

# The Story of Phosphorus

## Sustainability implications of global phosphorus scarcity for food security

PhD thesis

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This thesis is the product of a *cotutelle* agreement (collaborative doctoral degree)  
between the following two institutions:

Institute for Sustainable Futures, University of Technology, Sydney  
(PhD in Sustainable Futures)

and

Department of Water and Environmental Studies, Linköping University  
(PhD in Water and Environmental Studies)

## **CERTIFICATE OF AUTHORSHIP/ORIGINALITY**

I certify that the work in this thesis has not previously been submitted for a degree and nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and in the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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## ACKNOWLEDGEMENTS

When I told people I was undertaking a joint PhD literally between Australia and Sweden, they tended to visualize an exotic life of a young researcher networking the globe and chasing endless summers between Sydney's sunny beaches and Sweden's idyllic forests bursting with wild blueberries and *kantareller* mushrooms. While that image was relatively true, there was the less exotic side of physically shifting an office worth of literature and ideas back and forth across the globe; of never fitting into bureaucratic boxes of the universities, immigration board or insurance companies; of continually packing and unpacking apartments, of missing the births, weddings and birthdays of friends and family; not to mention the guilt of clocking up thousands of CO<sub>2</sub> miles, all in the name of 'sustainability' research.

Finding the motivation to work day and night for 3½ years was rarely a challenge in this doctoral journey. The topic was enthralling and the research exhilarating to me at (almost) all times. Even frequent face-to-face supervisor meetings across time zones that differed by eight hours were quite straightforward thanks to *skype* and *iCHAT* and inbuilt laptop cameras. The real challenges were: firstly, commencing research on a problem situation that many scientists and policy-makers dismissed because they believed 'the market would take care of it'; secondly, taking to the scientific investigation a non-conventional transdisciplinary approach that responded to the changing situation rather than adhering to a single, traditional disciplinary boundary; and finally, navigating a PhD between not just two countries, but two very different university institutions with different values, structures and approaches.

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## PAPERS

This thesis is based on the following five papers, which will be referred to in the text by their Roman numerals:

### ***Paper I:***

Cordell, D., Drangert, J.-O., and White, S., (2009), *The story of phosphorus: Global food security and food for thought*. **Global Environmental Change**, 2009. 19(2009) p. 292-305.

### ***Paper II:***

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### ***Paper III:***

Cordell, D. (submitted), *Phosphorus: A nutrient with no home – multiple stakeholder perspectives on a critical global resource for food security* (Submitted for publication).

### ***Paper IV:***

Cordell, D., Neset, T. S. S., Drangert, J.-O. & White, S. (2009), *Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand*, International Conference on Nutrient Recovery from Wastewater Streams, Vancouver, 2009. Edited by Don Mavinic, Ken Ashley and Fred Koch. ISBN: 9781843392323. Published by **IWA Publishing**, London, UK. (p.23-44 reprinted with permission from the copyright holders, IWA Publishing).

### ***Paper V***

Cordell, D. & White, S. (submitted), *The Australian story of phosphorus: Implications of global phosphate scarcity for a nation built on the sheep's back* (Submitted for publication).





