# The Phosphorus Challenge: Managing a Resource with Complex Patterns


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Beijing China, *June 19, 2013*

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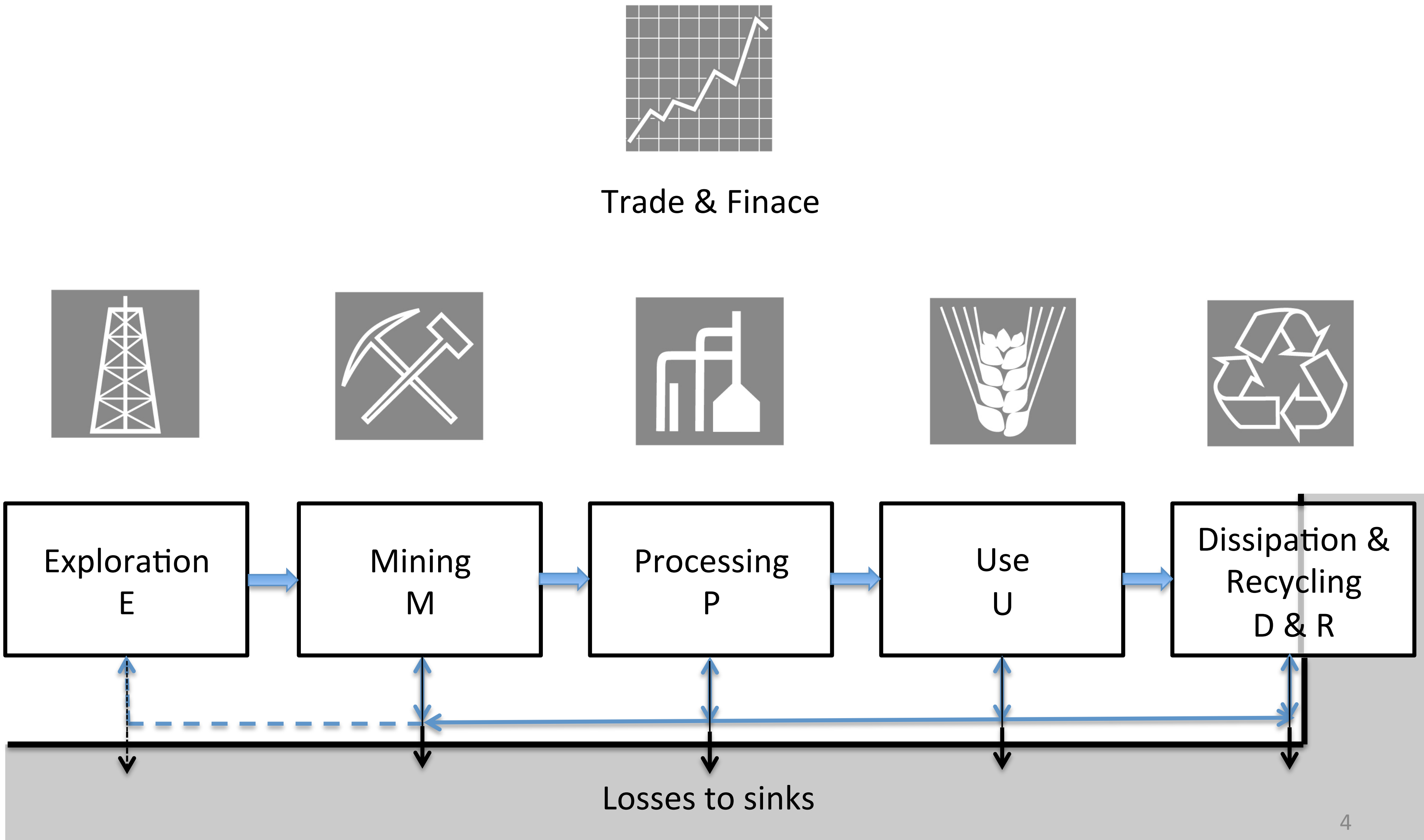
- Efficiency
- Environmental impacts
- Access

# Contents

- **Complexity** → What makes phosphorus resource a complex issue?
- Efficiency
- Environmental impacts
- Access

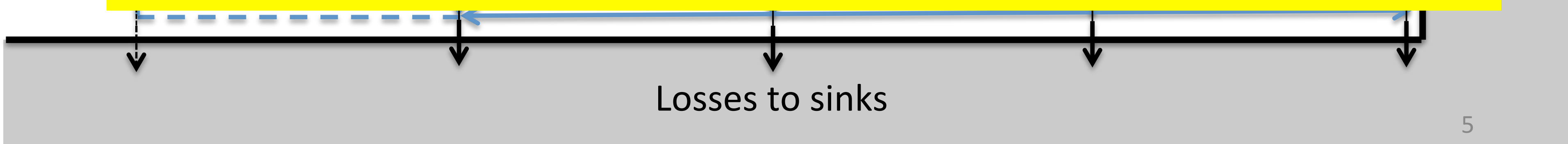
# The supply-demand chain is complex

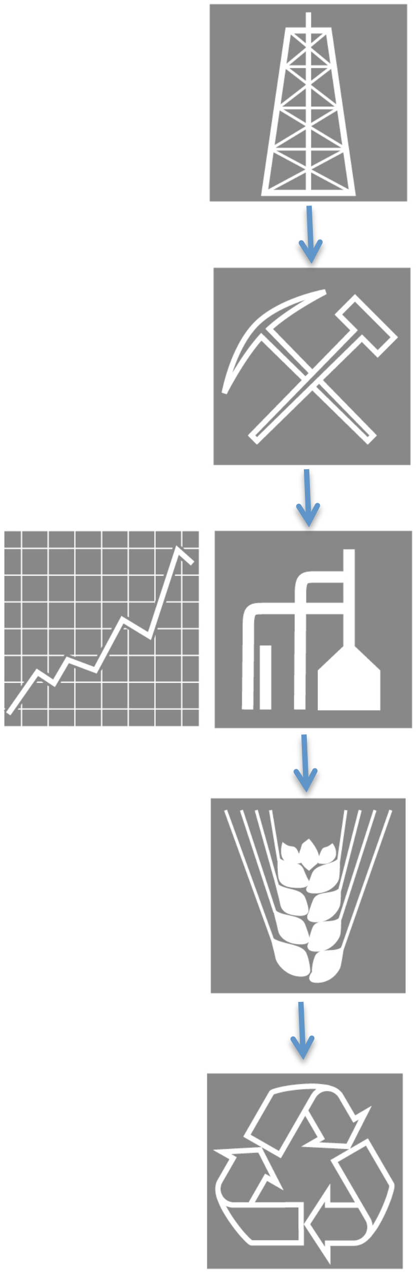


# The supply-demand chain is complex

With phosphorus management, we are facing different types of systems(*) with different spatial and temporal scales

I.e. material-physical (e.g. phosphorus rocks) vs. non-material socio-epistemic (e.g. monetary) systems
or human/social systems vs. geological systems

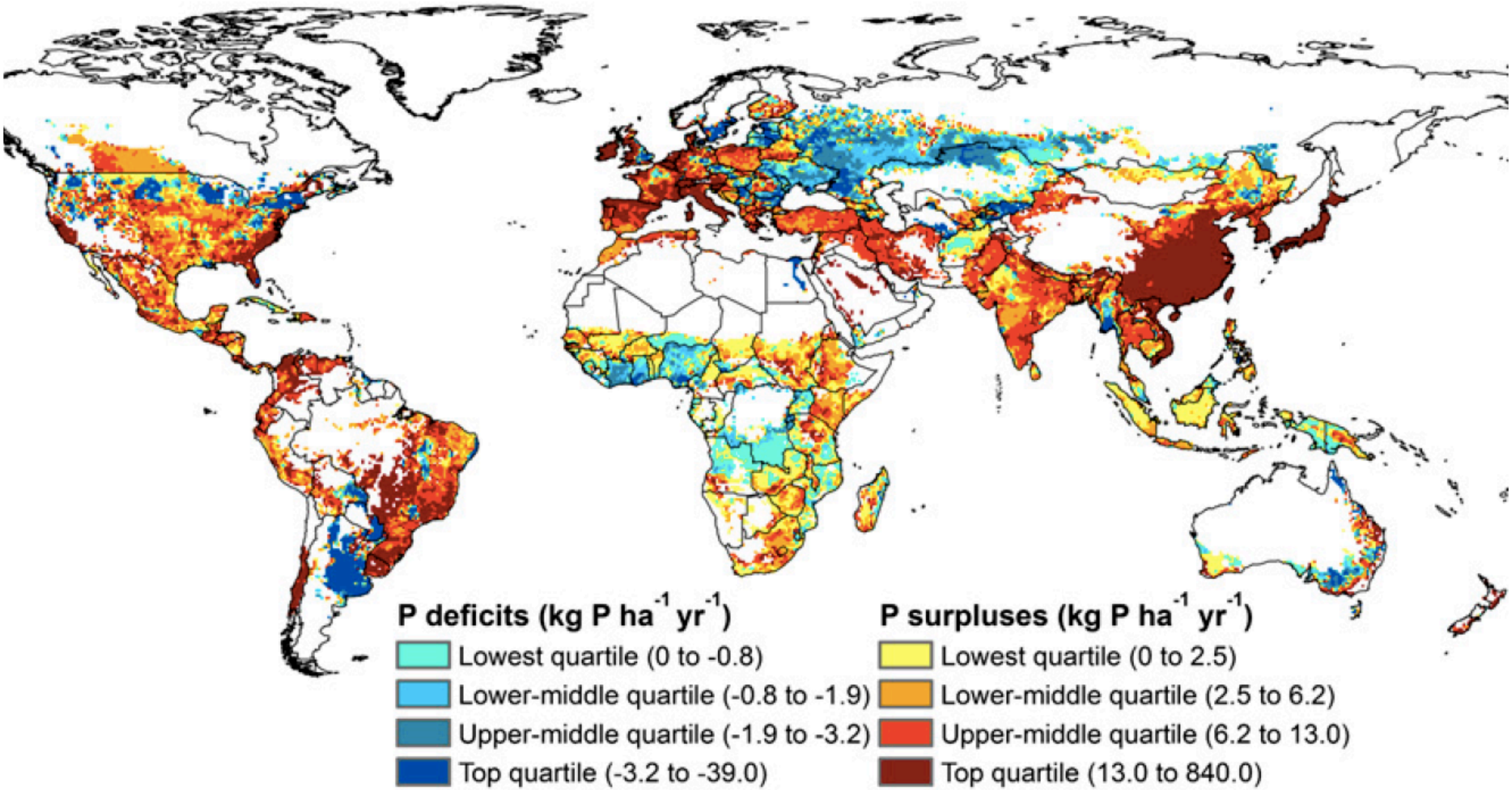




# What 'human systems' affect what flows?

- Individuals, e.g. make decisions what they eat or how much P-fertilizer is used
- Groups, e.g. neighbouring farmers or industry clusters develop reference strategies
- Organizations – e.g. companies sell products; NGOs induce norms
- Institutions; e.g. EPA set standards for monitoring sewage to fields
- Societies/nations; e.g. provide subsidies which affect flows
- Supranational Institutions; such as EU discuss detergent bans from phosphorus
- Human species evolves and e.g. consumes/uses more phosphorus

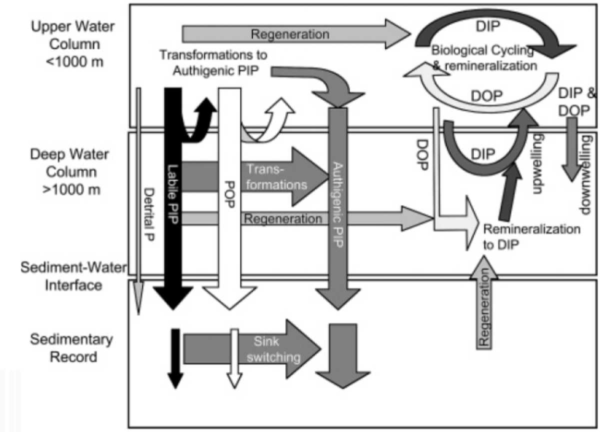
# World scale -- Different national P balances (There are high negative balances in some agrosystems)

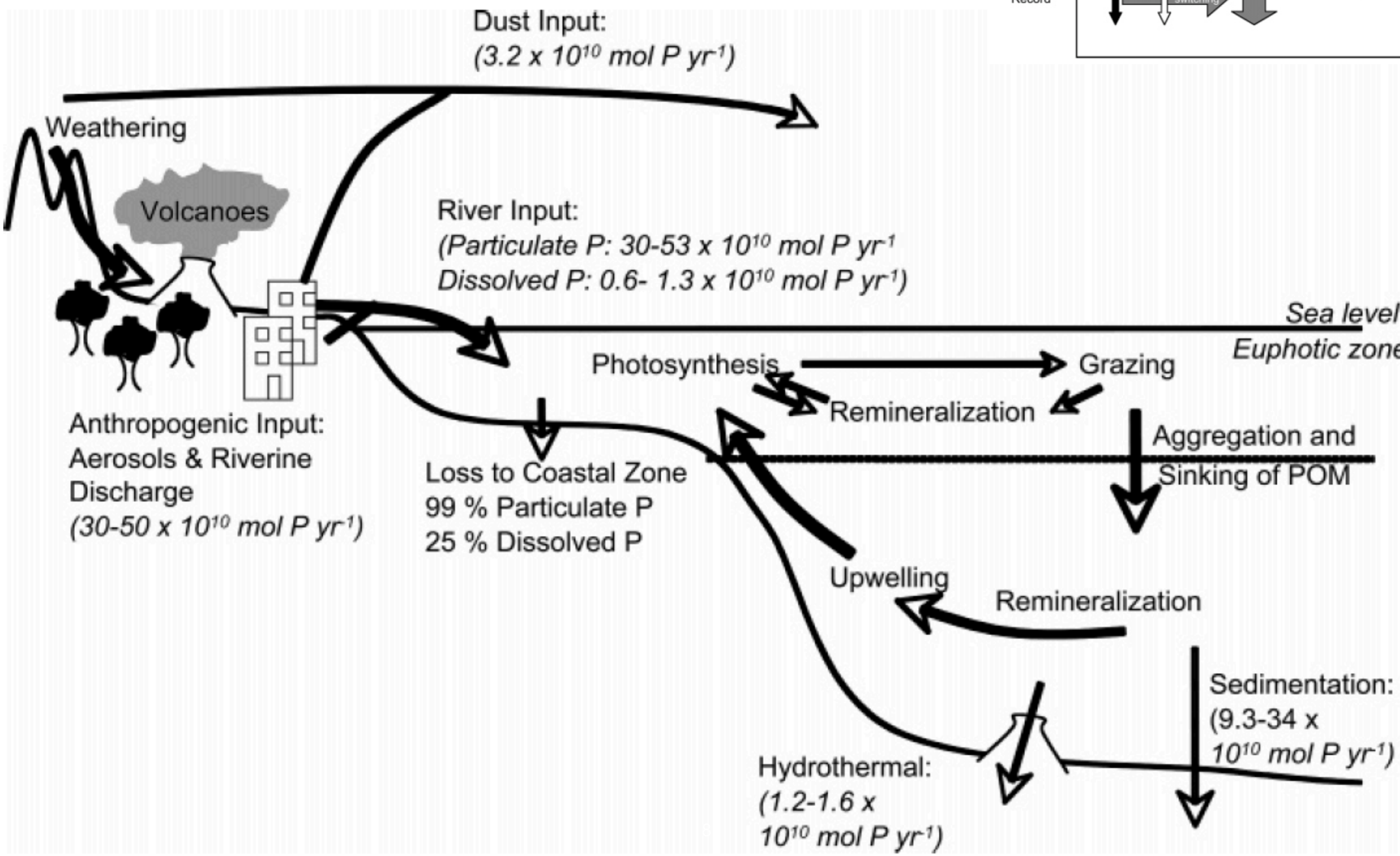



MacDonald, G. K., Bennett, E. M., Potter, P. A., & Ramankutty, N. (2011). Agronomic phosphorus imbalances across the world's croplands. Supporting Information. *Proceedings of the National Academies of Sciences of the United States of America, 108(7), 1-9.*

