A Nitrogen Budget for Scotland

Nourish Scotland is calling on the Scottish Government to develop a nitrogen budget by 2020. This briefing presents the issues related to nitrogen and explains how a nitrogen budget could help tackle nitrogen pollution.

Contents:

The new Climate Change Bill is a key opportunity to ground this policy in law. Nitrous oxide (N_2O) - a nitrogen-based greenhouse gas - accounted for 7.7% of Scotland's net greenhouse gas emissions in 2015[1]. These emissions are mostly related to fertiliser use and could be drastically cut with highly cost-efficient measures informed by a nitrogen (N) budget. Nitrogen is also a major air and water pollutant harmful to human health and natural ecosystems.

Scotland's nitrogen budget should create a clear picture of all key flows of nitrogen and indicate where major losses and inefficiencies occur. The Scottish Government should then use the N budget as a tool to develop dated targets and adopt a set of specific measures to improve nitrogen use efficiency in Scotland and reduce pollution of nitrogen in all its forms, including N_2O emissions.

Back to basics

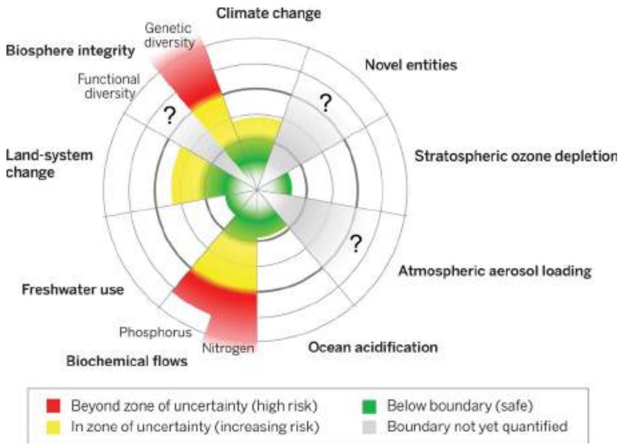
Crops need nitrogen (N) and phosphorus (P) – two macronutrients – to grow. Although N makes up most of our atmosphere, most plants are not able to capture it, and although P is stored in soils, plants can only use if the right micro-organisms are present in the soil to process it for them.

Traditionally, we supplied N and P to our crops by incorporating legumes into crop rotations and recycling the nutrients available in animal manures and other organic materials. Legumes are able to utilise the unreactive nitrogen (N_2) in the air through biological N fixation: they capture N_2 and convert it to its reactive form, N_r, which they leave in the soils, making it available for plant growth.

