
09

Towards our phosphorus future

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Left: Harmful algal blooms on Lake Erie in August, 2017. The impacts of climate change make such algal blooms more likely in the future. Photo courtesy of Aerial Associates Photography, Inc. by Zachary Haslick. www.flickr.com/photos/noaa_glerl/36546204842

There are abundant opportunities to transition towards more sustainable phosphorus use. Taken collectively, these solutions unlock multiple environmental and societal benefits. Actions must be delivered cooperatively, as part of an integrated plan across sectors and scales. Indeed, coordinated action on phosphorus to support governments, existing conventions, and intergovernmental frameworks, as well as stakeholders, to catalyse improvements in phosphorus sustainability is urgently required. An inter-conventional coordination mechanism to address fragmented phosphorus policy is proposed.

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9.1 Introduction

A decade has passed since the global anthropogenic flow of phosphorus (P) was assessed as having crossed the planetary boundary (Carpenter and Bennett, 2011) - a level of human interference in the global P cycle that results in significant environmental damage. The current societal burden of unsustainable P use is high and getting higher. Nevertheless, as described in the preceding chapters of this report, there are abundant opportunities to transition towards more sustainable P use. Taken collectively, these solutions unlock multiple environmental and societal benefits. Global-scale transition to a sustainable P cycle is essential and possible. By taking the necessary action, humanity can safeguard freshwater ecosystems through emissions reductions and the development of resilient food systems, both of which are fundamental to socio-economic development.

In 2013, the opportunity was highlighted for a 20% improvement in nutrient (P and nitrogen (N)) use efficiency by 2020 across the full chain of food and waste systems (Sutton et al., 2013). Since this time, several nutrient sustainability goals have been proposed. The United Nations Environment Programme (UNEP) Colombo Declaration (UNEP, 2019a) calls for the halving of N waste by 2030, understood as the sum of all N losses (including denitrification of reactive N to N_2). The working group of the Post-2020 Global Biodiversity Framework has proposed to reduce pollution from excess nutrients by 50% by 2030 (CBD, 2020). Similarly, the Farm to Fork strategy underpinning the European Green Deal calls for actions to reduce nutrient losses by at least 50% and fertiliser use by at least 20% by 2030 (European Commission, 2020). It is important to consider the key barriers to such goals.

As is recognised by the preceding chapters, progress on P is not hindered by a lack of scientific evidence on solutions, but instead by a lack of policy and public awareness, a lack of operationalisation of policies, fragmentation of policies, and the absence of intergovernmental coordination.

Signs of progress toward sustainable nutrient use are beginning to appear. The momentum for action on N pollution, for example, is building, with the first United Nations Environment Assembly (UNEA) resolution on Sustainable Nitrogen Management agreed in 2019 (UNEA, 2019a). The Our Phosphorus Future (OPF) project aims to catalyse similar progress for phosphorus. Indeed, the preceding chapters demonstrate that many solutions are within reach for P and would provide multiple benefits across sectors and scales. For example, optimising fertiliser application rates on farms and increasing P recycling reduces losses to fresh waters, which reduces the costs of responding to water quality degradation while supporting green economic growth. Building upon decades of research and innovation across multiple fields, the evidence base is now available with which to re-design the global anthropogenic P cycle. The challenge now is in mobilising governments, industry, stakeholder organisations, academics, and the public to provide leadership in shaping Our Phosphorus Future.

In this final chapter, we draw on the preceding chapters to propose ten key actions towards global P sustainability. We provide a perspective on the opportunities for converting knowledge into international action, noting the lack of inter-governmental attention on sustainable P use. We then identify high-level ambitions to reduce unsustainable P use globally, recognising the need for better integration of P across sustainability policies.

9.2 Ten key actions towards global phosphorus sustainability

We propose ten key actions across sectors that are central to improving sustainable P management globally. The list below is not exhaustive and is framed in a global context. It is important to acknowledge that priorities on actions will differ among regions, where issues may differ as will resources and ambitions to implement solutions.

1. Increase the use of recycled phosphorus in fertiliser and other chemical industries, as an alternative or supplement to phosphate rock.

Economic, legislative and communication instruments are required to support the mineral fertiliser and chemical industries to increase their use of recovered P materials as alternatives to P mined from phosphate rock (PR) (Hermann et al., 2019; Kabbe and Rinck-Pfeiffer, 2019; Matsubae and Webeck, 2019) (see Chapter 7). Common features that will make recovered P materials commercially viable as an industry-compatible raw material include homogeneous quality, low levels of contaminants, and production levels that are high enough to ensure a reliable supply (Schipper, 2019).

2. Optimise phosphorus inputs to agricultural soils and maximise crop uptake to minimise losses.

Fertiliser use can be optimised, as illustrated by the 4R (Johnston and Bruulsema, 2014; The Fertilizer Institute, 2017) and 4R Plus (The Nature Conservancy, 2021) approaches, described in Chapter 4. However, to achieve this, extensive soil P testing is needed. Identification of cost-effective, user-friendly testing methods is therefore critical. In some regions appropriate control limits on P inputs may be required, including consideration of interactions with other nutrient cycles (Masso et al., 2017; Blackwell et al., 2019) (see Chapter 4). In regions with soil P deficiency, P inputs that exceed crop uptake may be required, at least in the short-term (Cordell and White, 2014; Nziguheba et al., 2016) (see Chapters 2, 3 and 4). Soil-crop management to improve crop uptake of applied and legacy P in the soil may embrace integrated soil fertility management, including water and weed management (Blackwell et al., 2010; Vanlauwe et al., 2010), rhizosphere management and the use of P-efficient cultivars and biofertilisers (Shenoy and Kalagudi, 2005; Stutter et al., 2012; Adhya et al., 2015) (see Chapter 4).

3. Optimise animal diets and the use of supplements to reduce phosphorus excretion.

The P content in animal diets can be optimised to match animal growth stage requirements. As commonly practised in most more economically developed countries, supplementing the feed of monogastric animals with phytase enzymes can improve P uptake from grains, thereby reducing P excretion (Ferket et al., 2002; Dao and Schwartz, 2011; Menezes-Blackburn et al., 2013; Oster et al., 2018) (see Chapter 4). Dietary phytase supplements can also increase the bioavailability of P in manures, improving crop uptake when manures are applied to soils thereby reducing the need for mineral P additions (George et al., 2018). However, the impacts of dietary phytase on potential P mobility in the environment and fluxes from soils to waters remain to be explored (see Chapter 4).