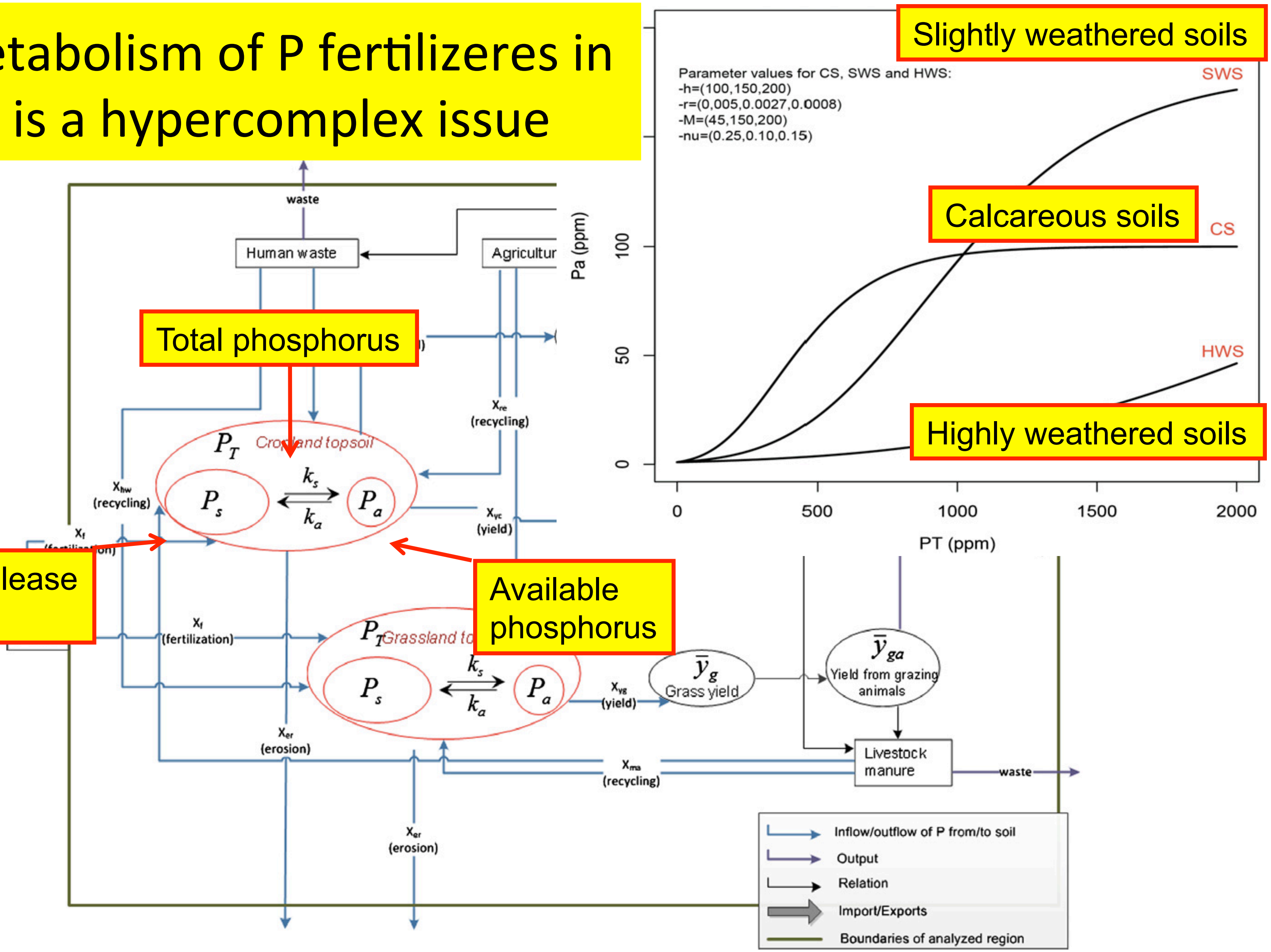
# The oceanic P cycle has become a coupled Human-Environment System (HES)

(Figure from Payton & McLaughlin; 2007)



# The metabolism of P fertilizeres in soils is a hypercomplex issue




Dumas, M., Frossard, E., & Scholz, R. W. (2011). Modeling biogeochemical processes of phosphorus for global food supply. *Chemosphere(84), 798-805.*

# Efficiency

Is an output-input relationship (O/I)

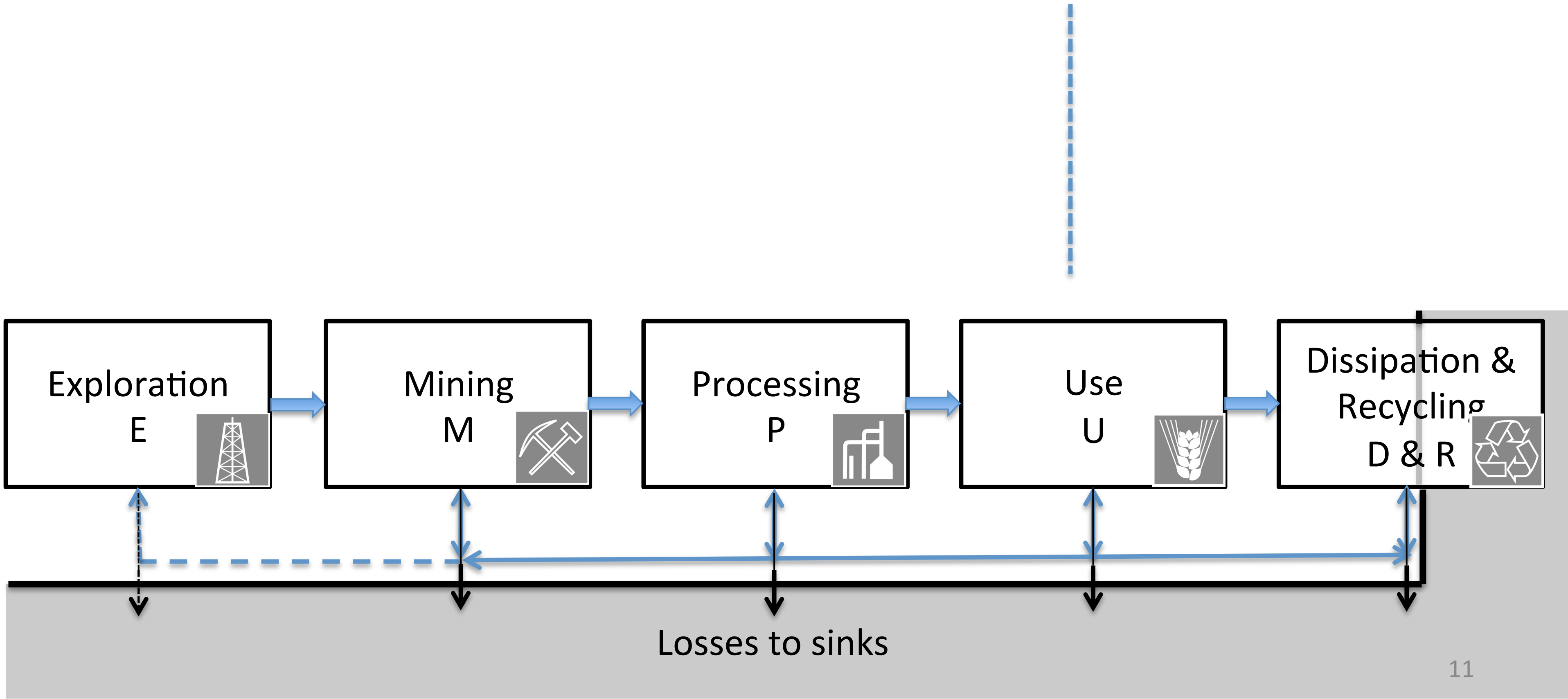
On what system?

For what outputs and inputs?

# How big is the input?

**I := Input** = Total P which has been 'affected' to produce the **Output**

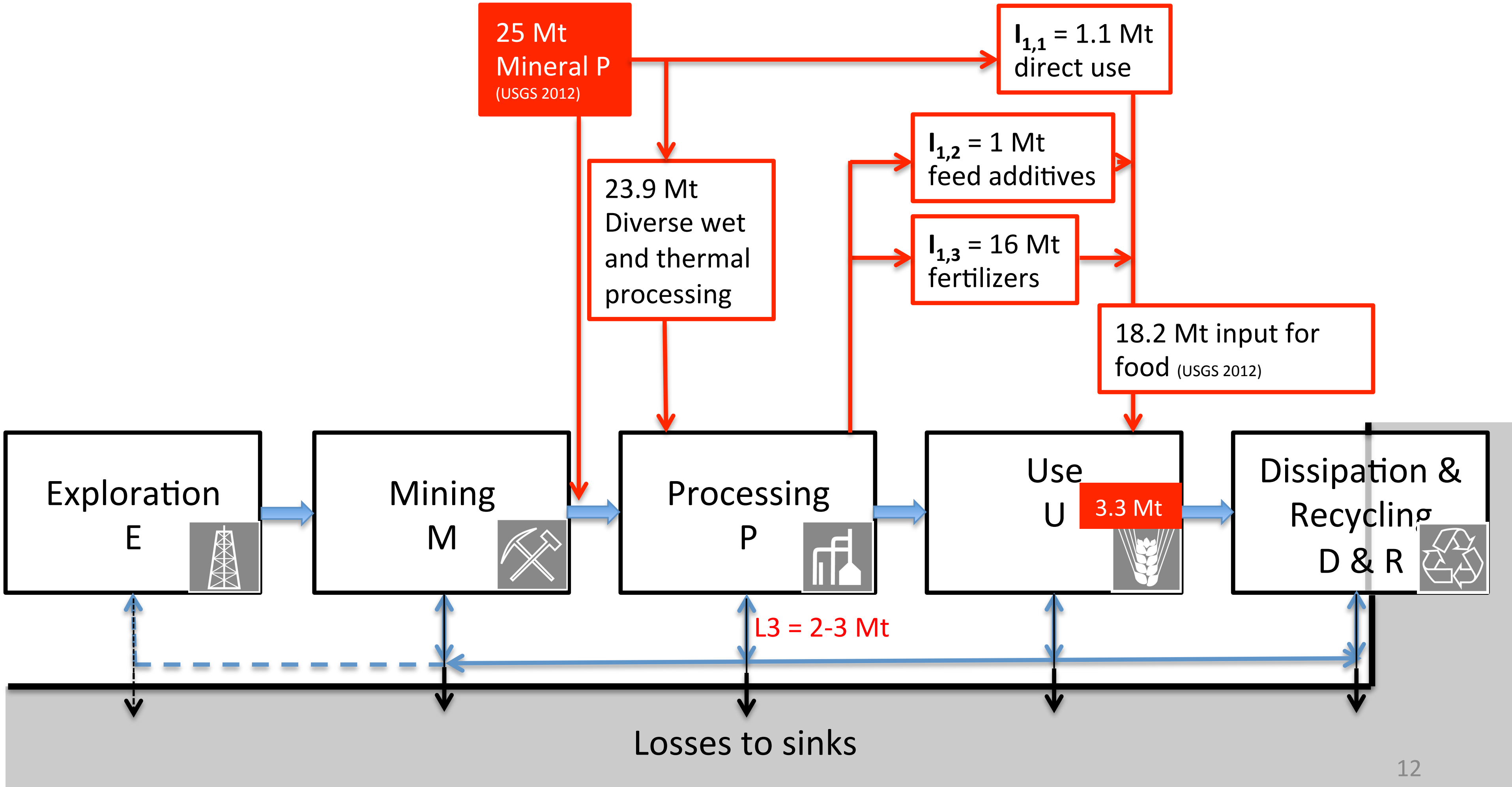
**O:= Output** = total P uptake by food; 1 g/d; $7*10^{12}$ people; ca. **3 Mt P*yr$^{-1}$**



