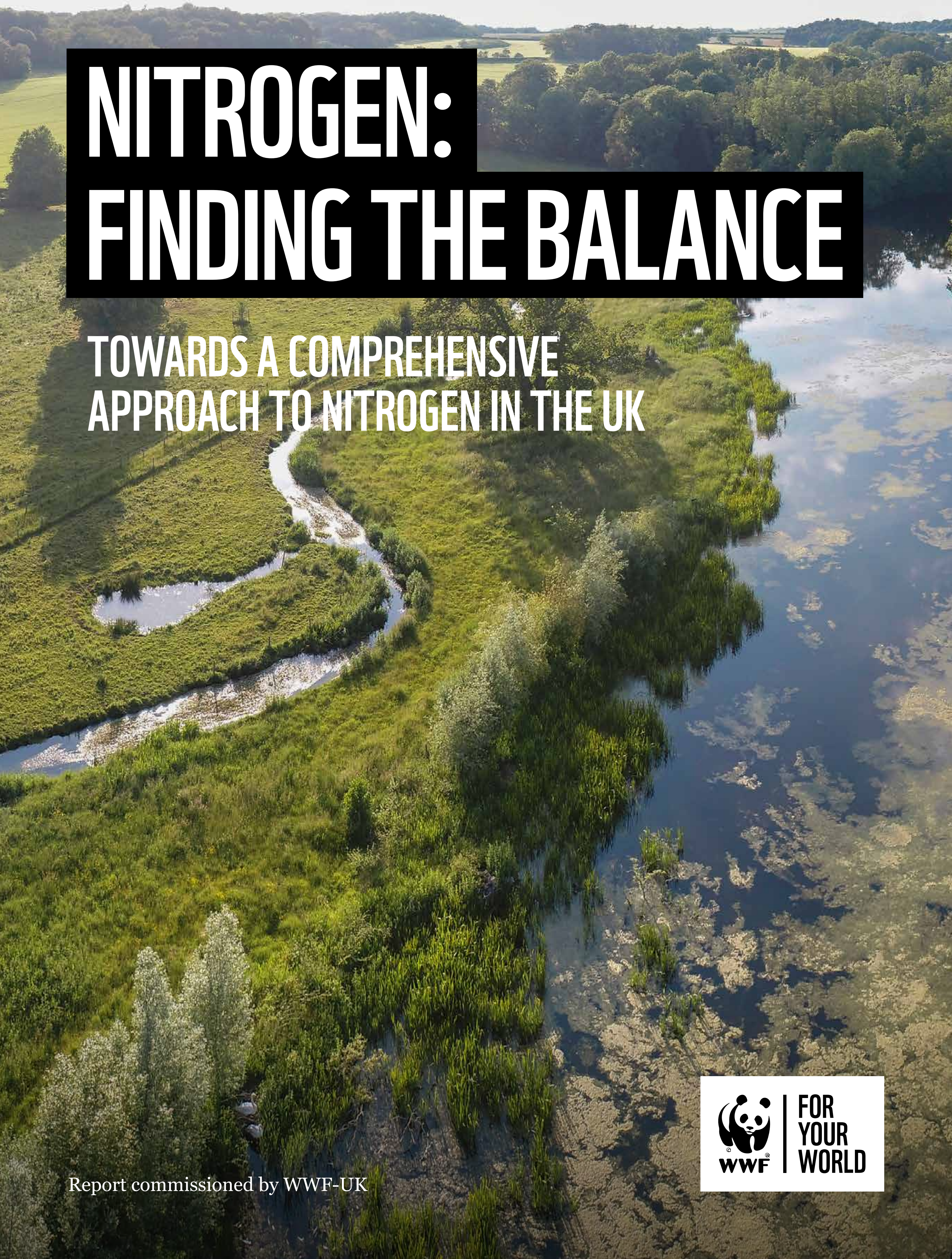
NITROGEN: FINDING THE BALANCE

TOWARDS A COMPREHENSIVE APPROACH TO NITROGEN IN THE UK



Report commissioned by WWF-UK

WWF FOR YOUR WORLD

Authors

Hicks W.K. & McKendree, J. (Stockholm Environment Institute (SEI) at the University of York, UK); Sutton M.A. & Cowan, N. (UK Centre for Ecology and Hydrology); German, R., Dore, C. & Jones, L. (Aether); and Hawley, J. & Eldridge, H. (Plantlife International)

The views expressed in this report are the views of the authors and do not necessarily represent WWF policy.

SEI Stockholm Environment Institute

UNIVERSITY of York

Aether

UK Centre for Ecology & Hydrology

Plantlife

Report produced for WWF UK, November 2021. This is a summary report to accompany the technical report, which contains expanded references, available at https://www.wwf.org.uk/sites/default/files/2022-02/WWF_Comprehensive_Approach_Nitrogen_Full_Technical_Report.pdf

Front cover photo:
© Joseph Gray / WWF-UK

Back cover photo:
© Simon Rawles / WWF

Design:
Clean Canvas Studio
www.cleancanvasstudio.co.uk

© Katharine Moore / Shutterstock

FOREWORD

The UK is one of the most nature depleted places in the world. Our soils are increasingly degraded, our rivers polluted and our health is impacted by noxious gases and particulates. A major driver of these issues is the industrialised part of our food system which has lost its connection with the natural processes that once sustained it. This is also causing the destruction of global habitats and pushing our climate ever closer to catastrophic tipping points.

The way we use, and waste, nitrogen is one of the key drivers of this harm. Nitrogen is one of the most abundant elements on the planet and a foundational building block of life. It forms almost 80% of the atmosphere as an inactive gas and is the main reason why the sky appears blue. It is essential to producing the food we eat and is a constituent of the protein in our diets.

But while nitrogen is essential, too much nitrogen is not. Since the 1960s, for example, human use of synthetic nitrogen fertilisers for food production has increased by nine times globally and if we were to continue with business as usual, a further increase of up to 50% can be expected over the next 40 years. Significant nitrogen emissions are also generated by industry, wastewater treatment and transport. Excess nitrogen leaches into the environment and atmosphere in many forms, harming nature, causing climate change and affecting air quality and human health. As a greenhouse gas, nitrous oxide is around 300 times more powerful than carbon dioxide over a 100 year period, yet is often overlooked, while in the UK, a third of the economy-wide losses of nitrogen to the environment are from agriculture into surface waterbodies and groundwater.

As humans, we have disrupted the natural nitrogen cycle for our own ends, leading to multiple impacts and costs to society. We tend to regulate these impacts in isolation from each other, without recognising the common sources and flows. Yet if we can restore the natural balance of nitrogen by using less and better using the nitrogen we do need, we will also help to tackle these climate, air, water and nature impacts together,

We see action on nitrogen as a key part of WWF's mission to bend the curve of nature loss and tackle climate change by 2030, in particular to restore the connections between the economic, environmental and social dimensions of the food system. This is why we have commissioned this report to be the most up to date and comprehensive source of evidence for decision makers, on how to maximise the co-benefits of improving our use of nitrogen across society.

The report is divided into three sections. Firstly, it sets out the impacts of our current misuse of nitrogen at a range of scales, from global to local, on the natural environment, on people and on the economy. Secondly, it identifies the key ways of reducing nitrogen use and waste, including adapting to regenerative forms of farming, reducing demand for animal feed, changing diets, reducing waste and cutting other combustion sources. And thirdly, it sets out the policy responses needed as part of a comprehensive package, from agreeing global priorities to introducing national nitrogen budgets and targets to guide action to halve nitrogen waste by 2030. Much more detail is contained in the full technical report.

Economically, the steep rise in fertiliser prices and the cost barriers to better storage, application and distribution of fertilisers and organic manures have brought nitrogen use into sharp focus. Indeed this report concludes that the overuse and waste of nitrogen across the UK agri-food chain would be worth approximately £2.3 billion each year to buy as fertiliser – equivalent to around half of all annual agricultural profits. Improving our use of nitrogen is not just a climate or environmental issue but can be at the heart of a just and resilient agricultural transition.

Many farmers and growers are already taking action to drive nitrogen use down and efficiency up, but we know much more can be achieved if the financial and technological support is available, and if there is a level regulatory playing field that is fair to those taking action and holds those who pollute to account.

Nitrogen is a system-wide issue requiring a system-wide response. This important report demonstrates how we can achieve change holistically, rather than unintentionally shifting problems from one form of pollution to another, or, geographically by importing goods and inputs produced to lower environmental standards. No one sector can deliver the vision, but now is the time for governments to act in unison with businesses and supply chains to 'find the balance' needed for nitrogen. We hope it starts a constructive discussion and leads to positive change for people, climate and nature.

Katie White

Kate Norgrove

Executive Directors
Advocacy and Campaigns, WWF-UK

CONTENTS

SECTION 1:

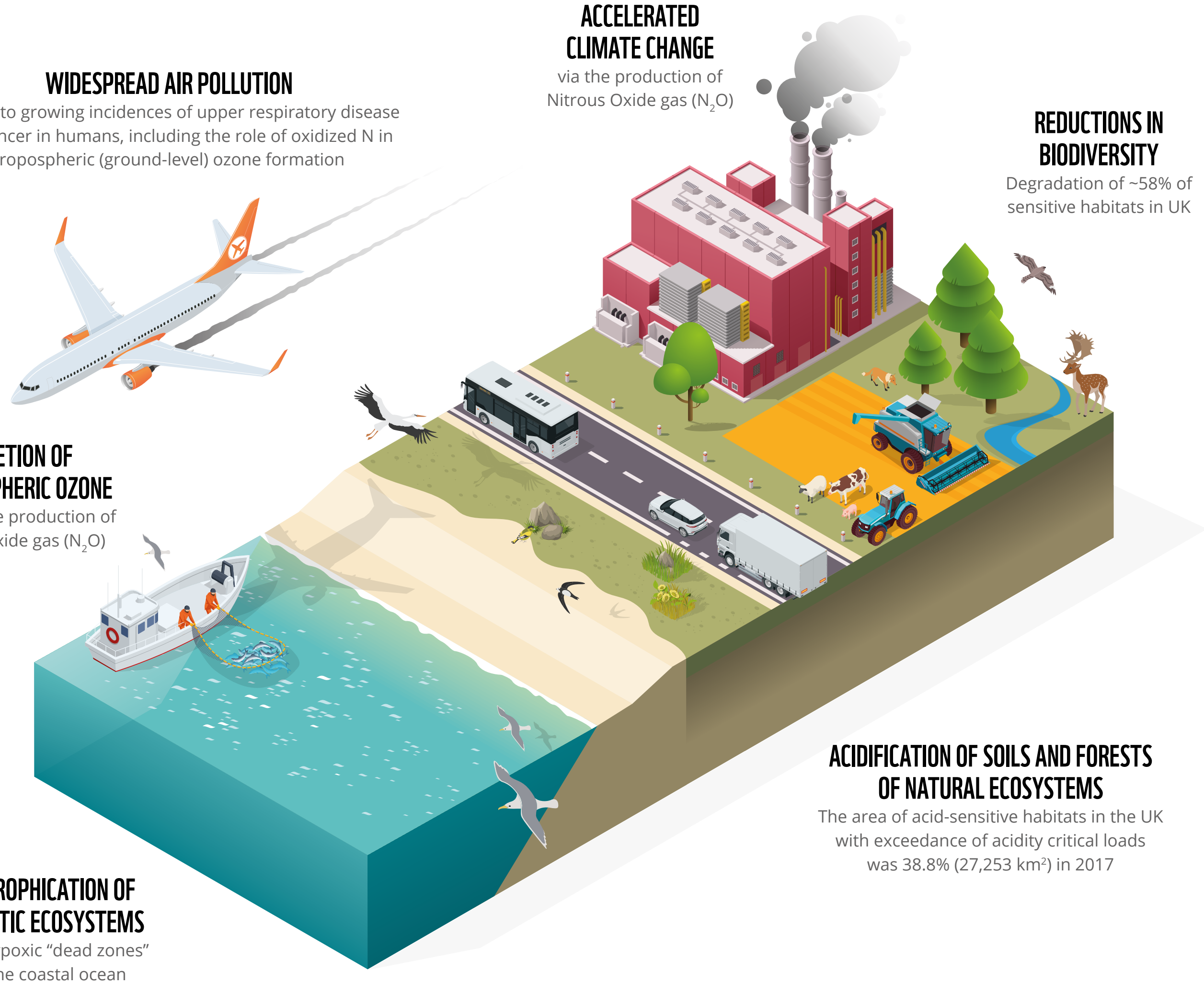
NITROGEN LOSSES TO THE ENVIRONMENT AND THEIR IMPACTS

1.1 INTRODUCTION

Nitrogen (N) is a naturally abundant element and forms nearly 80% of the Earth's atmospshere as the inert gas di-nitrogen (N2), indeed being primarily responsible for the sky appearing blue. However, reactive nitrogen compounds (Nr) – chemically active forms of nitrogen that interact with the environment and support plant growth – are typically scarce in the natural environment. Since the 1960s, human use of synthetic Nr fertilisers has increased 9-fold globally and a further substantial increase of around 40-50% is expected over the next 40 years based on current trends (Full Report (FR) Section 1.1). Together with increased fossil fuel combustion, humans have now created excess Nr pollution that spans all environmental compartments with multiple threats, to the extent that the disruption of the natural nitrogen cycle is now one of the greatest global threats to the environment of the 21st century. Key N threats and estimates for the UK from Section 1.1 in the full report include:

- **Reductions in biodiversity** (i.e. degradation of sensitive habitats) - the area of N-sensitive habitats in the UK with exceedance of nutrient N critical loads was 57.6% (42,049 km^2) in 2017;
- **Accelerated climate change** via the production of nitrous oxide gas (N2O) – representing 5% of UK GHG emissions in 2019;
- **Widespread air pollution** leading to growing incidences of upper respiratory disease and cancer in humans, including the role of oxidized N in tropospheric (ground-level) ozone formation (a potent GHG that can also impact on human health and crop yields) - current estimate of the mortality burden of air pollution in the UK is equivalent to nearly 29,000 deaths and an associated loss of 340,000 life years across the population annually of which nitrogen oxide (NOx) and ammonia (NH3) pollution plays a sig nificant role (FR Section 1.1.2);
- **Depletion of stratospheric ozone** layer via the production of nitrous oxide gas (N2O);
- **Eutrophication of aquatic ecosystems** and hypoxic "dead zones" in the coastal ocean – around 55% of England in 2019 was designated as a Nitrate Vulnerable Zone (NVZ) due primarily to elevated nitrate concentrations in groundwater and rivers; in England, only 16% of water bodies meet the criteria for 'good' ecological status, 50% and 40% of water bodies achieve good status in Scotland and Wales respectively;
- **Acidification of soils and forests of natural ecosystems** - the area of acid-sensitive habitats in the UK with exceedance of acidity critical loads was 38.8% (27,253 km^2) in 2017.

