



IPNC 2022
International Plant
Nutrition Colloquium

GLOBAL PHOSPHORUS AVAILABILITY FROM A DYNAMIC AND INNOVATION-BASED PERSPECTIVE: HOW TO MANAGE INFORMATION AND KNOWLEDGE RESPONSIBLY

GERALD STEINER

*GLOBAL PHOSPHATE DATA AND KNOWLEDGE HUB (P-DAKH) &
UWK - DANUBE UNIVERSITY AUSTRIA,
TRANSDISCIPLINARITY LAB SUSTAINABLE MINERAL RESOURCES (SMR TD-LAB)*

**19TH INTERNATIONAL PLANT NUTRITION COLLOQUIUM (IPNC),
AUGUST 22 TO 27, 2022, BRAZIL**

PHOSPHORUS AS LIFE'S BOTTLENECK

"... LIFE CAN MULTIPLY UNTIL ALL THE PHOSPHORUS IS GONE, AND THEN THERE IS AN INEXORABLE HALT WHICH NOTHING CAN PREVENT ..."

Asimov, I. (1974). Asimov on Chemistry; Doubleday & Company: Garden City, NY, USA, ISBN 978-0-385-04100-3.

↓

ARE WE RUNNING OUT OF PHOSPHORUS?

↓

REFUTING THE PHOSPHORUS SCARCITY FALLACY & INNOVATION-BASED DYNAMICS

↓

FUTURE IMPLICATIONS: FUNCTIONAL & INSTITUTIONAL REQUIREMENTS TO AVOID SIMILAR FALLACIES

WHO WE ARE:

**THE GLOBAL PHOSPHATE DATA AND KNOWLEDGE HUB
(P-DAKH)**

AS AN INITIATIVE OF THE

GLOBAL PHOSPHORUS INSTITUTE (GPI)

&

**TRANSDISCIPLINARITY LAB FOR SUSTAINABLE MINERAL
RESOURCES (SMR TD-LAB)
DANUBE UNIVERSITY AUSTRIA**

THE GLOBAL PHOSPHORUS INSTITUTE (GPI)

IS A GLOBAL ORGANIZATION WITH A HOLISTIC VISION, FOOTPRINT AND PARTICIPATION TO ENSURE RESPONSIBLE USE OF PHOSPHORUS THROUGH CUTTING-EDGE SCIENCE AND STAKEHOLDER DIALOGUE

<https://www.tgpi.org/en/home>



KNOWLEDGE

COLLABORATION

INTEGRITY

How to build a global data and knowledge hub for phosphorus based existing accomplishments and data-sets?

Our Vision

GPI envisions a world where food is plentiful for everyone, not just a few. By making a difference through excellence in knowledge management ...

[→ Read More](#)

Our Mission

As the global hub for all things phosphorus and the convener of stakeholders and networks GPI will strengthen collaborations ...

[→ Read More](#)

Our Values

We adhere to the highest professional standards and assure the integrity of our work by uncompromising truthfulness, transparency ...

[→ Read More](#)

THE TRANSDISCIPLINARITY LAB FOR SUSTAINABLE MINERAL RESOURCES

(SMR TD-LAB) WITH EMPHASIS ON GLOBAL FOOD SECURITY AND PHOSPHATE ROCK DOING RESEARCH FOR A RESPONSIBLE, SUSTAINABLE, AND EFFICIENT USE OF THE ESSENTIAL ELEMENT PHOSPHORUS.



Co-Lead Science (Full Professors)		Co-Lead Practice	
	Gerald Steiner (Danube University Austria & CSH, Systems- and Complexity Sciences)		Michael C. Mew (CRU International, Mineral Resources Management Advisor)
	Roland W. Scholz (Danube University & ETH Zürich, Environmental System Sciences)		Ludwig Hermann (President of the European Sustainable P Platform ESPP and Proman Consulting)
	Martin Bertau (TU Bergakademie Freiberg, Technical Chemistry)		Friedrich-W. Wellmer (Former president of The Federal German Geological Survey)
	Michael Obersteiner (Oxford University, Global Change)		

<https://www.donau-uni.ac.at/SMR-TdLab>



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Further Td-Lab Members			
	Matthias Raddant (Danube University Austria & CSH, Economics and Complexity Sciences)		
	Nils Haneklaus (UN & Danube University, Nuclear Energy)		

<https://www.donau-uni.ac.at/SMR-TdLab>



Global phosphorus availability from a dynamic and innovation-based perspective

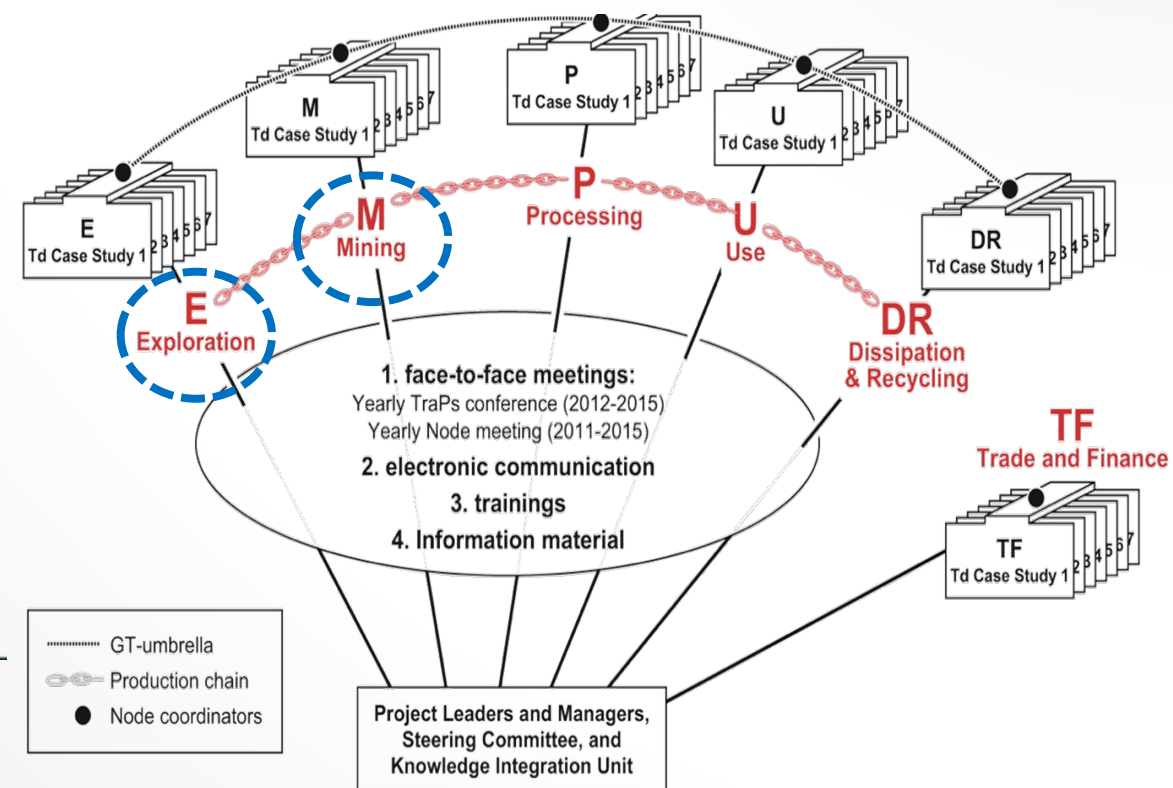
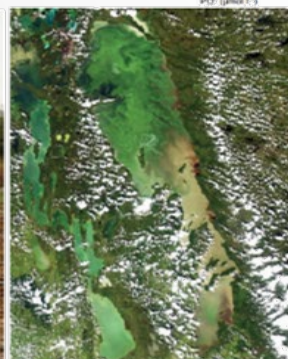
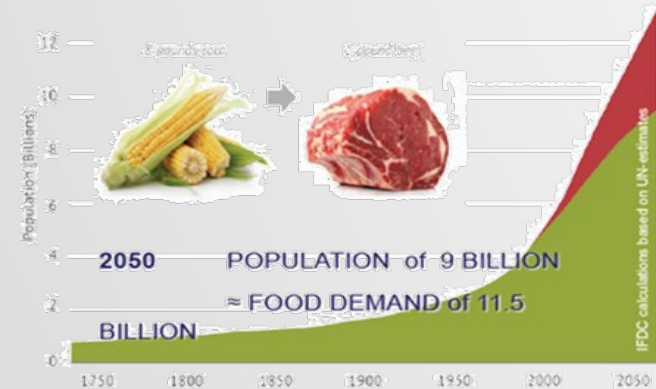
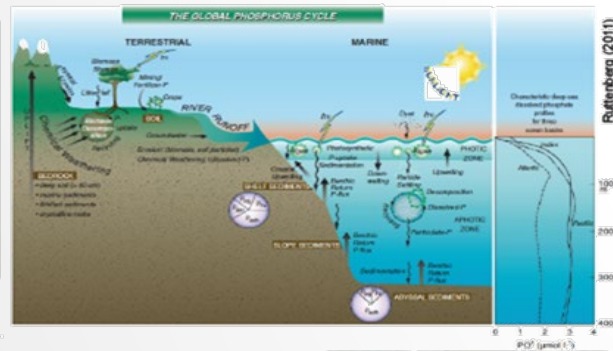