# How big is the 'total use efficieny' for human food uptake (2011)?

**$I^{hum}$ := Input** = Total P which has been 'affected' to produce the **$O^{hum}$ -Output**

**$O^{hum}$:= Output** = total human P uptake by food; 1 g/d; 7*10[12] people; ca. **3.3 Mt P*yr$^{-1}$**



# Incorporating upstream losses

**$I^{hum}$ := Input** = Total P which has been 'affected' to produce the **$O^{hum}$ -Output**

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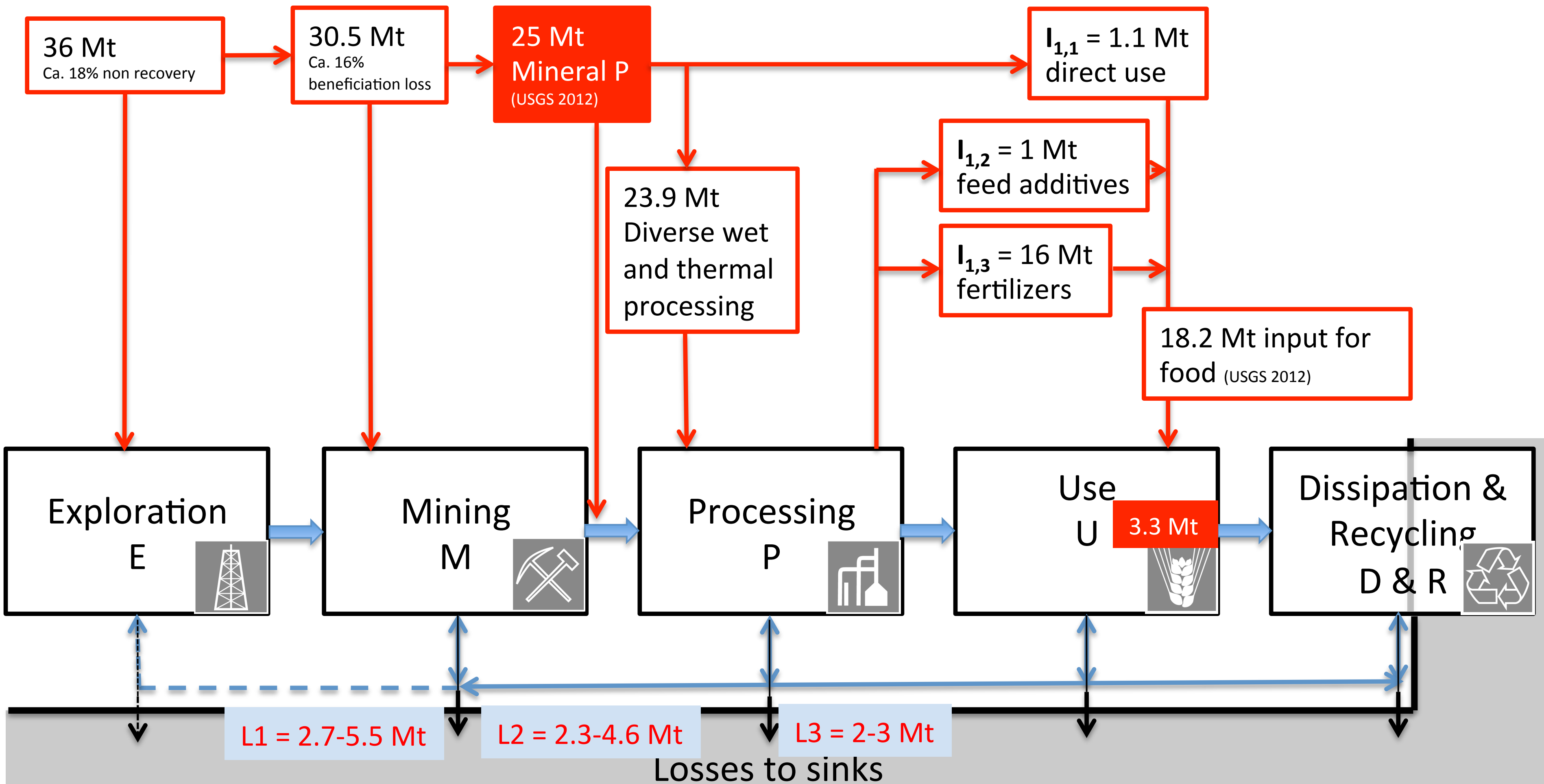
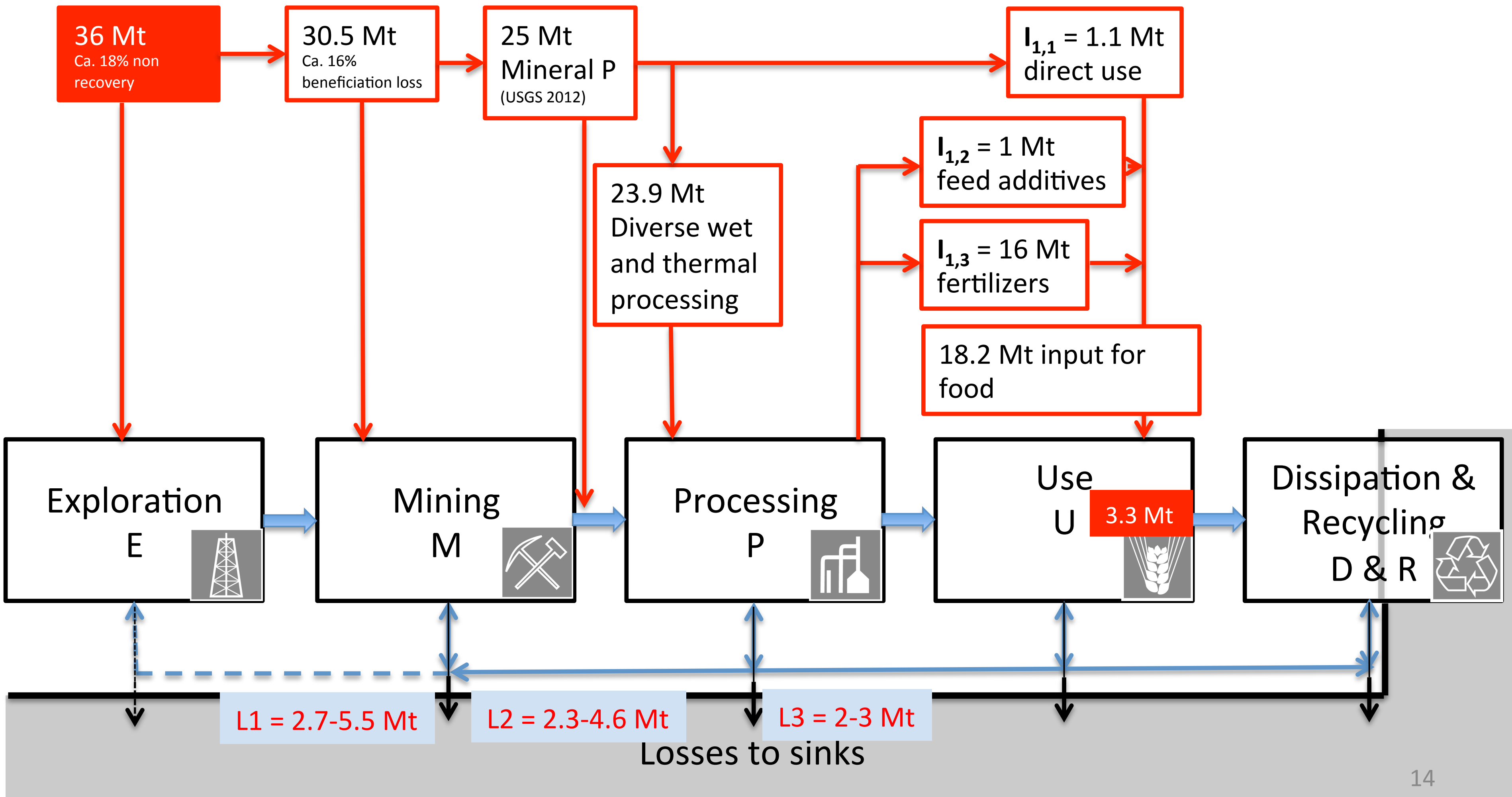


# Incorporating inputs from weathering & the sea

**$I^{hum}$ := Input** = Total P which has been 'affected' to produce the **$O^{hum}$ -Output**

**$O^{hum}$:= Output** = total human P uptake by food; 1 g/d; $7*10^{12}$ people; ca. **3.3 Mt $P*yr^{-1}$**



# Getting a total efficiency of ca. 10%, perhaps less

**$I^{hum}$ := Input** = Total P which has been ‘affected’ to produce the **$O^{hum}$ -Output**

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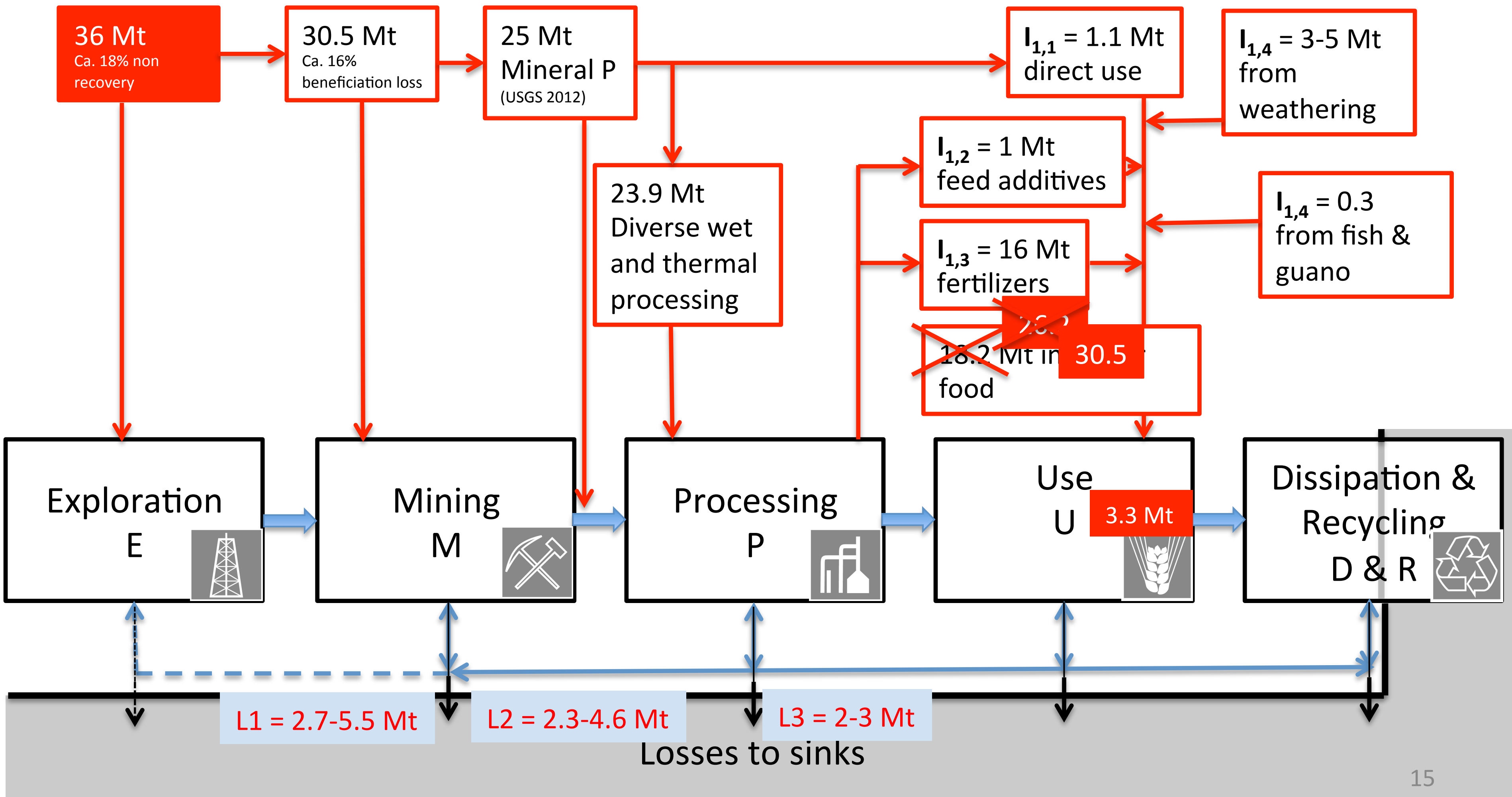
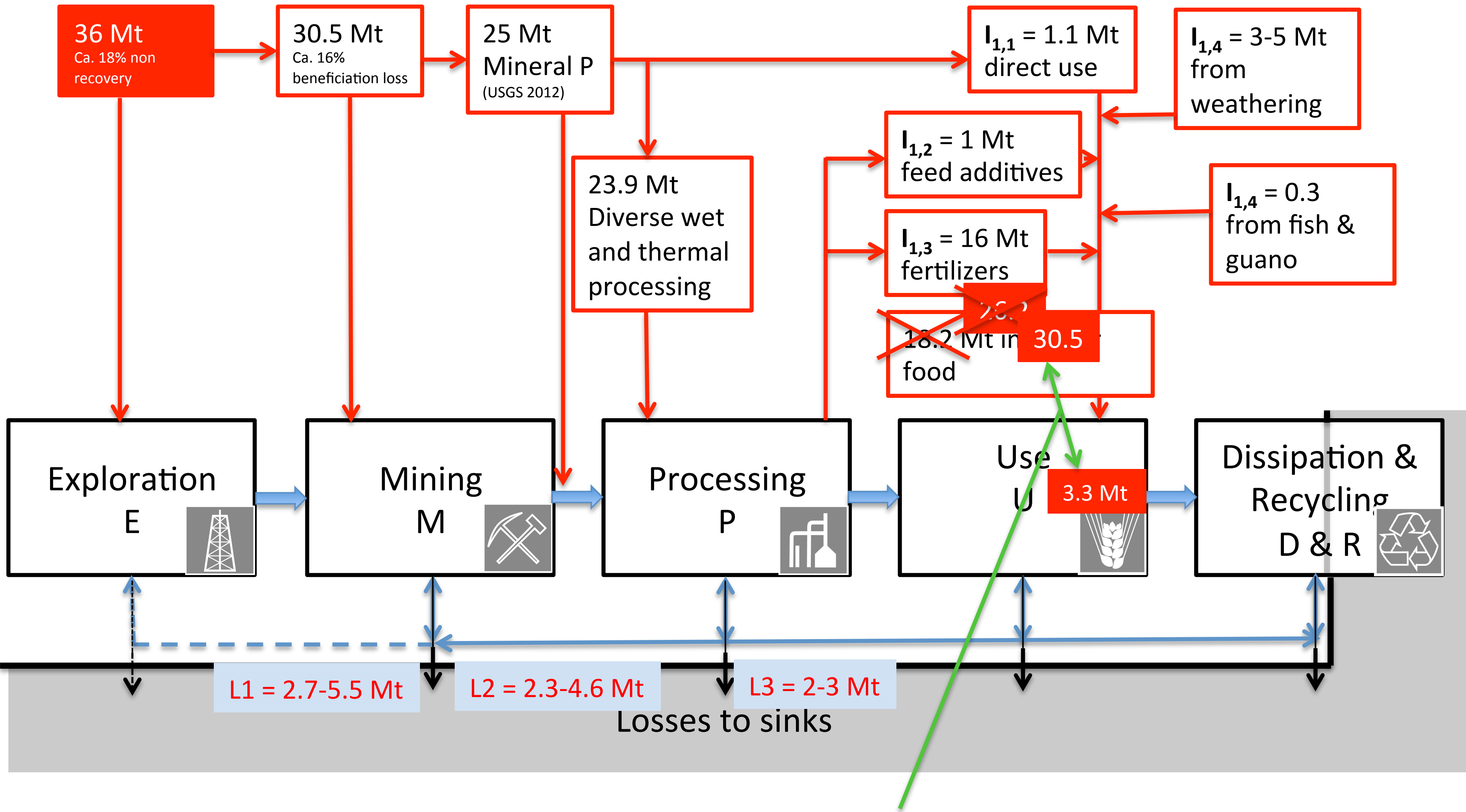
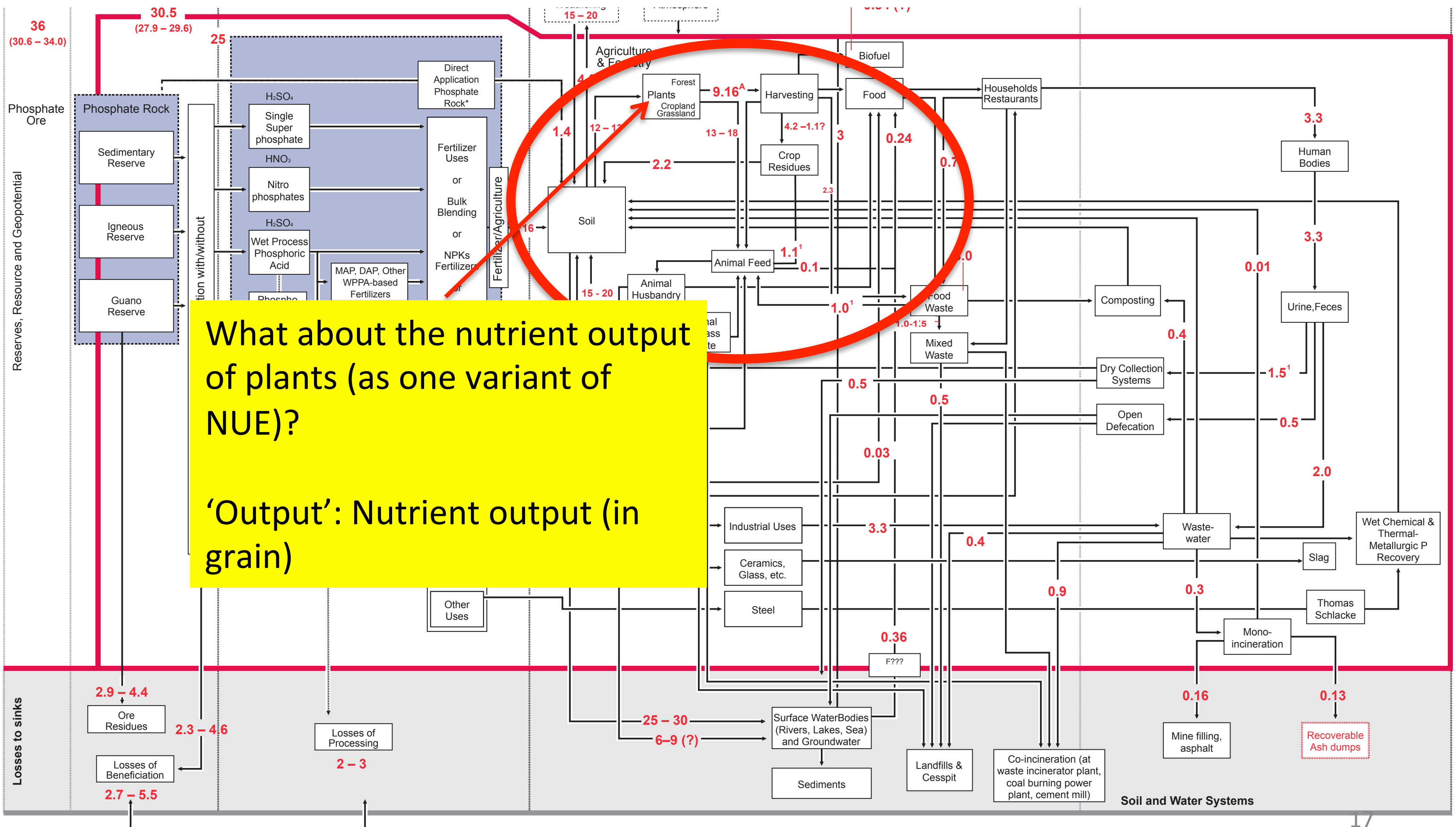