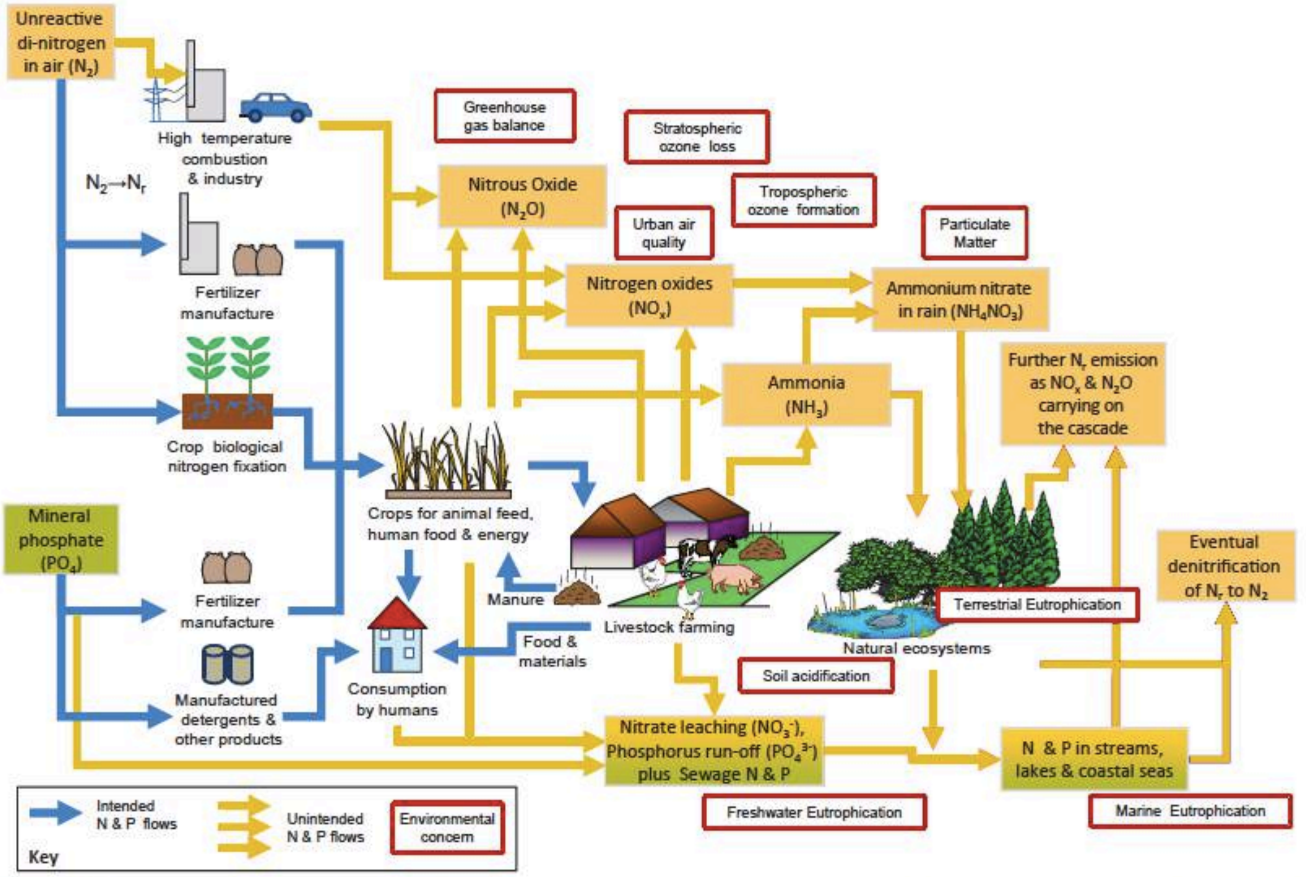
In the last century, we started to manufacture N fertiliser through the Haber-Bosch process and to convert mined phosphate rock into a soluble form which is immediately available to plants. This led the way for the so-called green revolution, with phenomenal yield increases and… proportionally phenomenal pollution.

Pollution sources and scale

The 9 planetary boundaries illustrate the scale of the most pressing environmental concerns. They show how far we have pushed the limits of what our planet can endure without catastrophic breakdowns. Biochemical flows of N and P have gone far beyond those limits.



Conventional agriculture is responsible for the lion's share of the explosion of N and P flows. Manufactured fertilisers bring new N and P into the system in great quantities. Crops cannot absorb endless quantities of N and P, so excess nutrients applied to fields lead to soil, air and water pollution which is detrimental to ecosystems, climate, and human health. In addition, intensive livestock farming concentrates huge quantities of nutrients as animal manures in often relatively small "hotspot" areas. A picture is worth a thousand words, so have a close look at the diagram below (adapted from the European Nitrogen Assessment, 2011).



The blue arrows in the flow diagram indicate the intentional movement of nutrients: we produce fertilisers that farmers apply to their fields and certain crops fix nitrogen, the harvest brings some nutrients direct to our plates and some (the vast majority: 80% of nitrogen![1]) become feed for livestock to produce meat, dairy products and eggs, with a large proportion of N ending up in manure. Manure is applied to fields and the cycle starts again.

However, this cycle of nutrients is only a small part of the picture. At every stage of the food production process and beyond, N and P are lost and leak out to the wider environment, through emissions to the atmosphere and run-off and leaching into watercourses and groundwater. The orange arrows represent those losses.

Applying N fertiliser produces direct emissions of N_20 which contributed **around 7% of Scotland's total GHG emissions** in 2004[1].

Spreading slurry using a **splash plate can lose up to 80% of the available N as ammonia gas** (NH_3) within 12 hours. This application method was banned in Denmark in 2001 but is still widely used in Scotland. Ammonia is an important air pollutant, it is highly damaging to sensitive vegetation and also implicated in human health issues.

