 20 million hectares – around 7% of the world's cropland[33]. It is also discharged into surface water. Maimunah Mohd Sharif, Executive Director of the United Nations Human Settlements Programme, has described the consequences as often "catastrophic"[34].

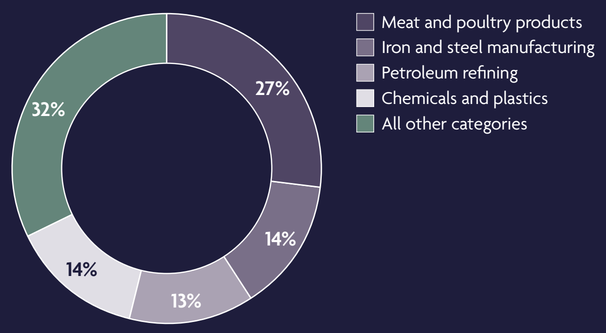
The largest meat producers in the US alone reuse millions of litres of wastewater, yet the details of treatment processes for nutrients, heavy metals[viii] or antibiotics are frequently unclear[35]. America's processing facilities are the biggest industrial source of nitrogen pollution in the country's waterways, 27% of total, also accounting for 14% of the phosphorus they contain[36] as shown on the pie chart on page 22.

viii Heavy metals found in livestock manure typically include copper, zinc, chromium, selenium, cadmium, nickel, arsenic and lead. The sources of heavy metals vary, with bioaccumulation and feed additives promoting health and growth mentioned as leading causes.

U.S. Slaughterhouses are the leading industrial point source of nitrogen discharged into waterways

Regulation is difficult to enforce without thorough inspection regimes, which are not the norm. Environment America, a federation of state-based environmental advocacy organisations, has argued that some US slaughterhouses are still required only to meet standards set more than four decades ago[37].

Slaughterhouses are the leading industrial point source of nitrogen discharged into waterways



Source: Frontier Group: Slaughterhouses are polluting our waterways

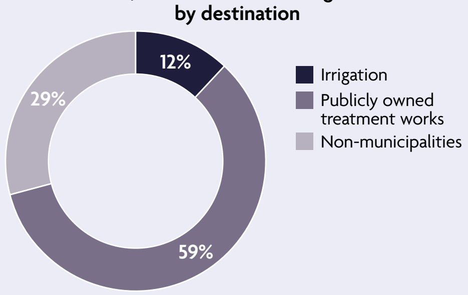
Oversight in emerging markets can be less rigorous too. This is illustrated by the comparison below, which shows the contrasting destinations of wastewater produced by the world's largest meat-processing company, JBS, through its US and global (primarily Brazil-based) operations.

Slaughterhouses tend to be enclosed and sizeable, which means they can accommodate the technology that enables the full treatment and recycling of water. Such processes might include pathogen removal, methane capture and nutrient extraction . Yet most facilities still appear to only partly achieve circularity, with reliance on public waterworks and discharges to surface water remaining high but with little transparency regarding the quality of the water discharged.

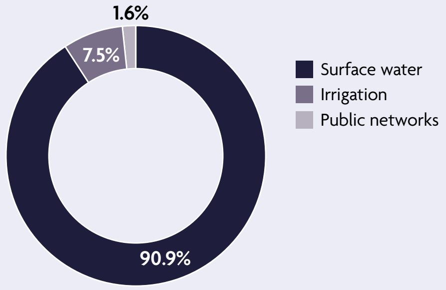
Regional regulation and wastewater treatment

In the US, where regulation is relatively constraining, JBS sends 59% of its processing plants' wastewater to municipal treatment facilities. By contrast, JBS SA, which operates primarily in Brazil, discharges 91% of its wastewater to surface water.

JBS USA water discharge by destination

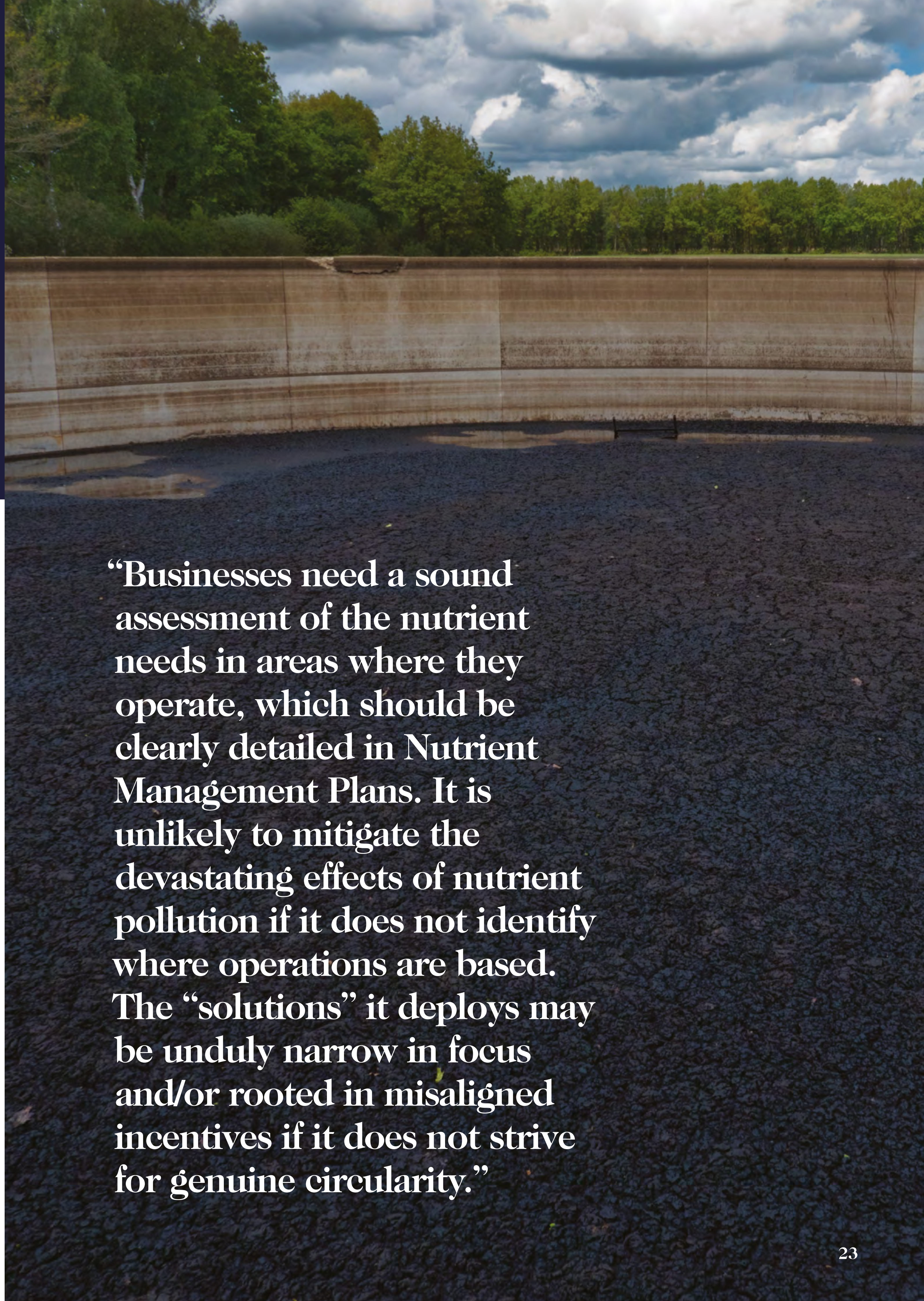


JBS S.A water discharge by destination from Sust. Report



Source: JBS filings and website

37 Ibid.



"Businesses need a sound assessment of the nutrient needs in areas where they operate, which should be clearly detailed in Nutrient Management Plans. It is unlikely to mitigate the devastating effects of nutrient pollution if it does not identify where operations are based. The "solutions" it deploys may be unduly narrow in focus and/or rooted in misaligned incentives if it does not strive for genuine circularity."

5. Current responses to an unfolding crisis

5.1. Nutrient management plans

The effects of nutrient pollution have been recognised and measured for several decades, yet they continue to worsen in almost every region. Alongside regulation, nutrient management plans (NMPs) have emerged as a potentially vital means of turning the tide. Company policies on NMPs should recognise how nutrition pollution can affect a producer both through its supply chain (upstream) and beyond its immediate areas of influence (downstream). Ideally, they should optimise the use of manure as fertiliser in both upstream and downstream operations by informing decisions on quantity, timing and the nitrogen/phosphorus balance to be applied.