Components of losses in the use stage/node:
- Manure 6-9 Mt

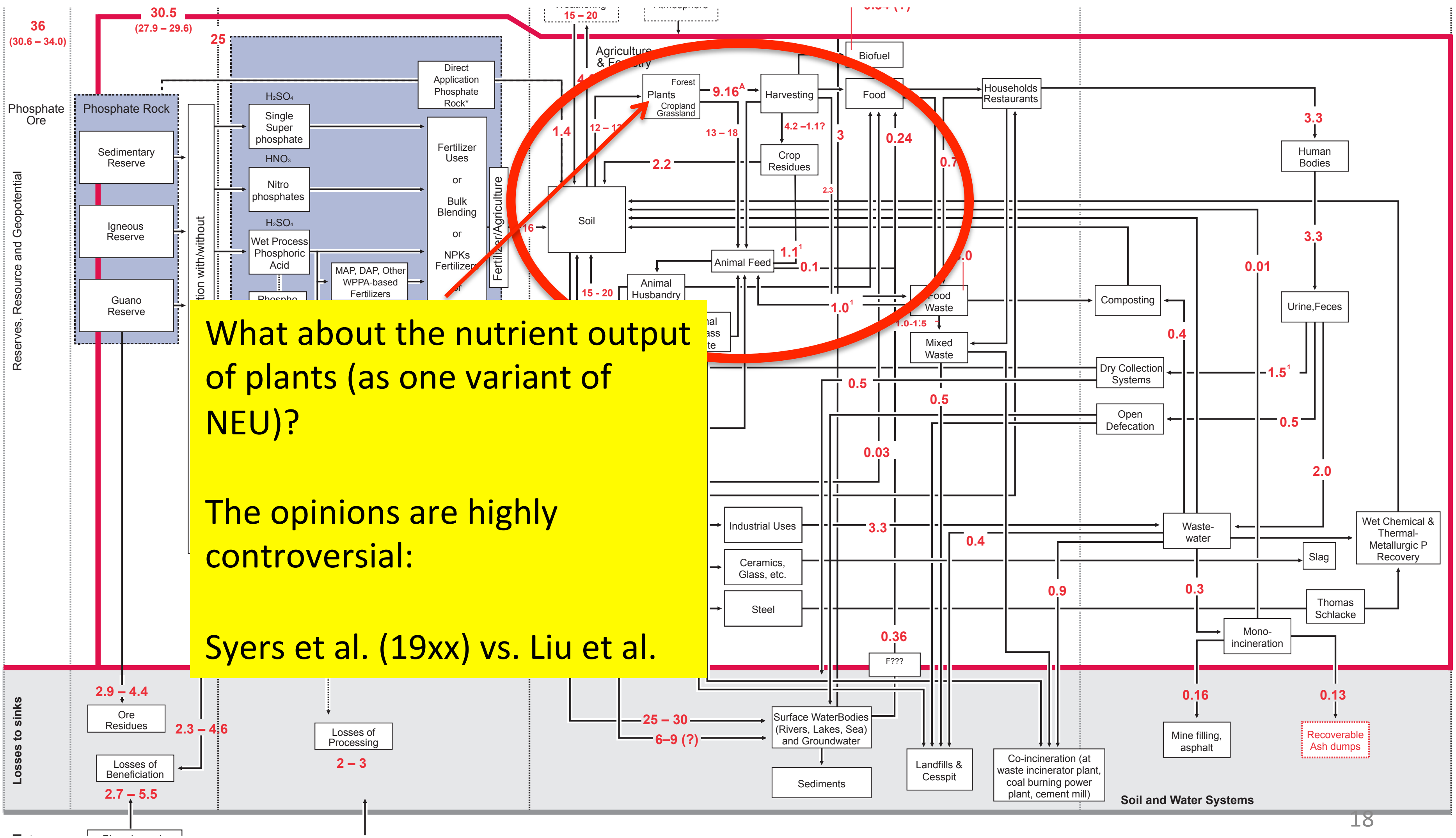
# Conclusion 1: The anthropogenic P cycle is complex and shows a low 'human uptake efficiency' of less the 10%




What about the nutrient output of plants (as one variant of NUE)?

'Output': Nutrient output (in grain)

# Conclusion 1: The anthropogenic P cycle is complex and shows a low 'human uptake efficiency' of less the 10%

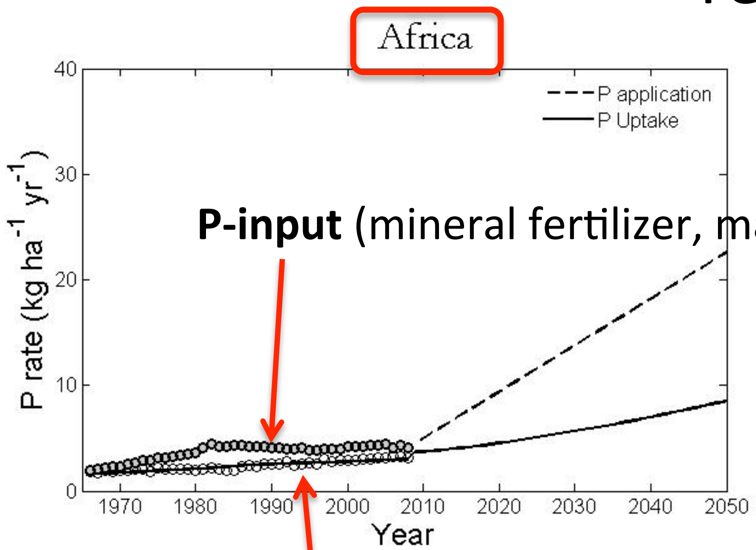



What about the nutrient output of plants (as one variant of NEU)?

The opinions are highly controversial:

Syers et al. (19xx) vs. Liu et al.

# How does the plant uptake efficiency for P (P-NUE) really look like?




**P-input** (mineral fertilizer, manure, weathering)

P-plant nutrient output

Sattari, S. Z., Bouwman, A. F., Giller, K. E., & van Ittersum, M. K. (2012). Residual soil phosphorus as the missing piece in the global phosphorus crisis puzzle. *Proceedings of the National Academy of Sciences of the United States of America, 109*(16), 6348-6353.

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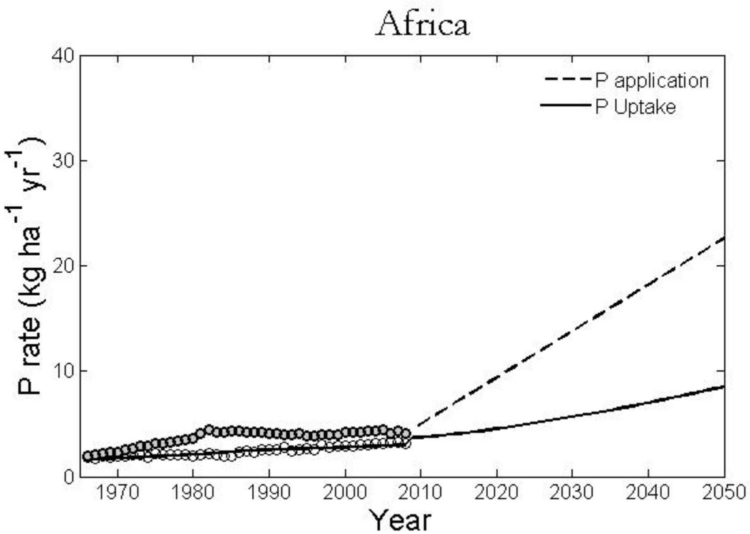


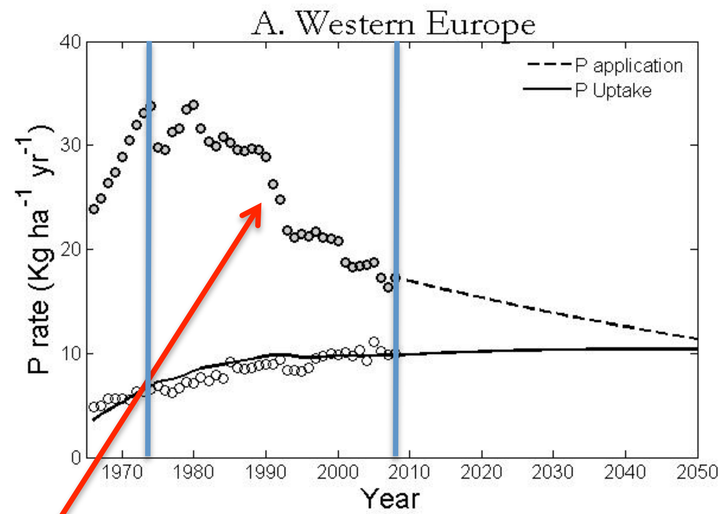


A nice learning curve
P-NUE increased from
20%-50%

Sattari, S. Z., Bouwman, A. F., Giller, K. E., & van Ittersum, M. K. (2012). Residual soil phosphorus as the missing piece in the global phosphorus crisis puzzle. *Proceedings of the National Academy of Sciences of the United States of America, 109*(16), 6348-6353.