DISRUPTION OF THE NATURAL NITROGEN CYCLE IS NOW ONE OF THE GREATEST GLOBAL THREATS TO THE ENVIRONMENT IN THE 21ST CENTURY



The main drivers contributing to the overuse of N, its loss to the environment in a wider context and the resulting impacts can be categorized as:

- Inefficient farming practices – the inefficient and unsustainable use of N-fertiliser and manure leading to large Nr losses to the atmosphere and to terrestrial and aquatic ecosystems;
- Fossil fuel combustion – increased demand for fossil fuels, increasing of Nr release to the atmosphere during combustion;
- Geographic concentration in urban sewerage via food – concentration of Nr food system flows in towns and cities producing wastewaters high in Nr which are lost to the aquatic environment;
- Protein consumption (multiplier of preceding drivers) – increased global consumption levels as a result of human population growth, increase in per capita consumption and a diet shift towards more protein-rich and animal derived food and a rise in the use of N-fertilisers.

This report shows that tackling nitrogen pollution by tightening the nitrogen cycle will have multiple benefits across the environmental, economic and social pillars of sustainable development. These include **meeting the 'Triple Challenge' of supplying the food needs of the world, while tackling the climate crisis and reversing the loss of nature,** while also protecting human health and ecosystems through improved air and water quality, and protecting the ozone layer.

1.2 GLOBAL NITROGEN: SOURCES, PROCESSES, DRIVERS AND FLOWS

Table ES1 shows the main pollutants related to disturbance of the nitrogen cycle in the UK, their sources, impacts on human health and the environment, and key mitigation options/policy requirements, as discussed in this report. A key concern with Nr is that it can move through the environment causing multiple effects in the atmosphere, in terrestrial ecosystems, in freshwater and marine systems, and on human health. This phenomenon is known as the 'Nitrogen Cascade', which can amplify Nr effects through both time and space and make them difficult to manage.

Figure ES1 shows that crop and livestock production systems to feed humans and animals are together the largest cause of human alteration of the UK N cycle. Major pollutant losses to the environment include: emissions to air of ammonia (NH3) from livestock excreta and synthetic fertilisers; nitrous oxide (N2O) from denitrification processes in soils, manure and stationary combustion sources; and nitrate (NO3-) from leaching and runoff to water, mostly from agriculture, rural land management and wastewater streams (such as sewage, urban runoff and agricultural runoff). There is also a large flux of nitrogen oxide (NOx) emissions from fossil fuel combustion, associated with transport, combustion in industry and public electricity and heat production. Finally, there is a considerable flux of nitrogen back to the atmosphere as Nr compounds are denitrified to N2, through a wide range of industrial, terrestrial and aquatic sources, which constitutes a major loss of a useful nitrogen resource. Assuming a full-chain approach (from creation of Nr to intended use), N use efficiency (NUE) from all anthropogenic sources of Nr is approximately 11% (FR Section 1.2), with the remaining 89% being lost into the environment in a variety of forms. As a result of this additional input of Nr into the environment, the planetary boundary for nitrogen (i.e. the environmental limits within which humanity can safely operate) has been estimated to be exceeded by a factor of at least 2 (FR Section 1.1). It has recently been estimated by WWF that to meet planetary boundaries, the UK's per capita nitrogen and phosphorus footprints need to be reduced by more than 80%.

Major nitrogen cycle related pollutants and estimated rate of loss for given year in UK	Main sources	Main impacts	Key mitigation and intervention points	Policy requirement
Nitrogen Oxides (NOx) 251 kt N yr^{-1} (2018)	Transport (~50%), combustion in industry (~30%); public electricity and heat production (~12%) (FR Section 1.4.2; Table 1.4.2)	Human health Soil acidification and eutrophication (nitrate) Major precursor for Tropospheric Ozone formation (FR Section 1.1)	Electrification with renewables and technology with remaining combustion e.g. catalytic reduction, non catalytic reduction, NOx recovery (FR Section 2.5)	Integrated policy framework across major impacts on Water, Air GHGs, Ecosystems and Soils (WAGES) to give flexibility of response (FR Section 3.1, 3.3, 3.7)
Ammonia (NHx) 228 kt N yr^{-1} (2018)	Soil Management Processes (~50%); Cattle (~26%); Waste (~8%) (FR Section 1.4.2; Table 1.4.2)	Human health Soil acidification and eutrophication (ammonium) (FR Section 1.1)	Human diet - reduced meat/dairy Improved nitrogen use efficiency and joined up nitrogen management practices (FR Section 2)	Nitrogen budget with key fluxes and relationship with net Zero GHG quantified (FR ection 3.4)
Nitrous Oxide (N_2O) 44 kt N yr^{-1} (2018)	Soil Management Processes (~50%); manure (~13%); waste (~7%); stationary combustion (~5%) (FR Section 1.4.2; Table 1.4.2)	Greenhouse Gas Stratospheric Ozone Depletion (FR Section 1.1)	Human Diet -reduced meat/dairy Improved nitrogen use efficiency and joined up nitrogen management practices Potential use of inhibitors (FR Section 2)	Tailored solutions and actions across the four UK nations (FR Section 3.5)
Total N flux from land to water, including all N fractions 712 kt N yr^{-1} (2010)	N loading from diffuse sources in agriculture to groundwater (41%), surface waters (37%); public sewage (19%), industrial (3%) and N deposition (~1%) (FR Section 1.4.3; Table 1.4.3)	Eutrophication of aquatic and marine systems (FR Section 1.1, 1.2 and 1.4.3)	Human Diet -reduced meat/dairy Improved nitrogen use efficiency and joined up nitrogen management practices (FR Section 2)	Key performance indicators and 'safe' N guidelines identified across WAGES including for biodiversity (FR Section 3.7)
Methane (CH_4) 2060 kt CH_4 (2018)	Food waste and landfill (~40%)/; enteric fermentation cattle (~40%) (FR Section 1.2.1)	Greenhouse Gas Major precursor for Tropospheric Ozone formation (FR Section 1.1 and 1.2)	Human Diet -reduced meat/dairy Improved nitrogen use efficiency and joined up nitrogen management practices (FR Section 2)	
Nitrogen (N_2) losses 434 kt N yr^{-1}	Industrial emissions (~60%); terrestrial denitrification (~40%) (FR Section; 1.4.3; Table1.4.3)	Loss of useful nitrogen resource (FR Section 1.1 and 1.2)	Industrial and agricultural nitrogen use efficiency and nitrogen recycling (FR Section 2)	Circular economy principles (FR Section 3.1, 3.7)
Ozone (O_3) in the troposphere and stratosphere	Chemical production in troposphere from emitted NOx and volatile organic compounds (VOCs) and destruction via N_2O in the stratosphere	Tropospheric O_3: - Human health via inhalation - Reduction in crop yield Stratospheric O_3: - Human health via increased UV radiation (FR Section 1.1 and 1.2)	Measures to reduce NOx, VOC emissions and N_2O	Integrated policy framework that links technical measures (clean technology) and consumption patterns (transport and energy) plus measures to reduce N_2O emissions from agriculture.

Table ES1:
The main nitrogen cycle related pollutants, their sources, impacts on human health and the environment, key mitigation options and policy requirements in the UK. Rates of loss of major Nr compounds to the environment in the first column are 2018 for NO_X, NH_X and N_2O, 2010 for flux from land to water and 2015 for losses of N_2 back to the atmosphere (see Tables 1.4.2 and 1.4.3 in full report). Although not nitrogen compounds, ozone and methane are also included in this table given their interaction with nitrogen flows and mitigation options. The acronym WAGES shown in this table refers to the five key threats of nitrogen pollution identified by the European Nitrogen Assessment (2011): Water, Air, Greenhouse balance, Ecosystems and Soils (FR Section 1.1 and 3).

1.3 NITROGEN AND GLOBAL TRADE

The demand for more protein rich food in regions with increasing consumption has been a major driver of international trade of agricultural products (containing N), which has increased by a factor greater than 10 during the past six decades and it is expected to continue to grow in the future. Such protein rich foods include animal products (meat and dairy) and plant-based products (soy and other legumes) which lead to a concentration of nitrogen flows in the food system.

Previous trends in N exports have strongly intensified (i.e. many countries have evolved from near equilibrium between nitrogen imports and exports in food and feed to a much more unbalanced situation). One way of illustrating this is by using the term Nitrogen Use Efficiency (NUE) which is the fraction of N output compared with input, and can be defined for different scales (e.g. crop, livestock, food chain, economy wide etc). While crop nitrogen use efficiency (NUE_{crop}) of some high income countries (e.g. in the European Union) has increased since action taken in the 1980s, efficiency is still low (~55%) and has also dropped in low income nations in which fertiliser use is less regulated. Soy exports (from countries such as US, Brazil, Argentina, etc…) have grown rapidly and account for a large proportion of international N exports (primarily as animal feed and feedstock for biodiesel). While these exports (legumes) may have a significantly lower N pollution burden associated than locally grown alternatives, the impacts of deforestation and loss of natural habitats as a result of converting land to grow these crops can be extreme and may outweigh any positive impact in regard to N pollution regardless of NUE.

When designing ways forward to improve this situation, the UN recommends that solutions need to differentiate between populations that consume more than the recommended healthy levels of animal-sourced foods, and, nutritionally vulnerable groups, particularly infants and children in low-income settings, among which nutritious animal-sourced foods consumption should be increased.

ESTIMATED UK LOSSES OF NITROGEN BY SOURCE AND CHEMICAL SPECIES

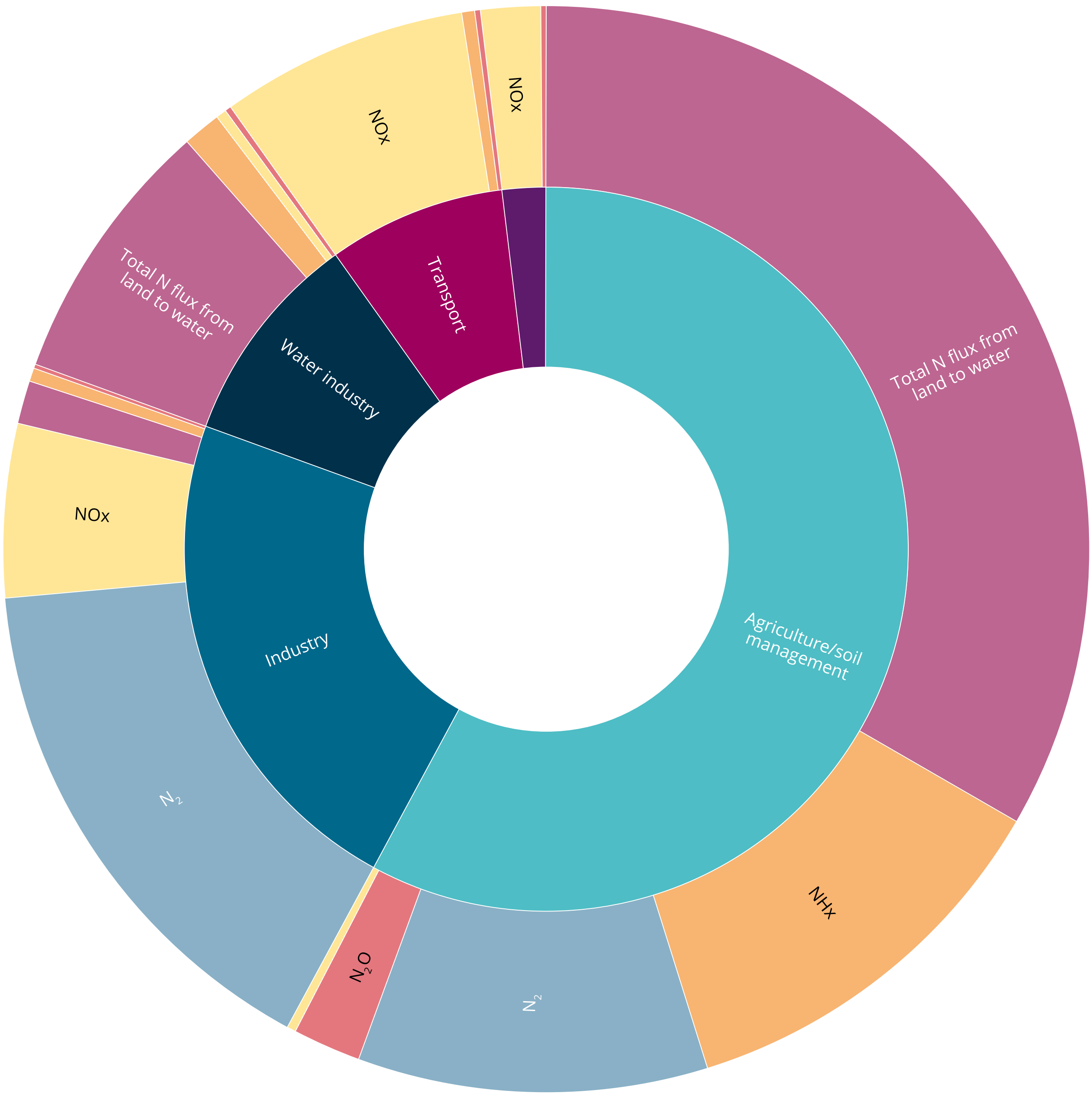


Figure ES1:
The relative magnitude of estimated rates of loss to the environment for the major nitrogen cycle pollutants by source and by chemical species. The chart, based on data summarised in Table ES1 shows the magnitude of losses by weight of nitrogen, but not the importance of their impacts, which vary from human health, through global warming, to waste of resources.