A key component of maximising the downstream effectiveness of NMPs is to assess the nutrient tolerance of lands around industrial farming and processing facilities in proportion to the nutrient properties of the manure produced. This approach might include surveying acreage, crops, soil types and water bodies, as well as an analysis of potential hazards such as aquifers, soil erosion and rainfall. This kind of control is likely to be made easier if the surrounding crops are feed crops purchased by a company or its contracted farmers than if the manure is spread on fields completely outside of its sphere of influence as a human or biofuel crop would be, for example.

x Livestock feed takes up 33% of the 92 million acres of corn in the US.

One example of a high-profile NMP is that of Tyson Foods, with the company seeking to improve the nutrient profile of two million acres of corn in the US – enough to feed the 2.3 billion chickens it processes annually[39]. Tyson Foods is the largest buyer of feed corn in the US, and those 2 million acres make up around 6.3% of the feed corn acreage in the country[40,x].

According to the United States Drug Association (USDA), US farms use approximately 150 pounds of nitrogen per acre (170kg per hectare) and 70 pounds of phosphates per acre (80kg per hectare) on average for corn crops[41]. For example, if Tyson Foods and its peers were able to collaborate with feed farms at scale to achieve a 25% reduction in fertiliser inputs that would mean around 540,000 metric tonnes less nitrogen fertiliser and 250,000 metric tonnes less phosphorus sprayed onto US corn fields. However, while the scheme could improve the company's upstream exposure to nutrient pollution, this initiative falls short of putting in place an action plan to manage downstream waste. Documentation available doesn't detail whether Tyson Foods' own manure is used within this scheme, how far the corn production is from chicken farms, or by how much it expects to reduce excess nitrogen and phosphorus for the crop.

In tandem, transparency is essential to enhancing the upstream effectiveness of NMPs. This might encompass not only the establishing of an NMP itself but the support and oversight offered – including regular testing of soil, monitoring of spreading periods and alignment of incentives with nearby manure recipient landowners. As shown in the 2022 results of the FAIRR Protein Producer Index, dairy producer Fonterra is closest to best practice, evidencing that its incentives truly encourage good practice, but there is still little transparency on the site specificity of their NMPs, based on the FAIRR Protein Producer Index findings.

At present, unfortunately, NMPs are not a requirement everywhere. In addition, a fully tailored NMP may be relatively expensive for smaller farmers supplying larger companies – more than $10,000 in the US, for example[42]. However, given their importance and the implications of nutrient mismanagement, cost should not be a barrier, and meat producers are able to offer support in this regard.

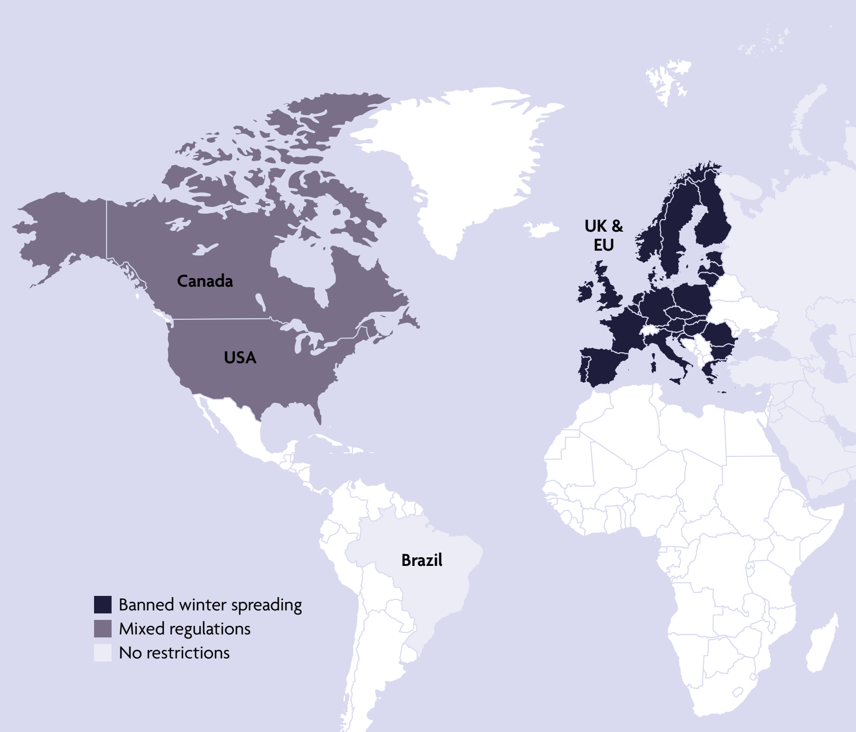
What an NMP should include – and the issues that might be encountered

An NMP can represent a complex undertaking. The tables below highlight some of the principal aims and challenges.

What should a Nutrient management Plan include
Farm and field maps showing acreage, crops, soils and waterbodies.
An evaluation of field features based on environmental hazards, such as aquifers, erodible soils, high rainfall seasons, or near-surface waterbodies.
A collection of information about the manure production, nutrient content and application system(s) for the farm
Documentation of agricultural waste, such as manure, runoff from contaminated surfaces, animal mortalities and leakages from silage piles.
Soil tests to determine nutrient requirements for the crops on the farm and the appropriate manure application rate – including pH, phosphorus, nitrogen and potassium tests.
Limiting the application of nutrients to periods in which crops most require them to prevent losses.
An erosion control plan for the fields that receive manure to reduce the risk of manure being washed off the fields by rain.
Potential manure export strategies for livestock operations without enough land to spread manure (based on soil tests and crop needs).
Additional steps to reduce excess nutrients, including feed management and waste treatment.

Factor	Potential issues
Soil nutrient measurements to optimise quantity of fertiliser	Soil measurements are encouraged every three to five years in the UK and Europe but less frequently or not at all in most other markets. In many places farmers can plan their nutrient needs through averages based on soil types, using government figures. This makes assumptions on nutrient requirements and capacity less likely to be exact.
Precise manure nutrient contents to suit needs	The nitrogen and phosphorus quantities to be applied from manure are calculated from averages. However, the actual concentrations can vary significantly – depending on diet, age and other factors. Tests can be affordable – £40 in the UK, for example – but are not required in many countries and regions.
Comprehensive assessment of phosphorus and nitrogen needs	Phosphorus is a limiting nutrient in many aquatic ecosystems, as discussed in section 3.3. Yet manure application rates are often calculated to optimise nitrogen, which has a higher potential to cause human health issues.
Location-specific application	The conditions for applying manure are usually based on standard criteria such as time of year, recent rains, visible water pooling in fields and distance from streams. This can help with compliance, but such loose guidelines can also lead to application in conditions that are less than optimal for the prevention of runoff. Site-specific assessments provide a more reliable picture.

Source: FAIRR



Source: Liu, J, et al: A Review of Regulations and Guidelines Related to Winter Manure Application, 2018

Seasonal constraints on the application of manure as fertiliser

Numerous regulations and guidelines compel businesses involved in intensive animal farming to store manure for lengthy periods – sometimes in circumstances that risk damaging leakages and spills.

5.2. On-farm manure storage

The timing of manure fertiliser application is dictated by regulation in many jurisdictions, specifically to partly reduce the biodiversity risks arising from nutrient pollution. Application can be restricted for entire seasons – usually winter. This is the case in Europe, some US states and numerous Canadian provinces. Soil water absorption is at its lowest at this time of year, increasing the likelihood of runoff. Even in the absence of such regulation, some locations have weather-related rules or best-practice guidelines associated with proximity to water sources.

As a result of these measures, whose geographic dispersion is shown in the illustrations below, livestock farmers often need to store manure for lengthy periods. This can augment the risk of accidents and spills and also imposes a financial and practical burden. Scrutiny around storage is intensifying in light of tougher environmental regulations in general. For example, new installations of uncovered manure stores have been banned in the UK, with older ones to be replaced by 2027[43].

Overall, however, approaches to manure storage remain deficient. The coverage of facilities is still not mandated in most US states, parts of Europe and the majority of emerging markets – including leading pork-producing nations such China, Brazil and Russia. Lagoons are the cheapest option, but they are especially prone to leakages and spills; covered tanks are safer and allow for methane capture, but they are still vulnerable to leaks and breakages. Many accidents involving leaks and spills have been recorded in Brittany, France for example, which produces 58% of French pork[44]. Incidents have included incorrect operation, collapses and overflows – all of which had affected animals, workers and local communities. Similarly, a study by the Socially Responsible Agriculture Project showed Smithfield Foods' hog facilities in Missouri suffered 748 spills in three decades, resulting in the release of an estimated 33.2 million litres of waste[45].

5.3. The biogas gold rush

As discussed in section 3.2, methane is among the key pollutants contained in animal waste and that must be managed adequately. A growing focus on agriculture's methane emissions has driven the adoption of biodigesters in intensive animal farming to produce biogas.