4. Increase appropriate application of manures, other phosphorus-rich residues, and recycled fertilisers to soils, to complement appropriate mineral fertiliser use.

Assessments have identified that recycling P, especially in manures, can support a significant reduction in mineral P fertiliser requirements (Vaccari et al., 2019; Powers et al., 2019), and provide additional agronomic benefits, including a source of N, micronutrients, organic carbon and improved soil water retention (Schröder, 2005; Lashermes et al., 2009; Diacono and Montemurro, 2010; Deeks et al., 2013; Pawlett et al., 2015). Phosphorus-rich residues must be appropriately processed to enable storage, transport, avoid decomposition, ensure sanitary safety and supply reliable and consistent agronomic characteristics (see Chapter 6).

5. Improve global reporting and assessments of phosphorus emissions and their impacts on freshwater and coastal ecosystems.

The available evidence on biodiversity loss and ecological sensitivity in response to nutrient pressures is compelling (Darwall et al., 2009; Smith and Schindler, 2009; Chen et al., 2009; Paerl and Paul, 2012) but incomplete. While phosphorus is one of the key drivers of the biodiversity loss emergency in freshwater and coastal ecosystems, the true scale of the problem globally is difficult to estimate as baseline data are lacking in many regions. It has been predicted that 31% of the global landmass contains catchments that may exhibit undesirable levels of algal growth; 76% of which is caused by P-enrichment, affecting 1.7 billion people (McDowell et al., 2020). Emerging evidence suggests that freshwaters may drive globally-significant emissions of greenhouse gases as a result of nutrient enrichment (Beaulieu et al., 2019). Investment in long-term monitoring across a wider range of biomes is necessary to track and study their response to mitigation and nutrient reduction strategies (see Chapter 5). These will provide a critical link between information, evidence-based decision making and policy development and should be used to inform adaptive management frameworks for reversal or halting of biodiversity loss in freshwater and coastal ecosystems.

6. Implement integrated approaches for freshwater and coastal ecosystem restoration and protection at catchment, national and transboundary scales.

Integrated P management strategies that cross scales and work in parallel with efforts to reduce other key nutrient stressors will be essential in achieving improved water quality, tackling biodiversity loss and generating significant socio-economic co-benefits (see Chapter 5). This will require the development of regional targets, mandates and incentives, and transboundary cooperation frameworks to integrate across multiple pillars - from governance to technology, monitoring and assessment - including effective stakeholder engagement (see Chapter 5). Examples of the application of such frameworks leading to fully-costed 'business plans' demonstrate that supporting P flux reductions for restoration makes financial sense (World Bank Group, 2018). However, the complexity of achieving these reductions across sectors must not be underplayed and requires engagement and transparency across both public and private sectors (see Chapter 5).

7. Implement national to global strategies to increase recovery and recycling of phosphorus from solid and liquid residue streams.

Currently, significant amounts of P are lost in 'waste' streams representing solid and liquid residues requiring disposal (Withers et al., 2015a; Vaccari et al., 2019). Multiple strategies exist to improve the recycling of P in manures, abattoir residues, food processing and domestic wastes, sewage derived biosolids and wastewaters (Kabbe and Rinck-Pfeiffer, 2019), all of which represent resources with potential for recycling (see Chapter 6). Such losses not only represent a waste of valuable P but in some cases a significant cause of P pollution to waterbodies (Withers et al., 2015a) (see Chapter 5). National policies that optimise P recycling, and hence reduce reliance on mineral P fertilisers, are acknowledged as pivotal to drive the transition to greater P sustainability (Koppelaar and Weikard, 2013; Cordell and White, 2014; Reijnders, 2014; Withers et al., 2015b, 2018; van Dijk et al., 2016; Chowdhury et al., 2017; van Kernebeek et al., 2018).

8. Ensure sufficient access to affordable phosphorus fertilisers (mineral, organic and recycled) for all farmers.

Improving farmers' access in developing regions to P fertilisers may include better access to credit, extension services, investment in sustainable infrastructure (such as local P recycling systems from food waste and sanitation), and knowledge exchange to support better P use efficiency and recycling (Cordell and White, 2014) (see Chapter 3). Ensuring that all farmers (in particular, small-scale farmers in low-income countries) can access sufficient P to grow crops and are buffered from fertiliser price fluctuations should be developed as a global ambition that will require international cooperation (Nziguheba et al., 2016; Teah and Onuki, 2017) (see Chapters 2 and 3).

9. Promote a global shift to healthy and nutritious diets with low phosphorus footprints.

Wider adoption of healthy diets with low to moderate amounts of meat and dairy could radically reduce demand for mineral P fertilisers (Elser and Bennett, 2011; Vaccari et al., 2019). The biggest gains can be made from reducing meat consumption in countries that already consume more than recommended (WHO, 1999; Metson et al., 2012; Kummu et al., 2017) (see Chapter 8).

10. Reduce the amounts of phosphorus lost as food waste in food processing, retail, and domestic consumption.

Strategies to reduce food waste should be supported by clear evidence on the benefits of change. Most food waste in low-income countries occurs before products reach consumers (see Chapter 8). Wealthier nations waste more food in retail and at home (Kummu et al., 2012). Whilst recycling P from food wastes can contribute to a more sustainable P system, the focus of efforts should be to reduce the production of food waste in the first place (and thereby cutting the resources used to produce it) (Vaccari et al., 2019).

9.3 Supporting International Cooperation

The actions listed above must be delivered cooperatively, as part of an integrated plan across sectors and scales. Whilst national framing of nutrient sustainability strategies is vital, we highlight several P sustainability issues that cannot easily be addressed without international cooperation.

9.3.1 Polices, regulations and initiatives for phosphorus sustainability

Strategies to improve P sustainability are conspicuously absent in most regions (Gross, 2010; Cordell and White, 2015; Rosemarin and Ekane, 2016; Jacobs et al., 2017). Few policies relating to sustainable P management exist at the national scale, and none at the global scale (Chowdhury et al., 2017; Kanter and Brownlie, 2019). Phosphorus was identified a decade ago as an emerging issue in the UNEP Year Book 2011 (Syers et al., 2011). However, relevant international sustainability initiatives rarely mention P, including the Sustainable Development Goals (SDGs) (United Nations Statistical Division, 2016), and the Aichi Biodiversity Targets (CBD, 2020). This is despite the considerable contribution that improving P sustainability can make to achieving their goals and targets (Kanter and Brownlie, 2019).