# TABLE OF CONTENTS

<b>CHAPTER 1: INTRODUCTION .....</b>	<b>1</b>
<b>CHAPTER 2: RESEARCH PURPOSE AND SCOPE .....</b>	<b>3</b>
2.1 SCOPE, GUIDING PRINCIPLES AND VALUES .....	3
2.2 PURPOSE .....	4
2.3 THESIS STRUCTURE AND CENTRAL ARGUMENT .....	5
<b>CHAPTER 3: TRANSDISCIPLINARY RESEARCH FRAMEWORK: FROM THEORY TO METHOD .....</b>	<b>9</b>
3.1 A TRANSDISCIPLINARY FRAMEWORK IN AN UNPRECEDENTED ERA OF GLOBAL ENVIRONMENTAL CHANGE .....	9
3.1.1 <i>Why transdisciplinarity?</i> .....	9
3.1.2 <i>Current challenges for transdisciplinary research: critical reflections</i> .....	14
3.2 SYSTEMS THINKING: AN OVERARCHING THEORETICAL FRAMEWORK FOR TRANSDISCIPLINARY RESEARCH .....	19
3.2.1 <i>Scope and boundary critique</i> .....	22
3.3 METHODOLOGICAL FRAMEWORK .....	25
3.4 DATA .....	28
3.4.1 <i>Data sources</i> .....	28
3.4.2 <i>Data scarcity and accountability</i> .....	31
3.5 METHODOLOGY FOR ANALYSING THE PHYSICAL SYSTEM .....	33
3.5.1 <i>Substance Flows Analysis (SFA) and Industrial Metabolism</i> .....	33
3.5.2 <i>Peak resource production curve</i> .....	36
3.5.3 <i>Future scenarios: probable, possible and preferred futures</i> .....	37
3.6 METHODOLOGY FOR ANALYSING THE 'HUMAN ACTIVITY' SYSTEM .....	39
3.6.1 <i>Soft Systems Methodology</i> .....	40
3.6.2 <i>Semi-structured stakeholder interviews: design and analysis</i> .....	42
3.6.3 <i>Institutional analysis: Young's 'Lack of Fit' framework and Vatn's social-ecological framework</i> .....	47
3.7 NATIONAL CASE STUDY .....	49
<b>CHAPTER 4: THREE GLOBAL CHALLENGES: ENVIRONMENTAL CHANGE, FOOD SECURITY AND RESOURCES SCARCITY .....</b>	<b>53</b>
4.1 AN UNPRECEDENTED ERA OF GLOBAL ENVIRONMENTAL CHANGE .....	54
4.2 DOMINANT DISCOURSES ON GLOBAL FOOD SECURITY .....	59
4.3 CONCEPTUALISING RESOURCE SCARCITY .....	64
4.3.1 <i>Peak everything</i> .....	71
4.3.2 <i>Comparing non-renewable and renewable resource attributes</i> .....	73
<b>CHAPTER 5: PHOSPHORUS USE, MANAGEMENT AND PERCEPTIONS IN THE GLOBAL FOOD SYSTEM .....</b>	<b>79</b>
5.1 CONCEPTUALIZING PHOSPHORUS IN SOCIETY .....	79
5.2 PHOSPHORUS FOR GLOBAL FOOD PRODUCTION .....	83
5.2.1 <i>The importance of phosphorus in crop growth</i> .....	83
5.2.2 <i>A new challenge: securing phosphorus sources in modern agriculture</i> .....	86
5.2.3 <i>The issue of scale</i> .....	94
5.3 PHOSPHORUS AS AN ENVIRONMENTAL POLLUTANT .....	96
5.4 PHOSPHORUS RECOVERY AND RE-USE IN THE SANITATION SECTOR .....	96
5.5 GOVERNANCE OF PHOSPHORUS IN THE GLOBAL FOOD SYSTEM .....	100
5.5.1 <i>Institutional architecture of phosphorus: policies, worldviews, actors and roles</i> .....	100
5.5.2 <i>Effectiveness of the global governance of phosphorus</i> .....	106
5.6 A CHANGING SITUATION: A PARADIGM SHIFT UNDERWAY? .....	111
<b>CHAPTER 6: FROM PHOSPHORUS SCARCITY TO SECURITY: SYNTHESIS OF FINDINGS..</b>	<b>115</b>
6.1 FIVE DIMENSIONS OF PHOSPHORUS SCARCITY .....	115
6.2 WHAT WE KNOW, WHAT WE GUESS AND WHAT WE DON'T KNOW .....	119
6.3 PHOSPHORUS SECURITY .....	122
<b>CHAPTER 7: CREATING CHANGE TOWARDS SUSTAINABLE FUTURES .....</b>	<b>129</b>
7.1 SCIENCE AS INTERVENTION .....	129