A large portion of biogas production already comes from animal and agricultural waste decomposing in controlled facilities. The use of biodigesters is increasingly incentivised, with the trend likely to gain further momentum in light of the agreement at COP26 to achieve a 30% cut in methane emissions by 2030[46]. This may sound encouraging, but there is a problem: incentivisation is artificially creating a market for livestock biogas, sparking a "biogas gold rush"[47] that fails to reach beyond carbon emissions and encompass nature as a whole in its scope. California alone has invested more than $600 million to subsidise the construction of biodigesters on intensive dairy farms – at the same time allowing both the agriculture and transportation sectors to account for the offset[48] – while France announced in 2015 that it hoped to fulfil 10% of its gas use through biogas by 2030. Without government subsidies and grants, according to a study conducted by the University of California, it would cost $294 a year to produce $68 of gas from a single cow[49].

Such an investment addresses only one of the GHGs emitted by manure – and none of the drivers of nutrient pollution. In fact, biodigesters further concentrate the nutrient density in manure and do nothing to reduce the near-perfect correlation between livestock density and nutrient pollution observed.

This market and regulatory focus on biodigesters to capture methane from livestock manure hence may carry a significant risk that misaligned incentives and a narrow carbon-centric vision linked to this solution could exacerbate biodiversity impacts.

Even with government support, biodigesters can represent a significant capital cost for most farmers. This high cost could eventually risk encouraging further industrialisation of livestock to raise the Return on Investment on large digesters, causing more deforestation and land conversion to make space for feed crops and thus offsetting any carbon benefit in addition to worsening biodiversity impacts.

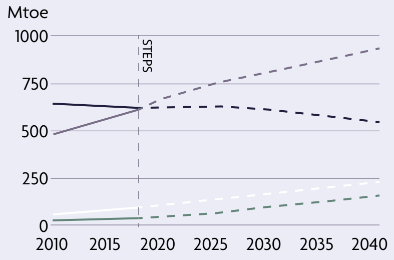
As stressed throughout this paper, the detrimental impacts of intensive farming practices represent a multifaceted issue. By providing only a fraction of the necessary solution, biodigesters highlight the difficulties surrounding well-intentioned incentives that ultimately fail to be nature-wide in their scope.

It is therefore critical that investment in methane capture from manure is paired with initiatives to enhance the economic value of the nutrients that come with it. This would raise the potential of circular solutions, raise the nutrients' economic value and hence their range, and reduce spreading onto neighbouring lands and pressure on biodiversity.

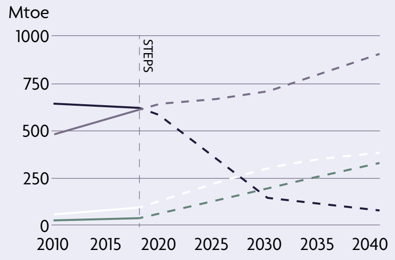
Animal waste's leading role in biogas production

According to the International Energy Agency (IEA), most biogas production comes from animal waste and from crops. In both scenarios described by the agency biogas production raises nearly tenfold from 38 million tonnes of oil equivalent (Mtoe) in 2018.

Breakdown of global bioenergy demand in the Stated Policies Scenario, 2010-2040



Breakdown of global bioenergy demand in the Sustainable Development Scenario, 2010-2040



Solid biomass (traditional use) | Solid biomass (modern use) | Biofuels | Biogas (direct use + upgrading)

Source: IEA Outlook for biogas and biomethane to 2040
Data sourced from the IEA Sustainable Development Scenario (SDS) due to its better data transparency. The IEA Net Zero Emissions scenario also assumes a strong increase in biogas use.

Key Manure Management Costs

FAIRR has identified some benchmark costs that can be used for scenario analysis and financial materiality assessments. While they are as accurate as possible, costs can vary depending on the size of installations, their location, and other factors.

Revenue from sale of manure fertiliser:

$12.50 to $20.00

per thousand litres in the US in 2022, up from $7.50 per thousand litres the previous year[51]

On-farm biodigester:

$400,000 – $5,000,000

depending on capacity and technology

Cost of manure-based biogas:

$0.22-.39

per m^3 (in the US), generally around 2% of the cost of the installation per year[50]

$10,000

Nutrient Management Plan

$10-14 per m^3

Uncovered Lagoon Storage

$56 per m^3

Covered Storage

Other key figures

- Solids per day: 570g per pig / 1500g per 100 chickens
- Solid content: 5% for pigs, 20-25% for chicken
- Storage capacity requirement: 0.5m^3 per pig / 1.25m^3 per 100 chickens

5.4. Regulatory and legal measures

Some of the most significant responses to the issues discussed in this paper are those of the regulatory and legal communities. Actions by governments, local and regional authorities and other stakeholders are gaining traction in numerous countries, as shown in the illustration on page 31.

One of the most dramatic moves came in late 2021 in the Netherlands, where the government announced a €25 billion plan to proactively buy out farmers in an effort to reduce nitrogen levels[52]. The focus is likely to be on independent and less profitable farms, but the initiative could still mean a medium-term shift in European protein supply chains.

"We can't be the tiny country that feeds the world if we shit ourselves," said MP Tjeerd de Groot, from the Democrats 66 party, which is part of the coalition government in the Netherlands in reference to the amount of manure produced by the national pig population– reported The Guardian[53].

The EU as a whole is also acting on its 1991 Nitrates Directive, which requires member states to monitor their waters and identify the effects of pollution from agriculture. Spain has been referred to the Court of Justice of the European Union after algal blooms in Mar Menor were linked to the region's pork production[54]. The EU's Farm to Fork strategy targets a 50% reduction in nutrient losses to the environment by 2030.

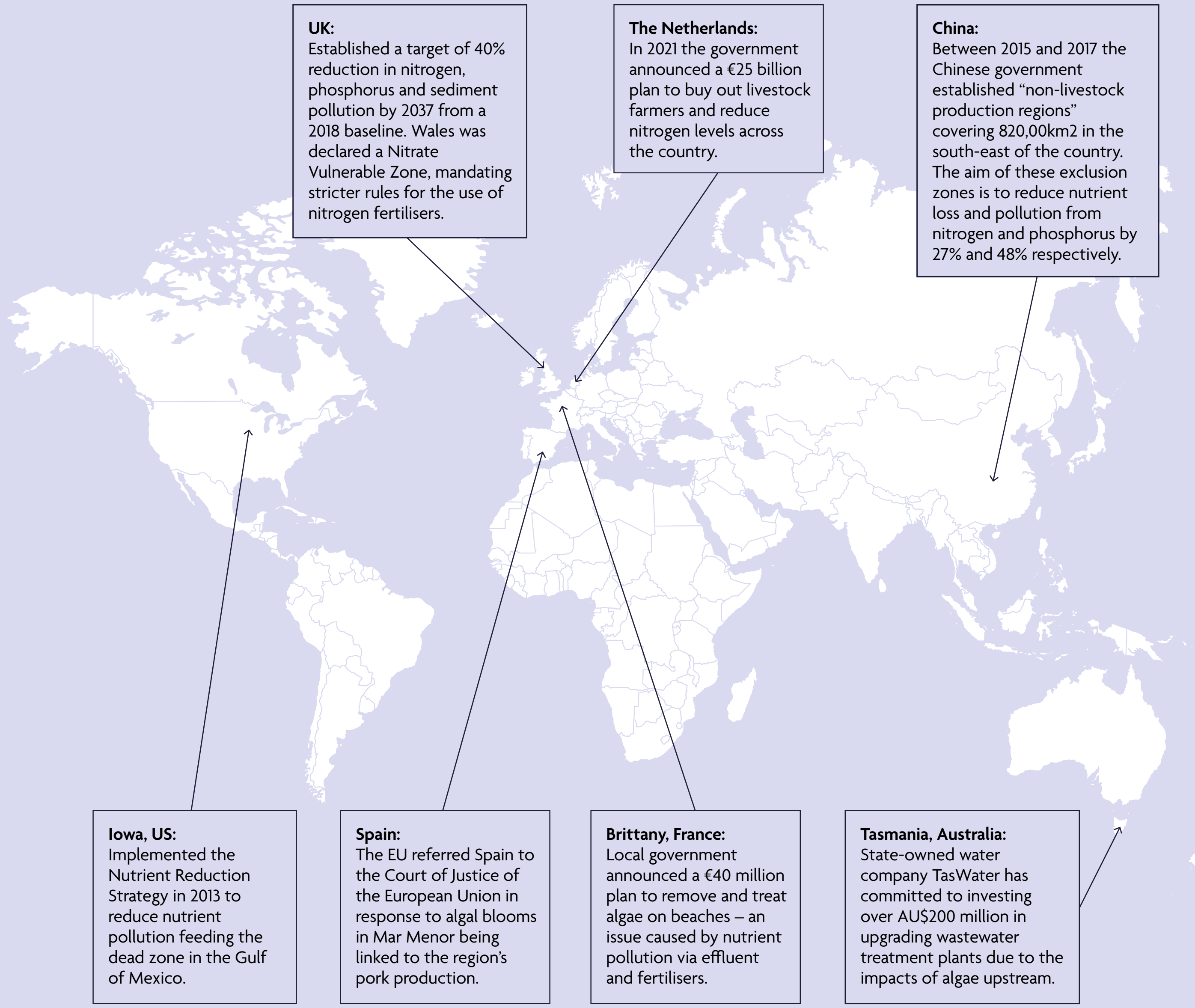
In 2021 the Welsh government declared the entirety of Wales a Nitrate Vulnerable Zone, mandating stricter rules for fertiliser use and manure storage. Not meeting these regulations leaves UK farmers ineligible for full payments from the Basic Payment Scheme and Rural Development Programme. The UK is aiming to reduce nitrogen, phosphorus and sediment pollution from agriculture by at least 40%, compared to a 2018 baseline, by 2037[55].