Slurry storage also leads to NH_3 emissions, and inadequate storage can lead to N and P run off, polluting groundwater and watercourses. Storing slurry in closed tanks minimises both types of pollution. In Scotland, most farms currently store slurry in open-air tanks or lagoons.

Our soils are saturated with N and P: Scottish agricultural land (excluding rough grazing) had an average **excess of 87 kg N per hectare** in 2015[1]. This compares with average applications of 84 kg/ha of nitrogen in mineral N fertiliser and 88 kg/ha in manure. In other words, half of the N applied in Scotland is being lost to the wider environment.

Diets that are high in animal proteins are the single biggest driver of nitrogen pollution. Intensive livestock farming comes with triple losses of nutrients: in the field to produce feed, in the animal mass that is not consumed, and in the poor management of manure. Only **5% - 40% of the nitrogen in feed (depending on the type of livestock) is converted into food that is consumed by humans**.

Of all N inputs to agriculture globally, only 16% on average is converted to food for human consumption but **only 11% is actually consumed** due to considerable food waste.

Other flows of N and P are relatively minor compared with agricultural activities. 90% of mined phosphorus is used to manufacture fertilisers, and 80% of human N_r production (transformation of N_2 into N_r, excluding crop biological fixation) is for agricultural purposes – the remaining 20% are emissions of NO_x from fossil fuel combustion in industry and transport.

Food waste is not represented in the diagram, yet it generates pollution at many stages. At a most basic level, a large amount of nutrient pollution is caused for nothing. Further, if wastage is not tackled, we need to produce even more food as the global population grows, which can only be done by further intensifying agriculture and/or by expanding the surface of land that's farmed, thereby exacerbating N and P pollution. Finally, food waste that is not properly recycled results in valuable nutrients being lost as they are buried in landfill (mined phosphate is a finite resource with uncertain long-term stocks), with continued pollution as they leak out as ammonia (NH_3), nitrates (NO_3) or methane (CH_4).

Impacts on ecosystems and human health

It may seem counter-intuitive that nutrients, the source of life, can actually cause considerable damage. However, excess may do harm: too many nutrients upset the delicate balance of ecosystems.

Excess phosphorus and nitrogen in water cause eutrophication: plants and algae grow excessively due to the nutrient-rich environment, which can result in dead zones and fish kills. Increased flows of atmospheric N_r mean that more N compounds are deposited from the air onto plants and soils leading to terrestrial eutrophication. Some plant species (nettles, tall grass and reeds, for example) benefit from the increased supply of nutrients and will thrive, crowding other more sensitive native species out. This loss of plant biodiversity negatively impacts species throughout the ecosystem as the primary feed of some species disappears, crowding them out too and creating a domino effect.

N compounds move freely in the atmosphere and can impact anywhere downwind of sources, at short distances and by long-range transport, including on protected areas. Therefore, eutrophication through excess N_r threatens species of high conservation value which are naturally adapted to few nutrients, even far from pollution hotspots.

Human health effects from nitrogen pollution in Scotland are mostly from air pollution, but poor drinking water quality due to N and P pollution can also be an issue.

The main health threatening air pollutants are nitrogen oxides (NO_x - in particular NO_2) emitted by burning fossil fuels in industry and transport. Nitrogen dioxide pollution has been related to decreased lung function, respiratory diseases, asthma, cancer, birth defects and premature death. Agriculture also contributes to poor air quality: ammonia (NH_3) emitted from agricultural activity plays a key role in the formation of airborne fine particulate matter which has been linked with significant increases in cardiovascular disease-related mortality.

Last but not least, nitrogen is a contributor to climate change at two levels. First, in the manufacture of N fertiliser, an energy-intensive process that currently relies on fossil fuels. It is estimated that 2% of global energy needs are for N fertiliser manufacture. Second, nitrous oxide (N_2O – not to be confused with nitrogen dioxide mentioned above) is a powerful greenhouse gas that is emitted when mineral fertiliser and livestock manure are applied to fields and in the longer-term from soils and nutrient-saturated watercourses and wetlands. Climate change is already starting to harm ecosystems and human health as we experience more extreme weather events, temperatures become more extreme in some regions, and a plethora of other environmental impacts threaten to make life on Earth more precarious. Finally, the icing on the cake is that nitrous oxide is the main cause of stratospheric ozone depletion, which increases the risk of skin cancer.