INTER- & TRANSDISCIPLINARITY FOR UNDERSTANDING & DEALING WITH COMPLEX SYSTEMS

THE COMPLEXITY OF SUSTAINABLE PHOSPHORUS MANAGEMENT: A SYSTEMIC PERSPECTIVE

ITS BEGINNINGS: TD RESEARCH APPROACH – GLOBAL TRAPS

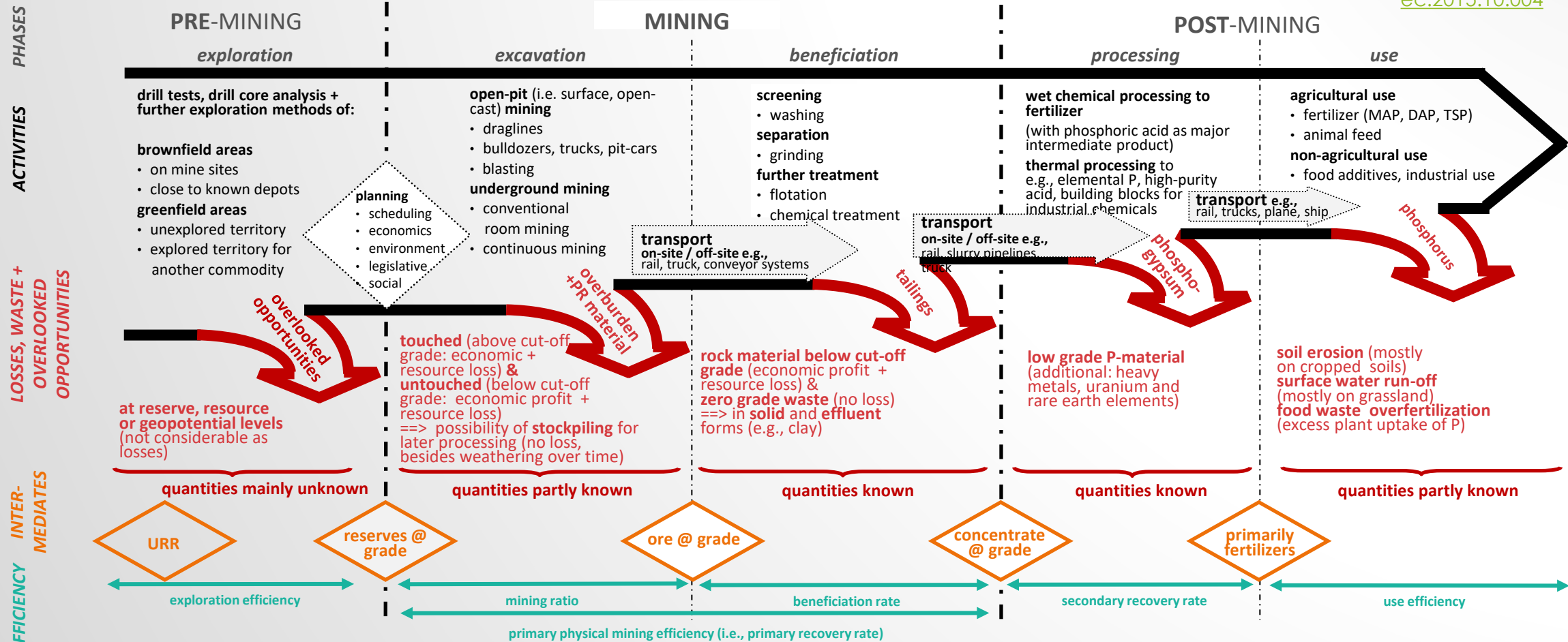
The global **P** issue



Scholz, R.W., Roy, A.H., Brand, F.S., Hellums, D.T., Ulrich, A.E. (Eds.) (2014). Sustainable Phosphorus Management: A Global Transdisciplinary Roadmap. Springer, Dordrecht Heidelberg New York London.