1.4 NITROGEN IN THE UK

The N footprint (consumption and production) across supply chains in the UK is estimated at 27.1 kg N per capita per year with food production constituting the largest proportion of the footprint (18.0 kg N per capita per year; FR Section 1.4.3). Annually, over 1000 kt N of mineral fertiliser is applied in the UK, which has remained fairly steady over the last decade, falling from a peak in the 1980s when synthetic N application reached 1674 kt N in 1987 (FR Section 1.4.1). A further 1000 kt N (approximately) is applied as animal manure, either via spreading or direct defecation into pasture. Efficiency of N applied as fertiliser in the UK is similar to other EU countries, with an average NUE_{crop} of approximately 55% (FR Section 1.6).

The largest component of N lost to the environment in the UK is as a result of losses to aquatic systems (in both mineral and organic forms) at ~712 kt N annually (Table ES1). This is heavily influenced by agricultural run-off and nitrate leaching from agricultural soils. The sum of all gaseous losses (N2, NH3, N2O, NOx) in the UK (960 kt N annually) is estimated to be of a similar magnitude to the aquatic losses (Table ES1).

Despite a drop of more than 70% in emissions since the 1970s, NOx emissions from combustion of fossil fuels are currently still the largest source of atmospheric N pollution to the atmosphere in the UK, accounting for approximately 250 kt N yr^{-1} (FR Section 1.4.2). The benefits of low-emission technologies in vehicles have been substantially offset by increased transport miles per year. Emissions of NOx are expected to reduce further with the electrification of the transport sector. By contrast, emissions of NH3 across the UK have remained steady for decades (actually increasing since 2013), and are currently approximately 228 kt N yr^{-1} (FR Section 1.4.2). These NH3 emissions in the UK are predominantly associated with agricultural activities (approx. 80%). UK emissions of N2O have more than halved since 1990, primarily due to a significant reduction in the industrial sector (a fall of 96%). However, emissions currently stand at 44.4 kt N yr^{-1} and are now also dominated by the agricultural sector for which emissions have been relatively stable during the same timeframe (FR Section 1.4.2). Approximately 30-40% of reduced N (NH3, NH4, amines etc…) is estimated to remain in the UK after emission, while only 16% of oxidised N (NOx, N2O, NO3, etc…) is estimated to remain in the UK (FR Section 1.6). It is estimated that the majority of Nr air pollution released in the UK ends up deposited in the Atlantic or North Sea, with a smaller percentage of reduced and oxidised N species reaching neighbouring states such as France, Germany and others. There can also be a significant flux in the opposite direction, for example, it has been estimated that about 50% of the particulate NH4 related fine particulate matter ($PM_{2.5}$) in the UK may originate from gases emitted elsewhere in Europe (see FR Section 1.1.2).

1.5 NITROGEN, AGRICULTURE AND NET-ZERO IN THE UK

Agricultural emissions of greenhouse gases (GHG) in the UK were 54.6 MtCO2e in 2018 (approx. CO2, 12%; N2O, 31%; CH4, 56%), which represents 10% of UK GHG emissions (FR Section 1.5). Emissions of CO2 from agricultural activities (e.g. transport, agricultural operations) need to be offset by land use changes, such as the expansion of forestry and the restoration of natural wetlands.

According to the UK's Sixth Carbon Budget, reaching Net-Zero will require significant changes to diet, releasing agricultural land by moving diets away from the most carbon-intensive foods, with a shift away from meat and dairy products (30-50 % by 2050) delivering the highest emissions savings (FR Section 1.5). N2O emissions from agriculture largely result from microbial processes that occur in soils after N is applied (fertiliser or animal excreta). In the agriculture sector, it has been estimated that technical actions to reduce N2O emissions include improved timing and correct amounts of fertiliser application, and of different nitrogen forms, including nitrification inhibitors, where a range of actions to improve NUE reduces the fraction of N lost as N2O (Section 2.3). As current reduction plans for net-zero are focussed on carbon equivalents (CO2e), and use carbon sinks to offset N2O emissions, concentrations of N2O can be expected to rise even if the most intense reductions in GHG emissions are achieved. Such a future would not be inevitable, however, if increased attention were given to adopt measures focused on sustainable nitrogen management (FR Section 2).

There is an ongoing risk that emissions of N2O will remain a low priority in future unless action is taken to highlight the opportunity for sustainable nitrogen management to offer win-wins between climate, wider environmental protection and economy. For example, if global warming potential (GWP) values are revised (in line with the IPCC Fifth Assessment Report (AR5), which includes climate-carbon feedbacks) from 100 to 25-year lifetime impact, then this will give an increased weight to CH4 (with shorter atmospheric lifetime), than to N2O (with longer atmospheric lifetime).

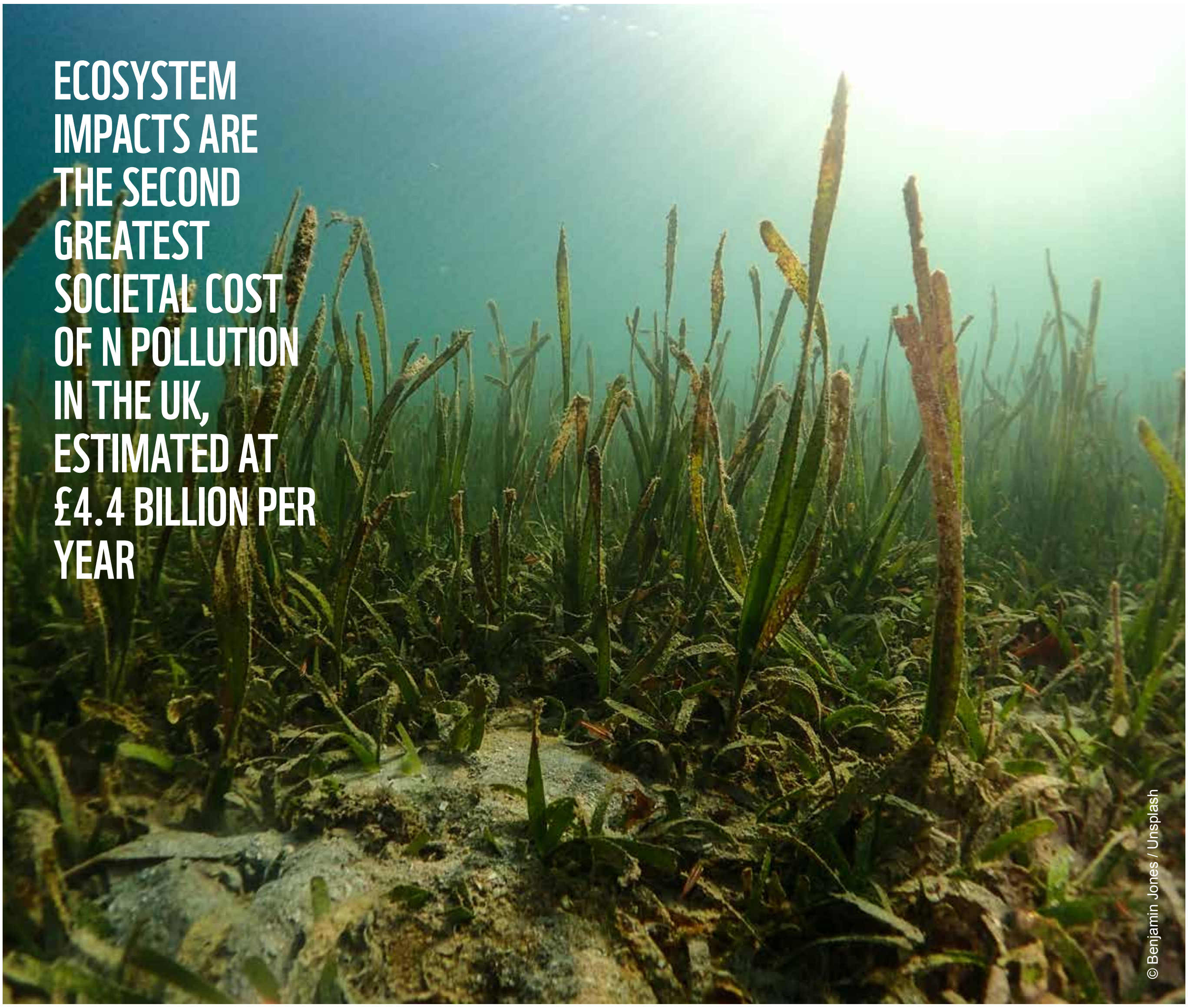
Although the impact of N emissions play only a modest role in the overall GHG budget in the UK (approx. 4% of the UK's greenhouse gas emissions in 2014; Section 1.4.2), there are significant dangers associated with N2O emissions that will have lasting effects on climate change and stratospheric ozone depletion. As a long-lasting gas species (with a lifetime longer than 100 years), N2O will have a warming impact for more than a century after its release. The planting of forests and regeneration of carbon sinks in the UK (or globally) will not result in falling N2O concentrations in the atmosphere. In parallel, it is estimated that N2O is now the major ozone depleting substance, indicating the priority for N2O emissions controls to protect the ozone layer (FR Section 1.5). So long as agricultural activities result in the release of N2O emissions beyond that which are naturally destroyed (reaction with stratospheric ozone), concentrations will continue to rise globally and the threat to the climate and the ozone layer will increase.

1.6 THE COSTS AND IMPACTS OF NITROGEN IN THE UK

There are different ways to value the costs and benefits of nitrogen to society, which are relevant across multiple scales. Valuing the benefits of nitrogen use in agriculture may consider the value of commodities produced, the profit to farmers, and even the value of the subsequent commodities including added value of processing. Concerning the costs of nitrogen pollution, this can be expressed as the total societal cost related to different threats (e.g. health, ecosystems, climate), or may be expressed as the total of nitrogen loss, expressed in terms of the lost fertiliser value that is no longer available (or could become available if not lost). For the latter approach, it is possible to include both the lost fertiliser value of nitrogen pollution and of nitrogen denitrified back to the atmosphere as N2. With this in mind, the concept of total 'nitrogen waste' has been used to express the sum of all nitrogen losses to the environment, including both polluting Nr compounds and denitrification to N2, which is equally a waste of resources (FR Section 3.1).

At a UK scale, a gross value of £9.4 billion was generated by farming in 2020, of which farmers were able to keep £4.1 billion as profit (FR Section 1.6). In terms of total profits, the cost of total nitrogen waste (from all sources) at a UK scale is estimated at £2.5 (£1.3 to 3.7) billion per year, i.e. approximately half the agricultural profits. It is estimated that wastage of available nitrogen resources is costing UK farmers approximately £21 - £52 per hectare per year in fertiliser costs (based on assumptions detailed in FR Section 1.6). With a total estimate of £397 million lost annually across the UK for synthetic fertilisers.

In addition to direct economic value of wasted nitrogen resources, a wider analysis needs to consider the societal value through the health, ecosystem and climate costs of nitrogen pollution. It has been estimated that a cost of approximately £10.9 (2.7 – 27.1) billion per year of societal costs can be attributed to N pollution in the UK, of which approximately 60% are attributed to the impact on human health, predominantly that of NOx and NH3 emissions (FR Section 1.6). The single greatest societal cost estimate of nitrogen pollution is related to the impact of urban concentrations of NOx on human health, the majority of which is generated by fossil fuel combustion (£3.9 billion), which can be combined with agricultural related human health impact (mainly particulates from NH3; £2.4 billion), followed by ecosystem eutrophication and biodiversity impacts (N deposition and NH3 and NOx gases; £4.4 billion) (Table 1.6.2). The trend towards electrification of urban transport (and potentially heating/heat pumps) is shifting that balance. There are also contributions from N2O as a GHG (£0.38 billion), crop damage via ground-level ozone (£0.32 billion), drinking water contamination via nitrate (£0.25 billion), energy use in N fertiliser production (£0.13 billion), and human health effect of UV light from high-level (stratospheric) ozone depletion via N2O (0.08 billion). There is also a climate benefit of NOx and NH3 related particulate matter, estimated at £0.84 billion (Table 1.6.2), as these particles have a climate cooling effect in the atmosphere, but this can be considered a necessary trade-off when compared to the considerable cost savings estimated for the mitigation of human health and biodiversity impacts.