Strategies that rely on voluntary uptake of P sustainability measures can also be effective. In an assessment of policies and actions to decrease water quality impairment from P, McDowell et al., (2016) showed that a combination of measures was necessary to reduce P pollution in New Zealand, the UK, and the USA. Relevant combinations included mandatory and voluntary measures at the farm to small catchment scale, in combination with policy instruments at larger scales. In some less-economically developed countries, ambitions for increased use of fertilisers to address P deficient soils have yet to be fully achieved. In Africa, the 'Abuja Declaration on Fertiliser for an African Green Revolution' of 2006 called for the elimination of all taxes and tariffs on fertiliser and fertiliser raw material to increase fertiliser use (African Union Special Summit of the African Heads of State and Government, 2006). By 2018, 47 of the African Union states had not yet achieved this, due to a lack of harmonisation on policy and regulation frameworks, lack of tax incentives, trade barriers, and poor quality control on fertilisers (African Development Bank, 2021).

Examples of policies, regulations, volunteer schemes and subsidies related to P sustainability in Australia, Brazil, China, the EU, India, Sub-Saharan Africa (SSA), and the USA are listed in Table 9.1 (see end of chapter), highlighting the high degree of fragmentation in government-supported actions. Experience shows that if policies are to optimise P sustainability, they must adopt a more joined-up approach between water, agricultural and urban planning policy sectors (Tong et al., 2017; Carvalho et al., 2019; Wurtsbaugh et al., 2019). A coordinated policy approach that aims to reduce P loading to water bodies, for example, should be supported by measures to increase P sustainability in agriculture. These must include improved farmer access to recycled P fertilisers, which itself should be supported by policies to encourage P recovery from residue/waste streams and the use of recycled P in the production of fertilisers. In some cases, better enforcement of existing policy measures is also needed, as highlighted by Teenstra et al. (2014) in their analysis of manure management policies in Asia, Africa and Latin America. Furthermore, flexibility should be built into new and existing policies to allow them to adapt to changing conditions, brought about, for example, by climate change, urbanisation, changes in P loading and ecosystem sensitivity to P (Chowdhury et al., 2017; Tong et al., 2017; Duncan et al., 2019).

Policy development and integration are needed across all regions to drive innovation and the behavioural changes needed to deliver P sustainability. To address this, raising government and policymaker awareness of the benefits of sustainable P use is an obvious but critical first step.

9.3.2 Raising awareness of the world's governments

The United Nations Environment Assembly (UNEA) is the world's highest-level decision-making body on the environment, with universal membership of all 193 Member States. A global intergovernmental agreement in the form of a UNEA resolution provides a key opportunity to raise awareness among the world's governments of the importance of P sustainability. UNEA resolutions, whilst not legally binding, represent the joint aspirations of governments, frame consensus around actions to be taken, and help coordinate development aid and technical assistance.

At the fourth session of UNEA (UNEA-4) in 2019, 23 resolutions were adopted (UNEA 2019b). These included resolutions on Sustainable Nitrogen Management (UNEP/EA.4/Res.14), Innovative Pathways to Achieve Sustainable Consumption and Production (UNEP/EA.4/Res.1), Mineral Resource Governance (UNEP/EA.4/Res.19) and Innovations on Biodiversity and Land Degradation (UNEP/EA.4/Res.10) (IISD, 2019). At the fifth session of UNEA (UNEA-5.2) in 2022 (UNEA 2022), a further resolution for Sustainable Nitrogen Management (UNEP/EA.5/Res.2), acknowledged the significant impacts of excessive levels of both N and P in the environment. Additionally, a resolution on Sustainable Lake Management (UNEP/EA.5/Res.4) called for Member States to protect, conserve, and restore, as well as sustainably use lakes. All the resolutions listed above are highly relevant to P sustainability. Development of a future UNEA Resolution on Sustainable P Management would provide a key opportunity to catalyse intergovernmental action on the global P challenge (Brownlie et al., 2021).

There is also a clear opportunity to raise awareness for P through UNEA. For example, the UNEA 4/14 resolution led to the launch of the UN Global Campaign on Sustainable Nitrogen Management, resulting in the development and adoption of the Colombo Declaration on Sustainable Nitrogen Management (UNEP, 2019a).

9.4 Improving governance models to recognise the need for intergovernmental cooperation

As with the experience from the N cycle, policies relevant to P are fragmented between component issues, which can lead to a lack of action and coherency (UNEP 2019d, Sutton et al., 2020; Brownlie et al., 2021). There is a need for coordinated action on P to support governments, existing conventions and intergovernmental frameworks, as well as stakeholders, to catalyse improvements in P sustainability. Possibilities to coordinate N policy engagement more effectively at the national, regional and global levels have been suggested (see Sutton et al., 2020, 2021). Based on these, the following four corresponding options to coordinate policies across the P cycle can be identified:

1. Phosphorus policy fragmentation across policy frameworks (e.g. business as usual).
2. Phosphorus leadership under one existing Multilateral Environmental Agreement (MEA).
3. Establish a new intergovernmental convention to address P sustainability.
4. Establish an 'inter-convention P coordination mechanism' to facilitate cooperation on P sustainability.

Business as usual is not sufficient to address the current P challenge (Carpenter and Bennett, 2011). Similarly, it appears that the mandates of existing MEAs are not broad enough to address the P challenge, providing a barrier to any one of them taking the lead on phosphorus. At present, there appears to be little to no foundation to establish a new intergovernmental convention on P in the near future (5-10 years). Experience with N points to the need to draw as far as possible on the work of existing bodies. This leads the discussion to the fourth option, which can draw on the experience related to the 'Inter-convention Nitrogen Coordination Mechanism' (INCOM), which is currently under development for N (UNEP, 2019b).

Building on this progress (see Sutton et al., 2020, 2021), we identify the need for a complementary 'Inter-convention Phosphorus Coordination Mechanism' (PHOSCOM), where lessons from the experience for N can also inform the possible relationships (Figure 9.1). For example, under the current development for INCOM, the International Nitrogen Management System (INMS) could be embedded as a science support process under the overarching inter-governmental mandate of INCOM. In the same way, an emerging concept for PHOSCOM could embed scientific assessments to outline risks and identify adaptation and mitigation options.