Steiner, G., , B., Watson, I., & Mew, M. C. (2015). Efficiency developments in phosphate rock mining over the last three decades. *Resources, Conservation and Recycling*, 105, 235–245.
<https://doi.org/10.1016/j.resconrec.2015.10.004>

EXTENDED PHOSPHORUS SUPPLY CHAIN (EPSC)



PHOSPHATES AT THE GLOBAL LEVEL: AN EXAMPLE OF POTENTIAL MISINTERPRETATIONS BASED ON SIMPSON'S PARADOX

	1983							2013						
	Grades PR-ORE in % P2O5	Volumes PR-ORE in Mt	Grades PR-M in % P2O5	Volumes PR-M in Mt	PR-ORE % Share of Total	PR-M % Share of Total	Beneficiation Rate %	Grades PR-ORE in % P2O5	Volumes PR-ORE in Mt	Grades PR-M in % P2O5	Volumes PR-M in Mt	PR-ORE % Share of Total	PR-M % Share of Total	Beneficiation Rate %
World	14.3	512.7	32.5	161.8	100	100	71.7	17.5	660.7	30.1	257.9	100	100	67.2
Major Producers Sedimentary ore:														
US	11.9	222.7	31.2	58.5	44.4	36.2	68.8	11.8	141.5	29.2	30.9	21.4	12	53.9
China	23.6	6.9	30.4	3.4	1.3	2.1	63.6	21.6	160.3	28.1	91.4	24.3	35.4	74.1
Morocco	27.2	50.9	32.1	29.9	9.9	18.5	69.3	26.4	68.6	31.5	39.3	10.4	15.2	68.5
Jordan	27.5	10.7	32.8	6.5	2.1	4	71.8	25.5	17.3	29.7	11	2.6	4.3	74.3
Mainly igneous ore:														
Russia	11.4	89.7	36.7	23.3	17.5	14.4	83.6	10.1	70.6	38.7	15.3	10.7	5.9	82.8
S Africa	5.9	33.6	36.5	4.5	6.6	2.7	82.9	7.0	26.7	37.3	3.2	4	1.2	63.8
Brazil	9.1	26.4	34.6	4.2	5.1	2.6	60.9	11.1	38.3	35.4	7.9	5.8	3.1	65.8
Others*	19.2	71.8	31.4	31.6	14.0	19.5	71.8	20.8	137.4	29.5	58.9	20.8	22.8	60.9

Steiner, G., Geissler, B., Watson, I., & Mew, M. C. (2015). Efficiency developments in phosphate rock mining over the last three decades. *Resources, Conservation and Recycling, 105*, 235–245. <https://doi.org/10.1016/j.resconrec.2015.10.004>

Scholz, R.W., Steiner, G. (2022). The Role of Transdisciplinarity for Mineral Economics and Mineral Resources Management. *Mineral Economics*; <https://doi.org/10.1007/s13563-022-00331-5>.

Simpson's paradox of an increase of global ore grades:
 → Emerged from data of the Chinese PR production
 → Relative share of China increased
 → Implications on global average ore grades
 → Masks the true trends in countries and deposits

NO PHOSPHORUS SCARCITY BUT WHAT IS NEEDED FOR THE FUTURE

→ TRANSDISCIPLINARITY AND STAKEHOLDER DIALOGUE

TRANSDISCIPLINARITY AS A MUTUAL-LEARNING PROCESS INCLUDING A TARGETED INTERDISCIPLINARY PROCESS AND A FACILITATED STAKEHOLDER DISCOURSE FOR PRODUCING SOCIALLY ROBUST ORIENTATIONS

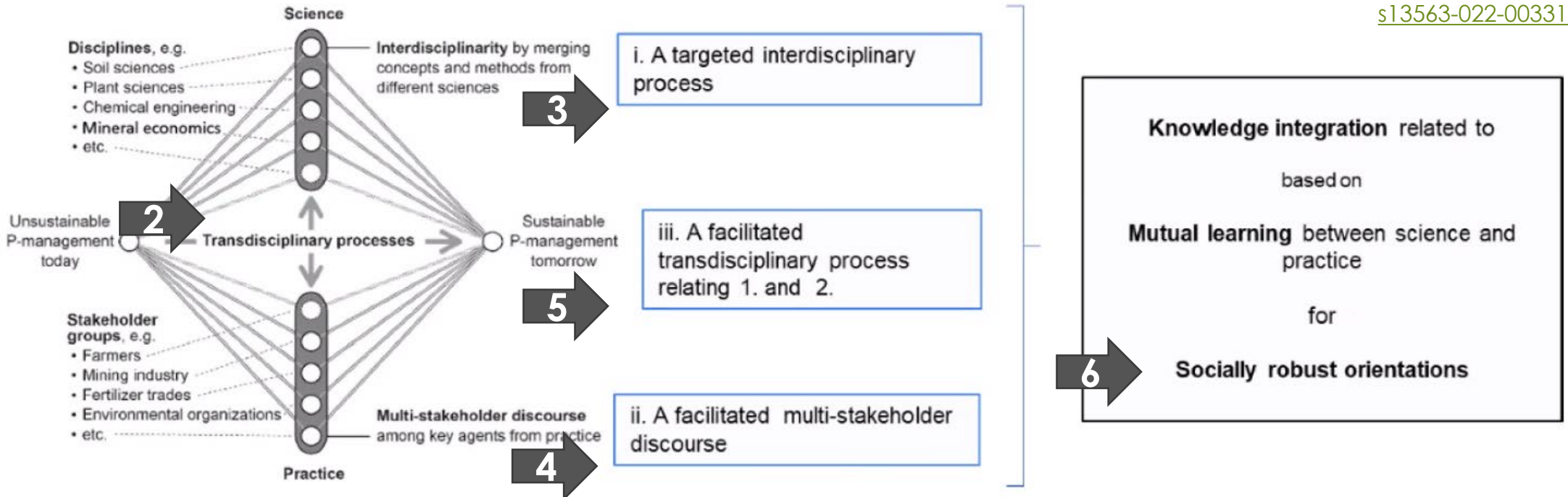
Scholz, R.W., Steiner, G. (2022). The Role of Transdisciplinarity for Mineral Economics and Mineral Resources Management. *Mineral Economics*; <https://doi.org/10.1007/s13563-022-00331-5>.

1

Complex, wickedly defined, societally relevant real-world problems in the interest of both science and practice