7.2	THREE OUTCOME SPACES: PEER-REVIEWED KNOWLEDGE, SOCIETAL CONTEXT AND MUTUAL LEARNING	132
7.2.1	<i>Benefits of contributing to situation (societal) outcome spaces</i>	133
7.2.2	<i>Benefits of transformative or mutual learning</i>	134
7.2.3	<i>Contributions of this thesis to three outcome spaces</i>	135
7.3	A PARTICIPANT OBSERVER IN A RAPIDLY CHANGING FIELD	136
7.4	MEASURING SCIENTIFIC INTERVENTION	140
<b>CHAPTER 8: RECOMMENDATIONS AND CONCLUDING REMARKS</b>		<b>143</b>
8.1	CONCLUDING REMARKS	143
8.2	RECOMMENDATIONS	147
<b>APPENDICES</b>		<b>153</b>
	APPENDIX A: PHOSPHORUS CALCULATIONS & ASSUMPTIONS	155
	APPENDIX B: STAKEHOLDER INTERVIEWS	167
	APPENDIX C: SOFT SYSTEMS METHODOLOGY	175
	APPENDIX D: STAKEHOLDER ANALYSIS	179
	APPENDIX E: NATIONAL STAKEHOLDER WORKSHOP ON 'FUTURE OF PHOSPHORUS'	183
	APPENDIX F: PARTICIPANT-OBSERVATION	189
	APPENDIX G: QUALITY IN TRANSDISCIPLINARY RESEARCH	199
<b>REFERENCES</b>		<b>201</b>

## LIST OF TABLES

<i>Table 3-1: For each important aspect of phosphorus in the global food system, the actor, conceptual role and stakeholder group interviewed is indicated</i>	44
<i>Table 4-1: comparison of attributes of peak oil and peak phosphorus</i>	74
<i>Table 4-2: comparison of attributes of water and phosphorus in food production</i>	76
<i>Table 4-3: Comparison of renewable vs non-renewable resources, in terms of their physical and institutional dimensions</i>	77
<i>Table 5-1: multiple roles or functions of phosphorus in society. Some functions are inherently biological in nature, while others are due to anthropogenic interventions</i>	81
<i>Table 5-2: Dichotomies in society's perception of phosphorus – both excess and lack of phosphorus are problematic on multiple scales</i>	82
<i>Table 5-3: Five key worldviews with differing goals and implications for future global phosphorus resources</i>	103
<i>Table 5-4: Common perceptions of phosphorus in the literature by different roles</i>	104
<i>Table 6-1: Five dimensions of phosphorus scarcity: physical, economic, managerial, institutional and geopolitical</i>	117
<i>Table 6-2: 11 Sustainability criteria for future phosphorus security. These criteria also address the current environmental, economic, institutional and ethical challenges relating to global phosphorus scarcity</i>	126
<i>Table 7-1: Key contributions to the three outcome spaces: Peer reviewed academic knowledge, situation and mutual learning</i>	135