In terms of likely impact on protein supply chains, the most notable regulatory response of all may be the creation of "non-livestock production regions" in China. Established between 2015 and 2017, covering 820,00km^2 and entailing the closure of 260,000 pig farms, these zones are intended to reduce nutrient loss by up to 27% for nitrogen and up to 48% for phosphorus in the south-east of the country[56]. From a corporate perspective, this can be viewed as both a threat and an opportunity for large producers such as New Hope Liu, Muyuan, Tech-Bank Foods and Wens which can rapidly gain market share from smaller and older facilities closing down. These companies' balance sheets and leverage inflated during the period, likely from seeking to capture the transition from smallholder farms to large-scale production models with their better capacity to absorb the higher capital cost of manure management.

Meanwhile, in the US, lawsuits and community opposition in relation to ecosystem degradation and biodiversity loss are becoming more common. They include actions by the city of Des Moines against the state of Iowa[57] which said the state isn't doing enough to control nutrient runoff and protect the Raccoon River from nutrient pollution, as well as an EPA inquiry into plans for biodigester-equipped pig farms over concerns they may lead to even more pollution affecting surrounding communities[58]. Smithfield, which is owned by WH Group, is aiming to cover 90% of its farms in North Carolina, Missouri and Utah with biodigesters by 2030, having previously paid more than $500 million in compensation to people living near farms with open-air lagoons – the largest direct financial impact from manure waste and pollution FAIRR has identified. Smithfield is discussed in more detail in section 6.2.

Mounting regulatory pressure around the world

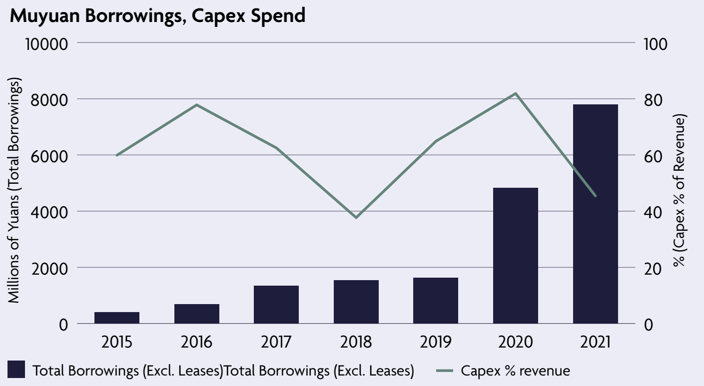
The map below highlights key examples of national, regional and local action to tackle pollution problems that can be directly linked to the use of animal waste as fertiliser.



Source: FAIRR

Muyuan Foods' borrowings soars with capital expenditures

Muyuan's total debt in dollars increased nearly twenty times to $7.8 billions between 2015 and 2021, based on Bloomberg data, as the company invested heavily in new facilities.



Source: Bloomberg

5.5. Knowledge gaps and limited action – Assessing twelve producers

The various responses discussed in this chapter suggest some progress on issues surrounding the inadequate management of animal waste. Yet the overall picture is one of only partial awareness and commitment. The findings of FAIRR's Protein Producer Index indicate that among the 40 producers that have exposure to pork and poultry, all but 14 make at least a high-level statement about on-farm manure and use as fertiliser. Yet just six disclose more thorough assessments of the risks that could arise from nutrient pollution in specific locations.

However, as shown in the table on page 35 assessing a sample of twelve companies with larger pork and poultry market share, while companies do mention manure or wastewater management, worryingly, phosphorus is seldom discussed. Given phosphorus' potentially detrimental effect on the biodiversity of surrounding livestock farms, companies' disclosures should contain details describing the limitation of runoff and other adverse effects.

In addition, while 7 of the 12 producers assessed below do make some mention of working with upstream feed farms to mitigate the risks associated with manure's use as fertiliser, only WH Group, Charoen Pokphand and New Hope clearly seek to retain influence over their own manure fertiliser once it leaves their farms or processing facilities. This underlines an important shortcoming previously mentioned: there generally is a lack of awareness and control of downstream implications of nutrient pollution in addition to that of the upstream feed supply chains.

Pork Producer Builds Manure Loop in Asia

Thai protein producer Charoen Pokphand's Northern China pork facility[59] was developed specifically to form a circular loop of resources and gain control of its nutrient cycle, thus minimising waste and pollution according to the company. The company dedicates swathes of land to a project where its own hog feedstock, as well as organic arable crops, are grown using the manure it produces as fertiliser. Wastewater from the facility is also captured to produce biogas.

Meanwhile, downstream, nutrient pollution is rarely discussed by consumer-facing businesses, including some of the largest consumers of pork and poultry. While not a comprehensive assessment, FAIRR's review of company documentation showed Danone and Unilever (mainly dairy consumers) are among very few companies referring directly to the issue. In addition, Walmart "invites" suppliers to work and report on fertiliser optimisation and manure management. Many companies, including Nestlé and McDonald's, have launched regenerative agriculture programmes. These may address fertiliser use and nutrient pollution as part of wider efforts to ensure soil health, but lack a broader discussion regarding the potential benefits that the circularity of manure could offer within such schemes.

Components of pork and poultry producers' risk assessments

The table on page 35 provides a snapshot of the extent to which pork and chicken companies assess the risks associated with the inadequate management of animal waste, and take into account the two often-neglected but key aspects discussed above: phosphorus and downstream control of manure waste[xi].

Currently, 'Best practice' could be considered to be a location-specific assessment identifying at-risk areas, with evidence of considering phosphorus and a discussion of the downstream use of manure and whether the company has control over this.

The twelve companies in the table were selected for their pork and chicken market share while also seeking a balanced geographic representation. This is not a comprehensive list of protein producers with exposure to the two proteins.

> "There is some progress on issues surrounding the inadequate management of animal waste. Yet the overall picture is one of only partial acknowledgment and commitment."

Company	Category	At-Risk Location Assessment	Mention of Phosphorus	Manure Used on Own Feed* or Evidence of Downstream Control
BRF	Pork, Poultry	Yes, self	No	No – Manure used as fertiliser , unclear if used in own feed supply[60]
Charoen Pokphand	Pork, Poultry	Yes, CDP Self-Assessment	No	Yes – Manure used as fertiliser on own feed in Chinese operation, % manure and feed unclear[61]
Cranswick	Beef, Pork, Poultry	Yes, WRI Assessment for direct operations	Yes[xii]	No – Manure applied on local arable crops following NMPs but unclear if own feed[62]
Hormel	Beef, Pork, Poultry	Yes, WRI Assessment for direct operations	No	No – Manure is used as fertiliser, unclear if own feed or where[xiii]
JBS	Beef, Pork, Poultry	Yes, self	No	No – Manure is used as fertiliser on local crops, unclear if own feed[63]
Maple Leaf Foods	Pork, Poultry	Yes, WWF Canada	No	No – Manure applied on local arable crops following NMPs but unclear if own feed[64]
Muyuan	Pork	Yes, but no detail of assessment	No	No – Processes own feed on site, but unclear if manure is used on this feed[65]
New Hope	Pork, Poultry	No, but waste metrics disclosed	No	Yes – Manure used on own diversified crops, % of manure unclear
Seaboard	Pork	No	No	No – Manure is used as fertiliser, unclear if own feed or where[66]
Tyson Foods	Beef, Pork, Poultry	Yes, WRI assessment	No	No – Aims to improve 2 Mill. acres of corn fields supply, unclear if through own manure[67]
WH Group	Pork, Poultry	Yes, WRI assessment	No	Yes – supports feed farms to use its own manure fertiliser[68], % of manure or feed unclear
Wens	Dairy, Pork, Poultry	Mentions risks, but no detail of assessment	No	No – No Information

KEY:

At-Risk Location Assessment
- No assessment
- Self assessment
- Assessment based on body of knowledge