↓

Transdisciplinarity as a key method of sustainable transitioning



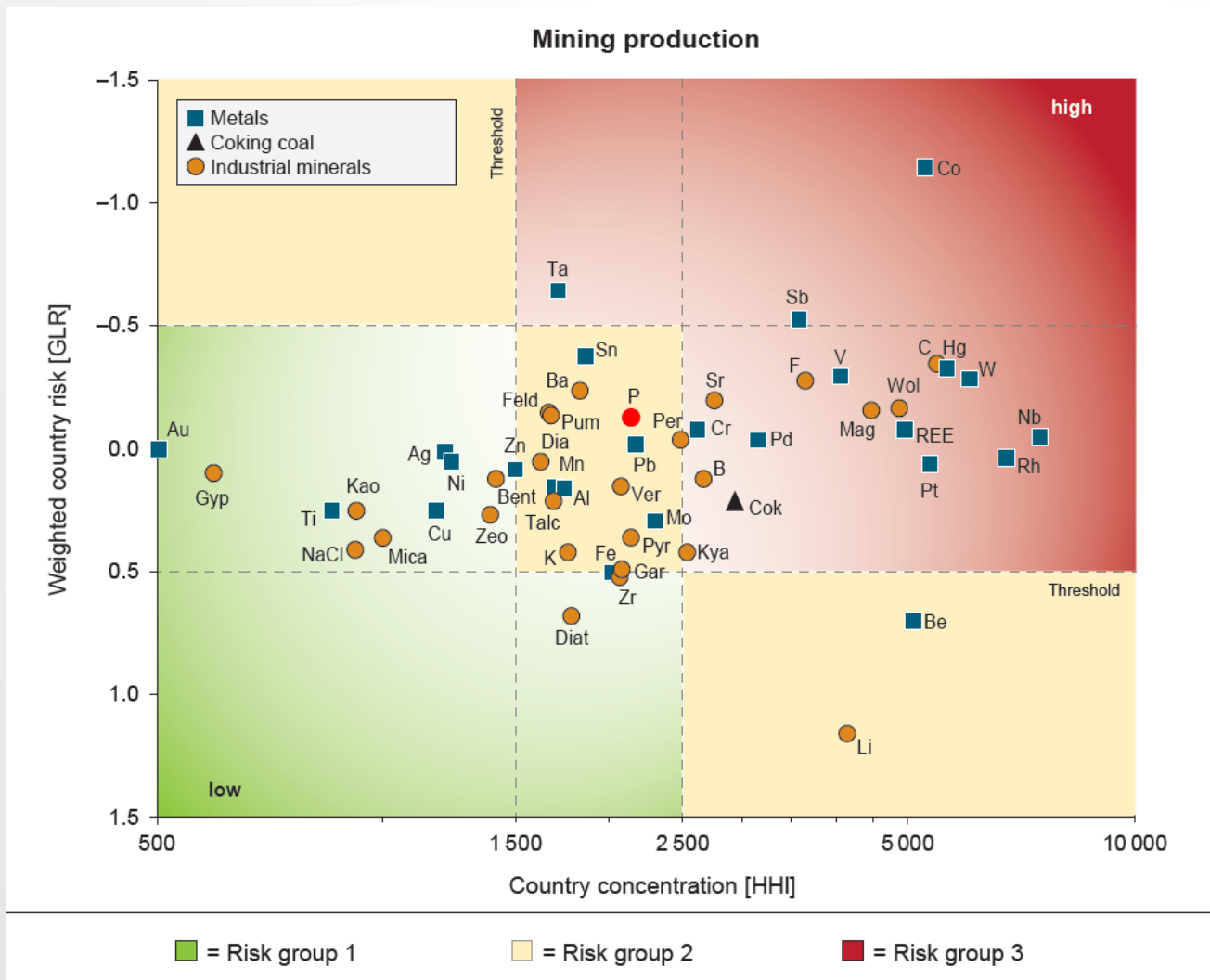
6



BACKGROUND:

TWO PERSPECTIVES ON SCARCITY
(1) SHORT-TERM CRITICALITY
(2) LONG-TERM PHYSICAL ACCESS

HHI-INDICES FOR MINING PRODUCTION OF 53 COMMODITIES IN 2018

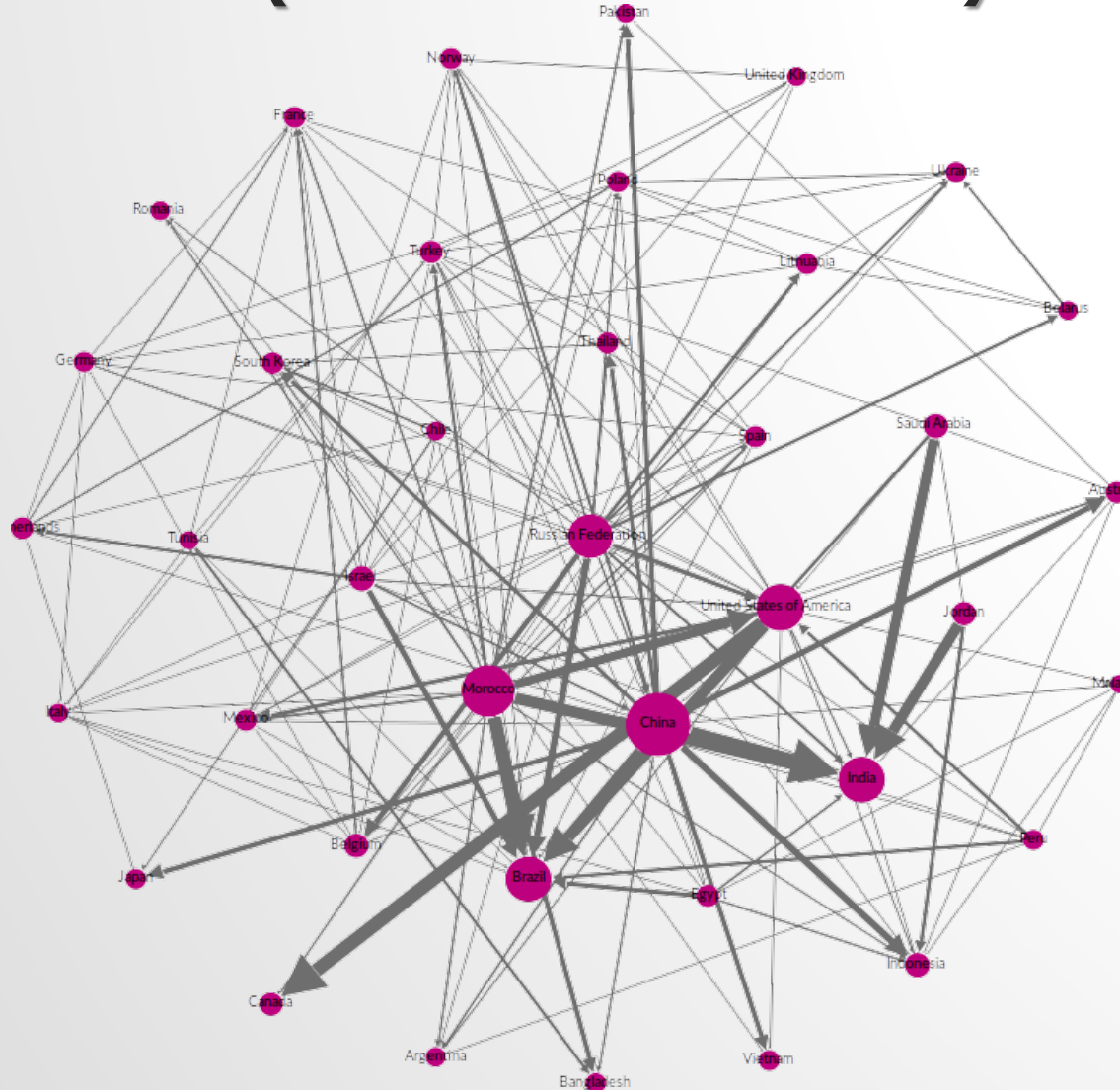


„The few countries fallacy“

BGR (2021): Bundesanstalt für Geowissenschaften und Rohstoffe BGR-raw materials databank;

Bertau, M., Wellmer, F.-W., Scholz, R.W., Fröhlich, P., Haneklaus, N., Laubichler, M.D., Birmann, B.M., Caniglia, G., Schernhammer, E., Weitzer, J., Steffelbauer, I., Zenk, L., Mew, M., Steiner, G. (2022). The Future of Phosphate Rock-Processing – Why We Have to Leave Trodden Paths (forthcoming).