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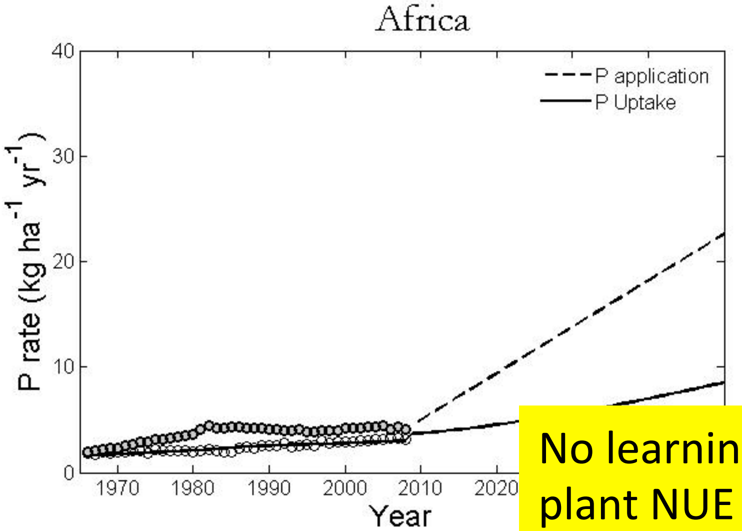
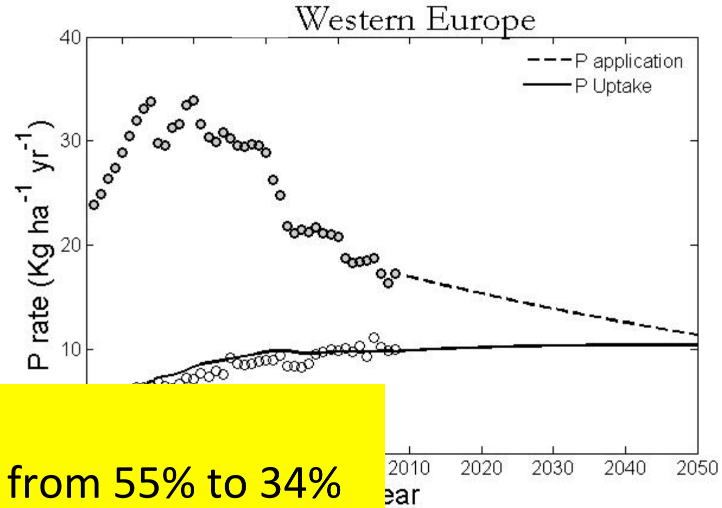
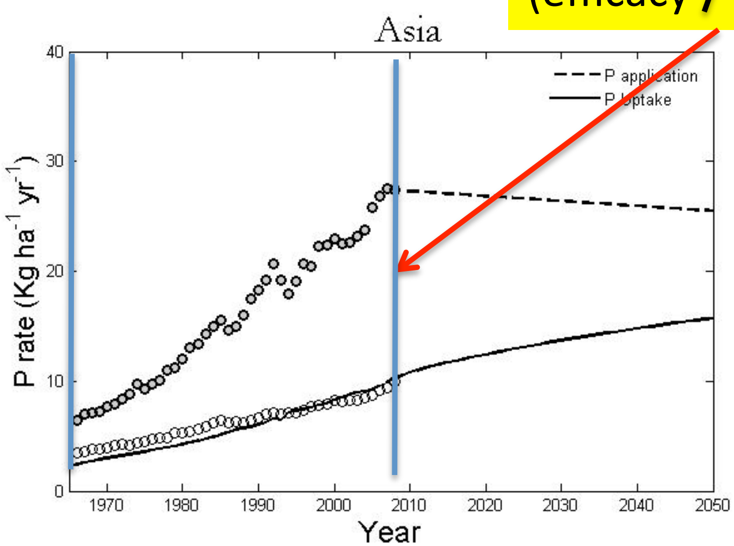



No learning yet:
plant NUE decreased from 55% to 34% when tripling the yield
(efficacy ≠ efficiency)





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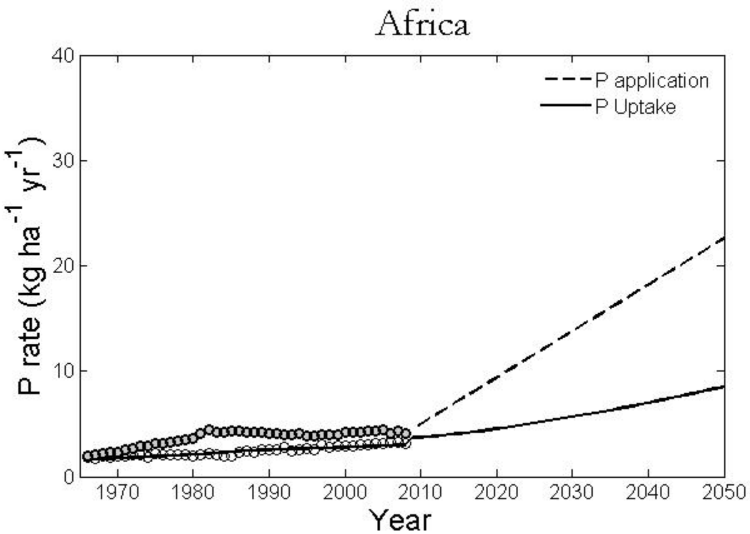


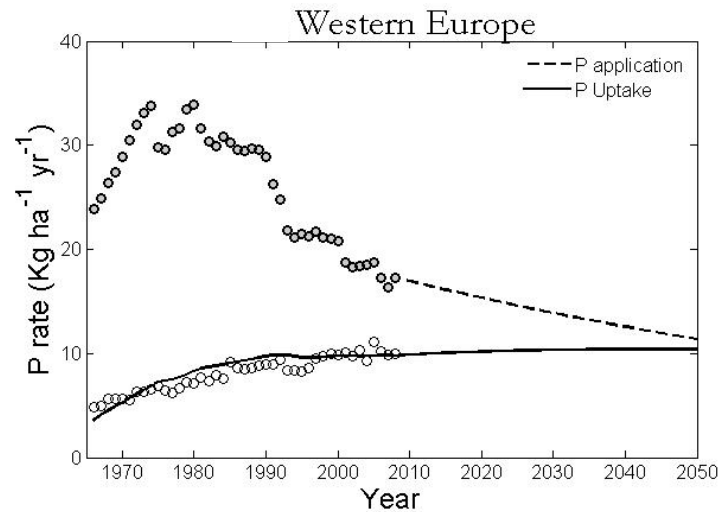


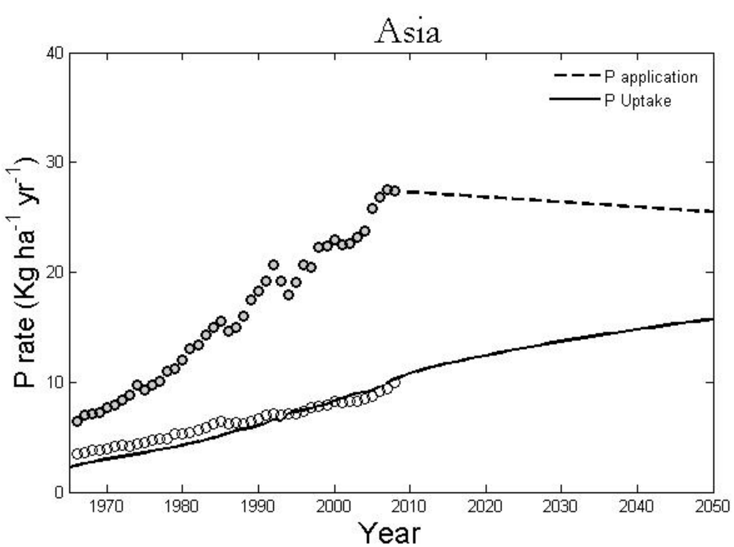


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Conclusion 2: The long term plant use "P-nutrient output efficiency" of plants (≈ 40%, after upstream correction by Sattari) is better than that of humans (< 40%).

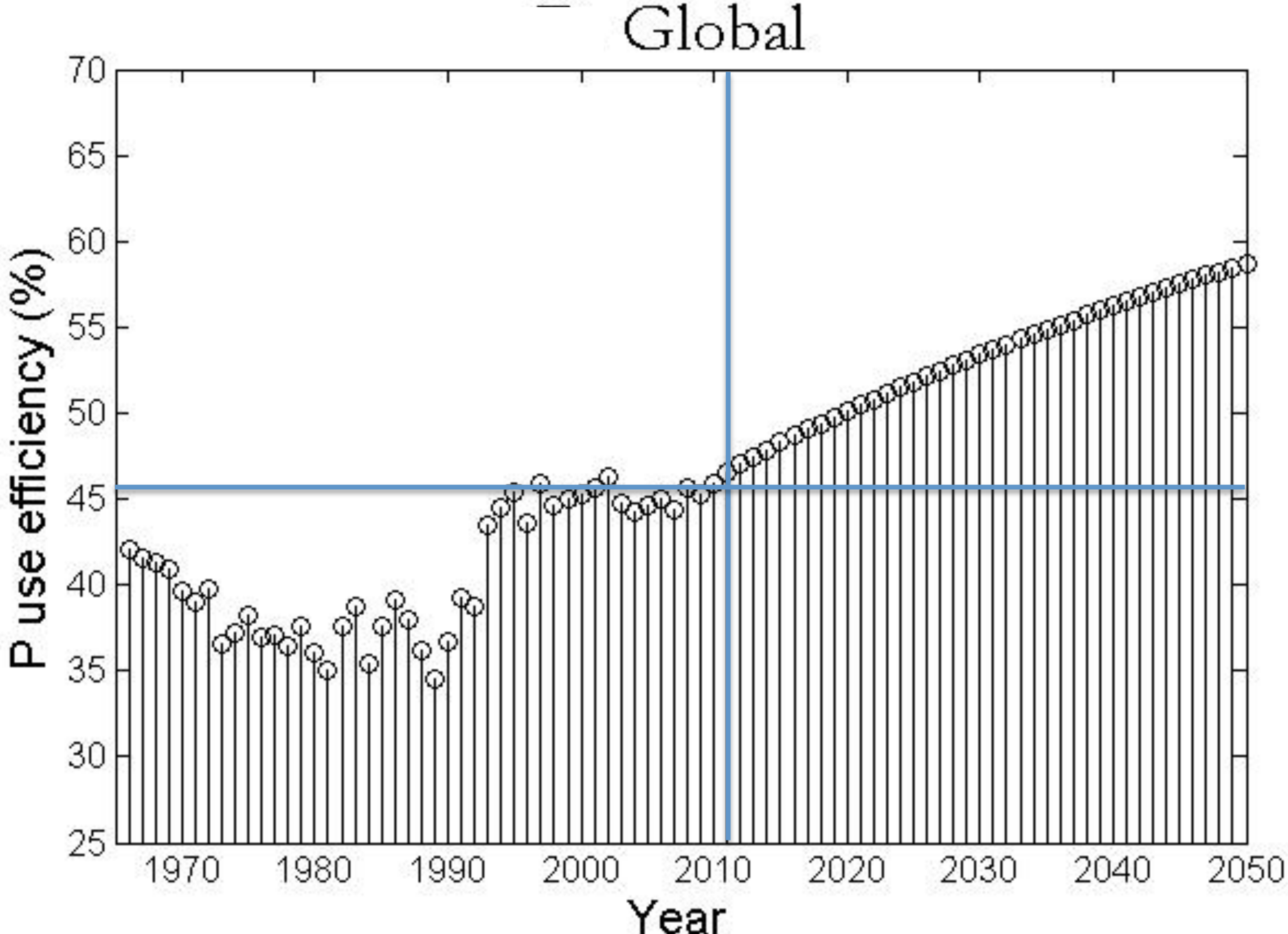



Figure by S. Sattari, 2013

# Environmental Impacts (of P fertilization)

- Cy Jones will tell more about it
- Aquatic systems are the most vulnerable unit

# Nutrients impacts are Janus-faced

# Environmental Impacts (of P fertilization)

- Cy Jones will tell more about it
- Aquatic systems are the most vulnerable unit
  - Freshwater (lakes) more sensitive than seawater; the dose matters (Paracelsus principle); avoid ‘phosphoric obesity’
  - Biodiversity (of different types) may be an issue; soil biodiversity as well
  - From an evolutionary development perspective, the rapid systemic change may show rebound effects and tipping points

