10 Transforming cities

Securing food and clean waterways through a transdisciplinary phosphorus approach

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Introduction

As an essential input to crop growth via soil reserves or fertilizer, phosphorus underpins global food security. Without phosphorus, food could not be produced, yet phosphorus is mined from finite reserves, most of which are controlled by only a few countries[1] (UNEP 2011; Jasinski 2015; Cordell and White 2014). Fertilizer prices are likely to increase as finite reserves become critically scarce. Globally, a billion farmers and their families cannot access fertilizer markets and many rely on phosphorus-deficient soils that produce low crop yields (IFPRI 2003). Moreover, mismanagement along the phosphorus supply chain from mine to field to fork has resulted in massive losses and waste, which largely ends up in waterways, causing nutrient pollution and algal blooms (Bennett, Carpenter and Caraco 2001). The global phosphorus challenge is inherently complex; it is as much about international relations as farm soil fertility. It transcends disciplines, sectors, and scales – from geopolitics to ecology to nutrition. In this chapter, we describe and reflect upon a new project using a novel transdisciplinary approach to address this phosphorus challenge.

Achieving phosphorus security will mean that all farmers have access to fertilizers, that all people have access to nutritious diets, that our rivers, lakes and oceans are clean, and that our soils are fertile and agriculture is productive (Cordell and White 2014). Without engaging stakeholders from key sectors – from agriculture to health to sanitation – the goal of phosphorus security probably cannot be achieved.

P-FUTURES[2] complements recent global and national phosphorus initiatives (Table 10.1[3]) by targeting the local urban scale across a range of low-, medium- and high-income countries. At the city level, the P-FUTURES collaboration aims to identify how urban food and water systems may cope, adapt or transform in response to the global phosphorus challenge. Cities are crucial entities in the response to this global challenge. More than half the world's population already lives in cities – demanding food, water, housing and jobs and putting huge pressures on existing land, energy, transport systems, social services and other resources. These pressures have led to pollution, social inequity, insecurity of land tenure, and congestion

in many cities (UN-Habitat 2013). Cities are centres of both food consumption and waste generation and so they are indispensable to phosphorus security (Metson et al. 2015).

It is important to note that while all countries, and cities, are exposed to the same global stressors and drivers – such as the market price of phosphate fertilizers – phosphorus vulnerabilities are very context specific (Cordell and Neset 2014; Metson et al. 2015). This means that what works in one region may be inappropriate or ineffective in another region. For instance, while recovering nutrients from wastewater to replace imported phosphate might be a possible pathway to phosphorus security in Europe, this alone would be insufficient for Australia. This is because much of Australia's phosphorus-rich agricultural products such as beef, wheat and dairy are exported and hence consumed overseas. At best, domestic wastewater recycling in Australia would only meet 3–5 per cent of national phosphorus fertilizer demand (Cordell et al. 2013; Cordell and Neset 2014).

Table 10.1 Global, regional and national phosphorus platforms that have formed since 2008 to address global phosphorus security

Program	*Scale*
Global Partnership on Nutrient Management's Phosphorus Task Team (United Nations Environment Programme) http://www.nutrientchallenge.org/press-release/launch-gpnm-phosphorus-task-team	Global
The Global Phosphorus Research Initiative (GPRI) http://phosphorusfutures.net	Global
Global TraPs http://www.globaltraps.ch/	Global
European Sustainable Phosphorus Platform (ESPP) http://phosphorusplatform.eu/	Regional: European Union
North American Partnership for Phosphorus Sustainability (NAPPS) and Sustainable Phosphorus Research Coordination Network (P RCN) https://sustainablep.asu.edu/about	Regional: North America
Dutch Nutrient Platform http://www.nutrientplatform.org/	National: the Netherlands
Deutsche Phosphor-Plattform http://www.deutsche-phosphor-plattform.de/	National: Germany
National Strategic Phosphorus Advisory Group (NSPAG) http://phosphorusfutures.net/national-strategic-phosphorus-advisory-group-nspag/	National: Australia

The P-FUTURES transdisciplinary approach was specifically designed to respond to three key complexities associated with the phosphorus challenge. First, the relatively unknown nature of the challenge means there is little pre-existing stakeholder awareness, interest or momentum. Second, the challenge traverses diverse sectors and the current governance of phosphorus is balkanized and fragmented where it exists at all. Third, adaptation is local and contextual; while there is a need for co-learning among cities, the way cities experience phosphorus vulnerability are unique, hence generic solutions cannot be universally applied.