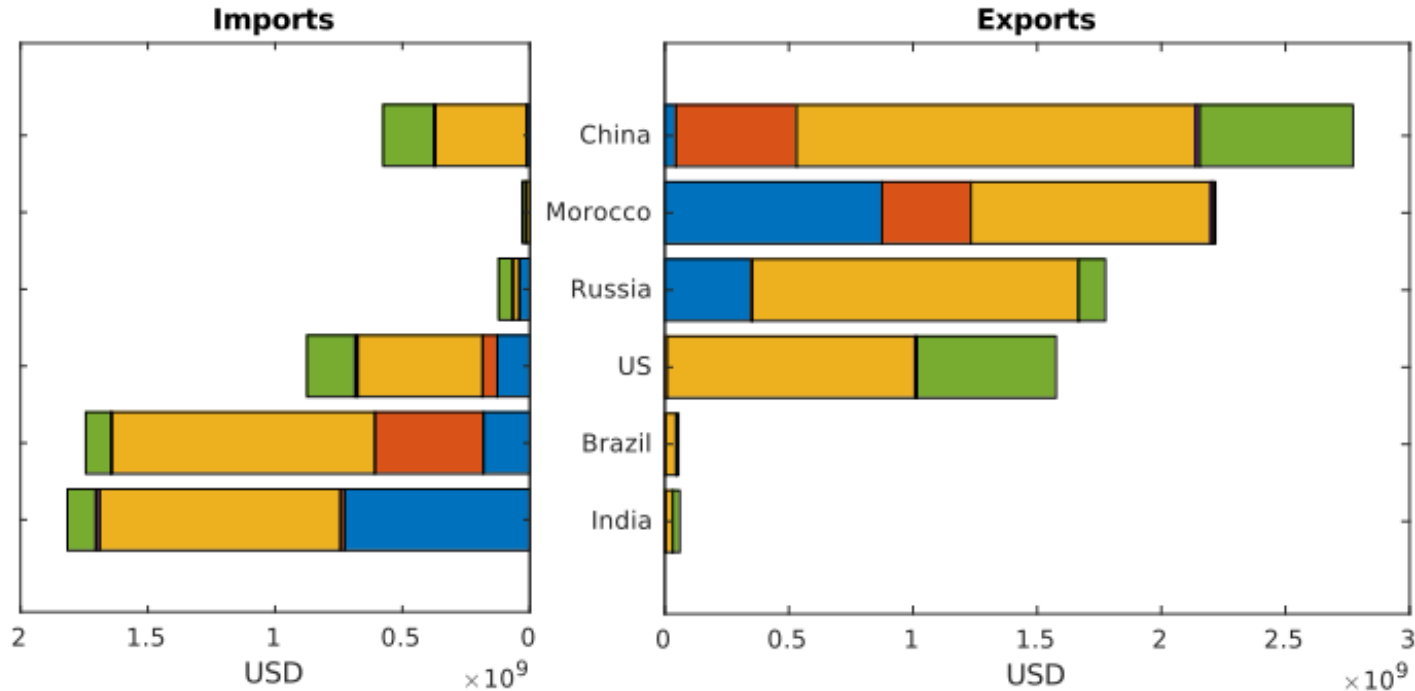
DISTURBANCES: POLITICAL TURMOIL RISK ANALYSIS (WORK IN PROGRESS)



Raddant, M. (& SMR Td-Lab). 2022. A new method for mapping global phosphorus flows (forthcoming).

- **Phosphorus-related trade flows**
- including raw minerals, fertilizers and chemical products for the 39 largest countries by trade. The node size and link width is proportional to the traded amount in USD. Bilateral flows are netted.*
- based on Comtrade data from Harvard Growth lab for 2019. Based on SITC (Rev2) 2713, 5622, 5222**, 5232**, 5629**
- *links with less than 10m USD are not visualized
- **weighted according to approx. P content

DISTURBANCES: POLITICAL TURMOIL RISK ANALYSIS (WORK IN PROGRESS)