SECTION 2:

IDENTIFYING THE KEY INTERVENTIONS

As set out in Section 1, there are many factors driving nitrogen over-use, low Nitrogen Use Efficiency (NUE) and high losses of reactive nitrogen. As disturbance of the nitrogen cycle crosses all sectors and scales, interventions are needed across multiple actors, including technical actions in agriculture, fossil fuel combustion, wastewater sectors, and by wider society in considering consumption patterns of food, transport and energy. UK consumption of overseas goods also has an impact outside UK territory, where supply chains are associated with nitrogen losses to the environment.

AGRICULTURE AND THE FOOD SYSTEM

Sections 2.1 to 2.5 of the full report and of this summary outline interventions relating to agriculture and the food system (including consideration of waste and wastewater).

At the UK scale, farming is a key sector to implement measures to reduce loss of nitrogen and nitrogen pollution, since the majority of ammonia, nitrous oxide and nitrogen losses from terrestrial systems to ground water and surface waters in the UK occur from the wider farming system (Table ES1). But farmers are part of a wider UK and global agri-food system of consumers, suppliers, retail, food and waste processors, government and scientists who all have a role in providing financial support, market signals, social norms, and regulations that influence farmers' decisions about what to produce, how much to produce, and how to go about it. At the simplest level there are two key components to reducing the total nitrogen waste from food production in the UK:

i. Reducing demand for food production (especially food with a high nitrogen footprint); and

ii. Reducing Nr emissions per unit of food produced (emissions intensity).

The UK population is projected to grow slowly over the next few decades. Despite this, demand for land and wasted Nr resources associated with food and feed production can be effectively reduced through a combination of technical measures in agriculture, by modified dietary choice and by reduction in food waste.

COMBUSTION SOURCES

Interventions to reduce Nr emissions from combustion sources are discussed in section 2.6 of the full report and this summary.

2.1. DIETARY CHANGE

In the UK, it has been estimated that people eat around 50% more protein than is recommended by WHO guidelines (estimated at 70% for Europe overall), and around 60% of this is consumed as animal products (meat, dairy, fish and eggs) (FR Section 2.1). The Nr emissions footprint of animal products (per gram of protein, as well as most other measures) is larger than that of plant- or fungus-based products. On average in Europe, beef and sheep and goat meat has almost 100 times the associated Nr emissions per kg of N in the product than do pulses, and the best-performing animal products (poultry meat and eggs) still have over 2 times the footprint of the worst-performing plant products (fresh fruit and vegetables). This difference relates to the low efficiency with which animals (especially slow-growing animals such as beef cattle) convert the plant protein they eat into protein in animal products.

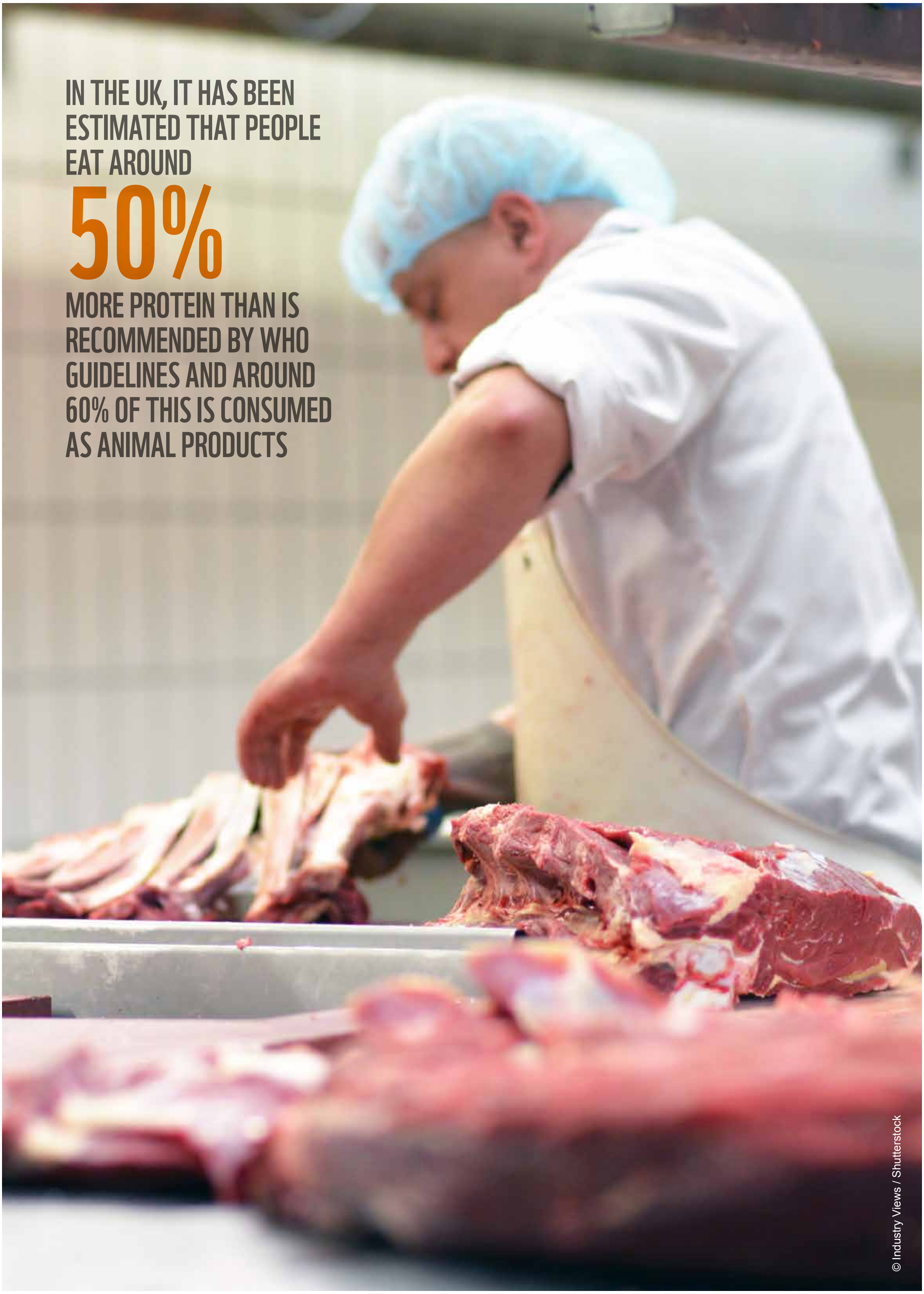
In Section 2.1.2 of the full report, a series of published dietary shift scenarios are compared with regards to impacts on Nr emissions, as well as GHG emissions and health. A "demitarian" diet, involving 50% reduction in consumption of all meat and dairy products, has been estimated to reduce Nr emissions by 42% across the EU (43% reduction in NH3, 35% reduction in leaching and runoff, and 31% reduction in N2O emissions), on the assumption that land freed-up (due to less land needed for livestock feed) would be used for restoring nature, extensive grazing, and bioenergy opportunities. GHG emissions would similarly be reduced by 42%.

WWF-UK have suggested that a reduction in meat and dairy consumption of around 30% by 2030 and 50% by 2050 is about right overall, especially considering the wider impacts of soy production and the need to cut methane as quickly as possible, alongside Nr impacts.

All studies reviewed showed that a reduction in animal product consumption bring reduction in emissions of Nr and GHGs, as well as health benefits, relatively independent of which assumptions were made. However, depending on which impacts are given priority, the relative benefits of emphasising a reduction in consumption of pork, poultry, and eggs on the one hand, or reduction in ruminant products (beef, dairy, lamb and goat meat) on the other hand, can vary widely. All types of meat consumption should be factored into interventions to shift diets, given their significance to Nr emissions (FR Section 2.1.3).

As well as switching to plant- and fungus-based protein sources, novel protein sources could also play a key role, including synthetic / lab grown meat, insect protein, and microbial cell-culture. All of these have the potential for significantly lower Nr emissions compared with animal products, as long as the choice of feedstock is made with environmental impact in mind. Challenges still remain for scaling-up production, including regulatory inertia, high costs and limited demand due to human behavioural inertia (FR Section 2.1.4).

Whatever the changes considered, shifting people's diets to the extent envisaged by the scenarios considered is not a straightforward path, but one that requires considerable behavioural change and integrated food policy. Food choices are influenced by a variety of interacting factors, including food prices, gender, health, income, geography, social identity and networks, exposure to marketing and media, and ease of access to supermarkets and other food outlets. Food choice decisions are made through both conscious rational choice, and unconscious responses to "choice architecture" (FR Section 2.1.5). There are a range of different types of intervention possible, ranging from strong interventions such as banning certain products, through to disincentives such as taxes and weaker interventions such as working with stakeholders to enable consumers to make better choices, labelling regulations, and education campaigns (FR Section 2.1.5; Figure ES2).


IN THE UK, IT HAS BEEN ESTIMATED THAT PEOPLE EAT AROUND
50%
MORE PROTEIN THAN IS RECOMMENDED BY WHO GUIDELINES AND AROUND 60% OF THIS IS CONSUMED AS ANIMAL PRODUCTS
© Industry Views / Shutterstock

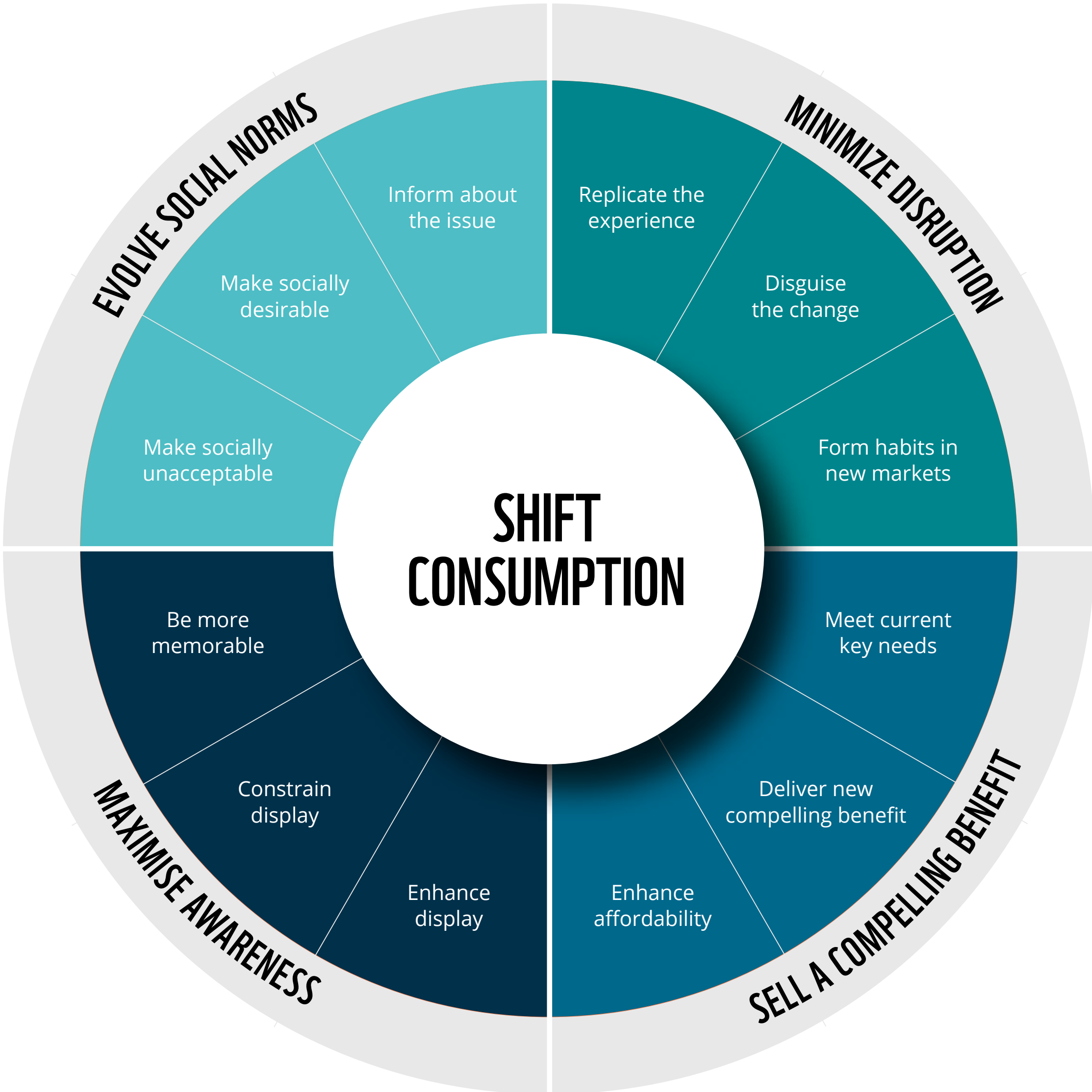


Figure ES2:
The "Shift Wheel" of strategies to shift consumer behaviour, adapted from Ranganathan, J. et al (2016) Shifting diets: Toward a sustainable food future. In Global Food Policy Report, Chapter 8, 66-79. Washington, D.C.: International Food Policy Research Institute (IFPRI).

There is evidence to suggest that a large portion of the UK population is willing to reduce meat consumption as long as they have the knowledge to cook balanced, varied and tasty meat-free dishes. According to a 2020 survey by the Eating Better Alliance, 65% of respondents indicated a willingness to reduce meat consumption and a recent study shows that there has been just under a 17% reduction in meat consumption in the UK between 2009 and 2019 (FR Section 2.1.5).