A transdisciplinary approach: the P-FUTURES transformation framework

The P-FUTURES transdisciplinary approach is explicitly future- and outcomes-oriented. As per Mitchell et al. (2015, and this book) we define a transdisciplinary approach as one that intentionally seeks to create significant change towards sustainability, through meaningful stakeholder collaboration and by traversing disciplines, sectors, time, and geographical scales. In line with recent literature around transformations (e.g. Hackmann et al. 2014; Moore et al. 2014), we seek to 'transform' rather than 'tweak' systems. Small tweaks and uncoordinated actions will not be sufficient to solve sustainability challenges. To confront these challenges, we need deliberate and collective visions of a preferred society and implementations of sustainable transformations. However, processes that seek to envision the future must be legitimate with respect to the assumptions, values, and principles that the future embodies (Fazey et al. 2015) and should seek to avoid lock-in traps (Xu et al. 2015) that might reinforce existing social inequalities. Transformational changes need to be visionary, persistent changes, affecting multiple scales from household to global, cross-sectorial, and be socially equitable. This requires reframing research-practice approaches to explicitly consider how and who addresses these challenges (Hackmann et al. 2014). The P-FUTURES transdisciplinary approach seeks to ultimately transform cities from being polluters and consumers of non-renewable resources, to producers of renewable fertilizers, enabling our farmers to feed our population and ensuring our waters are clean, especially in less affluent regions.

In this section, we elaborate on our transdisciplinary approach, which draws from sustainability science (Lang et al. 2012; Brandt et al. 2013), adaptive capacity and learning (Pahl-Wostl 2009; Jacobs et al. 2014), future desirable pathways (Leach et al. 2010; Wiek and Iwaniec 2014) and transition management (Loorbach and Rotmans 2006). Later we reflect upon what it really means to seek such transformational change through a collaborative, transdisciplinary approach with stakeholders.

In line with Midgley (2003) and others, P-FUTURES is explicitly purposive in seeking to create transformational change. To lay the foundations for such transformational change, we 'begin at the end' (Mitchell et al. 2015). That is, we explicitly define and plan desired outcomes upfront in order to maximize the impact and use of our outcomes by policy-makers, practitioners, citizens and the private sector. This in turn informs our research design, including which stakeholders to engage and the likelihood of implementation outcomes that are transformational. Outcomes from this first phase (Phase I) include diverse 'knowledge artefacts' that target different audiences, such as a website (http://www.p-futurescities.net/), journal articles, local and international media and proposals for further funding. Other important outcomes include 'mutual and transformative learning', such as trust, momentum or 'readiness for change' (Fixsen et al. 2013), and cross-city and cross-sector learning (Iwaniec et al. 2016). Desired outcomes for Phase II (currently in the planning stage) include changes in the 'situation', that is, shifts in strategic urban planning policy, changes in farmer behaviour and practice, changes in food consumption patterns and diet quality, and the formation of new, local networks committed to action.

P-FUTURES seeks to achieve these changes by first investing in strategic and collaborative approaches to identify key barriers and opportunities within each city, rather than rushing to implement shallow solutions that may prove ineffective and expensive. For example, instead of beginning work by implementing a technology to recover phosphorus from wastewater,

presuming this is the appropriate solution, we first explore '*What would it take for rivers and lakes to be clean from phosphorus pollution?*', '*What is stopping this from happening?*', '*What resources does our city have, and what do we need?*' and '*Who needs to be involved?*'.

To ensure this trajectory persists, we must co-develop the capacity and momentum to change how we govern phosphorus. Working collaboratively with city stakeholders in Vietnam, Australia, Malawi and the USA, P-FUTURES assessed each city's unique urban vulnerabilities to phosphorus insecurity and its capacity to transform. Local stakeholders included farmers, sanitation and waste managers and regulators, urban and land-use planners, food distributors, environmental protection agencies, water service providers, public health and nutrition specialists, and fertilizer producers and distributors.