An obvious question that needs to be considered is the relationship between the developing concepts for INCOM and PHOSCOM. This may be considered especially as a matter of timing and communication, noting that the issue of 'phosphorus hypersensitivity' can provide a barrier to progress on sustainable P management (Chapter 2). Care is needed to avoid that such specific barriers for P do not hold up progress on interconvention coordination on nitrogen. However, there is a need to further examine where policies for N and P can be aligned to maximise synergies (Kanter and Brownlie, 2019). While there are generic lessons, substantial differences between issues and the component interlinkages for P and N exist. For these reasons, it is acknowledged that at present there is an operational benefit in developing the processes in parallel, rather than a simple combination. However, it is also obvious that there is potential for sharing of lessons learned and for cooperation between the P and N communities, for example, as part of the UNEP Pollution Implementation Plan, which also makes links to the Basel Rotterdam and Stockholm (BRS) Conventions on toxic substances and to ongoing actions on plastic pollution (UNEP, 2018, 2019c). While recognizing the need to further develop such higher-level cooperation, we focus the following comments on the immediate challenges for phosphorus.

One of the key points to recognise in addressing international cooperation on P and N is the distinction between intergovernmental action and multi-actor engagement. In this regard, INCOM is developing as an intergovernmental process, following up UNEA Resolution 4/14, as illustrated by the agreement of member states under the Colombo Declaration (UNEP, 2019a). Conversely, UNEP established the Global Partnership on Nutrient Management (GPNM) in 2009, which represents a multi-actor partnership linking business, academia, civil society and governments among others. In the same way, substantial connections are relevant with the UNEP Global Wastewater Initiative (GW2I), with both these bodies established under the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA). These bodies have an important role to play in catalysing improved understanding between different actor groups across society. In this way, the parallel establishment of INCOM and PHOSCOM provides opportunities to increase the focus of intergovernmental action on both N and P, which in return may strengthen multi-actor engagement in both GPNM and GW2I as a basis to address barriers and accelerate change.

Figure 9.1 indicates potential intergovernmental contributions in delivering a joined-up approach to P management. The starting point is engagement by UN Member States. Knowledge exchange between Member States and the various intergovernmental bodies highlighted in Figure 9.1 would help guide specific actions on P sustainability. Such an intergovernmental coordinated approach is also necessary to develop a shared ambition by governments internationally (see Chapter 1).

Although national scale strategies to improve P sustainability are critical, a further challenge is that several P sustainability issues will be difficult to address without international cooperation. These include, for example:

- Displacement of ecosystem impacts of production (Nesme, 2016; Hamilton et al., 2018; Li et al., 2019).
- Phosphorus pollution of transboundary/shared waters (see Chapter 5; Bohman, 2017; Jetoo, 2018).
- Trade of contaminants in PR and P fertiliser (see Chapters 2 and 7).
- Creation of global markets for recycled P materials and products (see Chapter 7).
- Ensuring all farmers have sufficient access to P to grow crops (see Chapter 3).
- Responding to PR/mineral P fertiliser price volatility (see Chapter 2).

The breadth of these issues highlights the need for cooperation across the environment, through the agri-food chain, and embracing the development of the circular economy and engaging with issues of P trade.