Others have found that the public are surprisingly tolerant of - and even expect - government intervention to change diets. Recent research for the development of the National Food Strategy suggests that whilst public support is high for "softer" measures such as government setting a target to reduce meat consumption, harder measures such as a meat tax are, for the moment, very unpalatable (FR Section 2.1.5).

2.2 REDUCING FOOD WASTE AND WASTEWATER TREATMENT

Food waste occurs at all stages through the food supply chain, and a mix of strategies is required to address losses at different stages. Where food waste cannot be reduced, focus should fall on improving the efficiency of recycling of nitrogen in waste, ensuring it is kept within the system and thereby minimising the requirement to introduce additional N to the system. Reducing (and / or effectively recycling) food waste also has a significant impact on GHG emissions, as methane from decomposing food in landfill makes up around 4-6% of total GHG emissions globally. As CH4 is the primary GHG released during decomposition, if alternative, shorter time horizons for global warming potentials are considered, as recommended by the IPCC 5th Assessment Report, then the contribution of food waste decomposition to the global GHG inventory would increase further (FR Section 1.5).

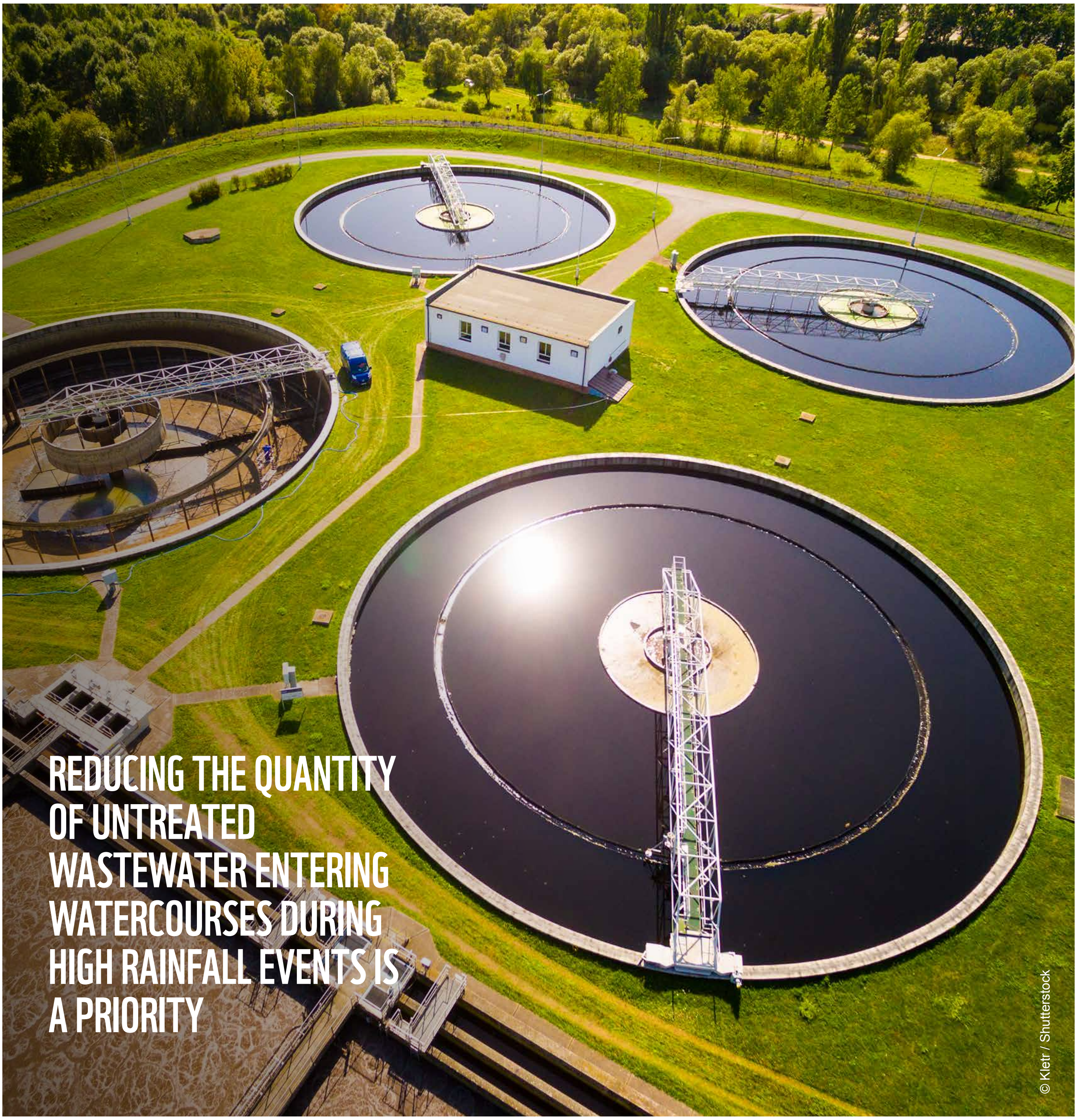
There are a number of targets in place that mandate reductions in waste over the coming decade, including the UK government's commitment to the targets set out in UN Sustainable Development Goal 12.3 of a 50% decline in edible food waste per capita by 2030, and WRAP's voluntary Courtauld Agreement setting a 20% reduction target in post-farm gate waste by 2025, to which many of the major retailers in the UK are signatories. Data suggests that more food is wasted at the primary production and consumption phases of the supply chain, although waste at processing, manufacturing, and distribution plays a not insignificant role.

Primary production refers to all initial stages of the food supply chain, encompassing pre-harvest, growing, handling and storage operations. At the farm level, food waste can occur for several reasons, including harsh weather conditions, pest infestations, or spoilage. More indirect factors, such as excess production, fluctuating market prices, quality control and aesthetic standards can also be major factors in food waste generation on farm. Whilst effective intervention on the indirect factors driving on-farm food waste would involve multiple elements rather than singular solutions, there are actions that can be taken to address direct factors and improve efficiency of food production at the farm level, such as utilising unused agricultural products for other purposes such as bioenergy generation. These, however, do not reduce the nitrogen requirements of growing the food, and therefore other actions are needed, including introducing crop and livestock health improvements, providing farmers with access to tools to improve decision-making, better harvesting equipment maintenance, increased recycling of non-marketable produce for animal feed, and ensuring detailed monitoring of food loss and waste is set up.

Reducing food waste from the consumption stage also requires addressing a range of indirect factors that influence consumer behaviour. These include raising awareness and educating about date markings, meal planning, appropriate food storage, and treatment of foods that fall outside of typical aesthetic standards. Other actions and measures to reduce food waste from all stages of the supply chain are included in the full report (FR Section 2.2).

Where food waste is unavoidable, an increase in use of food waste directly for animal feed, for composting, or as a feedstock for anaerobic digestion or insect breeding is possible through improved segregation of food waste streams from other kinds of waste. This prevents methane emissions and helps to produce sustainable animal protein or usable fertiliser products to recycle nitrogen back onto the land. Separate food waste collections will be mandatory in England from 2023.

Wastewater treatment is another hotspot of Nr emissions and nitrogen losses post farm-gate (FR Section 2.2.6). Increasing the use of tertiary treatment would reduce Nr emissions from this source by almost 50%, but also increase N2 emissions by 30%, thereby contributing to a linear rather than circular flow of nitrogen. In the UK where sewage sludge is already well-used, advanced N recovery technologies – such as ammonia stripping or struvite precipitation – could be a key measure to allow more of the N to be retained in useful products and returned to the land. Reducing the quantity of untreated wastewater entering watercourses during high rainfall events is also a priority. It has been estimated that there is ~17% reduction in total nitrogen losses for a halving of food waste in Europe (i.e. from 30-15% waste), which does not include farm level improvements or diet change (energy or protein reduction or type of foods) but does include better waste management (use of sewage etc.).



© Kletr / Shutterstock

2.3 ON-FARM MEASURES

Section 2.3 of the full report considers interventions on farms. Emissions of Nr on farms occur from livestock housing, storage of livestock manure, and application of manure and inorganic nitrogen fertilisers to soils. In the full report, effective measures to reduce Nr emissions (taken from a variety of sources, but especially UNECE, 2021) are evaluated, as well as trade-offs and synergies with GHG mitigation measures included in the Committee on Climate Change's 6th Carbon Budget. These are summarised below.

Measures which reduce N inputs to agriculture tend to lower Nr emissions through all pathways, and where inorganic fertiliser input is reduced this has the added benefit of reducing the GHG emissions impact of fertiliser production (Figure ES3). In contrast, to achieve overall reductions in N losses and avoid pollution-swapping, measures reducing emissions of a particular form of Nr often depend on application of other measures or adjustment of management practices to compensate for the additional N remaining in the system. Applicability of measures is also context-dependent, so farmers and their advisors should consider holistic "packages" of measures appropriate to specific contexts.

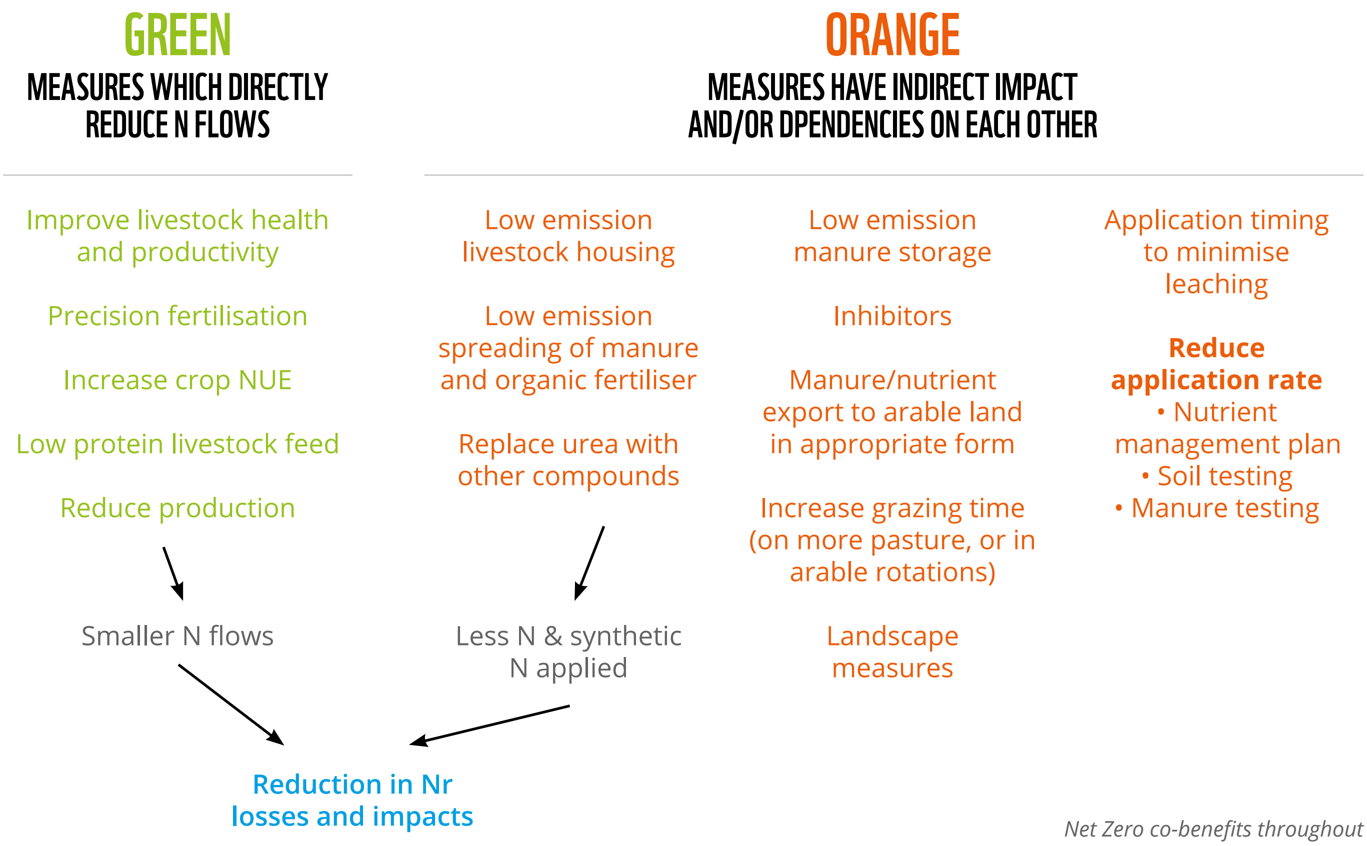


Figure ES3:
Nitrogen mitigation measures that directly reduce N flows (green) or have indirect impact and /or dependencies on each other calling for more holistic approaches (see Section 2 of full report)

2.3.1 LIVESTOCK DIETS, HEALTH AND BREEDING

In general, better health and disease management, and breeding for improved livestock performance, tend to reduce Nr emissions per unit of product produced, because a smaller fraction of protein intake is used for maintenance or non-productive growth. The GHG emissions intensity of livestock products also tends to decrease in tandem as a result of these measures. Importantly, higher productivity per animal per se does not always lead to lower Nr emissions, if this is achieved through high-protein feeding, or if rebound effects occur (e.g. Jevon's paradox where improved efficiency may lead to greater consumption). There is potential to increase access to high-quality breeding stock in the UK, and to a lesser extent to improve livestock health planning.