This broad stakeholder involvement ensures that emerging outcomes are legitimate, relevant and salient to both policy and practice (Cash et al. 2003) for a large cross-section of actors that affect, and are affected by, the phosphorus challenge. For example, in Hanoi, a lead urban planner at the government's Institute for Urban and Rural Planning, who is responsible for overseeing the implementation of the Greater Hanoi Master Plan, is a core P-FUTURES partner, ensuring that project outputs are policy-salient and will be included in the next phase of developing the Hanoi Master Plan.

Phase I process: identifying seeds for change

The P-FUTURES transdisciplinary approach created a hybrid top-down and bottom-up phosphorus vulnerability assessment framework, drawing from the Earth Systems Governance analytical framework (Biermann et al. 2009) and the Sustainable Livelihoods Approach (Ellis 2000) respectively (see Figure 1 in Iwaniec et al. 2016). Phase I first involved intensive stakeholder workshops and field visits in each city to explore local risks and opportunities associated with global and local phosphorus scarcity and pollution (see Figure 10.1). Experiential field visits enabled the international and local P-FUTURES researchers to gain a deeper understanding of local pressures, drivers and opportunities within each city. The teams were able to speak with local stakeholders in a range of locations, including smallholder peri-urban farms, under-serviced low-income neighbourhoods on the urban fringe, food markets, new residential development precincts, nutrient-rich lakes and rivers, landfills and composting plants, fertilizer production plants and wastewater treatment and recycling plants. The nature of each city's phosphorus vulnerability – and how they choose to cope or transform – is dependent on local factors like farmers' purchasing power, the sensitivity of waterways to nutrients, dependence on phosphate imports, and the status of transport and sanitation infrastructure (Cordell and Neset 2014; Metson et al. 2015).

A core activity was facilitating stakeholder dialogue to create shared visions, goals and pathways unique to each city. Linking global phosphorus issues to existing city priorities around food, energy and water security initiated the development of desirable scenarios and sustainable phosphorus strategies. For example, current stakeholder priorities across the four cities ranged from seeking total sanitation coverage in both urban and rural areas, through to ensuring viability of intensive horticultural producers and labour supply. Most priorities in

each of the four cities were not directly related to phosphorus. To identify the indirect links, we explored ‘what if?’ scenarios, such as ‘What if the price of phosphate fertilizers were to spike 500 per cent again, sustained over a year? How would our city or sector experience this?’.

Figure 10.1 Experiential learning and interactive workshops: (a) voting for priority actions in the Hanoi stakeholder workshop, (b) Sydney peri-urban farmer explaining the pressures on his livelihood due to rising land prices and urban expansion to Hanoi P-FUTURES partner, (c) Phoenix P-FUTURES partner led through the local Blantyre landfill and peri-urban maize plots, (d) Blantyre stakeholders mapping their city's food-water-sanitation-health system inter-linkages and vulnerability to phosphorus scarcity

The workshops, field visits and dialogues aimed to identify areas where capacity building is needed to deliver sustainable transformation, both individually and collectively. That is, novel use of available resources for adaptation and an enabling environment that allows transformational outcomes to be pursued. Specifically, workshop activities were designed to enhance: capacity for integrated systems approaches by identifying relationships among goals, strategies and challenges across sectors and scales; future-oriented capacity by envisaging and critiquing future scenarios and pathways; and solutions-oriented capacity by scrutinizing different potential solutions and strategies. Table 10.2 describes future transformational goals and transition pathways (i.e. initiatives identified to enable necessary shifts towards these goals). These goals and pathways were co-developed by stakeholders and researchers together in each Phase I city workshop.

Transformation insights and opportunities

Undertaking the P-FUTURES transdisciplinary process described above, in parallel in four culturally, geographically and economically different cities, and across four continents, resulted in unique insights and locally significant opportunities. This section highlights one transformation insight or opportunity that emerged from each city during Phase I, while the subsequent section reflects on the transdisciplinary process itself.