Towards a solution: a nitrogen budget

Despite this significant pollution problem, current regulations set a rather low baseline instead of mainstreaming best-practice. European Directives - such as the Industrial Emissions or the Water Framework Directives - address some parts of the nitrogen issue. Five Nitrate Vulnerable Zones – visible on the map at http://bit.ly/NVZmap5 – are the only areas in Scotland where nitrogen use is under closer scrutiny, but even there, the rules focus solely on water pollution, leaving the issues related to air quality and climate change unaddressed.

Nitrogen pollution affects all aspects of our environment – air, water, soils, and ecosystems – and damages human health. The good news is that this pollution is far from unavoidable. While human activity is inextricably linked with nutrient flows, we could drastically cut pollution by using those valuable nutrients more smartly. The key is to build a better understanding of how nitrogen flows in, through, and out of our food system, as well as the contribution of energy and transport and waste management. The crucial concept we need to focus on is Nitrogen Use Efficiency (NUE).

Nitrogen Use Efficiency (NUE):

At crop or field level, NUE is the ratio between the amount of N in harvested crops and the amount of N available to crops (from biological N fixation and from fertiliser and manure inputs). Low percentages mean large excesses of nitrogen were applied to fields, while NUE >100% indicates soil nutrients depletion. **Average crop NUE in the UK in 2008 was 29%.** In the same year, most European and North-American countries had higher crop NUE, up to 68% in Austria. The target for crop NUE recommended by the Centre for Ecology & Hydrology is 70%. If Scottish farmers were able to achieve a high field-level NUE, they would save substantial amounts of money by reducing the need for expensive fertilisers and spreading costs, while drastically cutting emissions of N_2O and NH_3 and leaching of N and P into our water.

CEH also recommends a target of 50% **national full food chain NUE**. National full-chain NUE expresses the quantity of N in food available for consumption compared to the total nitrogen inputs, accounting on both sides for imports and exports of fertilisers, livestock feed, and agricultural products. **Full-chain NUE in the UK in 2008 was 24%, meaning that 76% of the nitrogen entering our food system ends up lost to the environment.**

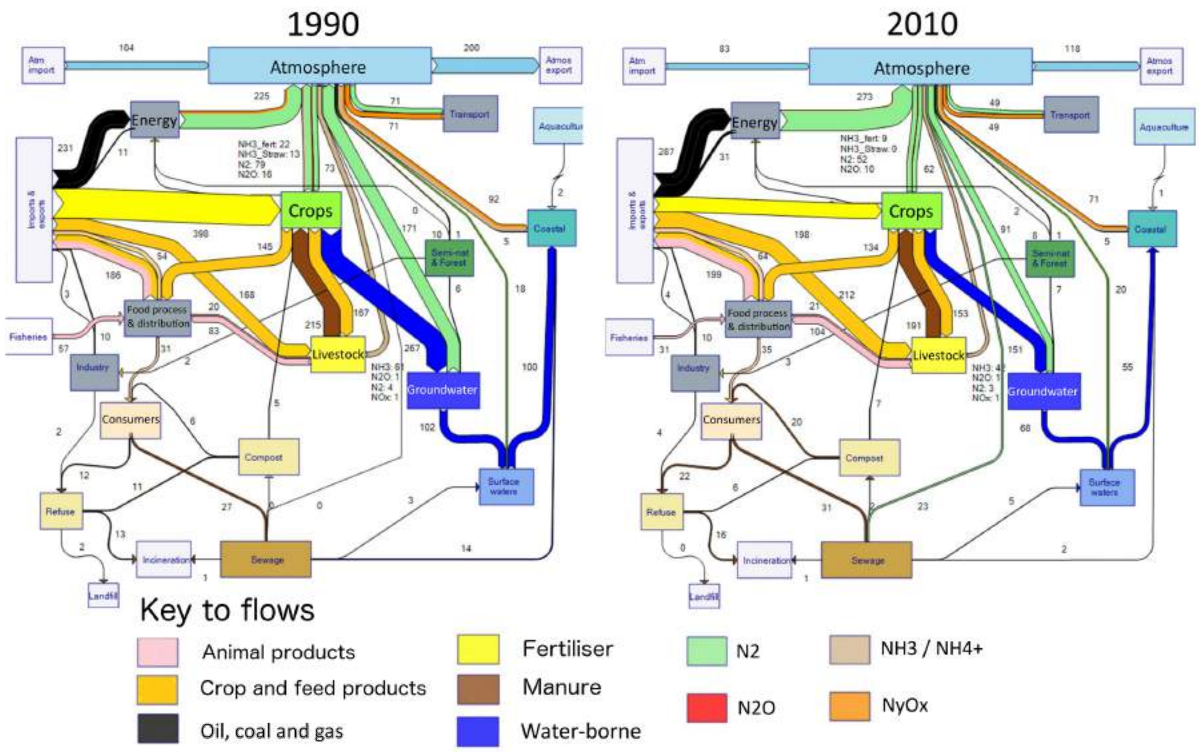
Because national full-chain NUE excludes non-food related N pollution and doesn't account for food waste, we suggest a more holistic concept: **full-system NUE.**