Low-protein diets reduce all forms Nr emissions by reducing the amount of surplus N eaten by animals. This can bring synergies with GHG mitigation, if high-digestibility and low-protein feeds can be combined. However, the N fertiliser inputs for growing some feed types such as maize silage and high-sugar grasses need to be considered, so taking a life-cycle perspective is vital. The largest potential for improvement in the UK is for cattle and sheep, but the need to keep animals housed to control diet may be difficult to reconcile with benefits of grazing. Whilst grazing, NH_3 emissions are much lower than for housed livestock, as it is quickly immobilised in the soil, and there are also system-wide advantages to making use of ruminants for nutrient cycling.

Greatest abatement potential in terms of GHGs is provided by the use of ruminant feed additives, a more innovative option that has highest uptake in the Widespread Innovation scenario of the UK Sixth Carbon Budget. There is no evidence for trade-offs between addition of enteric methane inhibitors (e.g. 3NOP and nitrate) and Nr losses.

2.3.2 LIVESTOCK MANURES

Waste management measures encompass reducing emissions from housing and storage, as well as processing manure to enhance recovery of nitrogen in a usable form for farmers. A key proviso of these measures is that low-emission application methods matched to crop needs are also employed, else the benefit is greatly reduced.

For housing, emissions mainly occur through ammonia volatilisation. Significant emissions reductions (of 20-70%) can be achieved through a range of housing design measures which reduce the temperature, surface area or pH of manure, immobilise ammoniacal nitrogen in bedding, reduce duration of exposure to air, or scrub ammonia from the air (up to 90% efficient). There is potential for greater use of low-emission housing in the UK, and mandatory design standards for new housing in England are proposed by the 2019 Clean Air Strategy.

For storage, covering manure stores with an impermeable cover and base, and slurry acidifcation are two key measures for reducing Nr emissions from manure storage, reducing NH3 emissions by up to 80% and 90% respectively (depending on a variety of factors). There are no major trade-offs with other outcomes such as N2O or CH4 emissions, and there is large scope for increasing their penetration in the UK, although financial and logistical barriers are present. Covering stores also helps to improve safety and increase storage capacity of stores by preventing rainwater incursion. Storage capacity – though not reducing emissions from storage per se - is vital to facilitate appropriate timing and application rates of manure to soils (i.e. to avoid spreading too much, or in conditions where Nr losses will be high). Currently one-fifth of farms only have 1-3 months capacity, below the 6 months recommended which can make it difficult for farmers to follow application restrictions of the Farming Rules for Water.

Anaerobic digestion (AD) and mechanical solid-liquid separation (SLS) of slurry are two key manure processing measures. The main benefit of these measures for Nr emissions is to help to improve the utility of nitrogen in manure, and thereby replace synthetic fertilisers, but the net Nr impact depends on low-emission storage being available. Digestate and the liquid fraction of separated slurry are low in dry matter content and high in mineralised ammonium salts, which are quickly absorbed into the soil and taken up by plants. AD also has GHG mitigation benefits by capturing methane emissions, then using this to displace fossil gas.

AD can make use of the solid fraction from SLS, and both methods can also be combined with other nutrient stripping / manure processing measures such as ammonia stripping to help create more useful fertiliser products. For both AD and SLS there is considerable scope for increased uptake in the UK, but there are financial and other barriers. For AD, there is also the risk of energy crops being favoured as a feedstock (with associated Nr emissions), if incentives are not structured to prioritise use of manure and waste.

For waste management, anaerobic digestion of cattle manure has the greatest GHG abatement potential and a medium to large magnitude effect on reducing NH3, NO3, N2O and total N losses, no direct impact on biodiversity and a small to medium effect on N2O emissions. However, currently less than 10% of manure is treated in this way in the UK. The feedstocks used for anaerobic digestion are also a crucial factor e.g., the use of maize where the crop is fertilized has been linked to nitrate pollution of rivers as it is usually harvested late in the year when soils are often wet and susceptible to run-off, particularly on slopes. To counteract this potential for perverse environmental consequences, in Germany and Denmark, a minimum manure quota is required to qualify for the feed-in tariff available on the electricity or gas generated (FR Section 2.3).

2.3.3 KEY MEASURES FOR REDUCING NITROGEN LOSSES FROM SOILS

As described above, measures to reduce N losses to the environment need to ensure that more N becomes available to meet crop and animal needs and the risk of pollution swapping needs to be avoided. Key tools to achieve this for soils are Nutrient Management Plans, precision application and placement of fertilisers, low emission spreading techniques, different types of fertiliser and the use of inhibitors to reduce N transformations to polluting forms. Where reductions in synthetic fertiliser application are achieved, this brings a co-benefit of reduced GHG emissions from fertiliser manufacture.

Creation and implementation of nutrient management plans is one of the linchpins of overall Nr emission reductions, as they enable reduction in overall N inputs by matching applications to crop needs. They depend on adequate skills and access to manure and soil testing. There is likely considerable scope to improve implementation and enforcement in the UK. For livestock farmers, an important pre-requisite for reducing application rates is the availability of enough land to spread stored manure onto or, failing that, an alternative means of exporting manure from the farm.

Variable-rate application techniques allow potentially lower total N application overall but have high technological and initial financial investment and studies have found relatively small benefits for Nr emissions.

In contrast, low-emission manure spreading techniques (injection, band spreading, rapid incorporation of solid manure), deep placement of mineral fertiliser, swapping urea for other N compounds, and use of urease inhibitors have all been shown to be highly effective (up to 90% reductions in NH3 emissions). There is still considerable potential for increased uptake of these measures in the UK. With reduced NH3 losses, there is some potential for pollutant-swapping with higher N2O emissions and nitrate leaching. This can be mitigated by adjusting application rates down appropriately, but this depends on a proper nutrient management plan.

2.3.4 KEY MEASURES FOR REDUCING NITROGEN LOSSES FROM CROP AND LAND USE

Permanent vegetation in the landscape, in the form of trees, hedgerows, constructed wetlands and fertilised or unfertilised grassland increases Nr retention in soils and plant biomass, and can intercept flows of leached Nr in the soil, or NH3 into the air around point sources. This can help to protect sensitive areas from the effect of N deposition. In general, these measures are also very beneficial for a range of other outcomes, such as carbon storage in biomass and soil, local biodiversity, use of woody biomass (e.g. from agroforestry) for bioenergy, as well as mobilising P and K from deep soil horizons. Potential trade-offs include possible indirect land use change caused by taking land out of production, and for constructed wetlands an increase in CH4 emissions.

Use of cover and catch crops – planted to reduce soil erosion and prevent N leaching during seasons where crops are not growing – can also be effective. They provide additional organic matter input to the soil, can serve to build fertility if N-fixing plants are used, help suppress weeds and provide additional grazing in mixed farms. However, timing of incorporation is important to prevent unwanted Nr losses.

2.3.5 SYSTEM MEASURES

Mixed farming combines livestock and arable agriculture either on the same farm or within the same landscape, providing opportunities to close nutrient cycles at a local scale and increase landscape-scale nitrogen use efficiency. This reduces the need for synthetic fertiliser application. In recent decades mixed farming has declined, and there are barriers to reversing this trend including a lack of local infrastructure for minority activities, and real or perceived poor suitability of manure for some fertilisation requirements and reluctance to use it on the part of arable farmers.

At larger scales nutrient cycles can be closed through redistribution of manure (or manure nutrients) over longer distances from high concentrations of livestock production to mainly arable areas (which also produce livestock feed), though there are practical and economic limits to how far manure can be transported.

A different kind of system-level measure would be to increase the quantity of food grown in “controlled environment” agriculture, including greenhouses and vertical farming. These are semi-closed systems which can recycle nutrients to bring very high nitrogen use efficiency, as well as low water use and high potential for biocontrol. However, currently there is a high fossil energy footprint (for heating and lighting), and very high capital costs.

2.4 REDUCING NITROGEN IMPACT OF IMPORTED FOOD AND FEED

The UK has a significant overseas Nr emissions footprint through imported food and animal feed. Broadly, this footprint can be reduced by: i) lowering demand for imported food and feed; and ii) reducing the Nr emissions intensity of overseas production.

Dietary shift away from livestock products would substantially reduce the amount of animal feed imported, and therefore the UK’s overseas nitrogen footprint. Reducing food waste would likewise reduce overall demand for food and feed.

Aside from reducing overall demand for food and feed, increasing demand for domestic produce to replace imports is another option. This would help to increase circularity of nitrogen use, as it is easier to close nutrient loops within the UK than when trading with other countries. For food this could be achieved through more seasonal eating or increasing controlled environment agriculture to provide fresh produce year-round. For animal feed, increased production of grain legumes in the UK could replace some imports of soy. Grain legumes can form an important part of organic crop rotations, but producing larger quantities in the UK than is implied by this role in crop rotations would need to be contingent on demonstrating a lower environmental footprint than imported protein crops, including from displacement of other crops. Alternative sources of protein - including from microbial and insect sources – can also help to reduce demand for imported soy. These are especially beneficial where they exploit waste or non-human edible food.

To reduce N losses associated with overseas production, the UK could influence production practices via supermarket sustainability standards and certification schemes, encouraging foreign governments to sign up to international agreements (such as the UN Colombo Declaration to halve nitrogen waste by 2030), and by including nitrogen-related sustainability criteria in free trade agreements. These measures also play a part in protecting UK farmers from being undercut by imported food and feed, if measures introduced in the UK were to increase the cost of production.

2.5 ALIGNMENT OF MEASURES WITH AGROECOLOGY

Around the world agriculture is starting to embrace more agroecological approaches, sometimes referred to as Conservation Agriculture or Regenerative Agricultural practices. Broadly speaking, the main dietary changes and reductions in food waste advocated to reduce nitrogen waste will also create the space required for extensive, low-input and lower-yielding agriculture to be adopted at scale. However, the choice of which kinds of animal products are the focus of the largest reductions in consumption is important. A large reduction in consumption of beef, dairy and lamb may hinder an agro-ecological transition, as ruminant grazing is a crucial element of organic systems for nutrient cycling, but to maintain livestock numbers demand for their products needs to be high enough. Therefore, greater reductions in pork and poultry consumption are most compatible with an agro-ecological transition.

For on-farm measures the situation is mixed. A large number of the measures identified above are indeed part of an agroecological (e.g. organic) system, so can help normalise and facilitate a transition. These include measures to increase biological N fixation using legumes, increase the value of manure processing, reducing N inputs through low-emission manure management and fertiliser spreading techniques, increasing grazing time, use of catch/cover crops and establishment of more permanent non-crop vegetation in the landscape.

In other cases, measures are not relevant to agroecological systems, will not facilitate the transition, are banned under organic rules, or may distract focus. This group includes use of controlled low-protein diets for all livestock, measures to reduce emission from intensive housing, chemical urease/nitrification inhibitors, indoor horticulture, and slurry acidification.

2.6 REDUCING EMISSIONS FROM COMBUSTION SOURCES

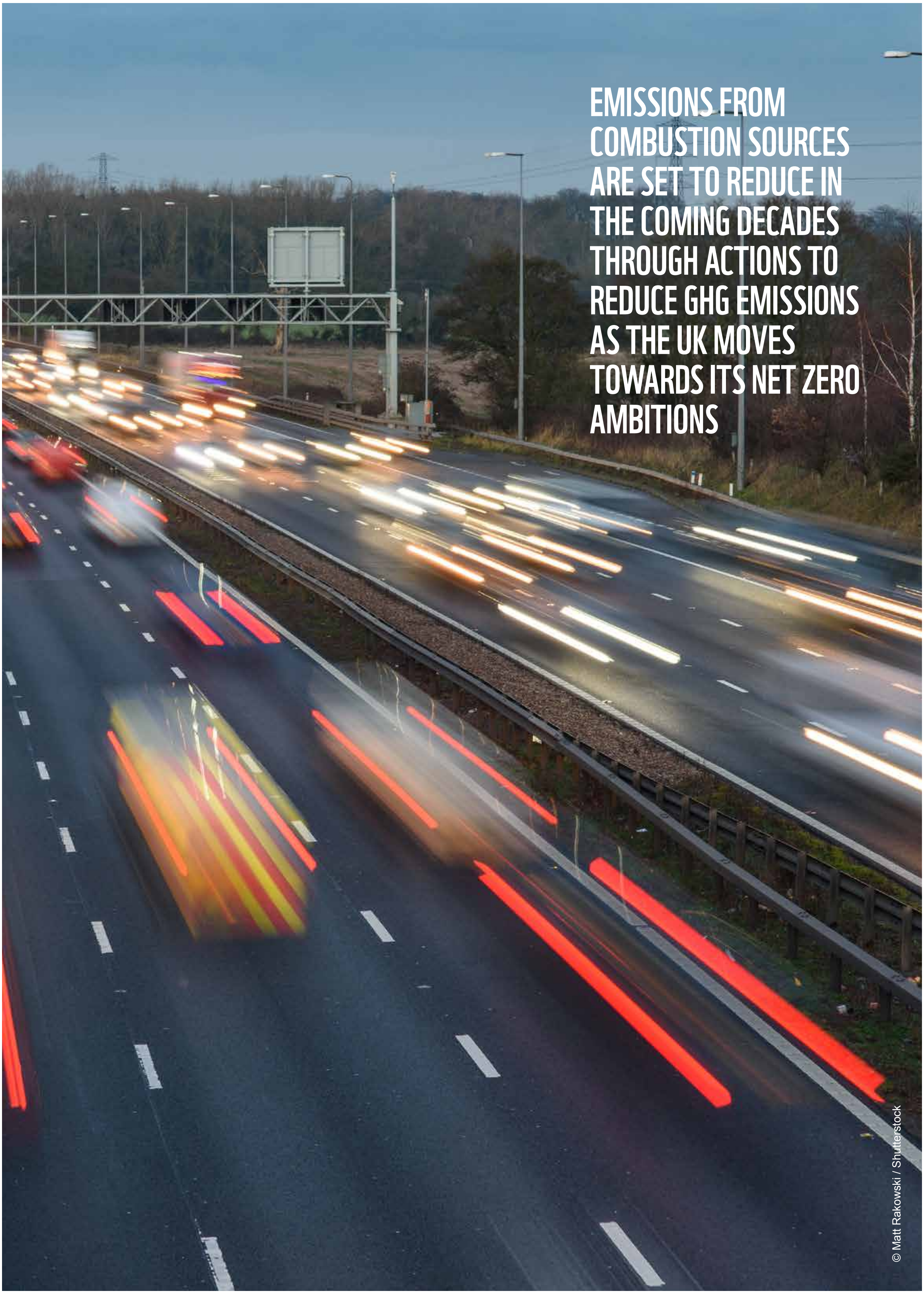
Emissions from combustion sources are set to reduce in the coming decades through actions to reduce GHG emissions as the UK moves towards its Net Zero ambitions, and as a way of improving air quality on a more localised scale. The primary form of Nr emitted from combustion sources is NOx, with the transport and industrial combustion sectors the most important sectors of emissions in 2019.