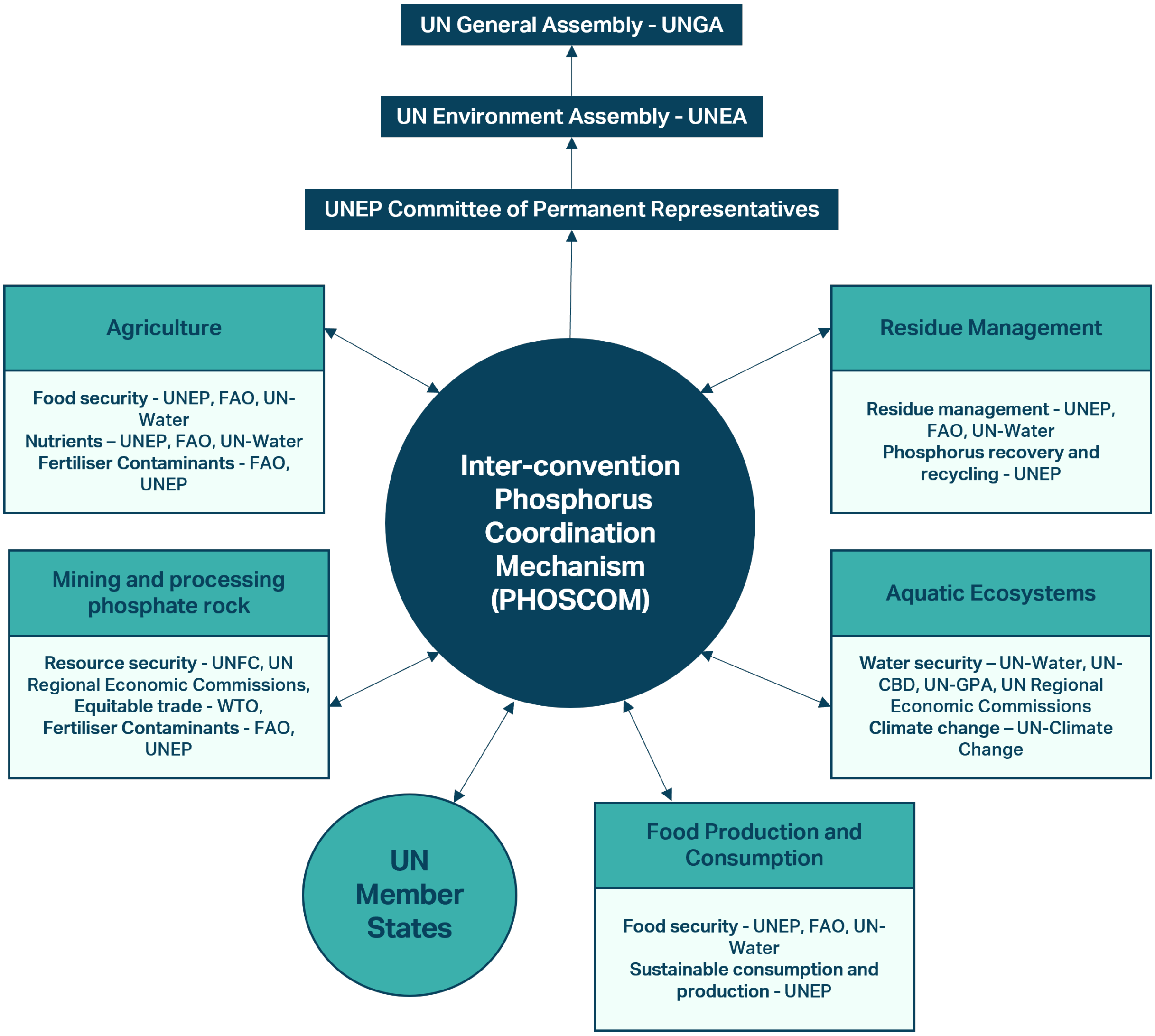

Figure 9.1 There is currently little policy coordination on phosphorus (P) across scales. Building on progress made in the nitrogen community (Sutton et al., 2020, 2021; UNEP 2019c), an 'Inter-convention Phosphorus Coordination Mechanism (PHOSCOM) is proposed to link P science-policy support among existing intergovernmental frameworks and other initiatives, under the auspices of the United Nations Environment Programme (UNEP). Key bodies with relevant interests include UNEP, the Food and Agriculture Organization of the United Nations (FAO), UN-Water (including the UN Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UN-WC)), Regional Seas Conventions (RSCs) and the UN Convention on the Law of the Sea (UNCLOS)), the UN Regional Economic Commissions (which includes the UN Economic Commission for Europe (UNECE) Convention on Access to Information (Aarhus Convention), and the UNECE Water Convention (UNECE-WC)), the UN Framework Classification for Resources (UNFC), the UN Resource Management System and its regional initiatives, the World Trade Organization (WTO), the UN Convention on Biological Diversity (CBD) and the UN Climate Change Convention (UN-Climate Change) and regional/national processes.

9.5 An aspirational goal for phosphorus sustainability

Time-bound goals have a critical role to play in developing environmental policy, serving as a 'starting gun' for action, and a 'finishing line' for delivery. To propose a meaningful aspirational goal for P, it is therefore useful to identify a potential finishing line for global P sustainability. In this regard, achieving 'P security' may be a suitable goal. This has been defined by Cordell (2010) as "…all the world's farmers have access to sufficient P in the short and long term to grow enough food to feed a growing world population, while ensuring farmer livelihoods and minimising detrimental environmental and social impacts". Achieving such a goal will not be possible without significant progress towards a 'closed human P cycle' (Childers et al., 2011). Opportunities to make greater progress towards a circular P system have been identified in the preceding chapters of this report.

Whilst closing the P cycle does not address P access issues directly, it is widely acknowledged in the literature as an overarching aim of strategies to improve P sustainability (Elser and Bennett, 2011; Childers et al., 2011; Bateman et al., 2011; Cordell and White, 2014; Shepherd et al., 2016; Scholz and Wellmer, 2018; Withers et al., 2018). The question then becomes, what goal will help make progress towards closing the global P cycle and is it appropriate across all regions?

A goal to reduce the rate of P mining or the use of mineral P in fertiliser production does not directly address P losses that cause pollution (e.g. those from inefficient agricultural management or sanitation). Furthermore, without the supporting policies and infrastructure in place to deliver large scale P recycling, food security could be compromised. This highlights the need to focus on mobilising increased P recycling, for which a goal for P-containing fertiliser products to contain a minimum fraction of 20% recycled P by 2030 was identified in Chapter 2.

A goal for improving P use efficiency is appropriate for all regions, recognising that this may not translate into improved yield in some places. Sutton et al. (2013) provide a strong argument for improvement to nutrient use efficiency (NUE) across the food-value chain (i.e. a 20% improvement in full chain NUE, by 2020, from 2008 levels) as a shared goal. However, whilst this may apply to N, in regions such as Sub-Saharan Africa where soils are P depleted, low agricultural PUE may be arguably desirable, provided excess P is stored in the soil, rather than exported from soil to water (Langhans et al., 2021). Such a long-term accumulation of P in P deficient agricultural soils could be considered an investment in the future (Syers et al., 2008; Menezes-Blackburn et al., 2018). Furthermore, using a relative improvement for use efficiency (i.e. 20% of NUE) implies those countries with the highest efficiency would need to improve more than those with low efficiency.

A high-level goal that directly addresses the reduction in P pollution and supports an increase in P recycling may therefore be most appropriate. Such a goal should be applicable to all countries, covering all sectors, and not adversely impact access to P fertilisers. Bearing in mind the necessity of sufficient time to mobilise change, we, therefore, propose **an aspirational goal of a 50% reduction in global P pollution and a 50% increase in the recycling of P lost in residues/wastes, by 2050. We term this the '50:50:50' aspirational goal.**

9.5.1 Unpacking the 50:50:50 goal

Achieving the 50:50:50 goal would reduce impacts to P polluted ecosystems (as outlined in Chapter 5), whilst still delivering enhanced resilience to the global food system (as outlined in Chapter 3) with far-reaching benefits across the seven OPF pillars (Figure 9.2). Whilst the strategies to achieve this goal may differ widely among nations, its overarching aims, to reduce P pollution and increase food system resilience, remain universally relevant.

Based on current estimates of global anthropogenic P loading to water bodies, a 50% reduction in global P pollution will require a reduction in anthropogenic P loading to water bodies by 3.1–7.0 Mt P year^{-1} (Chen and Graedel, 2016; Beusen et al., 2016). A 50% reduction in total annual P loading to surface waters is proportionately equivalent to 2.5–6.2 Mt P year^{-1} from agriculture alone (Chen and Graedel, 2016; Beusen et al., 2016). Opportunities to reduce P losses to water from agriculture are highlighted in Chapter 4. Assuming losses of P from agricultural systems are subsequently replaced with inputs of mineral P fertiliser, a 50% reduction in P pollution from agriculture could save the global farming community between $US8.0–19.8 billion year^{-1} in mineral fertiliser costs. This is based on a cost of P in diammonium phosphate (DAP) of US$3.2 P kg^{-1} (for September 2021)[i], and assumes all losses are replaced by DAP. With substantial fluctuations in DAP price (e.g. ranging from US$280-643 DAP t^{-1} between 2010 and 2021) this value varies greatly. Based on the average DAP price between 2010 to 2021 the annual global value of the saving would be US$5.7-14.1 billion.