Transforming Blantyre (Malawi): identifying change agents in the fertilizer sector

The Blantyre P-FUTURES process revealed that a key opportunity for unlocking the potential for renewable phosphorus fertilizers sourced from excreta may lie in a single change agent in Malawi's fertilizer sector. Creating a viable renewable phosphorus supply chain could have significant short- and long-term benefits in terms of security of fertilizer supply, sanitation coverage for peri-urban residents, improved river health and reduced disease transmission from polluted water. This insight emerged largely though the experiential field visit.

In land-locked Malawi, most phosphate fertilizers are imported from China and Morocco via a port in Mozambique. The country's only fertilizer company also manufactures fertilizers using local phosphate mined in Phalombe, about 90km from Blantyre, Malawi's second largest city. Most of the food crops grown using these fertilizers are consumed in and around Blantyre, or are used for growing tobacco and tea for export. Malawi's Ministry of Agriculture provides significant seed and fertilizer subsidies to farmers, 88 per cent of whom are subsistence maize farmers.[4]

Table 10.2 Examples of co-created transformative goals and priority transition pathways in Phase I across four P-FUTURES cities, indicating diversity and local context

Transformative goals	*Transition pathways*
Blantyre, MALAWI:	
• Reduce Malawi's (and hence Blantyre's) dependence on imported phosphate by 50% by 2025 and 80% by 2035 • Profitable nutrient recovery from all wastewater ensuring minimal nutrients are discharged to water and value-adding to waste management • Protection of drinking water sources for all Blantyre residents from upstream phosphorus pollution • Reforestation of all catchment areas in Blantyre by 2020	• Civic education through media campaign and engaging peri-urban block leaders and Village Chiefs • Farmer co-op for dialogue on the benefits of reuse & coordinate shared infrastructure needs for organic fertilizers • Regulation and enforcement, including those from the Ministry of Agriculture to implement a 50% reduction in the dependence on imports, effective coordination, reforestation, maintaining buffer zone for rivers etc • Temporary artificial incentives to encourage renewable phosphorus entrepreneurs to enter the market
Sydney, AUSTRALIA:	
• Waste is treated as a productive resource within Sydney's circular economy, contributing to agricultural production • Utilising majority of organic waste (80-90%) – set real targets for reuse • High level of on-farm recycling of nutrients through composting and wastewater management strategies	• Increasing awareness around the phosphorus issue among growers, the fertilizer industry, and the waste management industry • Create a market for the waste • Provide independent advice for farmers, including demo sites, good communication including digital resources

	• Require soil testing to ensure farmers apply the appropriate amount and form of phosphorus
Hanoi, VIETNAM:	
• Incentivise the reuse of huge stock of phosphorus from livestock manure, including adaptive technologies, farmer willingness & training. Involve extension service providers, NGOs (e.g. Farmers Union) and the Ministry of Agriculture & Rural Development • Create more effective government policy, tools & enforcement strategies around livestock manure reuse, taking into consideration the spatial and temporal variability in manure availability across regions	• Undertake a foundational phosphorus budget for Greater Hanoi in collaboration with utilities, academics & government authorities • Assess the viability of phosphorus-recovery technologies via pilots, in collaboration with farmers • Identify appropriate & effective policies to support sustainable phosphorus futures in Hanoi, in collaboration with government authorities • Analyse market demand for recovered phosphorus together with farmers, academics and wastewater & solid waste utilities
Phoenix, USA:	
• Effective governance for resource use / reuse • Increase small-scale urban agriculture (not intended to replace projected decreases in peri-urban agricultural land use) • Increase on-site and near-site recycling for agriculture and landscaping • Waste is treated as a productive resource within an "almost zero waste" circular economy	• Set ambitious and clear resource use / reuse targets • Develop Agriculture Hubs Master Plan • Link phosphorus management to existing municipal goals and challenges (water, energy, food, infrastructure) and increase awareness of goals and challenges • Programs to improve diet (food distribution and consumption) • Foster new waste markets and reuse innovations

Relying largely on imported phosphate via a foreign port makes Blantyre vulnerable to disruptions and price fluctuations in the global phosphate market. However, the potential production of local fertilizers using renewable sources may present an opportunity to increase farmer fertilizer security in Blantyre. The country's only fertilizer company, which has its production plant in the centre of Blantyre, has had recent, small-scale success producing the country's first commercial chicken manure fertilizer. The producer overcame odour challenges associated with manure use in urban areas by mixing the manure with local crop waste – tobacco husks.