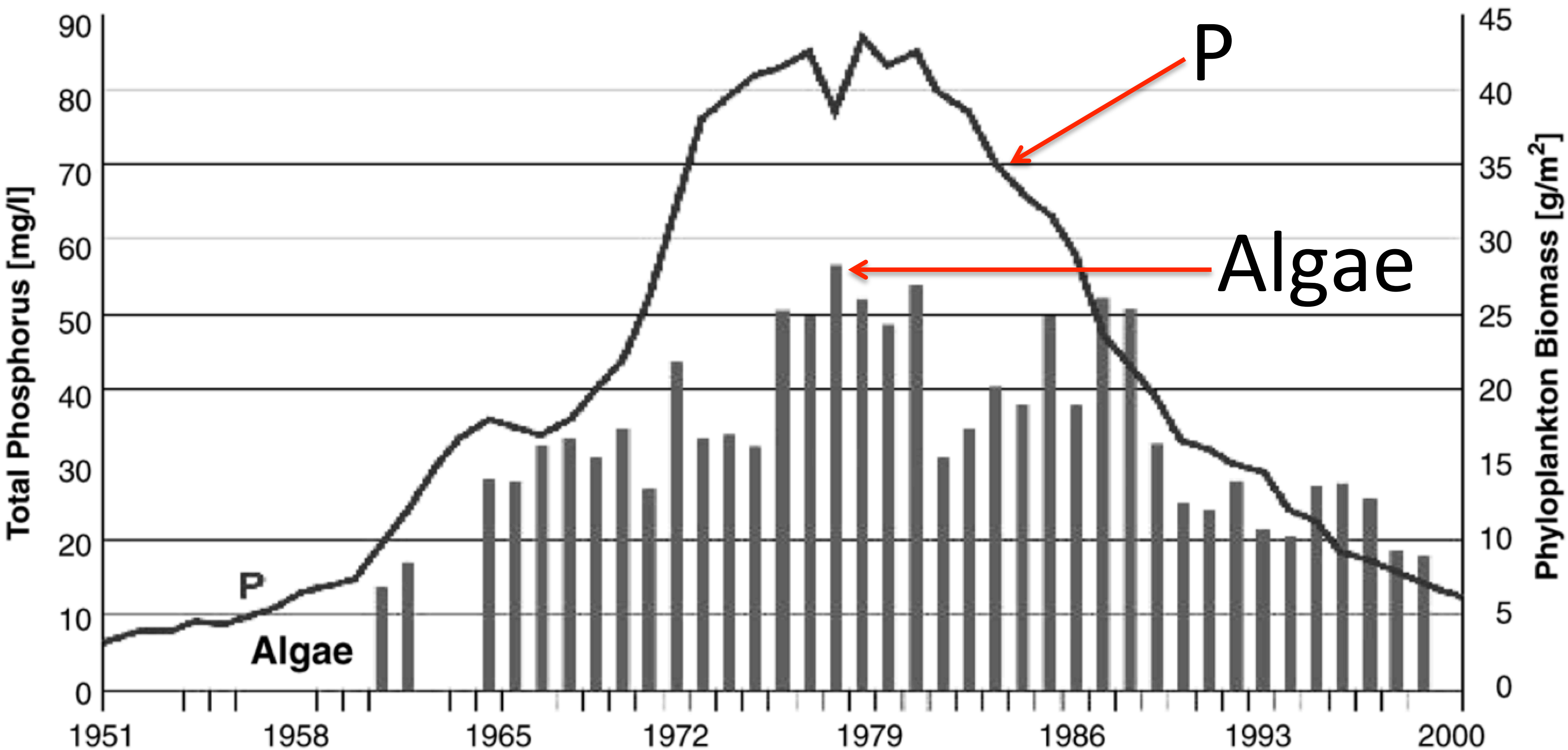
## Conclusion 3: The tradeoff between increasing food production by intense fertilization and the short and long term impacts of ‘environmental change’ (as well as industrial human health impacts) should be watchfully monitored

Aquatic systems are the most vulnerable unit

- Freshwater (lakes) more sensitive than seawater; the dose matters (Paracelsus principle); avoid ‘phosphoric obesity’
- Biodiversity (of different types) may be an issue, soil biodiversity as well
- From an evolutionary development perspective, the rapid systemic change may show rebound effects and tipping points

# Yes, we can … if we want and …

P-concentration in the Lake Constance
since 1951



# Access

# Access for (i) human species and (ii) for the poor

- Do we face scarcity with phosphorus?
- Is there a (supply driven) peak phosphorus in 2030/2070 (Cordell et al. 2009, 2011)?

ECOLOGIST
SETTING THE ENVIRONMENTAL AGENDA SINCE 1970 40 YEARS

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

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## Essential Element Becoming Scarce

# Experts Warn of Impending Phosphorus Crisis

*By Hilmar Schmundt*

AFP

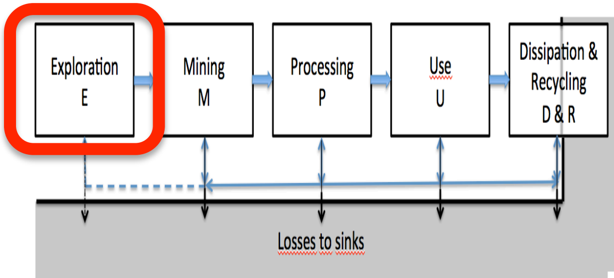
Phosphorus is essential to agriculture, but experts warn reserves are starting to run out.

**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?**

# Access for (i) human species and (ii) for the poor

- Do we face scarcity with phosphorus?
- Is there a (supply driven) peak phosphorus in 2030/2070 (Cordell et al. 2009, 2011)?

# Peak P in 2033? P reserves exhausted in 50-100 years?




- „The data for annual production is fitted using a Gaussian distribution (Laherrere, 2000), **based on the depleted plus current reserves estimate of 3240 MT P, and a least squares optimization which results in a production at peak of 29 MT P/a and a peak year of 2033**." (Cordell et al., 2009, p. 298)

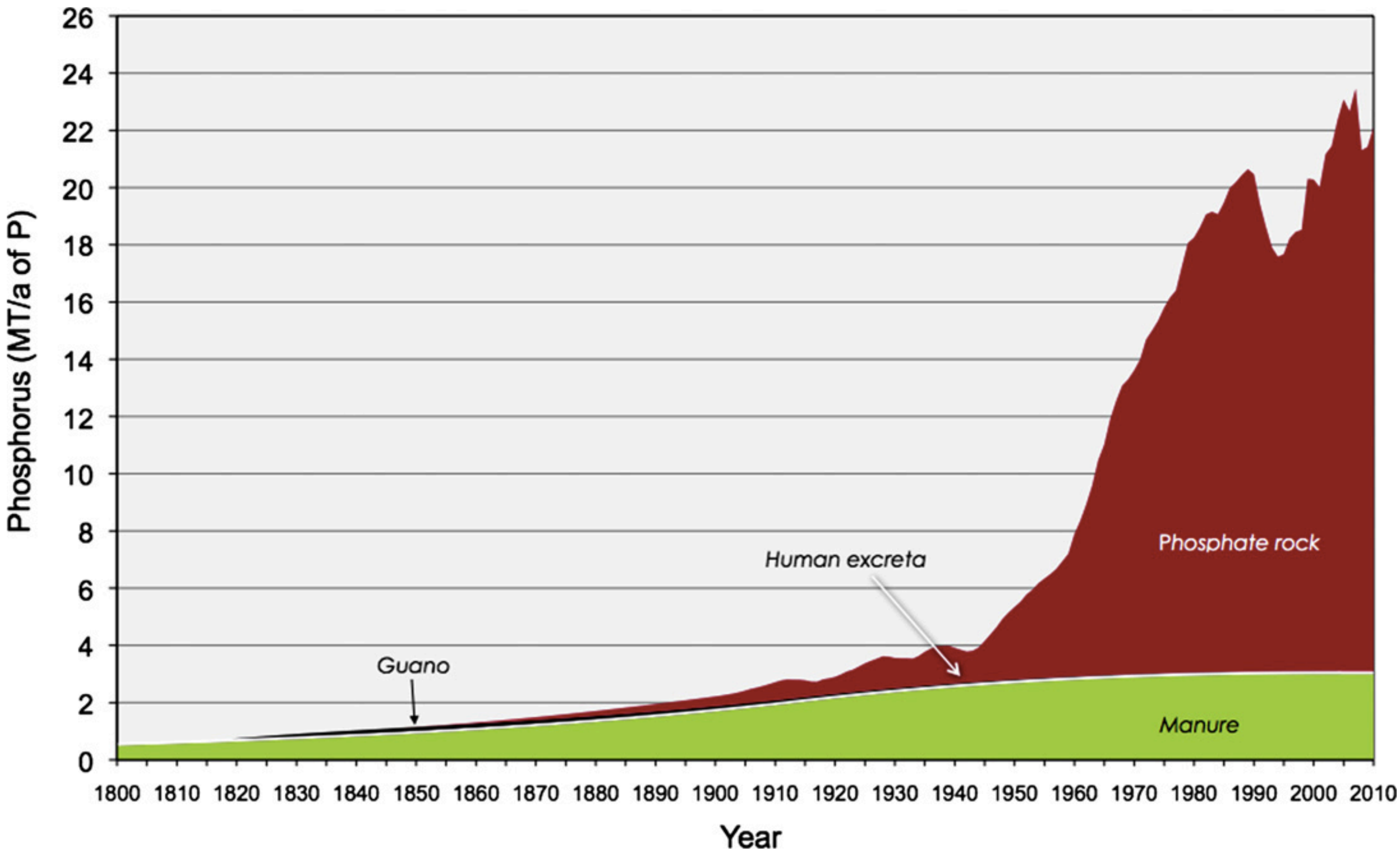
**= 221 Mt RP**
**= 0.02 Mt RP**

**= 25.000 Mt RP**
**= 25 Gt RP**

- Existing rock **phosphate reserves could be exhausted in the next 50–100 years** (Steen, 1998; Smil, 2000b; Gunther, 2005) (Cordell et al., 2009, p. 298)

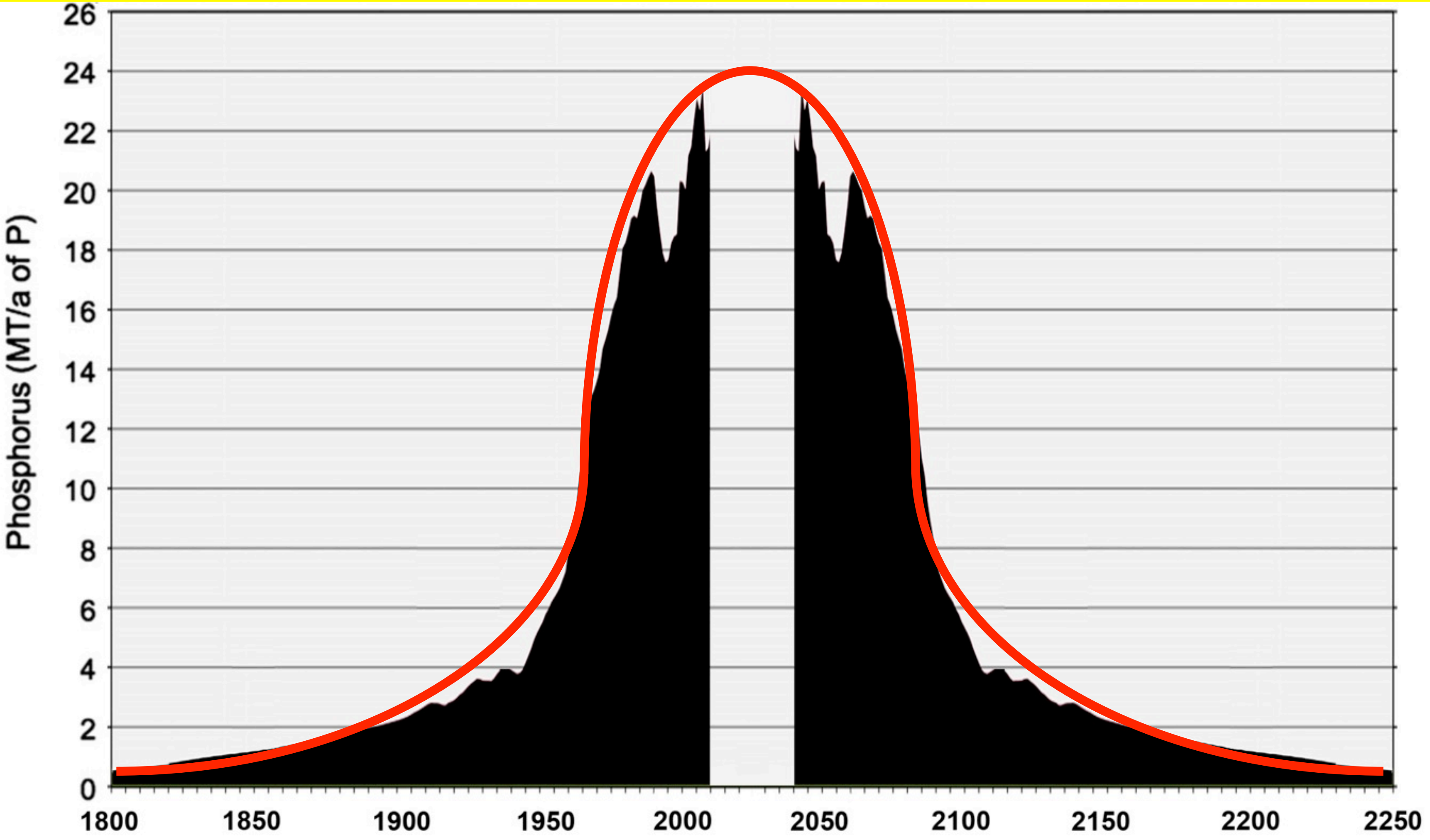
Cordell, D., Drangert, J., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change-Human and Policy Dimensions,* **19**(2), 292-305.

# A steep rise of P consumption emerged concern about scarcity

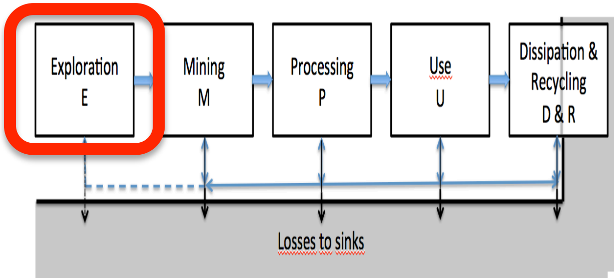


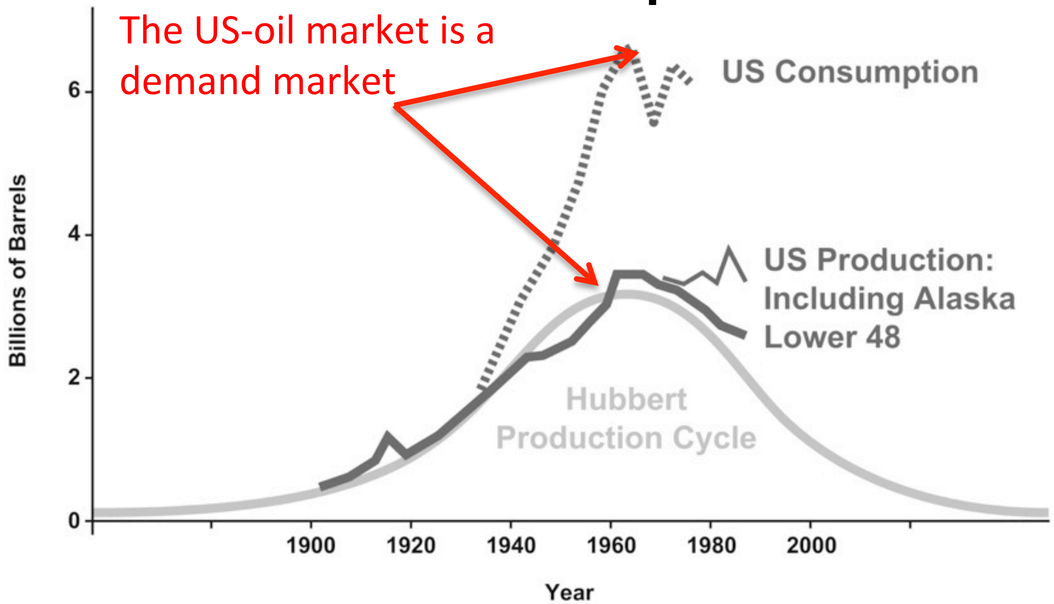

Ashley, K., Cordell, D., & Mavinic, D. (2011). A brief history of phosphorus: From the philosopher's stone to nutrient recovery and reuse. (84), 737-746.