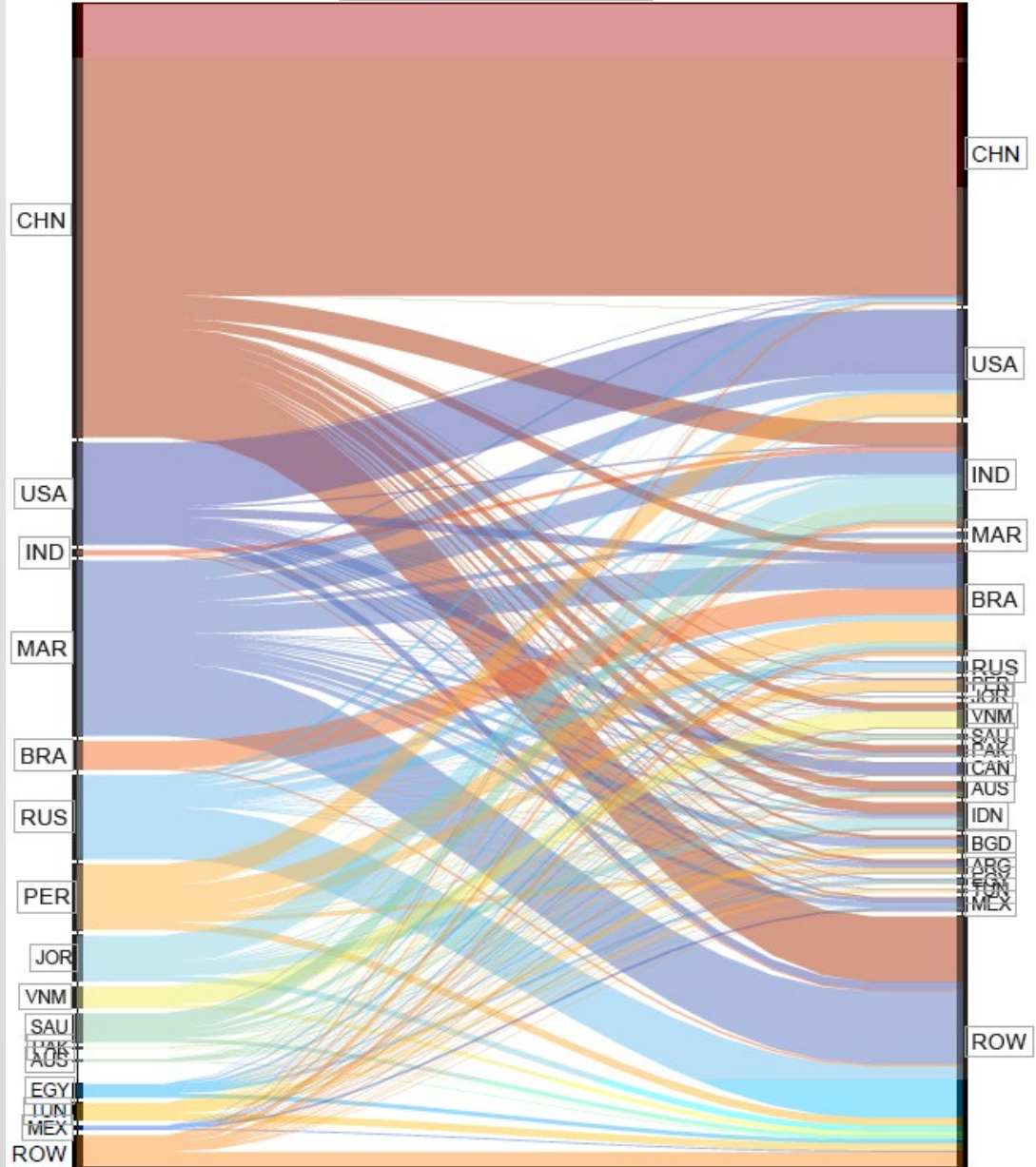


- 2713: Natural calcium phosphates...
- 5622: Mineral or chemical fertilizers, phosphatic
- 5629: Fertilizers, n.e.s.**
- 5222: Inorganic acids.../ incl. phosphoric acids**
- 5232: Metallic salts... /incl. phosphates**

Raddant, M. (& SMR Td-Lab). 2022. A new method for mapping global phosphorus flows (forthcoming).

- **Phosphorus-related Imports and Exports**
- including raw minerals, fertilizers and chemical products for the 6 largest countries by trade.
- based on Comtrade data from Harvard Growth lab for 2019. Based on SITC (Rev2) 2713, 5622, 5222**, 5232**, 5629**
- **weighted according to approx. P content

Global phosphorus flows



PHOSPHORUS ALLOCATION (WORK IN PROGRESS)

Raddant, M. (& SMR Td-Lab). 2022. A new method for mapping global phosphorus flows (forthcoming).

Note: Based on adjusted trade data for the 20 largest countries in terms of mining and use. The line widths are proportional to the share of approximated global P flow in 2019; including raw minerals, fertilizers and chemical products for the 6 largest countries by trade.

ORIGINS OF THE PHOSPHORUS SCARCITY FALLACY & COUNTER VOICES

ECOLOGIST
REVIVING THE ENVIRONMENTAL AGENDA SINCE 1970

The New York Times
Tuesday, September 27, 2011

WORLD U.S. N.Y./REGION BUSINESS TECHNOLOGY SCIENCE HEALTH SPO

April 27, 2010, 6:42 AM

Peak Phosphorus

Today's idea: Our dwindling supply of phosphorus for fertilizer threatens to disrupt food security across the planet during the coming century, an article argues. "This is the gravest natural resource shortage you've never heard of."

Stephen Morrison/European Pressphoto Agency

The world relies on phosphate fertilizer to meet rising demand for food: tilling the soil in Kenya.

SPIEGEL ONLINE INTERNATIONAL

04/21/2010 Print | E-Mail | Feedback

Essential Element Becoming Scarce

Experts Warn of Impending Phosphorus Crisis

By Hilmar Schmundt

Phosphorus is essential to agriculture, but experts warn reserves are starting to run out.

The element phosphorus is essential to human life and the most important ingredient in fertilizer. But experts warn that the world's reserves of phosphate rock are becoming depleted. Is recycling sewage the answer?

Potential P-Scarcity triggered by, e.g.:

Roosevelt FD (1938) Message to congress on phosphates for soil fertility, 20 May 1938. In: G Peters, JT Woolley, The American Presidency Project.

<http://www.presidency.ucsb.edu/ws/?pid=15643>

Déry P, Anderson B (2007) Peak phosphorus. Energy Bulletin.

Cordell D, Drangert JO, White S (2009) The story of phosphorus: global food security and food for thought. *Glob Environ Change-Human Policy Dims.*, 19(2).



Counter voices, e.g.:

van Kauwenbergh, S. J. (2010). World phosphate rock reserves and resources. Muscle Shoals, AL: IFDC.

Scholz, R.W., Wellmer, F.-W., 2013. Approaching a dynamic view on the availability of mineral resources: what we may learn from the case of phosphorus? *Glob. Environ. Chang.* 23, 11–27. <https://doi.org/10.1016/j.gloenvcha.2012.10.013>.

Jasinski, S. M. (2022). Phosphate rock. In US Geological Survey (Ed.), *Mineral Commodity Summaries 2018* (pp. 122-123). Washington, DC: USGS.

PHOSPHATE ROCK: WORLD RESERVES AND MINE PRODUCTION (2013/2020/2021)



2013

data for 2013	Production volume (USGS, 2015)	Reserves (USGS, 2015)
	million metric tons / [share of world production]	million metric tons / [share of world reserves]
Morocco	26.4 [11.73%]	50,000 [74.63%]
China	108 [48%]	3,700 [5.52%]
South Africa	2.3 [1.02%]	1,500 [2.24%]
United States	31.2 [13.87%]	1,100 [1.64%]
Russia	10 [4.44%]	1,300 [1.94%]
Brazil	6 [2.68%]	270 [0.4%]

2020/ 2021

United States
Algeria
Australia
Brazil
China ⁶
Egypt
Finland
India
Israel
Jordan
Kazakhstan
Mexico
Morocco
Peru
Russia
Saudi Arabia
Senegal
South Africa
Togo
Tunisia
Turkey
Uzbekistan
Vietnam
Other countries
World total (rounded)

Mine production

	2020	2021 ^e
United States	23,500	22,000
Algeria	1,200	1,200
Australia	2,000	2,200
Brazil	6,000	5,500
China ⁶	88,000	85,000
Egypt	4,800	5,000
Finland	995	1,000
India	1,400	1,400
Israel	3,090	3,000
Jordan	8,940	9,200
Kazakhstan	1,300	1,500
Mexico	577	530
Morocco	37,400	38,000
Peru	3,300	3,800
Russia	14,000	14,000
Saudi Arabia	8,000	8,500
Senegal	1,600	2,200
South Africa	1,800	2,000
Togo	942	1,200
Tunisia	3,190	3,200
Turkey	600	600
Uzbekistan	900	900
Vietnam	4,500	4,700
Other countries	870	1,000
World total (rounded)	219,000	220,000

Reserves⁴

United States	1,000,000
Algeria	2,200,000
Australia	51,100,000
Brazil	1,600,000
China ⁶	3,200,000
Egypt	2,800,000
Finland	1,000,000
India	46,000
Israel	53,000
Jordan	1,000,000
Kazakhstan	260,000
Mexico	30,000
Morocco	50,000,000
Peru	210,000
Russia	600,000
Saudi Arabia	1,400,000
Senegal	50,000
South Africa	1,600,000
Togo	30,000
Tunisia	100,000
Turkey	50,000
Uzbekistan	100,000
Vietnam	30,000
Other countries	2,600,000
World total (rounded)	71,000,000



U.S. Geological Survey, Mineral Commodity Summaries, Phosphate Rock, prepared by Stephen M. Jasinski, January 2022.