## LIST OF FIGURES

<i>Figure 2-1: Development of the central argument of this thesis. The location of each chapter and paper against each node is indicated.....</i>	8
<i>Figure 3-1: Transdisciplinarity as distinct from disciplinary thinking associated with disciplines, multidisciplinary and interdisciplinarity.....</i>	10
<i>Figure 3-2: The relationship between transdisciplinary research, systems thinking, resilience theory, action research and stakeholder engagement are indicated on the research hierarchy (y-axis) from theoretical framework to methodology to method. These approaches are all useful for addressing sustainability problems at the complex, messy end (x-axis).....</i>	12
<i>Figure 3-3: Interlinkages and influences of some systems approaches.....</i>	21
<i>Figure 3-4: Primary and secondary boundaries of the research scope. Issues on the boarder have been marginalized not because they are unimportant, but because they are being addressed in other research fora.....</i>	22
<i>Figure 3-5: Methodological framework indicating the scope of the analyses in three dimensions: 1) geographical scale (global to national), 2) time scale (short-term to long-term) and 3) epistemological perspectives (from more subjective perspectives (e.g. interpretivist) to more objective perspectives (e.g. post-positivist). Dotted lines indicate analytical connections between different components.....</i>	25
<i>Figure 3-6: Checkland's systems classification, indicating embeddedness and basic relationships between natural system, human activity system, designed physical system and designed abstract systems. Application to this doctoral research is also indicated.....</i>	26
<i>Figure 3-7: Transdisciplinary methodological framework: from data collection to analysis to findings. Other outputs have also been indicated and are explained in detail in chapter 7.....</i>	28
<i>Figure 3-8: Triangulating and supplementing data from primary and secondary sources.....</i>	29
<i>Figure 3-9: Conceptual substance flows analysis diagram showing the interactions between the 'anthroposphere' (human activity system) and the natural environment.....</i>	34
<i>Figure 3-10: Application of backcasting to sustainability studies. The conceptual diagram indicates that some studies, such as forecasting or short term studies may not be sufficient or powerful enough to reach a desirable level of sustainability, as they are more appropriate for marginal change, whereas backcasting is useful when extreme or radical change is required.....</i>	38
<i>Figure 3-11: Depiction of the Soft Systems Methodology as a dynamic and deliberative process moving between the 'real world' problem situation and the conceptual or abstract world.....</i>	41
<i>Figure 3-12: Description and positions of respondents interviewed and their stakeholder organisation associated with different aspects of the physical flows of phosphorus through the global food production and consumption system.....</i>	45
<i>Figure 4-1: Three global challenges that phosphorus scarcity directly relates to: global environmental change, global food security and global resource scarcity.....</i>	53
<i>Figure 4-2: "The Great Acceleration of the Human Enterprise": indicators of the exponential growth of human activity particularly since the post-World War II period.....</i>	55
<i>Figure 4-3: The Millennium Ecosystem Assessment's conceptualisation of ecosystem services supporting fundamentals of human wellbeing.....</i>	56
<i>Figure 4-4: Schematic diagram of the Integrated Model to Assess the Global Environment (IMAGE) version 2.4, indicating the absence of phosphorus next to carbon, nitrogen and water.....</i>	58

<i>Figure 4-5: ‘Safe operating space’ for nine planetary systems, indicating that the nitrogen cycle, climate change and biodiversity loss have exceeded the safe limit, while the phosphorus cycle is within safe limits.</i> .....	59
<i>Figure 4-6: Three dominant discourses on global food security: food availability (including energy and water scarcity discourses), food accessibility and food utilisation. Phosphorus scarcity is currently missing from the food availability discourse.</i> .....	60
<i>Figure 4-7: Factors limiting crop yields.</i> .....	61
<i>Figure 4-8: Conceptualisation of the food system, indicating the relationship between food system activities, outcomes (access, availability, utilization) and social-environmental drivers for change.</i> .....	63
<i>Figure 4-9: Resource scarcity conceptualized as occurring when societal demand cannot be met by supply due to various supply- or demand-side factors.</i> .....	65
<i>Figure 4-10: Cost of extraction (y-axis) of non-renewable resource (e.g. oil) increases exponentially as % resource remaining (x-axis) declines below a certain point.</i> .....	68
<i>Figure 4-11: Some analytical dimensions of resource scarcity along the (simplified) resource value chain. Resource scarcity can be analyzed for a range of resource units, sustainability dimensions, stakeholders and scales.</i> .....	69
<i>Figure 4-12: Classification of important resources by the UNEP-facilitated International Panel on the Sustainable Use of Natural Resources, indicating how phosphorus would fall through this net as it is both critical to food production and a non-renewable resource.</i> .....	70
<i>Figure 4-13: Conceptualisation of the ‘mineral fertilizer life cycle’, depicting how phosphorus and potassium are returned to the environment, essentially implying a closed loop system. Whilst phosphorus is indeed returned to the environment after consumption or from losses, the time gap between the environment sink and the source is approximately 10 million years. Hence this is more an open-looped, linear system.</i> .....	71
<i>Figure 4-14: Key theoretical phases of a peak curve during the lifetime of a critical non-renewable resource, where demand continues to increase.</i> .....	72
<i>Figure 4-15: The relative rate of natural recycling of renewable and non-renewable resources on a spectrum of time.</i> .....	77
<i>Figure 5-1: The evolution of phosphorus discourses: from the Philosopher’s Stone to use in war, food production, and more recently implication in water pollution. As argued in this thesis, the newest emerging discourse of the 21<sup>st</sup> century may be global phosphorus scarcity.</i> .....	80
<i>Figure 5-2: Origins of phosphorus in food in natural systems: humans get phosphorus from eating plants or animals, plants obtain phosphorus from soil solution, phosphorus in soil comes from weathered bedrock, which in turn comes tectonic uplift of the seabed. Time taken for phosphorus to convert from one form to another is indicated in order of magnitude.</i> .....	83
<i>Figure 5-3: Biochemical phase of the phosphorus cycle: phosphorus cycles naturally between plant and soil. Organic phosphorus in a dead plant decays, mineralizes to inorganic phosphorus and returns to the soil from where it came, ready to be assimilated via the roots of a new plant.</i> .....	84
<i>Figure 5-4: Availability of soil phosphorus to plants in four different phases, indicating that phosphorus is immediately available to plants for uptake when it is in soil solution, while at the other end of the spectrum, availability is very low when phosphorus is very strongly bonded, inaccessible, mineral or precipitated in the soil.</i> .....	85
<i>Figure 5-5: Historical (1800-2000) sources of phosphorus for global fertilizer use, including guano, excreta, manure and phosphate rock.</i> .....	86
<i>Figure 5-6: Peak phosphorus curve based on industry data, indicating a peak year of global phosphate rock production in 2033.</i> .....	87