The production manager and the company are proud of the success the product has had on the market, and are conceptually open to other organic feedstocks for fertilizer production, such as human excreta. However, procuring sufficient quantities of organic feedstock continues to be a challenge for commercial production. Due in part to lower prices, there is a perceived strong market demand for commercial 'renewable fertilizer'. However, the volume and reliability of supply from manure (or wastewater) is a limitation for commercial viability. As the production manager noted with respect to excreta 'don't talk to me about five tonnes a day, come back when you have 100 tonnes a day'. A next step could be to assess the feasibility of logistics, farmer preferences, demand and co-benefits in collaboration with sanitation providers, ecological sanitation NGOs and farmers.

Transforming Sydney (Australia): strategic planning for peri-urban food production creates opportunities for local renewable fertilizers

The Sydney P-FUTURES approach tapped into the city's current strategic urban planning process coupled with increasing stakeholder concerns regarding the vulnerability of Sydney's food system to urban expansion in a geographically constrained basin (Jacobs et al. 2014). Integrating both strategic food production and phosphorus management into the planning process could contribute to improved farmer terms of trade and a more resilient Sydney food system while reducing phosphorus-induced water pollution in the surrounding Hawkesbury Nepean catchment.

Sydney's Metro strategy 'A plan for growing Sydney' (NSW Government 2014) focuses primarily on the provision of housing, jobs and transport (mainly roads). It mostly ignores the strategic prioritization, preservation or even identification of fertile agricultural land within the Sydney Basin. This creates a risk to Sydney's food supply, public health and places further pressure on Sydney's farmers – many of whom are leaving or selling due to increasing land prices and unworkable terms of trade and development requirements (ISF 2016).

Local food production can have the benefit of shorter supply chains, which reduce food's energy footprint and waste generation, buffer against fuel price spikes, supply disruptions and climate change impacts, while providing fresher produce for increased health outcomes. Several projects and collaborations are directly responding to such threats and opportunities (Edge Land Planning 2015; ISF 2016) by identifying the future feasibility and desirability of local food production to meet demand from Sydney. Spatial maps of current and future food production and demand can create an evidence base to support local and state government decision-making to stimulate and support agricultural productivity in the Sydney Basin (e.g. through appropriate zoning).

Importantly, stimulating and supporting urban and peri-urban agriculture also creates an opportunity for recycling nutrients like phosphorus locally in urban wastes instead of relying on imports. Further, the high charges imposed on disposal to landfill in Sydney are a strong driver to divert organic waste from landfill. However, the Sydney P-FUTURES stakeholder workshop identified a need for an evidence base and for increasing awareness around the phosphorus issue among growers, the fertilizer industry and the waste management industry in the Sydney Basin.

To address these gaps, the P-FUTURES Sydney team created geospatial maps of phosphorus supply in the Sydney Basin (including spatially explicit sources from urban food and green waste, excreta and manure). These maps revealed that in Sydney there is the potential to obtain from urban organic waste fifteen times more phosphorus than is required for peri-urban agriculture (Metson and Cordell forthcoming).

Lack of awareness and knowledge gaps between sectors were addressed through a second Sydney workshop held to bring together a diverse set of supply-chain actors, including farmers, agronomists and waste managers.[5] This workshop revealed an initial understanding of 'what farmers want' (i.e. their needs and preferences) with respect to fertilizers and soil amendments. Group activities also identified preliminary bottlenecks preventing uptake, including institutional, financial, psychological and technical barriers, through asking critical questions such as 'What would stop you from using/advising/selling these composts and renewable fertilizers?' In some cases obstacles can be as simple as a farmer lacking access to suitable equipment to apply organic materials to the land. A comprehensive social research

project is now under way to probe deeper and more methodically into such barriers and opportunities to unlock the potential for reusing phosphorus-rich urban waste in vegetable production in peri-urban Sydney. Collectively, these initiatives seek to enable new market opportunities for renewable fertilizers and soil amendments, transformation of waste managers into resource entrepreneurs, increases in farmer fertilizer security and prevention of urban nutrients from being lost through the deep ocean outfalls at Sydney's coastal wastewater treatment plants or through being buried in landfill.