Phosphorus
- No mention
- Mentioned in assessment

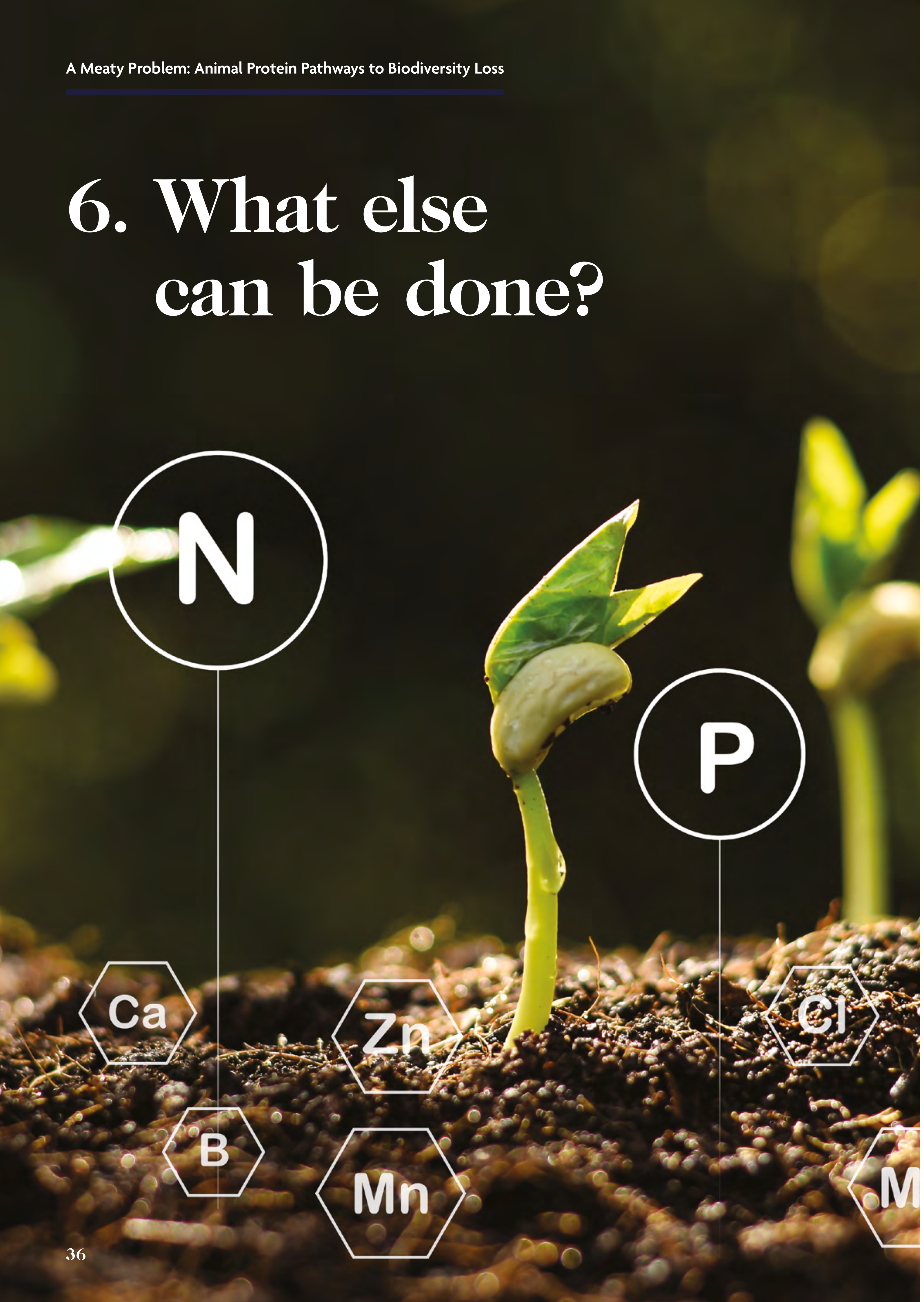
Downstream control
- No evidence of downstream control of manure or circularity
- Some evidence of downstream control but with little detail
- Evidence of downstream control

xi Information on how companies dispose of manure is often unclear and needs to be pieced together from various sources. References to the most relevant are included in the table.
xii Details can be found by visiting the CDP website's "Search and review past CDP responses" page at https://www.cdp.net/en/responses/30215. Locate the company's "Water Security Response 2021" entry and refer to section W-FB3.1a.
xiii Ibid.

Source: FAIRR, company filings and websites

* this suggests control of the manure-fertiliser-feed-crop cycle; feed grown outside the local meat production area means manure is used on crops that are not purchased by the producer or its contracted livestock farmers
** Formerly the Carbon Disclosure Project
••• World Resources Institute
*** World Wildlife Fund Canada

6. What else can be done?



6.1. Creating a circular nutrient cycle

The globalisation of livestock feed means some regions are effectively importing the nitrogen and phosphorus absorbed by feed grains such as soy or maize. That same feed is then partly excreted by livestock as manure – exacerbating the local nutrient buildup over time. The two illustrations below underscores the global scale of this issue.

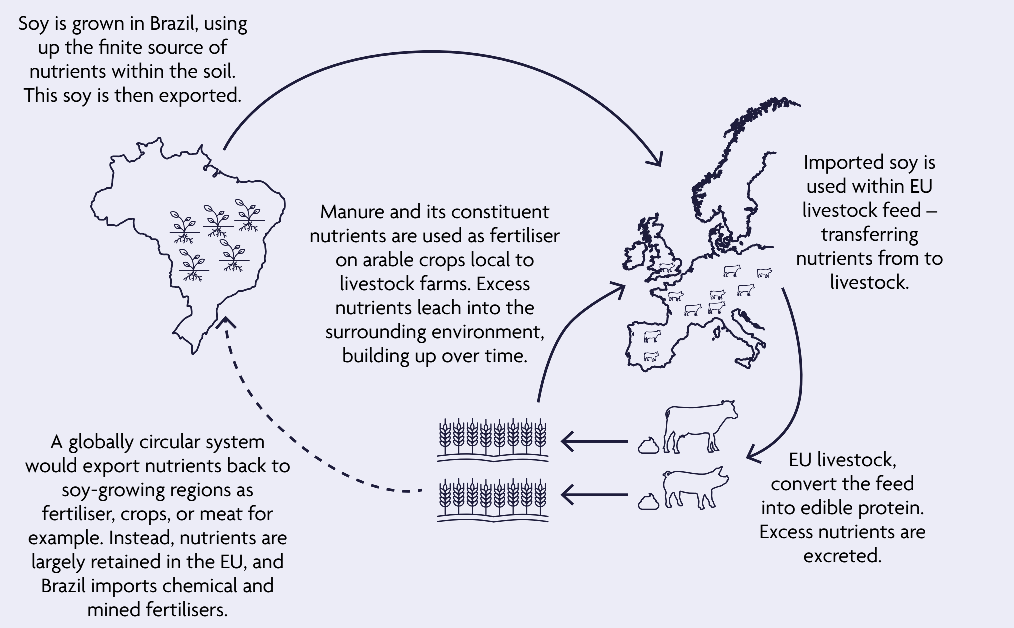
However, there are solutions – some technology-dependent, others not – that could encourage a circular nutrient system that would significantly reduce pollution. **Biodigesters** were discussed previously, and may have a role to play but need to be used in combination with other measures in recognition of the multifaceted challenge that this issue presents or risk worsening the biodiversity impact of manure.

One potentially feasible option is to **directly support the movement of manure to nutrient-poor crop areas on a regional basis**. For example, Tyson Foods supports the transport of chicken manure from the company's Illinois River watershed sites straddling Oklahoma and Arkansas to areas with a lower nutrient density[69] – albeit after high profile lawsuits and fines[70]. Such an approach can help reduce the

The nutrient cycle lacks circularity

The example below shows a typical system where feed containing nutrients is imported (in this case to the EU) to feed livestock, gradually building up as it fails to export nutrient back where it is most needed.

Regions such as China and the EU (the first and second largest importers of soy respectively) in effect import nitrogen and phosphorus from these countries while failing to export the nutrients back to where they are needed to create a circular transfer of nutrients.



Source: FAIRR

nutrient load in other areas under similar pressure, although it's not a silver bullet. In 2014, the Netherlands imposed a similar plan and yet the country still felt compelled to introduce farm buy-outs instead reducing pig headcount and thus reducing nitrogen levels.

Another possibility lies in **the full aerobic composting and processing of manure**. This can create dry horticultural fertiliser, which has a higher market value and is easier to transport. The composting of manure – as opposed to the spreading of raw manure on crops – can produce EPA Class A bio-solids (high quality compost where pathogens including viruses have been entirely removed) when mixed with other waste; it also leads to high nitrogen conservation[71], which is suitable for organic farming, nursery crops, orchard mulching and other horticultural uses.
At present, however, the energy needed to evaporate the water from the manure and extract the solid content can make up 80% of the total[72], meaning a much higher operational cost and representing a downside to this avenue. This is in addition to storage costs – inclusive of technology to reduce ammonia volatilisation.