<i>Figure 5-7: Global phosphorus reserves as reported in 2008. Remaining reserves are highly geographically concentrated and are under the control of only a handful of countries.....</i>	89
<i>Figure 5-8: Global phosphorus fertilizer consumption between 1961-2006 (in million tonnes phosphorus, P). The figure indicates that while demand in the developed world reached a plateau and then declined around 1990, fertilizer demand has been steadily increasing in the developing world.....</i>	90
<i>Figure 5-9: Key phosphorus flows through the global food production and consumption system, indicating phosphorus usage, losses and recovery at each key stage. Units are in million tonnes phosphorus/yr. While phosphorus in the natural system cycles at rates of ‘millions of years’, flows in the human food system cycle orders of magnitude faster at ‘days to years’.....</i>	91
<i>Figure 5-10. Major phosphorus flows in the food production and consumption system in Australia. The phosphorus content in the production, consumption, excretion and trade of fertilizers and food are indicated in thousand tonnes per year.....</i>	94
<i>Figure 5-11: Spatial profile of an urban-rural landscape – indicating that while agricultural and horticultural fields demand continual phosphorus fertilizers, cities are ‘phosphorus hotspots’ of food waste and human excreta that could be productively utilized to meet some of the fertilizer demand. The phosphorus in the ‘hotspots’ originated from local or distant agricultural fields, hence returning the phosphorus to these sources would be closing the loop to an extent.....</i>	95
<i>Figure 5-12: Proportion of each major nutrient coming from different household wastewater fractions – greywater, faeces and urine.....</i>	97
<i>Figure 5-13: Evolution of sanitation throughout human history, from ‘Early civilisation and the middle ages Era’, to the ‘sanitary awakening and advent of waterborne sanitation era’, through to the ‘waste water reclamation and eutrophication control Era’, and possible future ‘Ecological sanitation Era’.....</i>	98
<i>Figure 5-14: Map of various institutional elements governing global phosphorus, including regulations, policy, actors, sectors and discourses or framings.....</i>	101
<i>Figure 5-15: Roles and dominant frames of phosphorus in each key sector related to the phosphorus cycle through the global food production and consumption system. Speech bubbles indicate the way phosphorus is conceptualized in the major sectors. None of these prioritize phosphorus scarcity linked to food security.....</i>	105
<i>Figure 5-16: A social-ecological framework for analysing global non-renewable resource use. Seven ‘steps’ of phases are indicated, including 1. The attributes of the resource, 2. Technological aspects, 3. Agents and agent choices, 4. Action area which is influenced both by powerful actors, and prevailing institutions, 5. Institutions, 6. The outcomes of the choices made by agents on the use and state of the resource, and 7. The relationship between the prevailing institutions and the attributes of the resource.....</i>	107
<i>Figure 5-17: Phosphate rock commodity price (Morocco) increased 800% between January 07 and September 08.....</i>	112
<i>Figure 6-1: Current narrow system boundary around phosphorus. The spotlight indicates the actors, entities and issues that are largely currently included in the governance of phosphorus, predominantly due to the market system, and those that are largely marginalized or ignored. A more sustainable situation would require the system boundary to be redrawn more broadly to equally include other important actors (such as poor farmers), environmental issues (such as physical scarcity), other sources of phosphorus (such as excreta or food waste) and longer time frames.....</i>	119
<i>Figure 6-2: From phosphorus scarcity and pollution (a hard-landing) to phosphorus security (a soft-landing).....</i>	123
<i>Figure 6-3: Meeting future phosphorus security through a range of demand and supply-side measures.....</i>	124
<i>Figure 6-4. Conceptualising the goal of phosphorus security as a set of 11 sustainability criteria. Such criteria can address the complex web of current challenges associated with phosphorus scarcity (depicted in the outer shaded area). Linkages indicate some of the current challenges presented throughout this thesis.....</i>	125