Transforming Hanoi (Vietnam): ambitious recovery of organic solid waste

Hanoi's P-FUTURES process identified current drivers in the city's urban planning process to stimulate phosphorus management. This could enable long-term strategic, efficient and coordinated planning for the composting of organic waste from sources including household and market food waste and septic tank sludge across the city. In peri-urban areas, composting of manure with enzymes to make fertilizers for farming has been a common practice for decades because of the rich nutrients (i.e. phosphorus) in manure. However, there has been no control in quality of these fertilizer products at the household scale in terms of health risks.

The city of Hanoi has ambitious goals through its 2030 Greater Hanoi Master Plan, which addresses the current challenges of increasing urbanization and competing land uses, rising land prices and industrialization.[6] Such challenges have led to serious concerns regarding the relocation of rice paddies and other agricultural land, food security, resource scarcity, sanitation and pollution of water bodies. The timing of the strategy creates an opportunity to link identified phosphorus priorities within their implementation plans, which are under development. Further, the administrative boundaries of Greater Hanoi, which now include a third of the province and substantial agricultural land, create an opportunity for streamlined urban planning of reuse of the city's organic waste in agriculture.

Hanoi's waste management sector is making great progress towards the city's ambitious goal of 70 per cent organic waste recycling by 2050.[7] Every day, approximately 6500 tonnes of household waste are generated in the city and this is expected to double by 2030.[8] Ninety per cent of this waste is currently landfilled. One landfill operated by Hanoi's main waste service provider produces compost from municipal waste that is made available free of charge to farmers and urban landscapers. The compost is in high demand, especially in the landscaping sector associated with new construction. However, agriculture accounts for approximately 70 per cent of the national economy, creating a large potential demand and market for recycled phosphorus through high quality compost.

Next steps could be to continue working with Hanoi's planning department to operationalize and scale up compost production by integrating phosphorus governance into the Greater Hanoi Master Plan's sub-sector implementation plan – for example by including phosphorus reuse targets in the compost strategy and for the proposed food growing districts. Further research projects could focus efforts on increasing household separation of waste to reduce organic waste contamination with plastics, metals and other non-compostable fractions, a problem which is currently unresolved. Evaluation of markets and quality assurance of fertilizers could be other aspects for future research.

Transforming Phoenix (USA): unlikely drivers for phosphorus stewardship

In Phoenix, P-FUTURES leveraged existing scenario co-development research to explore potential implications for global and local phosphorus sustainability. Workshop activities focused on identifying synergies and linkages between phosphorus sustainability goals and adaptive scenarios that were created in response to extreme drought, heat and flooding rain. For example, one group focused on how worsening drought conditions could decrease water availability and thus the amount of viable agricultural land and associated pathways for phosphorus recycling (as recycled water would be used for direct human consumption). This could increase the city's dependence on imported food and thus imported phosphorus, potentially increasing local vulnerability to phosphorus price fluctuations, while also outsourcing potential water pollution risks associated with phosphorus losses.

These insights built on work which identified serendipitous recycling schemes already existing in the region. The greater Phoenix area currently recycles significant amounts of phosphorus through the reuse of wastewater, manure and biosolids in the surrounding agricultural landscape (Metson and Hale et al. 2012). However, this is not because the city is currently making phosphorus recycling a priority. Indirect market forces and concerns about water scarcity have encouraged high phosphorus recycling in local agriculture (Metson, Aggarwal and Childers 2012). A drop in cotton prices and an increase in milk prices created a situation where it was easy to reuse phosphorus from dairy cattle manure on alfalfa crops (planted instead of cotton to support milk production). In addition, Phoenix relies on water resources from outside the state, so the region is concerned with water availability and thus reuse. Having crops, animals and human settlements in close proximity allows crops to be watered and fertilized through recycling.

However, this is not a transformational ‘sticky’ change (Levin et al. 2012) because if market forces or water accessibility conditions were to change, phosphorus recycling could disappear as quickly as it appeared. The P-FUTURES workshop highlighted how such recycling could indeed disappear as phosphorus was not considered to be a priority. Current serendipitous recycling does however give us a glimpse into what could be done if municipalities decide to purposefully manage phosphorus as an alternative to current strategies.