A 50% reduction in P pollution would have a significant impact on the costs associated with the management of P loading to water bodies. As discussed in Chapter 5, the most effective and least expensive strategy is to stop P pollution at its source (e.g. improving fertiliser management, improving sanitation). The second is to implement adaptation interventions in the landscape to intercept P flows from reaching water bodies (e.g. buffer strips, erosion control). The median estimated cost for P pollution adaptation interventions is US$46 kg^{-1} of P intercepted (see Chapter 5). A 50% reduction in P pollution could therefore reduce the requirement for annual adaptation costs[ii] by between US$143–322 billion.

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[i] Data from https://blogs.worldbank.org/opendata/fertilizer-prices-expected-stay-high-over-remainder-2021. It is assumed DAP contains 46% P_2O_5; therefore, DAP has a ~20% P content. Based on the cost of DAP in Sept 2021 (US$643 t^{-1}), 4.98 t of DAP would contain 1.0 t of P, and would cost USD$3203.

[ii] Costs are calculated by multiplying the estimated range of P pollution by interventions costs (see Chapter 5). A 50% reduction in global P pollution will require a reduction in anthropogenic P loading to water bodies by 3.1–7.0 Mt P year^{-1}, whilst adaptation interventions are estimated at US$46 kg^{-1} P intercepted (see Chapter 5).

Where the preceding steps cannot be achieved, measures to capture the P within the waters can be implemented. A 50% reduction in pollution would slow the increase in global P stockpiles retained in freshwater ecosystems, currently increasing by 5 Mt $year^{-1}$ (Beusen et al., 2016). Geoengineering techniques as described in Spears et al. (2013), to control the additional P being loaded into these stockpiles (e.g. make it not bioavailable) would cost US\$122–220 billion $year^{-1}$ (see Chapter 5). A 50% reduction in P pollution could therefore reduce the requirement for additional geoengineering costs by US\$61–110 billion $year^{-1}$. Whilst such estimates are difficult to make with accuracy, recovery of waterbodies at this scale is unlikely to be implemented due to high costs and, instead, the cost of damaged ecosystems are paid by society in terms of losses in ecosystem service.

A 50% reduction in P pollution would have a significant impact on the economic losses associated with eutrophication impacts. As examined in Chapter 5, quantitative data on these costs is lacking in the literature. Of the few studies published, the costs of eutrophication of fresh waters in the US was estimated at US\$2.2 billion annually (covering losses to industry, real estate, and management for conservation of endangered species and drinking water supply) (Dodds et al., 2009). Similarly, for England and Wales in the UK, losses as a result of eutrophication of fresh waters were estimated at £75–114 million $year^{-1}$ (US\$104–158 million $year^{-1}$) (covering damages and management interventions), with an additional £55 million $year^{-1}$ to cover the policy response (Pretty et al., 2003). A similar assessment updates this figure, estimating eutrophication in the UK in 2018, to cost £173 million (US\$220 million) (Jones et al., 2020). We note, for some polluted lakes, a 50% reduction in P pollution may not be sufficient for ecological recovery, whilst for pristine lakes, a 50% reduction may not be required. Targeting of action to reduce P pollution should be implemented through national strategies, to identify where reductions will make the most impact.

In addition to the direct costs of P driven water pollution, recent reports indicate that P-enriched waterbodies are also an important source of greenhouse gas emissions (Beaulieu et al., 2019). Downing et al. (2021) estimate the global social cost of eutrophication-driven methane emissions from lakes between 2015 and 2050 to be \$7.5–\$81 trillion. These values warrant further investigation and critical analysis, given the very large estimated costs.

A 50% increase in the recycling of P lost in organic waste streams represents an increase in 8.5 Mt P returned to food production annually (based on data presented in Chen and Graedel, 2016).[i] This could offset US\$27 billion $year^{-1}$ as spent by farmers on mineral P fertilisers (based on a DAP price in September 2021 of US\$643 t^{-1} - see footnote on page 362). By increasing the conversion of P-rich organic wastes into value-added products (e.g. fertilisers), waste-producing industries may also avoid/offset waste disposal costs (Peccia and Westerhoff, 2015).

[i] This is composed of a 50% increase in the recycling of crop residues by 1.3 Mt P $year^{-1}$, animal manures by 2.2 Mt P $year^{-1}$, food processing wastes by 1.6 Mt P $year^{-1}$, human excreta and other human wastes by 3.5 Mt P $year^{-1}$, based on the analysis of global P flows in 2013, as presented in Chen and Graedel (2016).

Overall, considering these potential savings, a global total of US$150-369 billion year^{-1} of resource-saving would be provided by the 50:50:50 goal,[i] which could stimulate the circular economy for sustainable P management. This does not include savings made through reductions in economic losses associated with eutrophication impacts or eutrophication-driven methane emissions. The financial value of these benefits provides the opportunity to mobilise action on processing, storing, and transporting P-rich organic materials, where financial synergies may be found in simultaneously mobilising recovery of N and other elements.

Besides the agronomical benefits of recycling organic residues (see Chapter 6), short-term benefits may also include a potential reduction of P losses to waterbodies (assuming P-rich organic materials are sustainably managed) (see Chapter 5), and reduction in the externalities associated with mining PR and the manufacture of mineral P fertilisers (see Chapter 2; World Bank, 2007; U.S. Environmental Protection Agency, 2010; Tonini et al., 2019). A long-term benefit is the preservation of finite PR reserves for the protection of food security for future generations (see Chapter 2).

There are also benefits for food system resilience. A recent study by Vaccari et al. (2019) demonstrated if global P losses from agricultural land, manure use, and food waste were reduced by 50%, and recycling of P from food and human wastes were simultaneously increased (by factors of 5.5 and 3.3, respectively), then enough P would be provided to sustain over four times the current population. Additionally, if the consumption of animal products was also reduced by 50%, almost six times the global population could be sustained (Vaccari et al., 2019).

The '50:50:50' goal aligns with several aspirational goals that have also called for reductions in nutrient losses in recent years. In 2018, the INI announced its commitment to halve N waste by 2030, at the Our Ocean Conference in Bali (https://ourocean2018.org/). This was adopted as an ambition by a group of UN Member States in the Colombo Declaration in 2020 (UNEP, 2019a). As mentioned above this concept has also been embraced by the EU Farm to Fork strategy (European Commission, 2020) and in proposals from the working group of the Post-2020 Global Biodiversity Framework to reduce pollution from excess nutrients by 50% by 2030 (CBD, 2020). Whilst it can be argued these messages carry a high degree of subjectivity (e.g. the definition of loss and pollution), the priority of these messages is to be easily understood and to provide direction (i.e. pollution reduction, recycling increase). Importantly, all these goals identify that those that cause the greatest pollution/losses have the most work to do.