<https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-phosphate.pdf>

Steiner, G., , B., Watson, I., & Mew, M. C. (2015). Efficiency developments in phosphate rock mining over the last three decades. *Resources, Conservation and Recycling, 105*, 235–245. <https://doi.org/10.1016/j.resconrec.2015.10.004>

Geissler, Bernhard, Mew, M. C., Weber, O., & Steiner, G. (2015). Efficiency performance of the world's leading corporations in phosphate rock mining. *Resources, Conservation and Recycling, 105*, 246–258. <https://doi.org/10.1016/j.resconrec.2015.10.008>

(Data in thousand metric tons)

NO PHOSPHORUS SCARCITY BUT WHAT IS NEEDED FOR THE FUTURE

In a nutshell: A rough static 'rule-of-thumb calculation' (all data from the USGS Mineral Commodity Statistics, 2022)

→ Annual PR consumption for 2021	0.22 Gt PR
→ Current reserves:	71 Gt PR (=318 times of the 2021 PR consumption)
→ Current resources:	300 Gt PR (=would last for 1,681 years based on 2021 PR consumption)

BUT

(1) These figures will increase if prices increase, technology improves, or new phosphate rock resources are identified (Scholz & Wellmer, 2013).

(2) The rule that price increases reserves (as lower ore grades can be mined) raises these numbers.

NO PHOSPHORUS SCARCITY BUT WHAT IS NEEDED FOR THE FUTURE

A rough static 'rule-of-thumb calculation'

→ Annual PR consumption for 2021	0.22 Gt PR
→ Current reserves:	70 Gt PR (=318 times of the 2021 PR consumption)
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BUT

(1) These figures will increase if prices increase, technology improves, or new phosphate rock resources are identified (Scholz & Wellmer, 2013).

(2) The rule that price increases reserves (as lower ore grades can be mined) raises these numbers.

Consequence: For a better understanding of this reserve-resource dynamics we need a new institutional setting and a rigorous science approach relying on transdisciplinarity (as an enabler of mutual learning).

- Building a knowledge **network**
- Standardization of data and classification schemes**/instruments
- Conceptual Framework of system mechanisms** (feedback loops) of future P supply dynamics as a basis for the **data architecture**
- Sufficient analysis and **state-of-the-art modeling** (e.g., complexity science with network analysis, ABM etc.) & **digitalization** (e.g., digital twin, decision theatre etc.)

What is needed for doing so: A Global Phosphate Data and Knowledge Hub



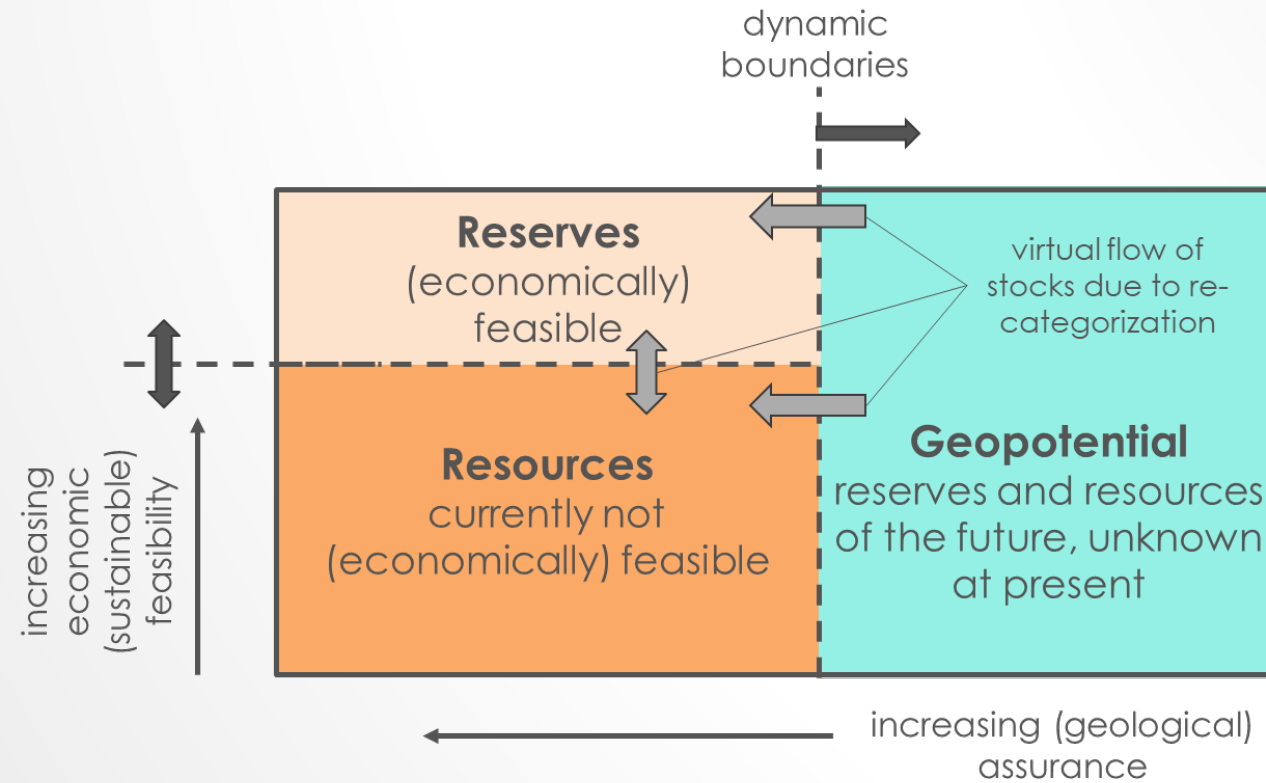
FUTURE IMPLICATIONS: FUNCTIONAL & INSTITUTIONAL REQUIREMENTS TO AVOID SIMILAR FALLACIES

RESERVES, RESOURCES, AND GEOPOTENTIAL: A DYNAMIC CONCEPT

→ **Reserves:** share of resource which can be economically extracted at currently given price and available technology under socio-ecologically acceptable conditions

→ **Resources:** known to a certain level, but economically not viable at the moment