<i>Figure 7-1: Some research theories and approaches that explicitly aim (at least in part) to create change towards more sustainable (or desirable) futures (i.e. concentrated at the top end of the y-axis spectrum of science as intervention versus science as observation). Many of these approaches also involve multiple methodologies or even epistemologies that transgress disciplinary boundaries (i.e. they are concentrated on the right end of the x-axis spectrum disciplinary to ‘meta’-disciplinary research).....</i>	131
<i>Figure 7-2: Three outcome spaces of transdisciplinary research: 1. peer-reviewed academic knowledge, 2. the problem situation or context, and 3. Transformative or mutual learning.....</i>	132
<i>Figure 7-3: Key observations and participation relating to global phosphorus scarcity over the period 2006-2009.....</i>	137
<i>Figure 7-4: The dynamic journey of a transdisciplinary, systems-thinking, action-researching doctoral researcher.....</i>	138
<i>Figure 7-5: logo of the Global Phosphorus Research Initiative (GPRI). The GPRI was developed as a timely outcome during this doctoral research. The aim of the GPRI is “to facilitate quality interdisciplinary research on global phosphorus security for future food security.....</i>	139

## LIST OF ABBREVIATIONS

CEEP	<i>Centre Européen d'Etudes sur les Polyphosphates (representing the European industrial/cleaning sector of the phosphate industry)</i>
CGIAR	<i>Consultative Group on International Agricultural Research</i>
CSIRO	<i>Commonwealth Scientific and Industrial Research Organization (Australia)</i>
CST	<i>Critical systems thinking</i>
CRU	<i>British Sulphur Consultants</i>
DAP	<i>Diammonium phosphate</i>
ESG	<i>Earth System Governance project</i>
ESSP	<i>Earth System Science Partnership</i>
FAO	<i>Food and Agricultural Organization of the United Nations</i>
FAOSTATS	<i>Online statistical database of the FAO</i>
FIFA	<i>Fertilizer Industry Federation of Australia</i>
GEC	<i>Global environmental change</i>
GECAFS	<i>Global Environmental Change and Food Systems program</i>
GPRI	<i>Global Phosphorus Research Initiative</i>
IAASTD	<i>International Assessment of Agricultural Knowledge, Science and Technology for Development</i>
IDGEC	<i>Institutional Dimensions of Global Environmental Change</i>
IFA	<i>International Fertilizer Industry Association</i>
IFADATA	<i>Online statistical database of the IFA</i>
iFOAM	<i>International Federation of Organic Agriculture Movements</i>
IFPRI	<i>International Food Policy Research Institute</i>
IMPHOS	<i>The World Phosphate Institute</i>
K	<i>Potassium</i>
MAP <sup>1</sup>	<i>Monoammonium phosphate</i>
MDG	<i>Millennium Development Goals</i>
MT	<i>Million metric tonnes</i>
N	<i>Nitrogen</i>
OCF	<i>Office Cherifien de Phosphate (Morocco's phosphate company)</i>
P	<i>Phosphorus</i>
SEI	<i>Stockholm Environment Institute</i>
SFA	<i>Substance Flows Analysis</i>
SSM	<i>Soft systems methodology</i>
TSP	<i>Triple Superphosphate</i>
UDHR	<i>Universal Declaration on Human Rights</i>
UN	<i>United Nations</i>
USGS	<i>US Geological Survey</i>
WHO	<i>World Health Organization of the United Nations</i>
WTO	<i>World Trade Organization</i>

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<sup>1</sup> Struvite is also referred to as MAP (magnesium-ammonium-phosphate), however to avoid ambiguity, the common name struvite has been used.