# The Hubbert curve idea is that of a symmetric curve



# Four reasons why the Hubbert curve is not the right model for P



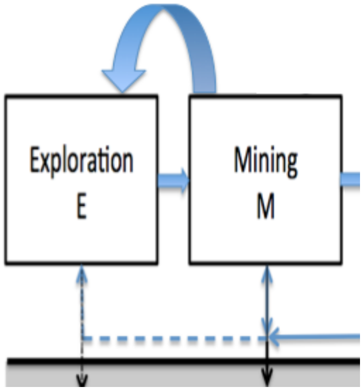




The (logistic) model is nothing else than Verhulst's 1844 population model with
*P* := production at year *t*
*Q* := cumulative production till year *t*

$$P(t) = \frac{dQ(t)}{dt} = rQ\left(\frac{Q_\infty - Q}{Q_\infty}\right) = rQ\left(\frac{URR - Q}{URR}\right)$$

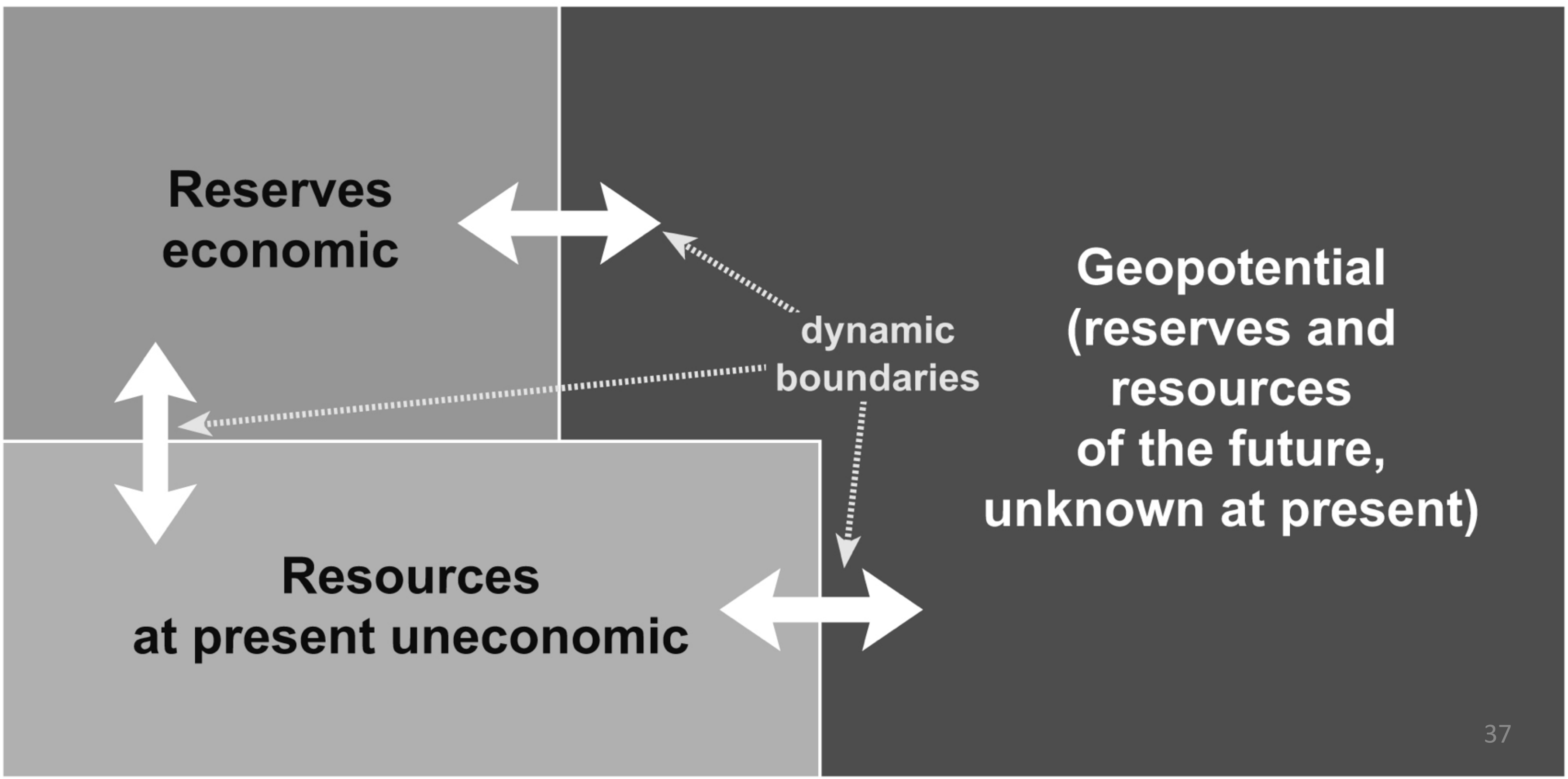
$$P/Q = r - rQ/URR$$ Is a linear function (Hubbert linearization)

1. **It is the wrong model for global P**
   - There is no symmetric increase and decline of production
   - There is no static URR (ultimate recoverable resource, **2008 15 Gt PR**, **2009 65 Gt PR**, **2010 71 GT PR, 67 GT 2012)**
   - We have facing **dynamics/improvement** of technology, demand (supply driven model, the market takes everything)
2. **The difference between a supply and demand market logics has been ignored**
3. **Geological data have been ignored (Western Phosphorus Fields)**
4. **The "classical application" of the Hubbert curve provides a resource estimate of 8 Mt P?**

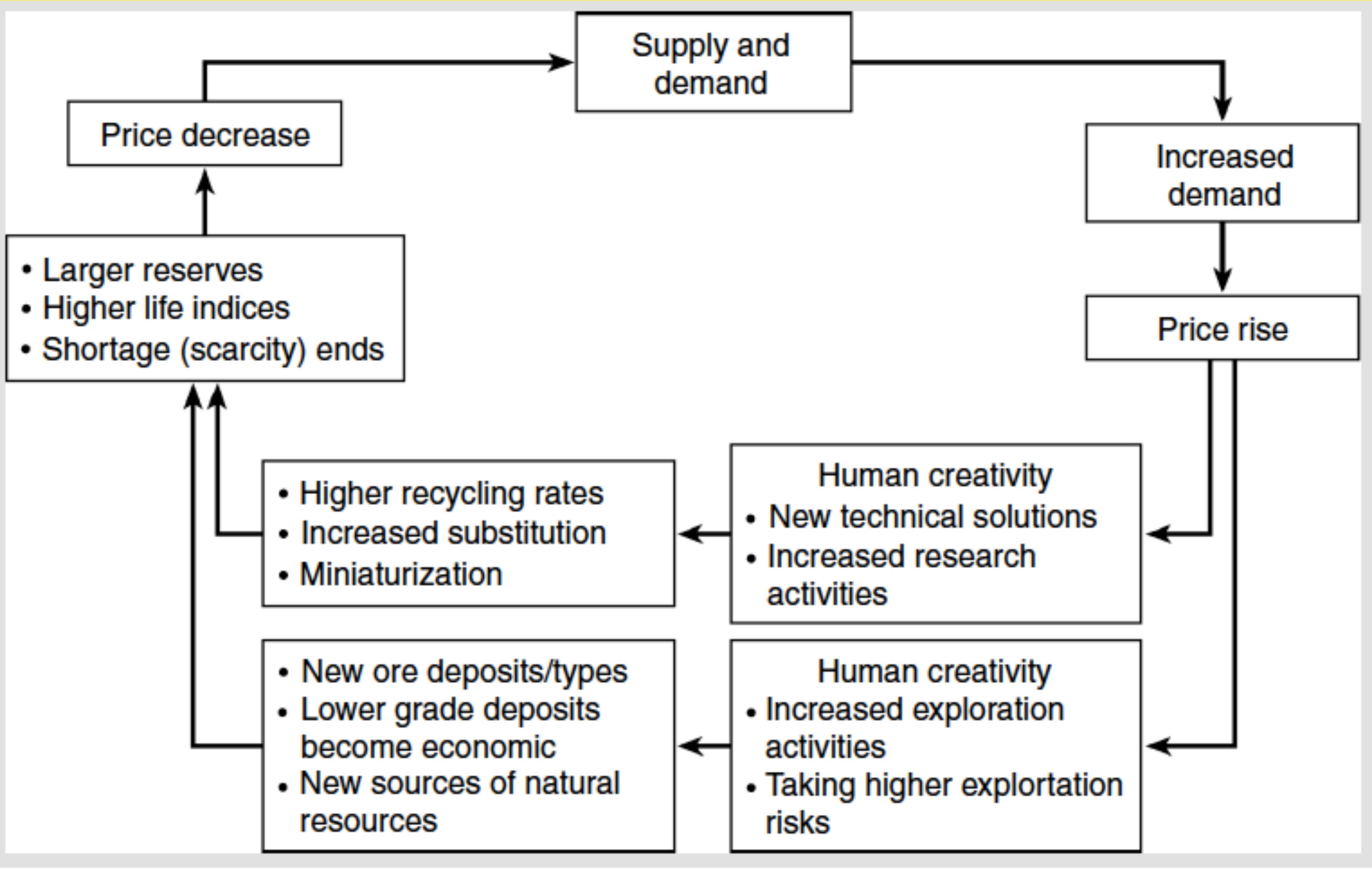



# We have to understand the dynamics of reserves?

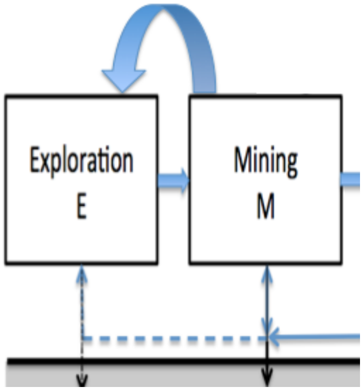
Scholz, R. W., & Wellmer, F.-W. (2013). Approaching a dynamic view on the availability of mineral resources: what we may learn from the case of phosphorus? *Global Environmental Change, 23*, 11-27.
Sinding-Larsen, R., & Wellmer, F.-W. (2012). Introduction. In R. Sinding-Larsen & F.-W. Wellmer (Eds.), *Non-Renewable Resource Issues. Geoscientific and Societal Challenges. International Year of the Planet Earth (IYPE) Series.* (pp. 1-19). Dordrecht: Springer.



# Resources follow a feedback control cycle: Prices increase resources and recycling




Wellmer, F.-W., & Dalheimer, M. (2012). The feedback control cycle as regulator of past and future mineral supply. *Mineralium Deposita, 47*(7), 713-729.