→ **Geopotential:** only known by geological reasoning



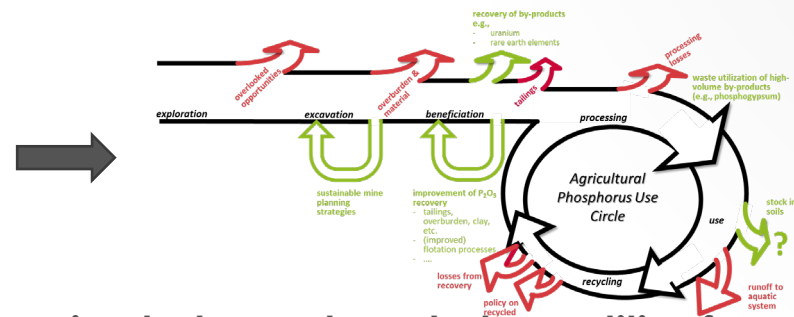
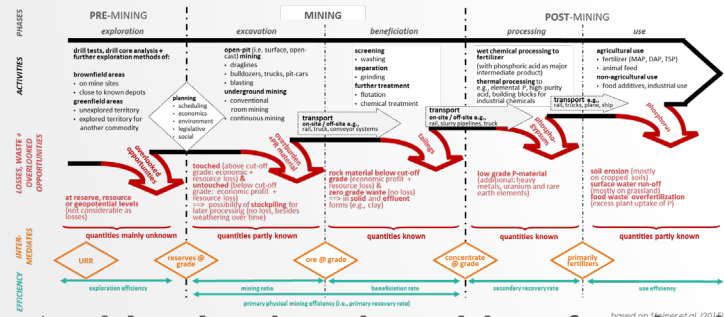
Scholz, R.W., Wellmer, F.-W. (2013). Approaching a dynamic view on the availability of mineral resources: what we may learn from the case of phosphorus? *Glob. Environ. Chang.* 23, 11–27. <https://doi.org/10.1016/j.gloenvcha.2012.10.013>.

Geissler, B., Mew, M., Steiner, G. (2019). Phosphate supply security for importing countries: Developments and the current situation. *Science of the Total Environment*, 677: 511–523. <https://doi.org/10.1016/j.scitotenv.2019.04.356>

This is how we want to answer the question how much phosphorus will be available in the future, and with how much effort/at what price.

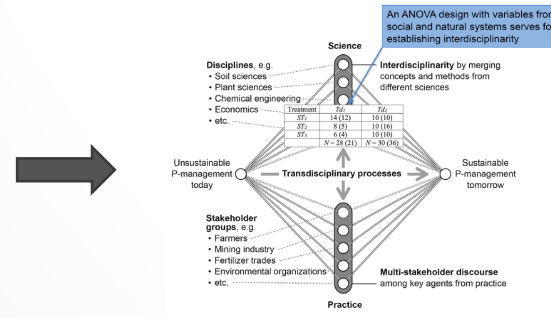
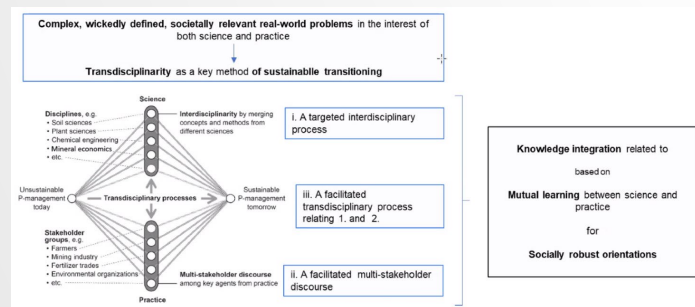
AN OUTLOOK FOR BETTER UNDERSTANDING & INNOVATION

I. GPI: As knowledge hub for orchestrating knowledge generation



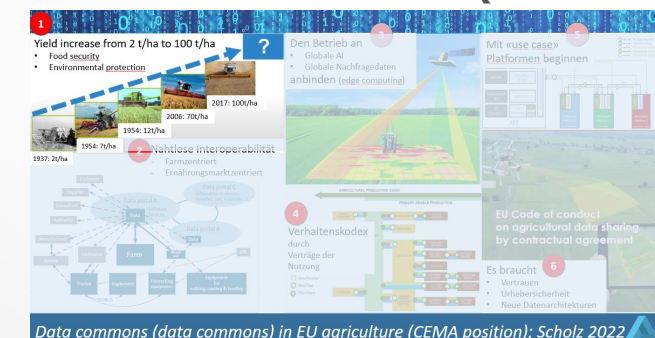
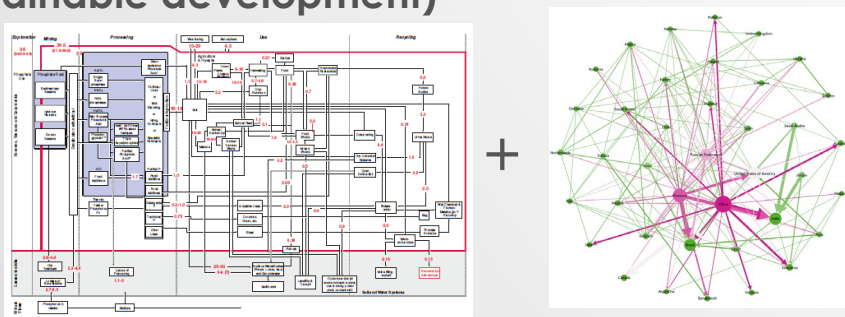
Geissler, B., Hermann, L., Mew, M., Steiner, G. (2018): Striving toward a phosphorus circular economy: The role of phosphate rock mining. *Minerals*, 8, 395: <https://doi.org/10.3390/min8090395>.

II. Transdisciplinarity as a 'golden key' and enabler of mutual learning between knowledge entities from science and practice



Scholz, R.W., Steiner, G. (2022). The Role of Transdisciplinarity for Mineral Economics and Mineral Resources Management. *Mineral Economics*; <https://doi.org/10.1007/s13563-022-00331-5>.

III. SMR Td Lab & P-DaKH: Mineral economics and -engineering, complexity science et al. for vulnerability modeling in support of getting a better picture of potential future scenarios and the affect of interventions (future development paths and sustainable development)



Scholz, R.W. et al. A:2022 "Data" & B:2014 "P" A:https://publications.iiasa-potsdam.de/rest/items/item_6000749_7/component/file_6... B:http://dx.doi.org/10.1007/978-94-007-7250-2_1

AN OUTLOOK FOR BETTER UNDERSTANDING & COLLABORATION

Looking forward to collaborate with you!

Executive Director Kaushik Majumdar and Mr.
Abdellah El Houari & colleagues

Co-Leaders from Science and Practice &
colleagues Roland Scholz, Friedrich Wellmer,
Martin Bertau, Michael Mew, Ludwig
Hermann, Michael Obersteiner & colleagues



**Global Phosphate Data and Knowledge Hub
P-DaKH**

Global phosphorus availability from a dynamic and innovation-based perspective



THANK YOU FOR YOUR ATTENTION!
gerald.steiner@donau-univ.ac.at

*GLOBAL PHOSPHATE DATA AND KNOWLEDGE HUB (P-DAKH) &
DANUBE UNIVERSITY AUSTRIA,
TRANSDISCIPLINARITY LAB SUSTAINABLE MINERAL RESOURCES (SMR TD-LAB)*

**19TH INTERNATIONAL PLANT NUTRITION COLLOQUIUM (IPNC),
AUGUST 22 TO 27, 2022, BRAZIL**