Historically, mitigation measures to reduce emissions of NOx from road transport have focused on improving engine combustion conditions and exhaust filter technology in the vehicle fleet. For example, the European Union began adopting EURO standards in 1993, which requires all new vehicles to meet emissions standards for a range of pollutants, including NOx. These standards have become progressively more stringent over time and have led a widespread reduction of emissions of NOx. UK policy includes strategies to retrofit and upgrade parts of the vehicle fleet to accelerate to uptake of newer vehicles and technologies that meet the latest EURO standards. However, it should be noted that whilst reducing NOx emissions, the N in the fuel and the air can instead be released as other forms of Nr (namely N2O and NH3) which would still have an impact on the N cycle. As fuel combustion requires the use of an air/fuel combination, and results in the oxidation of N in both the air and the fuel, all fuel combustion will continue to emit forms of Nr to some degree, which cannot then be recovered. As a result, mitigation options that do not require fuel combustion would have the most impact on reducing emissions of Nr.

The focus on decarbonisation in the road transport sector has led to the continued penetration of electric vehicles (EVs) into the road fleet. As EVs do not burn fuel, they do not emit NOx, NH3, or N2O from their tailpipes, but if electricity is generated from a fuel that produces high levels of Nr, then this will not represent a true saving in Nr emissions. It is clear that as the UK moves towards Net Zero, the share of energy produced through non-thermal sources, such as renewable energy, will increase and emissions will be reduced. The UK is supporting the uptake of EVs, through a number of schemes and financial incentives announced within their Road to Zero strategy.

The same principles hold true for other forms of transport, including marine traffic which contributes a significant amount of NOx emissions to the overall UK inventory. However, as the technology currently used in EVs is not currently scalable for ships, the mitigation options for the marine sector are less clear. Standards introduced by the International Maritime Organisation (IMO) have required the reduction of NOx emissions from vessel tailpipes, and like EURO standards are being progressively strengthened for the international marine sector. However, a recent switch of focus towards decarbonisation of the shipping sector may have a negative impact on the Nr cycle. One of the favoured candidate technologies to enable rapid decarbonisation of the international shipping sector is the combustion of NH3, which when burned would release NOx and N2O that will largely be unrecoverable and so reduce the efficiency of nitrogen use. Other alternatives for shipping exist, including fuel cell systems, but no non-thermal alternative technology has reached the stage of readiness required for widespread introduction into the shipping fleet.

Emissions from industrial combustion and power stations have historically been regulated under the Industrial Emissions Directive (IED), an EU Directive that came into force in 2011 and was transposed into UK law. In general, as with other forms of fuel combustion, many mitigation and abatement techniques involve improving the conditions of combustion and after treatment systems. The general shift away from the use of fossil fuels, however, is the most promising route to reducing emissions of Nr from the sector. The UK Renewable Energy Roadmap (2011) outlined the UK's ambition to increase renewable capacity to 2020 in response to EU-wide policy, and in 2019, data shows that renewables contributed 35% of the overall electricity generated in the UK (BEIS, 2020). This seems set to yet increase further, as the UK ramps up its commitment to decarbonisation under the Paris Agreement.



EMISSIONS FROM COMBUSTION SOURCES ARE SET TO REDUCE IN THE COMING DECADES THROUGH ACTIONS TO REDUCE GHG EMISSIONS AS THE UK MOVES TOWARDS ITS NET ZERO AMBITIONS

SECTION 3:

IDENTIFYING THE POLICY/REGULATORY FRAMEWORKS IN A FOUR-COUNTRY CONTEXT

3.1 INTERNATIONAL AND NATIONAL PROGRESS WITH NITROGEN POLICY

International science to policy mechanisms for N are evolving significantly, especially in the last ten years, with international inter-governmental agreements/resolutions to reduce N losses to the environment at global level (UN Colombo Declaration) and regional level (e.g. European Green Deal Farm to Fork Strategy). A focus on reducing N losses (targeting the most inefficient N uses) may be a fairer way of promoting action on N waste and losses to the environment than a focus on increased Nitrogen Use Efficiency (NUE) across the board, which requires even the most efficient users to improve. It has been estimated that halving nitrogen waste by 2030 using integrated approaches could save US$100 billion annually, contributing to post-coronavirus disease 2019 (COVID-19) economic recovery and multiple SDGs.

Even in countries that have made good progress on nitrogen (e.g. Denmark and the Netherlands) significant problems remain and there is a strong requirement for more joined up approaches, with a systems approach including integration of environmental protection schemes across sectors and a better utilization of nitrogen in the whole production chain. For example, in the Netherlands a measure was introduced to bring the motorway speed down from 130km to 100km per hour and the nitrogen saved through this enabled the building of 75,000 homes. This is a good example of the type of tradeoffs that may be required to meet legally binding N reduction targets.

© Red Charlie / Unsplash

Experience in European countries where there has been unrest over agricultural policy in recent years, notably the Netherlands, France, Germany, Italy and Spain, has shown how divisive the nitrogen issue can be, although the underlying causes of unrest are complex and can also be related to other issues such as pesticide use, climate policy on herd numbers and trade issues. This means that any new policy developments need to be perceived as fair and be based on consultations with key stakeholders. In practice, this will entail spreading the responsibility for N losses across society as a whole and the food supply chain in particular. Such a process will require critical framing and co-design from the bottom up to avoid the type of negative reaction experienced in the Netherlands to the recent call for transformation of the land use in rural areas. There is also considerable knowledge from Europe on livestock feed and manure management measures in advisory (e.g. Denmark) and voluntary (e.g. Sweden) settings that may be applicable to the different N management needs found in UK devolved nations.

Headline indicators such as the Planetary Boundary or Footprint for N and Integrated National Targets for Nitrogen (INTN), such as that being developed in Germany, are potentially useful to increase awareness and provide a science to policy framework for connecting N impacts across global to local scales. International experience shows that integrated approaches are required at all scales (e.g. from UK and devolved nation, to sub-national, catchment and farm scales), with N targets that acknowledge the inter-linkages between key impacts and the different sensitivities of environmental receptors.

A balanced, spatially explicit and integrated approach is required that considers the interactions between the main impacts of N in the environment. This could be facilitated by **commissioning national nitrogen budgets as a dynamic policy tool (similar to carbon budgets) to provide evidence of current nitrogen flows and impacts, to inform target-setting for reducing pollution and to shape future policy and strategy.**

3.2 THE ROLE AND DESIGN OF FISCAL MEASURES FOR NITROGEN

Fiscal drivers such as levies or trading schemes are widely used to change behaviour and influence markets, including to benefit the environment. However, such measures proposed on N fertilisers in other countries are highly controversial and often perceived as punitive by farmers. An effective fiscal system must be carefully designed and transparent about its purpose. Exemplary cases include tradable quotas, emission taxes, incentives and inducements, and subsidies which in some cases have resulted in companies implementing emission measures ahead of the introduction of the fiscal driver. Any realistic regulation should consider differentiation to avoid unacceptable disadvantage for some groups. Credit systems could facilitate the fair distribution of abatement costs across all stakeholders. Where governments regulate for clean air and water and healthy soil by establishing pollution standards they need to ensure the fair sharing of costs and benefits among farmers, suppliers, processors, retailers, consumers, and financial organizations.

The literature also shows that measures such as market-based taxes on nitrogen and the set-aside of agricultural land from agricultural production as an obligatory command and control policy instrument to reduce pollution, may show relatively low ecological effectiveness and can be less cost efficient than, for example, the restoration of peatland in terms of GHG reductions. In addition, the nitrogen tax brings high relative income loss for intensive crop producing areas, so would require regional adjustment to avoid unacceptable disadvantage for regional producers. This highlights the problem of a singular focus, for example on an issue such as climate change, and shows that a more holistic analysis might raise the profile of N and potentially avoid displacement/offshoring risks, as measures such as peat restoration are always going to achieve a range of benefits for carbon sequestration, soil loss and biodiversity at national level.

This report recommends that, in parallel with urgent action to take forward our other policy recommendations, the UK Government commissions an independent economic assessment of the costs and benefits of N pollution, considering options for action. Such an assessment should consider the range of possible fiscal measures in detail and make recommendations to government, e.g. a nitrogen credit system combined with current subsidies and/or a levy on N fertiliser use whereby the income generated would be ring-fenced to support the adoption of nitrogen-efficient sustainable farming practices that deliver public goods (FR Section 3.2).

3.3 NITROGEN BALANCE SHEETS AND BUDGETS

National nitrogen balance sheets and budgets (terms used interchangeably) are an enabling tool, presenting a picture of nitrogen flows into and out of a country. They can be used to inform and motivate the setting of priorities for reducing nitrogen pollution. They are being used in Scotland to underpin future action to reduce overall nitrogen use.

The approach under development in Scotland is a requirement of the Climate Change Act 2019 as a mechanism for reaching net zero emissions by 2045. The Scottish methodology is replicable in other countries and equivalent datasets are available. However, the Scottish approach is still in development and significant challenges remain in quantifying important nitrogen flows or disaggregating data within economic sectors.

Collaboration across the UK and internationally would help to develop national nitrogen budgets which provide an effective basis for policy and legislation and are compatible with UN Economic Commission for Europe (UNECE) Guidance.

A nitrogen budget for each country, as part of a package of climate solutions, and potentially sitting within a wider international nitrogen budget, could feature the following:

- Each country's nitrogen budget will vary, depending on a range of factors, but food and agriculture will feature prominently across the UK as the dominant source of excess nitrogen to be addressed;
- Reducing excess nitrogen will deliver co-benefits for climate adaptation as well as mitigation as part of the package of climate solutions, and these co-benefits should be highlighted and pursued in each country;
- Nitrogen budgets to inform and establish policy for progressive emissions reduction, as a component of carbon dioxide (equivalence) budgets – not just quantifying current or historic nitrogen flows;
- UK Government and devolved authorities to engage with the UN Environment Programme's (UNEP's) Towards International Nitrogen Management System (INMS) project to assess the suitability of available UK data sources for feeding into the international assessment.

THE CURRENT ENVIRONMENT BILL REPRESENTS GOOD PROGRESS, BUT HAS A NUMBER OF GAPS THAT MUST BE ADDRESSED

3.4 EXISTING UK AND DEVOLVED NATIONS POLICY LANDSCAPE AND POLICY OPTIONS

The key EU and international legal mechanisms set out below apply to the whole UK through primary and secondary legislation in each country, with some additional domestic regulation. However, certain binding targets (such as National Emissions Ceilings Directive (NECD) targets) have not been transposed into each country's legislation. This report considered the following:

- **Water quality** regulation is the most highly developed area of nitrogen regulation based on EU Directives. This provides limited benefits for controlling NH_3 and N_2O emissions. However, this regulation has not been successful in reducing nitrate levels significantly, due to insufficient advisory and enforcement resources to drive compliance.
- **Air quality regulation** (for public health) and climate regulation (as a co-benefit of action to reduce CO_2) have been effective in reducing NO_x emissions but as yet, there is very little direct regulation controlling NH_3 emissions, despite legally-binding NECD targets.
- **The Habitats Directive** and national conservation designations (SSSIs/ASSIs) entail certain limits on air and water pollution from new development affecting habitats and species but these are not well-respected and dependent on decisions of local planning authorities. The permitting and planning systems have not been successful in preventing the harmful impacts of excess nitrogen on biodiversity, ecosystems and public health.
- **Emerging climate targets and legislation** have the potential to trigger more effective regulation of greenhouse gas emissions, leading to direct (N_2O) and indirect reductions of excess nitrogen (including NO_x, NH_3 and NO_3).

A lack of integrated regulation (and the guidance accompanying it) has led to a siloed and piecemeal approach to nitrogen management and regulation, making compliance and enforcement more complex for private actors and public agencies. This report recommends that this situation is addressed by analysing the least integrated/effective parts of N management and regulation and replacing them with something more coherent. **The UK's exit from the EU** means that environmental and agricultural regulation is in a period of immense change and has left significant regulatory and enforcement gaps in terms of governance, principles and binding targets.