Producers might also consider **investing in insect-based feed**. Some salmon and poultry producers, including Cargill[73], are exploring alternatives to their traditional sources of protein, with black solider fly larvae gaining particular traction. Additional inputs to the manure are needed for larvae to thrive, but these can largely be other forms of agricultural and food waste and still add to the overall circularity of manure. FAIRR's engagements with salmon producers suggest insect-based feed is being studied but is not yet ready to be used at scale, despite the interest of start-ups and venture capital funds in this approach.

For all the above, the manure – and hence its nutrient content – has a higher chance of being spread beyond the immediate proximity of intensive livestock farming areas, which as previously discussed, is a key reason those regions tend to be overloaded with nutrients. Yet, unless they are coupled with lower animal protein consumption globally, it is unlikely that any of the above solutions will bring nutrient pollution down to a safe level. Yet they at least have the benefit of mitigating the problem and potentially help avoid the worst of the impacts to biodiversity and local communities.

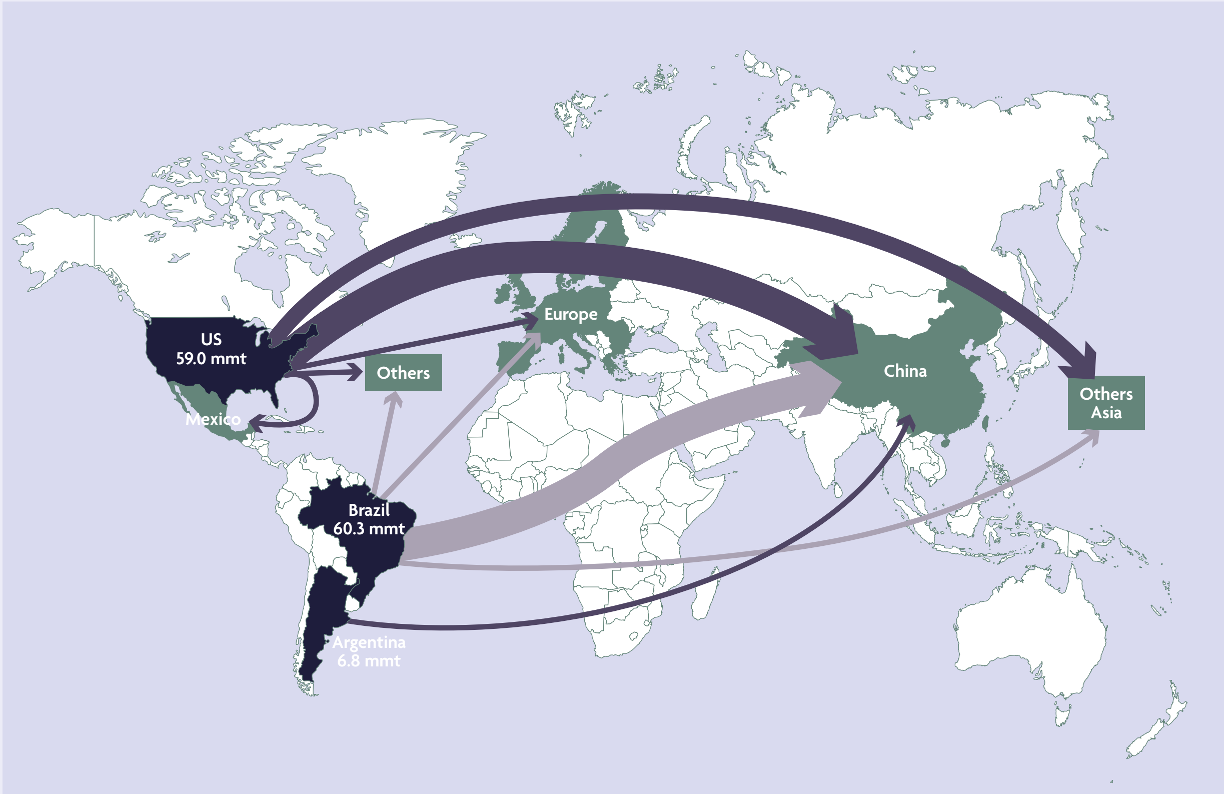
6.2. Collaboration and innovation

FAIRR's engagements with producers, academics, industry experts and other stakeholders have highlighted the potential of further innovation in the nutrient management space. One route that may hold promise is collaboration with the agrochemical sector to leverage the extraction and distribution of nutrients. Through FAIRR's research found two listed agrochemical companies were identified that explicitly offered an agricultural waste service beyond municipal sewage: Ecoson[74] (subsidiary of Darling Ingredients, based in the US) and Yara (based in Norway)[75]. However, several smaller privately held companies do offer this service,

For example, Smithfield Foods and its North Carolina pig farms' manure management practices may be of particular note. The waste at these facilities was previously collected in open-air lagoons then sprayed on to fields surrounding the farms, resulting in air and water pollution that impacted neighbouring communities and biodiversity – eventually leading to a $550 million lawsuit that was eventually settled[76]. Smithfield – part of WH Group since 2013 – subsequently

The global non-circularity of the nutrient cycle

The map below shows the volume of production (in millions of metric tonnes) and the intensity of exports (as represented by the width of arrows) for soybeans produced in the US, Brazil and Argentina in 2016/2017. Regions such as China and the EU (the first and second largest importers of soy respectively) in effect import nitrogen and phosphorus from these countries while failing to export the nutrients back to where they are needed to create a circular nutrient system. Since most the nutrients exported to Europe and Asia are destined to feed livestock, the only way to achieve global circularity would be to export an equivalent amount of nutrient in the form of manure – or products using raw materials grown using this manure – back to the US and South America.



Source: Gale F, et al: Interdependence of China, United States, and Brazil in Soybean Trade, 2019.

embarked on a major programme to reduce manure pollution. This represents the largest such initiative FAIRR has encountered among pork and poultry producers. The company invested in safer, covered lagoons to produce biogas through anaerobic digestion and use it to provide power to surrounding communities .

Smithfield also has a partnership with Anuvia Plant Nutrients, whose SymTRX product uses nutrients extracted from manure and other organic waste[78]. The fertiliser is then sold at subsidised rates to feed crop farmers working for Smithfield. Described as "a prototype for a circular economy"[79], the concept gives Smithfield increased control of not only its downstream waste, but also the pollution and economics of the manure fertiliser used by feed suppliers.

Anuvia, the unlisted agrochemical company in the partnership, has cited a range of further benefits. These include an increase in organic matter and microbial activity, which improves soil health and encourages biodiversity. The fertiliser was found to reduce the leaching of nitrogen by 50.2% compared to traditional products and to cut GHG emissions by 32% per acre of crop compared to conventional products[80].

This initiative might still be relatively small in scale, but it shows circularity is possible. As detailed in the table on page 41, it is currently one of only a handful of innovative approaches employed by pork and poultry producers in FAIRR's Protein Producer Index.

Added-value initiatives among major pork and poultry producersnutrient cycle

At present there are only isolated examples of companies trialling genuinely innovative initiatives around the management of animal waste. The table includes biogas production to illustrate the fact that being the only profitable waste by-product it is key to enabling other initiatives for most companies without necessarily assuring further treatment of the waste. It also includes the use of feed supplements to improve nutrient absorption by animals, evidence of expanding the manure's spreading range to control nutrient pollution on surrounding lands, and most importantly evidence of investment in added-value product which are most likely to improve circularity and address the root causes of biodiversity loss from nutrient pollution discussed throughout this report. Most of these schemes remain small-scale, and it appears that none has involved comprehensive feasibility research.

As for the table on page 35 describing risk assessments, the following uses a sample of 12 pork and poultry producers with leading market shares, adjusted to be geographically representative. It is not intended to be comprehensive of every producer in FAIRR's Protein Producer Index.