The '50:50:50' goal aligns with existing international initiatives, such as the targets of the SDGs, which may help to initialise the coordinated actions that will be needed. The goals mentioned above call for action by 2030. The '50:50:50' goal can thus be considered as a starting point for discussion by governments and stakeholders across society concerning both the ambition level and urgency in relation to dates for other international goals.

[i] This figure combines estimated costs benefits of a reduction in 50% losses from agriculture which would be subsequently replaced with inputs of mineral P fertiliser (up to 19.8 billion year^{-1}), the increase of 8.5 Mt P returned to agriculture through a 50% increase in recycling, which could offset US$27 billion spent by farmers on mineral P fertilisers, and a reduction in the requirement for eutrophication adaptation costs of up to 322 billion year^{-1}.

Figure 9.2 Key benefits to the environment and society of delivering a 50% reduction in global phosphorus (P) pollution and a 50% increase in the recycling of P lost in wastes, by 2050 (as outlined by the OPF 50:50:50 goal). Benefits are observed across all seven of the OPF pillars.

For example, governments might wish to align with a more urgent ambition for 2030, which would be technically feasible and consistent with other initiatives (e.g. UNEP, 2019c; CBD, 2020; European Commission, 2020). Conversely, it is recognised that there are substantial barriers to change for P, including barriers associated with P hypersensitivity (Chapter 2), while timescales of restoration of lakes laden with excess P can take decades (Chapter 5). For these reasons, we here focus the goal on 2050, not only because there is also still significant work to do to get to the starting line but also because policymaker and public awareness of P issues (in comparison to N) are generally low, and work is needed to catch up.

Finally, this goal is not designed to supersede existing legislation on meeting environmental quality standards for P in water bodies, as covered in the assessment of SDG 6.3.2 (UNEP, 2021). Instead encourage actions towards meeting such targets, or implementing them, where they do not already exist.

We note, in addressing this goal, there are considerable opportunities to align with the ambitions for other nutrient cycles, especially N (Sutton et al., 2013; Kanter and Brownlie, 2019). There is also a need to do so to avoid pollutant swapping between nutrient forms and environmental domains. Whilst the global cost of nutrient pollution has not yet been comprehensively assessed and will inevitably be subject to many uncertainties and debate, global annual societal costs of N pollution have been estimated at between US$ 200-2000 billion (Sutton et al., 2013).

9.6 The next steps for delivering a sustainable phosphorus future

Ten years have passed since UNEP acknowledged a critical need to identify a route-map for sustainable P management, built on consensus among stakeholders at national to global scales (Syers et al., 2011). Here we propose the next steps to build on the efforts of past and existing projects, platforms, conferences, and publications that have developed the field of global P sustainability (Figure 9.3). We expect that the next steps will require a simultaneous top-down and bottom-up approach.

The top-down approach aims to see governments agreeing that addressing P sustainability is a critical issue and ultimately agreeing to goals for improvement. A major part in the success of this step will be to capitalise on the momentum already established by past efforts and to ensure the publication of this report and its associated media continues to raise public and policymaker awareness of the opportunities to improve P sustainability. As noted, this could be recognised in the form of a UNEA resolution.

The bottom-up approach aims to establish a framework to exchange and consolidate the evidence from within the P community to develop the strategies to deliver on-the-ground improvements to deliver the goals.

Building on such actions, work will be needed to convert the aspirational 50:50:50 goal into more specific targets to be achieved. This would set the opportunity to inform national legislative actions by each country/government, which would account for the highly diverse and regional context of nutrient issues and can be supported by the mobilisation of evidence and awareness through the proposed PHOSCOM approach (Figure 9.1).

The steps proposed here have been informed by the progress made by the international N community over the last decade (see UNEP 2019d, Sutton et al., 2020, 2021). This includes the development of a joined-up approach to N management through the integration of international knowledge facilitated by the 'Towards an International Nitrogen Management System project' (INMS) (www.inms.international/), with current work looking to embed this within the intergovernmental INCOM approach. Such a science-based approach is also needed for phosphorus. For example, developing aspirational goals for a UNEA resolution on P will greatly benefit from data outputs of a project to establish an International Framework for Phosphorus, the development of which can be informed by lessons learned from INMS. A science-based international framework for P could play an instrumental role in establishing a PHOSCOM, as many of the bodies involved in a potential PHOSCOM may work together as partners within such a framework. For example, further analysis will be needed to respond to concerns over slow progress made to date, as highlighted in the Helsinki Declaration.[i] What is abundantly evident is the present lack of coordinated intergovernmental action on P urgently needs to be addressed. The ideas expressed here should be seen as a starting point to mobilise actions by UN Member States, and actors across society, all of whom stand to gain from sustainable P management for multiple environmental, health, climate and economic benefits.

Action is needed now to ensure the global 50:50:50 goal can be reached. Unlike actions to address carbon emissions, the benefits of implementing measures to improve P sustainability will be observed mostly at local to national scales. Whilst some countries may not be able to take immediate action, any delay will only accrue further impacts and societal costs.

[i] In 2019 over 500 scientists signed 'The Helsinki Declaration' calling for transformation across food, agriculture, waste and other sectors to deliver much-needed improvements to global P sustainability - mobilised through intergovernmental action. The Helsinki Declaration is available at www.opfglobal.com

Figure 9.3 Steps proposed to consolidate the knowledge, identify opportunities, and catalyse the political support needed to achieve significant improvements in phosphorus sustainability over the next decade.

Table 9.1 Examples of relevant policy/regulations, volunteer schemes and subsidies that have considered phosphorus (P) sustainability, and key references that discuss policy and regulations regarding P sustainability.