Scotland needs a nitrogen budget that creates a clear picture of our national full-system NUE. This can then be used to inform policies and regulation to improve NUE.

It is not impossible: Denmark has done it.

Danish scientists developed a national nitrogen budget for Denmark for the years 1990 to 2010. The Danish N budget is represented in the diagram below, showing inputs and outputs of nitrogen at national level and the internal flows of nitrogen between the relevant sectors.

Alongside this budget, Denmark adopted a wide range of measures to improve NUE. Most measures were cost-neutral or even cost-negative.



The success of Danish NUE policies can be seen with just a quick look: most arrows shrank between 1990 and 2010, meaning that food-related flows of nitrogen have been reduced and NUE increased. This has had significant benefits for the environment; **without a corresponding fall in production, leaching of nitrogen to the aquatic environment has been halved, and emissions of N_2O and NH_3 have been reduced by a third**.

Scotland needs to create a similar picture of our nitrogen flows. That picture can then be used as a basis for setting targets and regulations that will improve our NUE and reduce nitrogen pollution.

Examples of such regulations include:

- Blanket ban on winter spreading of slurry for spring crops
- Ban on construction of new open-air slurry storage (including subsidies to invest in new slurry tanks and to cover existing storage)
- Promotion of low-emission spreading techniques and ban on splash plate slurry spreading
- Tax on mineral phosphorus in feed
- Subsidies to promote low-emission manure management and animal housing
- Mandatory fertiliser management and crop rotation plans.
- Minimum proportion of area with winter crops.
- Subsidies to promote organic farming, wetlands, extensification and afforestation
- Maximum level of nitrogen application set at the economic optimum (in Denmark it is 15% below the economic optimum since 2009)
- Dated target and corresponding incentives for anaerobic digestion of animal manure

Such measures will benefit our environment, our health, and our wallets. Nitrogen pollution comes at a huge societal cost. The European Nitrogen Assessment estimates those costs to be €70–€320 billion per year for all European Union member states. 60% of that cost is related to adverse effects on human health. The total damage cost equates to €150–€750 per person, or 1–4% of the average European income. And of course, farmers will benefit too by making better use of expensive nutrients.

Further reading

Sutton, M. A. et al (2013) **Our Nutrient World**: the challenge to produce more food and energy with less pollution. Centre for Ecology and Hydrology.

Sutton, M. A., van Grinsven, H. et al. (2011) **European Nitrogen Assessment** - summary for policy makers.

Dalgaard, T. et al. (2014) **Policies for agricultural nitrogen management:** trends, challenges and prospects for improved efficiency in Denmark.

Hutchings, N. J. et al. (2014) **A nitrogen budget for Denmark**: developments between 1990 and 2010, and prospects for the future.