3.5 OPTIONS FOR INTEGRATED APPROACHES AND TARGETS

As policy and regulatory frameworks move towards more integrated approaches required to tackle the nitrogen issue effectively, a major new development in recent years is the push towards Net Zero and carbon neutrality in all sectors under the Paris Agreement, and in this regard agricultural practices in particular have a key part to play as society moves in this direction.

The assumptions on how agricultural management and production practices may change in the future in the UK's Sixth Carbon Budget, especially related to land release, are ambitious and warrant a more comprehensive analysis than currently exists, especially in the context of N use and dietary change. This report shows that **efforts to achieve Net Zero have considerable implications for reductions of N losses to the environment (including N_2O, NO_x, NH_3 and NO_3), and N use efficiency, related to the consumption and production of food products** in the agricultural sector in the UK and its devolved nations.

A balanced, spatially explicit and integrated approach is required that considers the interactions between the main impacts of N in the environment, on Water, Air, GHGs, Ecosystems/biodiversity and Soils (e.g. similar to Germany's integrated national target for nitrogen), which takes a systems approach to analysing associated co-benefits and tradeoffs. Evidence gathered by this report shows that there are significant co-benefits to be obtained through integrated nutrient management, GHG abatement and carbon sequestration measures.

3.6 PRINCIPLES FOR ACTION ON NITROGEN AND POLICY RECOMMENDATIONS

Below, we first establish a set of principles for action on nitrogen issues (FR Section 3.6.1), followed by a set of policy recommendations for UK Government actions at international level (FR Section 3.6.2), national actions by devolved administrations and UK Government for England (FR Section 3.6.3), agriculture policy actions (FR Section 3.6.4), and biodiversity policy actions (FR Section 3.6.5). Finally, we list recommendations for further research to improve the availability of more detailed information on how nitrogen flows link to targets for the protection of human health, the climate and the environment (FR Section 3.6.6).

3.6.1 PRINCIPLES OF ACTION:

- Adopt a full-cycle approach to quantifying nitrogen use and losses, including transboundary imports and exports embedded in food, feed and fertiliser, as well as transboundary pollution via air and water;
- Integrate action to reduce all forms of nitrogen losses to the environment, maximising the co-benefits and minimising trade-offs;
- Integrate action to reduce nitrogen losses with action to reduce environmental losses of carbon, methane, phosphorus, pesticides and other forms of pollution;
- Action should be taken at every stage of the food supply chain from primary production to consumers in order to share responsibility for reducing waste and negative impacts in an equitable way;
- Quantify and raise awareness of how reduction of nitrogen losses across **W**ater, **A**ir, **G**HG, **E**cosystems/Biodiversity and **S**oils (WAGES) contributes to achieving multiple Sustainable Development Goals, benefiting people, climate and nature;
- Use these co-benefits to make the case for new policy, legislation and investment. For example:
    - action to reduce ammonia emissions and fine particulate matter (PM) for public health provides powerful leverage for action which will also reduce greenhouse gas emissions and biodiversity loss;
    - a focus on N2O and climate impacts alone may not provide sufficient justification for action; demonstrating the co-benefits for public health, water quality and biodiversity (from related reductions in NH3 emissions and nitrate pollution) may provide this.
- Optimise available resources to focus on major nitrogen flows and priorities for action to avoid delay and use of disproportionate resource on items of lesser importance ("don't let the perfect be the enemy of the good").
- Government action needs to be a package of legislation, compliance and enforcement, financial support, fiscal measures, collaboration with industry, and specialist advice to farmers and other stakeholders. A mix of regulation and advice is required that is easily understood and applied, and which aligns financial support to achievement of targets/ regulations (above minimum expected baseline).

3.6.2 UK GOVERNMENT ACTIONS AT INTERNATIONAL LEVEL

- Provide active support for the **UN Inter-convention Nitrogen Coordination Mechanism** (INCOM) and identify a UK Government National Focal Point for the UNEP Nitrogen Working Group under the UNEP Committee of Permanent Representatives.
- Support delivery of the **UN Environment Assembly - 4 Resolution** on Sustainable Nitrogen Management (UNEP/EA.4/Res.14).
- **Collaborate through INCOM on developing nitrogen budgets** as a dynamic policy tool at country and international levels. This should encourage mutual learning between experience of carbon and nitrogen budgets and improved literacy in interpreting the policy implications of nitrogen budgets, and a mechanism for national governments to report their nitrogen budgets (through UNEP's INMS and eventually through INCOM).
- Assess the **suitability of available UK data sources** for feeding into the international nitrogen assessment and nitrogen budgeting.
- Support the **#Nitrogen4NetZero** campaign and promote global action on nitrogen into the outcomes of the **UN Framework Convention on Climate Change CoP26 and 27.**
- Ensure that nitrogen pollution is addressed as key driver of biodiversity loss at the **Convention on Biological Diversity** (**CBD) CoP15** and as part of the **post-2020 Global Biodiversity Framework.**
- Support the establishment of global and national NOx and NH3 emissions reduction goals for 2030, 2040 and 2050 through the **UNECE Gothenburg Protocol** review process. This should include accounting for NOx emissions from soils in the Protocol's inventories.
- Continue to provide active support for the **Towards INMS** project to ensure that the INMS is established on a sustainable basis within the UNEP system.

© Paul Adepoju / Shutterstock

3.6.3 NATIONAL ACTIONS BY DEVOLVED ADMINISTRATION & UK GOVERNMENT FOR ENGLAND

- Establish **legally-binding targets** for 2030, 2040 and 2050 for reducing all forms of nitrogen emissions to air and losses to water. These could support the global target of halving nitrogen waste by 2030 and be linked to national environmental policy targets for air, water and habitat quality, as well as GHG mitigation.
- Establish an **integrated and comprehensive strategy** for reducing nitrogen pollution through policy and legislation across government. This could support delivery of existing goals and targets, including for net zero GHG emissions, sustainable development, air and water quality and biodiversity, maximising co-benefits and minimising trade-offs. It should include mechanisms for monitoring, reporting and review.
- Establish a **cross-government working group** with representatives from relevant departments and teams to develop and deliver the national nitrogen strategy.
- Commission **national nitrogen budgets** as a dynamic policy tool (similar to carbon budgets) to provide evidence of current nitrogen flows and impacts, to inform target-setting for reducing pollution and to shape future policy and strategy.
- Commission **independent analysis of the economic costs and benefits** of reducing nitrogen pollution at a national level and for farm businesses, exploring how a circular economy approach to resource use and fiscal measures can be applied to nitrogen resource management fairly and effectively.
- Initiate further research and programmes of action on **awareness-raising and stakeholder engagement** on nitrogen. For example, public information on air quality often contains little or no reference to ammonia emissions or the impacts of air pollution on biodiversity. Increased awareness will also help build understanding of the importance of this issue within the food manufacturing and retail sectors, to help share the costs of action throughout the food supply chain and across public and private sectors.
- The full range of devolved and reserved policy levers must be used together (as suggested by the UK Climate Change Committee). Delivering the transition in the devolved nations will require effective collaboration between the devolved and UK governments, and a strong policy framework that works across all levels of government. For example, in Wales, policy areas relevant to decarbonisation that are partially or fully devolved to the Welsh Government include agriculture and land use, planning, transport, energy efficiency for new-builds, and waste.

3.6.4 AGRICULTURE POLICY ACTIONS

- Policy and regulation to reduce nitrogen losses from agriculture should be consistent with the transition to more **environmentally-sustainable land management,** taking an integrated approach to improving air, water and soil quality, biodiversity and ecosystems. A 'land-sharing' approach through, for example, more extensive livestock grazing on permanent semi-natural grasslands and less intensive field crop production is more consistent with this than the 'land-sparing'/agricultural intensification approach.
- Agricultural policy actions must be integrated with a **national food and farming strategy** to ensure that sustainable food producers are supported and protected from unfair practices and trading rules throughout the supply chain.
- A **package** of legislation, financial support, fiscal measures, collaboration with industry, and specialist advice should be devised as appropriate to each devolved nation's agricultural system, including:
    - Integrated **baseline regulation** applicable to all farm businesses and other land managers. This should:
        - cover nitrogen losses to air (inc. GHGs) and water;
        - require nutrient management planning and use of low-emission techniques by all farm businesses;
        - require the use of low-emission livestock housing, slurry stores and other infrastructure on all new farm developments and (phased in over time) for existing farm operations;
    - Strengthened **environmental permitting** system for large and indoor livestock units and slurry/waste contractors including:
        - Regulation of wastes from intensive operations;
        - Lower thresholds for intensive pigs and poultry units;
        - Introduction of permit requirements for intensive beef and dairy units;
        - Introduction of permit requirements for slurry contractors (following the precedent from transport providers and emissions standards).
    - Strengthened **spatial planning system** for new developments including on farms to ensure:
        - full compliance with all relevant legislation and regulation;
        - alignment with local development plans;
        - high standards of nutrient management planning and waste management planning;
        - assessment and control of cumulative impacts of pollution sources within the local area are taken into account;
        - protection of biodiversity, ecosystems and public health & wellbeing.
    - Integrated, tailored **advice & training** to farm businesses on nutrient management planning to reduce nitrogen losses to air and water, and improve soil health and biodiversity.
        - **Adequate government funding** and political support to ensure effective compliance and enforcement with regulation, to administer relevant schemes and to provide advice and training to local planning authorities, farmers and other stakeholders.

- **Financial support** from government and private sources (e.g. water companies) including:
  - payment for environmental services above and beyond regulatory requirements, such as the Environmental Land Management scheme in England and Sustainable Farming Scheme in Wales;
  - grants for capital costs, such as precision technology, low-emission spreading equipment and more efficient livestock housing and fertiliser storage (e.g. the Slurry Investment Scheme in England).
- **Fiscal measures** – such as a tax or levy on artificial N fertiliser

Such measures should be explored in an independent economic analysis as outlined above for national policy actions (Section 3.2).

3.6.5 BIODIVERSITY POLICY ACTIONS

- Address the impacts of nitrogen pollution by air and water at a strategic level in **biodiversity policy** and strengthen the capacity of statutory nature conservation and environmental agencies to take action.
- Introduce a **targeted site-based programme** to reduce emissions close to the most sensitive and vulnerable designated sites and other sensitive priority habitats, such as Site Nitrogen Action Plans and Diffuse Water Pollution Plans in England and Wales which have been developed at a small number of Special Areas of Conservation (SACs) to date.
- Extend and adapt the Local Air Quality Management (LAQM) system and measures such as Clean Air Zones to reduce ammonia emissions and address the impacts of air pollution on local biodiversity and ecosystems, as well as public health.
- Strengthen **environmental monitoring and development control** for pollution sources, in particular those close to sensitive habitats. For example, there is currently no information about where, when or how much slurry, manure or litter is stored or spread on land near sensitive habitats.
- Integrate available data on atmospheric nitrogen concentration, deposition/diffuse pollution levels and impacts into the monitoring, assessment and management of sensitive habitats in **designated sites and other sensitive priority habitats.** This should then inform and enable site managers to:
  - Identify and monitor the sources and impacts of atmospheric and waterborne nitrogen input to the site;
    - Engage local land managers to help reduce nitrogen pollution through Site Nitrogen Action Plans;
  - Manage sensitive habitats (SNAPS) to reduce the impacts on biodiversity, such as by:
    - controlling dominant species that are adapted to higher nitrogen levels;
    - removing excess nitrogen from the system using techniques that avoid trade-offs;
  - Plan tree-planting schemes to help intercept nitrogen emissions before they reach species-rich habitats.
  - Control emissions from heavily-stocked grazing of cattle and evaluate the impact of grazing ruminants on land close to sensitive habitats including SSSIs.
- **Commission research** into the impacts of nitrogen pollution on biodiversity and ecosystems at a UK/country level, including ecosystem recovery following reduction of pollution and the impacts of terrestrial pollution on taxa other than wild plants and fungi, such as pollinators and birds.

3.6.6 RECOMMENDATIONS FOR FUTURE RESEARCH

Considering the principles for action and policy recommendations above, studies are needed to:

- analyse the least integrated/effective parts of nitrogen management and regulation in the UK and devolved nations and make recommendations to replace them with something more coherent, maximising the co-benefits and minimising trade-offs;
- conduct a full-cycle approach to quantifying nitrogen use and losses, including transboundary imports and exports embedded in food, feed and fertiliser, as well as transboundary pollution via air and water;
- develop nitrogen budgets linked to impact thresholds to quantify and raise awareness of how reduction of nitrogen losses across Water, Air, GHG, Ecosystems/Biodiversity and Soils (WAGES) contributes to achieving multiple Sustainable Development Goals, benefiting people, climate and nature;
- identify the most likely suite of low carbon measures that will be taken up by farmers in the UK and devolved nations and assess qualitatively and quantitatively (where possible) the full chain implications for N losses and the required N management guidance, especially for manure management;
- conduct an independent economic assessment of the costs and benefits of N pollution, including circular economy considerations and options for action. Such an assessment should consider the range of possible fiscal measures in detail and make recommendations to government that spreads responsibility fairly across supply chains, including incentives for farmers to use more innovative practices;
- assess integrated actions to reduce nitrogen losses with action to reduce environmental losses of carbon, methane, phosphorus, pesticides and other forms of pollution for major farming types while protecting biodiversity, considering dependencies, including N, P, pesticides etc and housing gains lost in the field when manure is applied;
- Involve farmers in enhancing knowledge on how farm businesses can be made more environmentally and financially viable and disseminate knowledge widely using peer-to-peer networks. Including developing guidance on how to minimize losses in different conditions and implications of moving to more agro-ecological practices.

For a future where people and nature thrive | wwf.org.uk

WWF