Bringing phosphorus into the urban research and planning arena is no small feat in Phoenix, given that other global change challenges are already in the spotlight. Future research directions will focus on creating greater awareness and understanding of the linkages between phosphorus sustainability and these other priorities in order to facilitate the creation of more robust win-win solutions.

Reflections and implications: creating transdisciplinary transformations in practice

Undertaking such an ambitious and deeply collaborative research project across four countries, incorporating over 95 researchers and stakeholders as partners, and traversing and transcending divergent disciplines, was destined to be a deeply challenging yet insightful exercise. Lessons learnt in this project about the challenges and successful strategies for

transdisciplinary transformations largely related to team dynamics and interpersonal traits, including relationships, agendas and perspectives, commitment, flexibility, and critical reflection. We now discuss the four main lessons learnt.

First, co-development in practice, that is, involving researchers and stakeholders as full partners, has pragmatic and political implications. By definition, diverse stakeholders will have a diverse set of agendas. While some agendas may be complementary, others may conflict, or sit outside the scope of the project. Finding the balance between honoring a commitment to participating stakeholders, the spirit of collaboration, and the integrity of the project can be arduous and time consuming. Even within research teams, tensions and trade-offs can exist. For example, some partner cities began the project with a strong interest in wastewater technology, which conflicted with the funder's strong desire for social science approaches, and the project coordinators' desire for a strongly transdisciplinary approach that integrated both social-institutional systems with biophysical systems. Consequently, project management for P-FUTURES was often challenging, and at times this led to long debates on the ethics and risks of true stakeholder co-development. While committing to such stakeholder involvement can be a high-risk approach, it can also have a high pay-off, leading to 'aha' moments and the emergence of new insights (such as in the Malawi case regarding the potential for commercializing excreta-derived fertilizer) that are often crucial to creating the kinds of bold transformative changes necessary for responding to complex challenges such as phosphorus security.

For such complex transformative projects with an inherent high level of uncertainty and many moving parts, the agility of the team was crucial. That is, all partners needed to be committed to openness to new ideas, directions, approaches and opportunities. Both researchers and stakeholders developed transformational research capacity through Phase I of the project, including agility in methodological approaches and malleability of views of the 'challenge'. While the overall framework for transdisciplinary, transformational change was consistent among the four diverse cities, the P-FUTURES team tailored workshops and field visits to be locally relevant and culturally sensitive. For example, Malawi's engagement process started with the co-development of new scenarios and visions, whereas in Phoenix the entry point was focused on existing futures work. The malleability of researcher and stakeholder perspectives was apparent; one research partner, who emerged as central to the project, noted at the outset of the project that he had never thought of phosphorus as more than an environmental chemical pollutant (his area of expertise) and that participating in this project transformed his worldview on phosphorus and what is possible.

Secondly, bringing the conversation back to the ultimate goals of the project – creating cities that are food and water secure – made it possible to step outside one's own particular field of expertise as a researcher, or one's agenda as stakeholder, and focus on understanding the challenges and opportunities of phosphorus governance from a full systems perspective. In Hanoi, for example, when workshop activities were not eliciting the enthusiasm for the broader project goals that was desired by the P-FUTURES research team, a local researcher was able to re-energize the workshop by synthesizing each project participant's interest in finding future solutions pathways into diverse research and practice agendas. Participants then voted on these priorities and scrutinized why and how such solutions could work and

complement each other.

Third, the strategic entry points into this project were crucial to getting the right stakeholders around the table, and to fostering deep learning. After eight years of leading phosphorus-related projects, it became apparent to the core research team that, unless there is a specific, direct and immediate driver for improved phosphorus governance (a 'hook' such as persistent and costly algal blooms or serious fertilizer supply disruptions), many stakeholders are not interested in the phosphorus challenge – a challenge which they may never have heard of before. Instead, P-FUTURES was designed to start with stakeholders' priorities and agendas, scaling out from there towards global phosphorus vulnerability. This successful hybrid bottom-up/top-down approach enabled the project to combine short-term, local goals with long-term, global sustainability goals. For example, although Sydney's short-term focus has been on urbanization at the expense of agricultural land preservation, the P-FUTURES project demonstrated that longer-term sustainability for the city must include a food system that is less dependent on volatile global phosphorus markets, and that such a system could include jointly prioritizing agricultural production and local phosphorus reuse to increase local food security and water quality.