Company	Category	Biogas production	Feed supplements	Expanded spray range	Added-value manure products
BRF	Pork, poultry	No	No	No – Local farms[81]	No – Composted fertiliser, quality or % of total manure unknown
Charoen Pokphand	Pork, poultry	Yes – 97 million m^3 wastewater and manure, % of total unknown[82]	Yes – Feed cuts nitrogen excretion from pork by 20-30% and chicken by 12-13%[83]	Yes – Pork manure fertiliser sent to Chiang Mai Province[84], scale unknown*	No – Composted fertiliser, quality or % of total manure unknown
Cranswick	Beef, pork, poultry	No	No	No – Local farms[85]	No
Hormel	Beef, pork, poultry	No**	No	No – Local farms[86]	No – reference only to food waste
JBS	Beef, pork, poultry	No***	No	No – No mention of manure from facilities[xiv].	No – Composted fertiliser, quality or % of total manure unknown
Maple Leaf Foods	Pork, Poultry	Yes – % of total manure unknown[87]	No – Risk assessment does recommend feed optimisation to reduce methane[88]	No – Local farms[89]	No
Muyuan	Pork	Yes – % of total manure unknown[90]	No	No – Local farms	No – Composted fertiliser, quality or % of total manure unknown[91]
New Hope	Pork, poultry	Yes – % of total manure unknown[92]	Yes – Invests in "bio-environmental feed" to reduce production of manure[93]	No – Local farms	No – Composted fertiliser quality or % of total manure unknown
Seaboard	Pork	Yes – % of total manure unknown	No	No – Local farms[94].	No – Composted fertiliser, quality or % of total manure unknown
Tyson Foods	Beef, pork, poultry	Yes –% of total manure unknown[xv]	No	Yes – Manure moved from Illinois River watershed– no mention of scale[95]	Yes – Mentions added value products without detail
WH Group	Pork, poultry	Yes – % of total manure unknown[96]	No	No	Yes – Commercial grade fertiliser, % of total manure unknown
Wens	Dairy, pork, poultry	Yes – % of total manure unknown	Yes – Promotes low-protein feed to reduce nitrogen[97]	No[98]	No – Composted fertiliser, quality or % of total manure unknown

KEY:
- No indication of progress
- Some progress, no detail of scope
- Some progress, scope partly quantified
- Progress, clear scope

xiv Details can be found by visiting the CDP website's "Search and review past CDP responses" page at https://www.cdp.net/en/responses/30215. Locate the company's "Water Security Response 2021" entry and refer to section W-FB3.1a.
xv Details can be found by visiting the CDP website's "Search and review past CDP responses" page at https://www.cdp.net/en/responses/30215. Locate the company's "Water Security Response 2021" entry and refer to section W7.3.

* CPF discloses that 77 thousand tonnes of manure is used to enhance soil quality in agriculture, but does not disclose the proportional geographic spread of this manure.
** Hormel states that food waste can be used as a feedstock for anaerobic digestion, but does not reference manure[99]
*** 12 of JBS facilities use biogas, but it is unclear from company disclosure whether the biogas is produced on-site from its own manure[100]

> "Even companies striving to augment nutrient circularity and exploring innovative approaches are falling short."

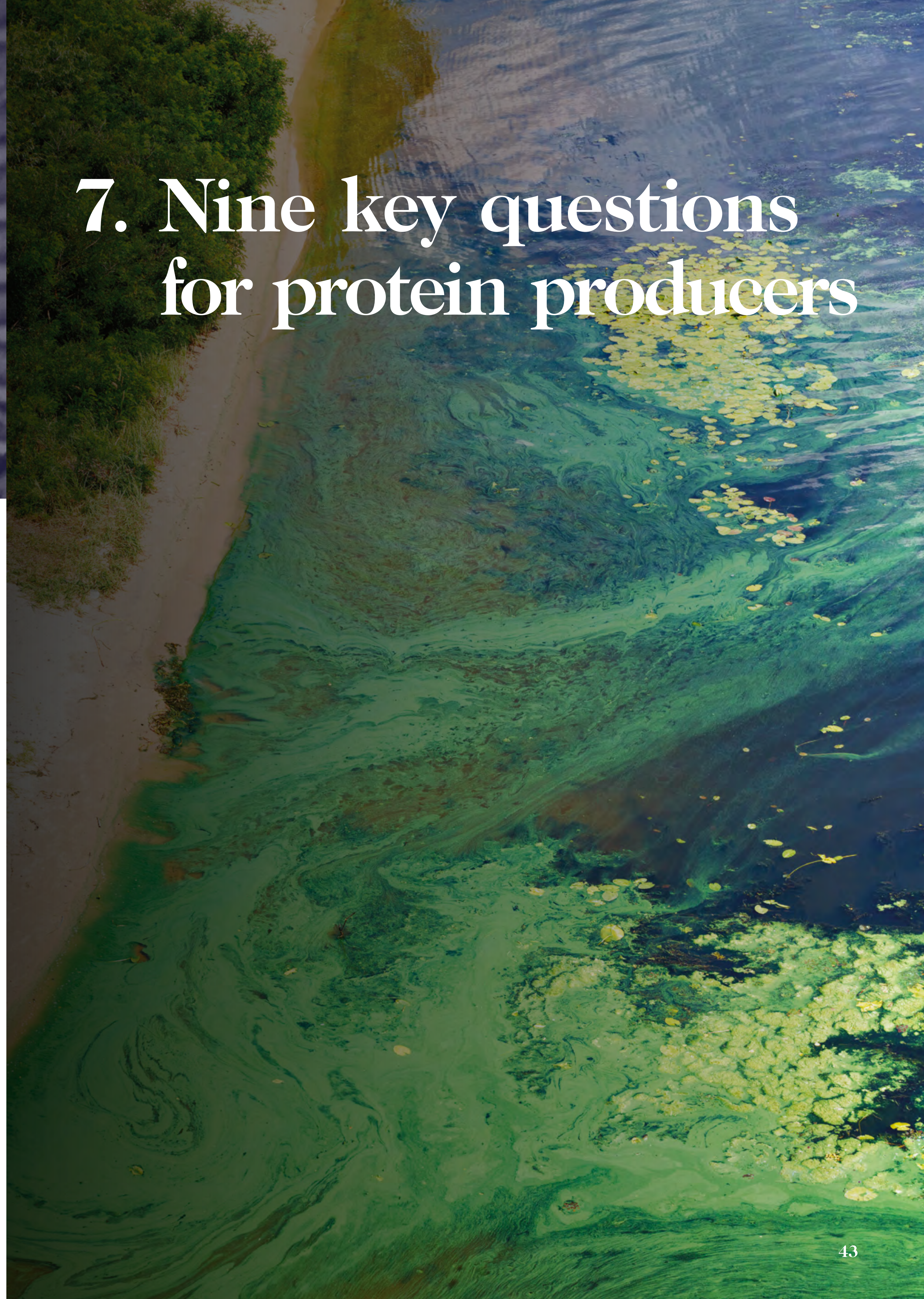
6.3. The importance of assessing risk

One of the main takeaways from FAIRR's analysis of how leading protein producers address the management of animal waste is that, not only does there seem to be a general lack of acknowledgement of the myriad risks surrounding this issue, but even those who are implementing mitigation measures provide little disclosure about their approaches. This inevitably suggests that producers are not fully assessing the risks, or being fully transparent with investors with regards to the result of these assessments. The findings suggest that even the companies that are striving to augment nutrient circularity and exploring innovative approaches are simply falling short.

Given the magnitude of the problem, it is clear that every producer should conduct a comprehensive risk assessment inclusive of a global baseline beyond the legal minimum of countries they operate in. As this paper has explained, there is too much at stake – in terms of environmental, social, economic and even reputational costs – to take this issue lightly.

Companies should begin the risk-assessment process by considering a number of key questions which fall under two broad themes: risk assessment and action plan. The questions also approach the issue from the angles of NMPs in feed supply, location and management of processing facilities, and circularity of manure. These can help investors form the basis for a more in-depth discussion with companies on the issues of nutrient and waste management as one of the three key pathways to biodiversity loss described at the beginning of this paper.

First, a business cannot begin to appreciate the matters at hand if it lacks a sound assessment of the nutrient needs and capacity of the areas with operates clearly detailed in its NMPs. It is unlikely to mitigate the devastating effects of nutrient pollution if it does not identify where operations are based. Finally, the "solutions" it deploys may be unduly narrow in focus and/or rooted in misaligned incentives if it does not strive for genuine circularity.



7. Nine key questions for protein producers

Nine key questions for protein producers

FAIRR uses the following questions to help protein producers better understand the risks and opportunities surrounding their management of animal waste.