## ABSTRACT

The story of phosphorus began with the search for the philosopher's stone, and centuries later the critical role of phosphorus in soil fertility and crop growth was highlighted. Eventually, phosphorus was implicated in the global environmental challenge of eutrophication. Now, we are on the brink of yet another emerging chapter in the story: global phosphorus scarcity linked to food security. Through a transdisciplinary and systemic inquiry, this thesis has analyzed, reconceptualized and synthesized the physical and institutional dimensions of global phosphorus scarcity in the context of food security, leading to a new framing, 'phosphorus security' to guide future work towards a more sustainable and food secure pathway.

In a world which will be home to nine billion people by the middle of this century, producing enough food and other vital resources is likely to be a substantial challenge for humanity. Phosphorus, together with nitrogen and potassium, is an essential plant nutrient. It is applied to agricultural soils in fertilizers to maintain high crop yields. Phosphorus has no substitute in food production. Therefore, securing the long-term availability and accessibility of phosphorus is crucial to global food security. However the major source of phosphorus today, phosphate rock, is a non-renewable resource and high quality reserves are becoming increasingly scarce. This thesis estimates peak phosphorus to occur before 2035, after which demand will exceed supply. Phosphorus scarcity is defined by more than just *physical* scarcity of phosphate rock and this thesis develops five important dimensions. For example, there is a scarcity of *management* of phosphorus throughout the entire food production and consumption system: the global phosphorus flows analysis found that only 20% of phosphorus in phosphate rock mined for food production actually reaches the food consumed by the global population due to substantial inefficiencies and losses from mine to field to fork. There is also an *economic* scarcity, where for example, while all the world's farmers need access to sufficient fertilizers, only those with sufficient purchasing power can access fertilizer markets. *Institutional* scarcity, such as the lack of governance structures at the international level that explicitly aim to ensure long-term availability of and access to global phosphorus resources for food production that has led to ineffective and fragmented governance of phosphorus, including a lack of: overall coordination, monitoring and feedback, clear roles and responsibilities, long-term planning and equitable distribution. Finally, *geopolitical* scarcity arising from 90% of the world's remaining high-grade phosphate rock reserves being controlled by just five countries (a majority of which are subject to geopolitical tensions) can limit the availability of phosphorus on the market and raises serious ethical questions.

The long-term future scenarios presented in this thesis indicate that meeting future global food demand will likely require a substantial reduction in the global demand for phosphorus through not only improved efficient use of phosphorus in agriculture, but also through changing diets and increasing efficiency in the food chain. The unavoidable demand for phosphorus could then be met through a high recovery and reuse rate of all sources of phosphorus (crop residues, food waste, manure, excreta) and other sources including some phosphate rock. A 'hard-landing' situation could involve further fertilizer price spikes, increased waste and pollution (including eutrophication), increased energy consumption associated with the production and trade of phosphorus fertilizers, reduced farmer access to phosphorus, reduced global crop yields and increased food insecurity. A preferred 'soft landing' situation will however require substantial changes to physical and institutional infrastructure, including improved governance structures at the global, national and other levels, such as new policies, partnerships and roles to bring together the food, fertilizer, agriculture, sanitation and waste sectors for a coordinated response.

Finally, this thesis proposes a new global goal – *phosphorus security* – to be integrated in the dominant research discourses and policy debates on global food security and global environmental change. Among other criteria, phosphorus security requires that phosphorus use is decoupled from environmental degradation and that farmers' access to phosphorus is secured.

**Keywords:** *global phosphorus scarcity, peak phosphorus, global food security, sustainable resource use, food production and consumption system, transdisciplinary, systems thinking.*