Country /region	Policy/regulations specifically designed to address P sustainability	Policy/regulations that contain measures that address P sustainability	Policy/regulations that support measures that address P sustainability, but do not mention P directly	Volunteer schemes and subsidies to address P sustainability	Key References
Australia	None	Nutrient discharge limits (only for wastewater treatment plants in sensitive catchments).	Unclear	The 'FertCare®' program; a voluntary industry mechanism led by Fertiliser Australia (industry association); consistent with the 4Rs. Limited guidance on P discharge provided for private sewage works/septic tank owners provided by the government.	Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council (1997) Cordell et al. (2013)
Brazil	None	Some local environmental laws limit organic residue application based on P content and soil properties (not well documented).	Unclear	Industrial practices for P recycling can apply for special financial support from governmental agencies. Some governmental programmes exist such as the 'ABC' programme (a low carbon agriculture programme) where farmers can receive subsidies for better agricultural practices.	Ministerio Do Meio Ambiente (2016) Marques de Magalhães and Lunas Lima (2014)

Country /region	Policy/regulations specifically designed to address P sustainability	Policy/regulations that contain measures that address P sustainability	Policy/regulations that support measures that address P sustainability, but do not mention P directly	Volunteer schemes and subsidies to address P sustainability	Key References
China	None	In 2015, the Zero Increase Action Plan was announced by the Ministry of Agriculture (MOA). This plan required the annual increase in total chemical fertiliser use to be less than 1% from 2015 to 2019 without any yield losses and with no further increases from 2020. China's Water Pollution Prevention and Control Action Plan ("10-Point Water Plan"), and national wastewater discharge standards and pollutant cap-control targets address nutrient pollution. The Ministry of Ecology and Environment (MEE) of China issued a notice on strengthening P management of point source pollution in 2018. The notice requires that key industries establish their baseline of P emissions.	Unclear	In 2005, the technology of soil-testing and fertiliser recommendation (STFR) was strongly advocated by the Chinese government as a national action. To encourage farmers to adopt STFR, the Chinese government committed RMB700 billion in subsidies to provide technical service on soil testing for 190 million farm households, covering 80 million hectares of arable land.	Standing Committee of the National People's Congress (2008) Ministry of Environmental Protection of the People's Republic of China (2012, 2014) MOA (2015) National Health and Family Planning Commission of the People's Republic of China (2015) Liu et al. (2016) MEE (2018) Jiao et al. (2018) Wang et al. (2018)

Country /region	Policy/regulations specifically designed to address P sustainability	Policy/regulations that contain measures that address P sustainability	Policy/regulations that support measures that address P sustainability, but do not mention P directly	Volunteer schemes and subsidies to address P sustainability	Key References
EU	The EU Critical Raw Materials List (contains PR and white P). The EU Fertilising Products Regulation (EU) 2019/1009, opens the market for recycled P and sets cadmium limits for phosphate fertilisers. Several national policies address P recovery from wastewaters (e.g. in Germany, Switzerland) and the Baltic Sea Region (HELCOM) and limit P inputs to crop- or grassland (e.g. Belgium, the Netherlands).	Nitrates Directive, Urban Wastewater Treatment Directive, Water Framework Directive, all address water quality issues (e.g. related to nutrient pollution).	Common Agricultural Policy, Industrial Emissions Directive (e.g. Best Available Techniques (BAT) for large poultry and pig farms). The EU Environmental Action Plan and national environmental legislation, EU and national soils policies, pharma-ceuticals and microplastics policies and landfill taxes (impact sewage biosolids valorisation), and numerous EU and national Circular Economy policies.	National and regional support schemes in place to reduce land degradation (e.g. Austria's ÖPUL).	Hermann and Hermann (2019) Kabbe et al. (2018)

Country /region	Policy/regulations specifically designed to address P sustainability	Policy/regulations that contain measures that address P sustainability	Policy/regulations that support measures that address P sustainability, but do not mention P directly	Volunteer schemes and subsidies to address P sustainability	Key References
India	None	National Food Security Mission; Fertiliser subsidy schemes.	The 'Doubling farmers income' policy and Vision Ganga 2017 (which has provisions for the circular economy through recycling of nutrients from wastewater).	Soil Health Card scheme by the Government of India, which provides farm-level fertiliser recommendations based on soil nutrition and the types of crops grown. The Government of India's Ministry of Agriculture and Farmers Welfare promotes the Small Farmers' Agri-business Consortium (SFAC), with a mandate to not just raise awareness but also encourage the formation and growth of Farmer Producer Organisations (FPOs) http://sfacindia.com/, including efficient use of fertilisers.	Srinivasarao et al. (2013) NGBRA (2017) Chand (2017) Department of Agriculture, Cooperation & Farmers Welfare (2008) National Mission for Sustainable Agriculture (2015) cGanga & NMCG (2019)
New Zealand	None	Nutrient discharge limits for streams and rivers, as related to dissolved P and periphyton growth, and total P to limit phytoplankton growth in lakes. Guidance on default guideline values for further investigation of P contamination of freshwaters.	Unclear	Mandatory farm plans to reduce loss of P from land to water. Fertmark and FertSpread schemes consistent with the 4Rs.	ANZG (2018) McDowell et al. (2013) New Zealand Government (2020) Office of the Minister for the Environment and Office of the Minister of Agriculture (2020)

Country /region	Policy/regulations specifically designed to address P sustainability	Policy/regulations that contain measures that address P sustainability	Policy/regulations that support measures that address P sustainability, but do not mention P directly	Volunteer schemes and subsidies to address P sustainability	Key References
Sub-Saharan Africa	The 'Abuja Declaration on Fertiliser for an African Green Revolution' (2006) calls for the elimination of all taxes and tariffs on fertiliser and to increase fertiliser use.	Unclear	Unclear	Fertiliser subsidies were meant to improve access to the input, but remain controversial, with limited success (e.g. Malawi).	Chirwa and Dorward (2013) Jayne and Rashid (2013) African Development Bank (2021)
USA	None	Clean Water Act (33 U.S.C. §1251 et seq.) almost exclusively regulates point-source pollutants. States have varying levels of regulations on P from both point and non-point-sources. For non-point sources, some states require nutrient management plans from farms, sometimes tied to a P-index.	Food waste recovery mandates are being instituted by many cities, including San Francisco and New York.	Farmers are incentivised to adopt conservation practices through grant programs, most notably the USDA's Environmental Quality Incentives Program (EQIP). There are over 20 such USDA programs. Water Quality Trading Programs have emerged in dozens of watersheds that do/will permit trading of rights to pollute between and among point sources and non-point sources of nutrients.	Breetz et al. (2004) Stubbs (2010)
World	None at the global scale	None at the global scale	None at the global scale	The United Nations 'Sustainable Development Goals' provide a range of ambitious goals from improved water quality to reduced food waste, but do not mention P directly in targets.	United Nations (2014) Kanter and Brownlie (2019)

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