First theme: Risk assessment

1 Can the company provide details of:
   a. Who within the company would be considered expert on manure management, nutrient management, and biodiversity
   b. Who within senior management holds ultimate accountability for ensuring biodiversity, climate and community risks are assessed and managed

2 Can the company provide details of how it assesses the biodiversity and community impacts of nutrient pollution to soil and water in the catchment areas where it operates facilities
   a. Which portion of facilities does this cover and how does the company plan to ensure full coverage
   b. How is this risk assessment integrated to its methane climate risk assessment

3 Can the company detail the process through which it identified and disclosed locations where it operates that are at a high or rising risk of biodiversity loss from nutrient pollution as part of this risk assessment
   a. Does the company demonstrate an understanding and impact of current and upcoming regulation related to manure management

4 To what extent does the risk assessment cover:
   a. Its own processing facilities
   b. All farms, both owned and contracted, supplying animals for its facilities
   c. Nutrient management in feed farms supplying livestock facilities the company operates or contracts
   d. Whether the company has assessed its downstream control over manure use and identified the proportion used for its own feed (or other crops it purchases if applicable) for which it has the capacity to influence nutrient management
   e. Whether both nitrogen and phosphorus are considered as part of the risk assessment

5 Will the company commit to a timeframe to implement a thorough risk assessment of this driver of biodiversity loss, climate change and community health issues

Second theme: Action plan

1 Can the company offer detail regarding the manner and the scale at which it tackles biodiversity risk arising from manure nutrient pollution at the livestock farm level (direct investment, support, supplier agreements)
   a. Is the company directly supporting manure management, for example through supporting transportation to low nutrient density regions
   b. Is biogas production combined with any initiative to enhance nutrient circularity beyond local spreading
   c. Has the company piloted or considered any other circular solutions to manage manure nutrient pollution such as insect farming for feed

2 Will the company set targets to improve circularity of both nitrogen and phosphorus created by processing facilities and livestock farms
   a. Will it offer disclosure on how such actions help address biodiversity risk within its own operations as well as upstream and downstream

Engagement questions for agrochemical companies

As discussed previously, agrochemical companies can play a critical role in reducing nutrient pollution by leveraging their expertise of isolating nitrogen and phosphorus, as well as their global reach in distributing those. Likewise, several of the world's largest food sector companies are setting regenerative agriculture targets that include reduced use of inputs in their supply chains. Agrochemical companies should envision new, circular revenue stream for fertiliser products.

Yet, very few aim to produce fertilisers using waste as a raw material, instead focusing on the chemical production of nitrogen fertilisers and mining of phosphorus. Consequently, the following questions may be useful for investors seeking to better understanding the risks and opportunities of such products:

Fertiliser Producers

1 Can the company provide details on which senior management role holds ultimate accountability of ensuring biodiversity, climate and community risks are assessed and managed

2 Can the company offer details of how it assesses the biodiversity impact of downstream fertiliser use through nutrient pollution to soil and water
   a. Is this assessment adapted to specific markets where its products are used

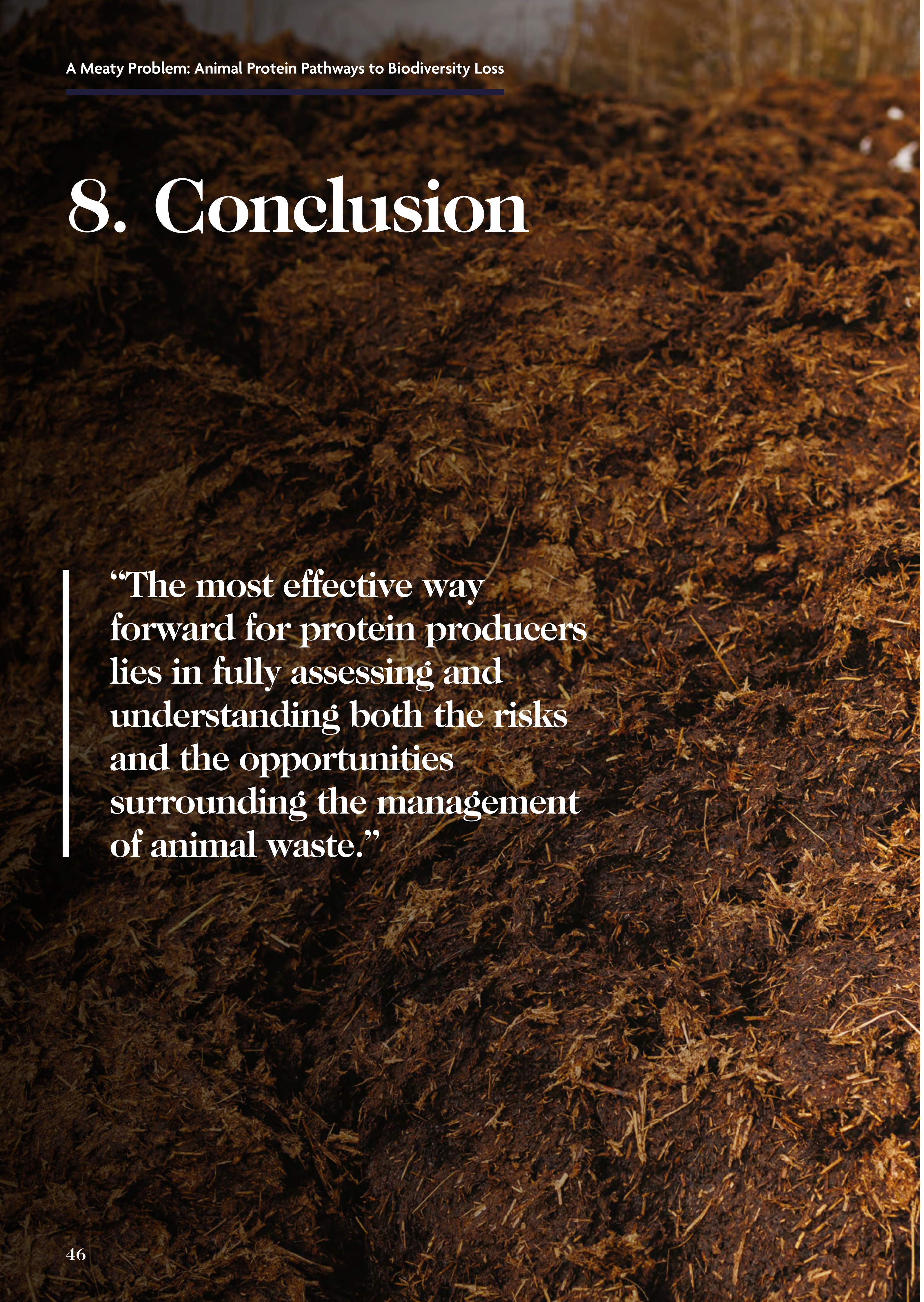
3 Has the company identified and disclosed locations where its products are used that are at a high risk or rising risk of biodiversity loss and community health impacts from nutrient pollution as part of this risk assessment

4 Can the company discuss specific projects aiming to use waste as a raw material and create circularity of nitrogen and/or phosphorus
   a. More specifically, can the company discuss specific projects or partnerships with a meat producer to extract nutrient from manure into a format or product that can easily be transported and commercialised

5 Does the company disclose its percentage of fertiliser revenue coming from circular sources or that uses waste as a raw material

6 Will the company set targets for diversifying fertiliser revenue away from fossil-fuel based nitrogen fertiliser and mined phosphorus, and toward circular sources and cycling nutrient
   a. If not, can the company offer details as to what is preventing such a target – economics, scalability, technicality, etc
   b. Has the company assessed the climate and biodiversity risk profiles of such products compared to traditional fertilisers

Source: FAIRR



8. Conclusion

> "The most effective way forward for protein producers lies in fully assessing and understanding both the risks and the opportunities surrounding the management of animal waste."

The mismanagement of nutrients – in large part originating from manure – is causing harm to people and planet which currently will take decades to reverse even with immediate action at scale. Put simply, too much manure is being distributed on too little land. The costs of following even baseline, often insufficient, regulatory treatment, storage and spreading regulation are mounting in many markets.

Even from a climate perspective, the efforts to capture methane emissions from manure to produce biogas only address one greenhouse gas. Ammonia could be captured and used as fuel similarly to methane if and when demand for hydrogen as a fuel gains traction in the long term. Until then, they are likely to be partly mitigated through feed and spreading adaptation, hardly making a dent in the climate and community health issues. Antibiotics and other pharmaceutical products require advanced treatment to be removed, but FAIRR's research and engagement on animal pharma shows their day-to-day use can be reduced considerably.

Technology is developing, including innovation in diets and feed as well as increased training on fertiliser application practices. New approaches from the agtech (agricultural technology) sector[101] will likely also assist in measuring, administering and tracking a shift toward more nature positive approaches.

Yet, many of these responses are narrow in focus. Some are overly reliant on seemingly well-intentioned incentives that fail to address the problem through a nature-wide lens. Others could in some ways eventually do more harm than good. The proliferation of biodigesters and the "gold rush" mindset that accompanies the trend can be seen as a classic illustration of misaligned interests that could support further industrialization of animal farming and worsen the harm to biodiversity for example.

In a business-as-usual scenario, the volume of waste and manure will continue to accumulate unless there is a concerted effort to shift away from animal proteins. Other measures are mainly mitigatory by nature, and even if full circularity of manure was achieved, they could risk creating even more incentives to further concentrate and industrialize protein production, thus raising exposure to other factors such as disease or animal welfare, for example.

Opportunities can likely be captured by unlocking the economic value of the nutrients within manure, as shown by initiatives that are starting to appear in this field. Even if regarded as a cost, the operational, legal, and reputational downside of seeking to perpetuate an unsustainable status quo is likely to be much higher over the longer term. An informed and nature-wide view is required to avoid further environmental, economic, social and reputational impacts.

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