Finally, constant critical questioning was a necessary and ongoing theme nurtured in both individual and group settings. For example, a table group at the Malawi stakeholder workshop first identified 'improved wastewater treatment' as a key action to achieve their transformative goal of 'Reduc[ing] Malawi's dependence on imported phosphate by 50 per cent by 2025' (Table 10.2). P-FUTURES researchers probed iteratively: '*Is this transformative? Is there any current incentive or driver to take action? Who needs to (or could) make this goal happen? Who holds the power?*' Such probing yielded a completely new proposed pathway from local stakeholders: 'civil education through media campaign and engaging peri-urban Village Chiefs' (Table 10.2).

Conclusions

Phosphorus security is a truly 'wicked problem', yet an essential one to tackle for food and water security. By bringing together diverse partners from different sectors, countries, levels of seniority, genders and cultures, P-FUTURES Phase 1 has planted the seeds of a long-term transdisciplinary partnership. That is, it has established fundamental relationships, trust, motivation, common ground and initial identification of phosphorus-related risks and opportunities unique to each city's context. Achieving phosphorus security for health, sanitation, water and livelihood outcomes is a highly complex challenge requiring an equally creative and ambitious approach.

The P-FUTURES Network of researchers and stakeholders goes beyond observing, facilitating or analyzing the process. We seek to co-create deep and 'sticky' change – that is, pathways to an agreed future that are durable and not easily undone or lost due to a change of government or other external factors. In order to achieve these ambitious outcomes in vastly different settings, the research team drew from a variety of disciplinary tools and global and local knowledge, but perhaps most importantly remained open and highly reflexive throughout the process. All partners, researchers and stakeholders sought to enhance adaptive capacity,

building on their existing interests and skills to address the demands, required technologies, effective policies/incentives and business potential to make P-FUTURES a sustainable approach.

However, we acknowledge that this first phase, in and of itself, does not constitute transdisciplinary, transformational change. Instead, it is only a trajectory towards co-producing more inclusive and equitable change. Much of the literature defines transdisciplinarity as the integration of different disciplinary and non-academic perspectives. We define transdisciplinarity as intentionally seeking solutions-oriented knowledge and significant change towards sustainability, through meaningful collaboration among stakeholders.

Notes

1 Morocco controls 74 per cent of the world's remaining high-quality phosphate rock (Jasinski 2015).
2 http://www.p-futurescities.net
3 Some P-FUTURES partners are members and/or co-founders of these national and international platforms.
4 The subsidies started in 1995 as Targeted Farm Inputs. Farmers received 5kg fertilizers and seed as a starter pack (Dorward and Chirwa 2011). Currently, about 1.5 million farmers are targeted and each farmer receives 2 bags of fertilizer, 5kg maize seed and 2kg of legume seeds (personal communication, officer at Ministry of Agriculture, Irrigation and Water Development).
5 Workshop 'The changing phosphorus landscape: Risks and opportunities for agriculture and waste management in the Greater Sydney Basin' (http://www.p-futurescities.net/the-changing-phosphorus-landscape-risks-opportunities-for-agriculture-and-waste-management-in-the-greater-sydney-basin/)
6 Prime Minister's Decision 1239/QD-Ttg, dated 26 July 2011. Decision on approval of General Master Plan for construction of Hanoi Capital to 2030, vision to 2050 (in Vietnamese).
7 Prime Minister's Decision 609/QD-Ttg, dated 25 April 2014. Decision on approval of General Master Plan for Solid Waste Management of Hanoi Capital to 2030, vision to 2050 (in Vietnamese).
8 Prime Minister's Decision 609/QD-Ttg, dated 25 April 2014. Decision on approval of General Master Plan for Solid Waste Management of Hanoi Capital to 2030, vision to 2050 (in Vietnamese).

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