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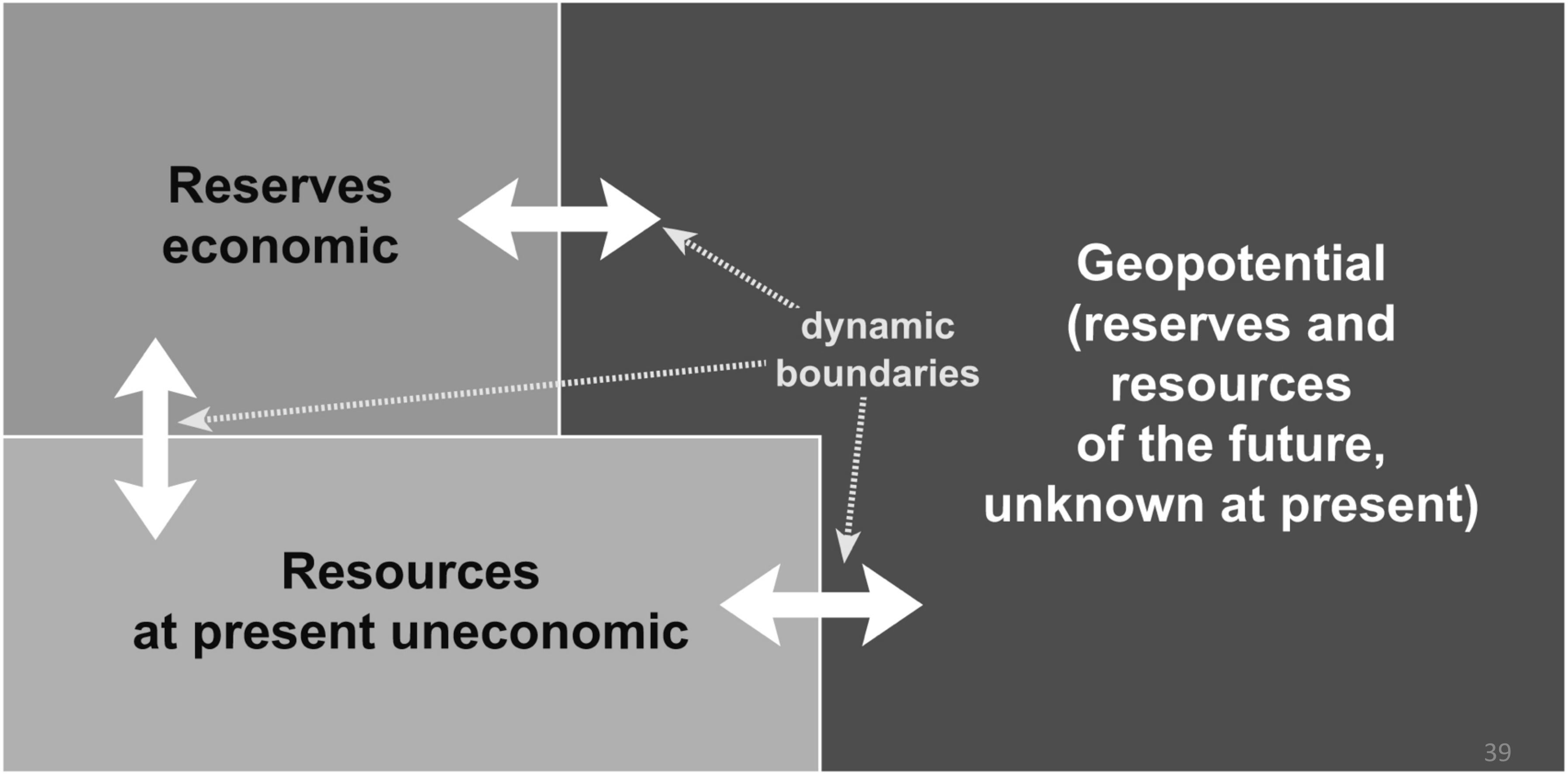
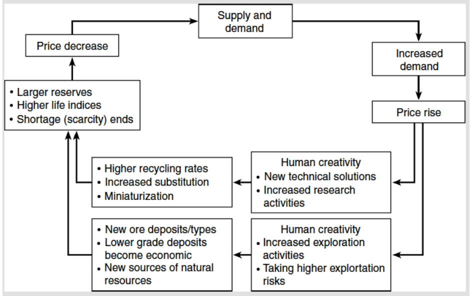
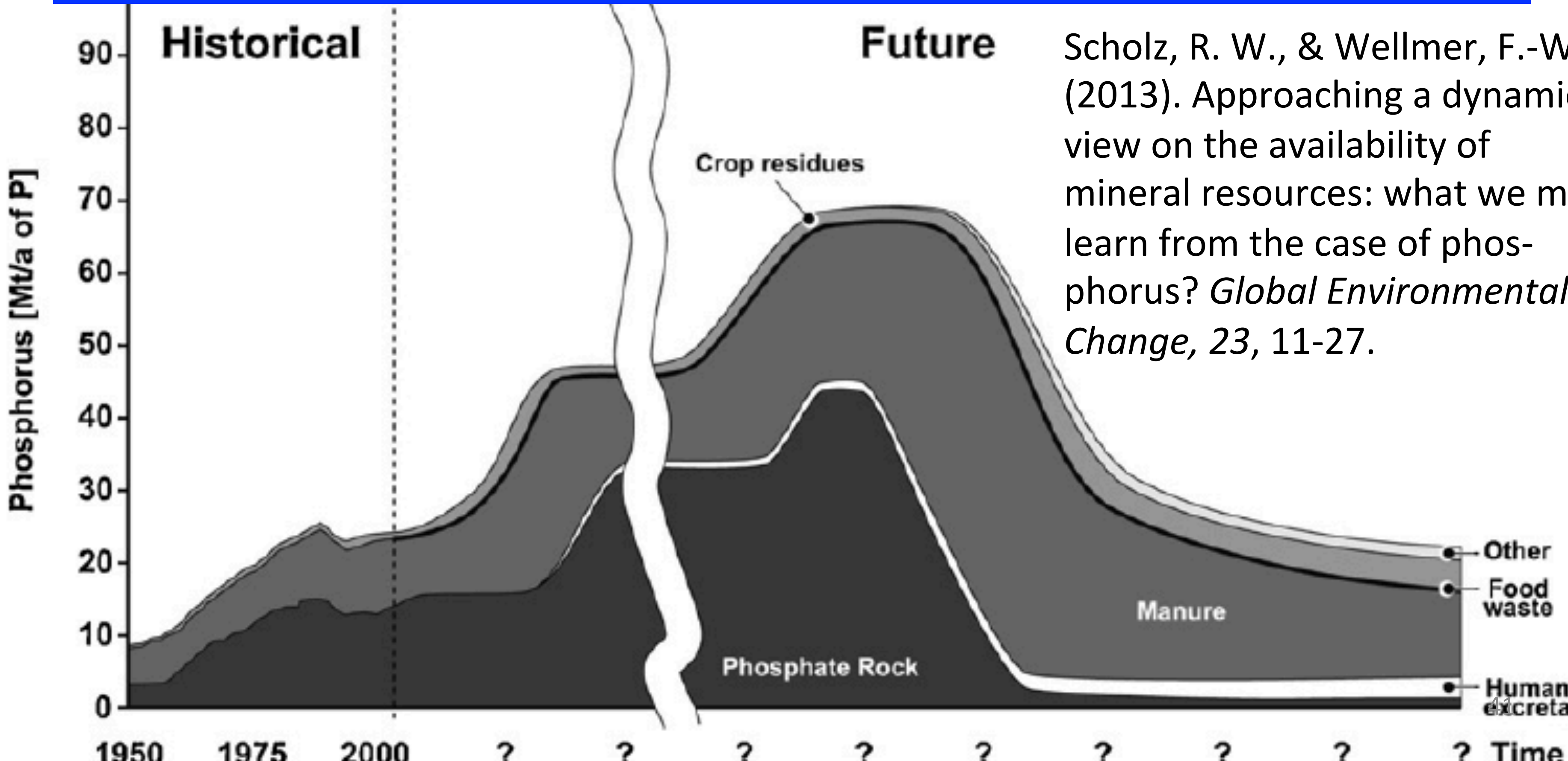





# When does the feedback control cycle not 'function'?

- **When the P prices become intolerably high**
  - Not likely for P on a average world level ("P is most vulnerable for scale")
  - Low cost commodity (30 kg PR*$y^{-1}$*$cap^{-1}$, 6 USD per person, 40 BUSD*$y^{-1}$)
- **When the time scale of demand changes do not meet the time scales in supply** (that's the case with minerals)
- **When wrong subsidies are provided** (subsidies to fertilizer companies and as a buffer after price peaks)
- When **wrong information about reserves/demand/technologies are around** (Peak P may cause some nedative feedback loops; prices, geopolitical control etc.)
- When **markets become distorted** (e.g. by monopoly, illiquidity of actors, obscuring information, wrong subsidies, ...) and **bottlenecks** in some domains emerge (e.g. 2007/8 a couple of US fertilizer companies closed); good monitoring and prospection (e.g. scenario-based models are needed)
- In **financial crises** ...
- If **technology innovation fails/stops** ... (decreasing ore grades seem not to be a problem in the next decades/century)
- When (**irreversible**) **external costs/effects bounce back** ... the systemic effect of doubling/tripling P flows will change the ecosystem matrix

Conclusion 4: There will be (with close to certainty) no necessary supply driven Peak P in the next decades/ centuries (if resources management runs well). Acknowledging that rock phosphate is a finite resource and P has a Janus face, the challenge is to work for a demand driven peak P.

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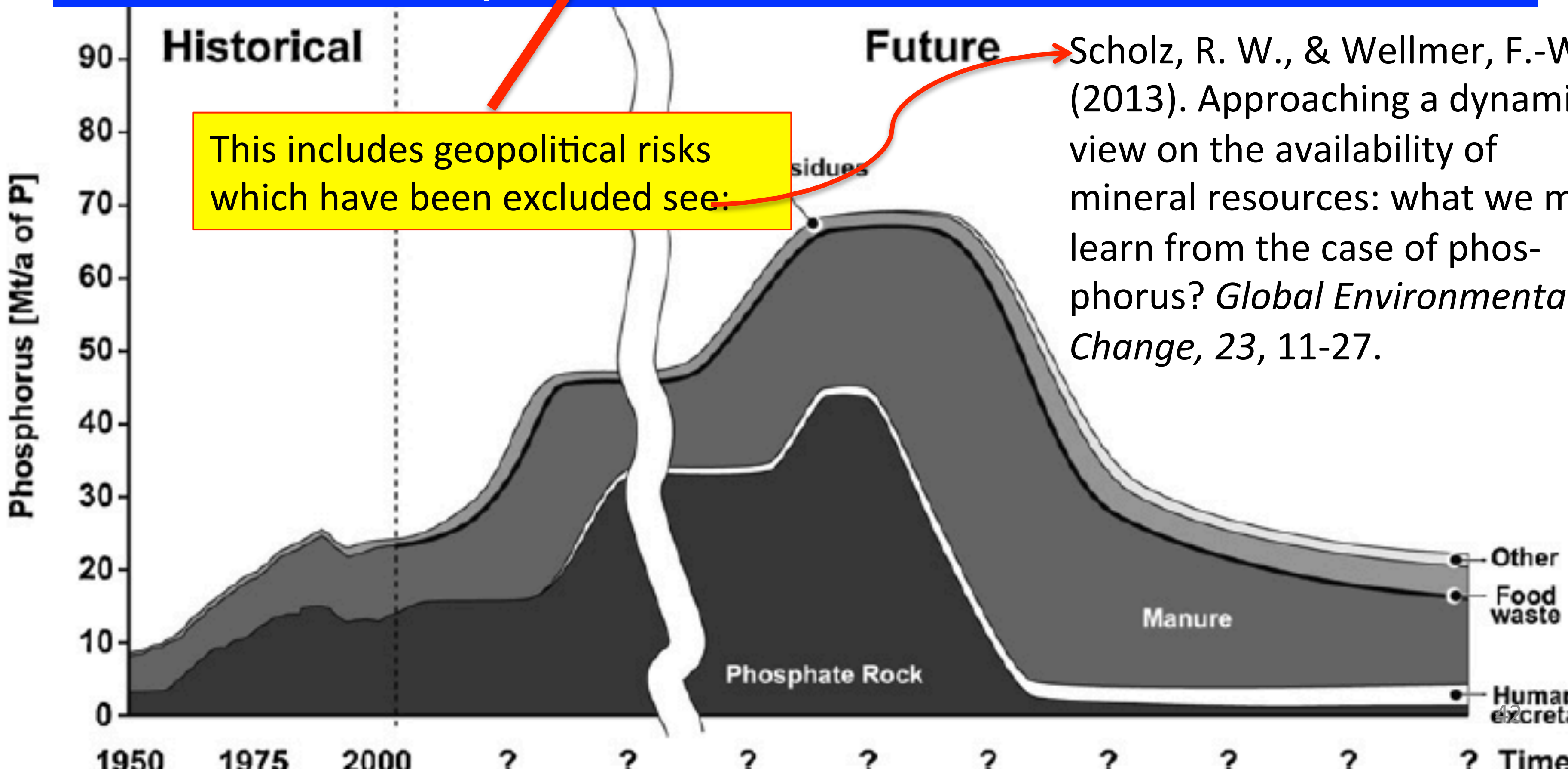
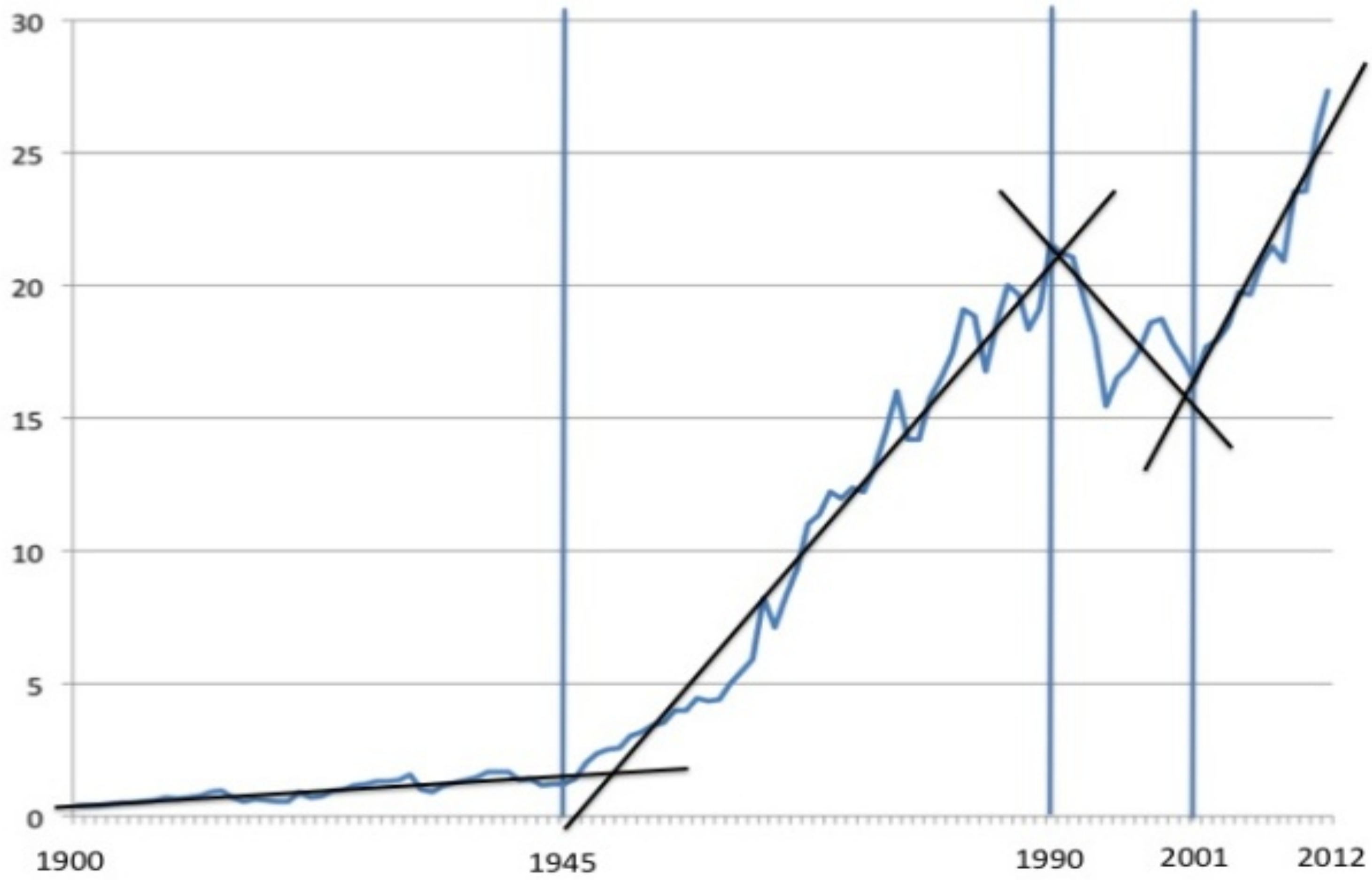


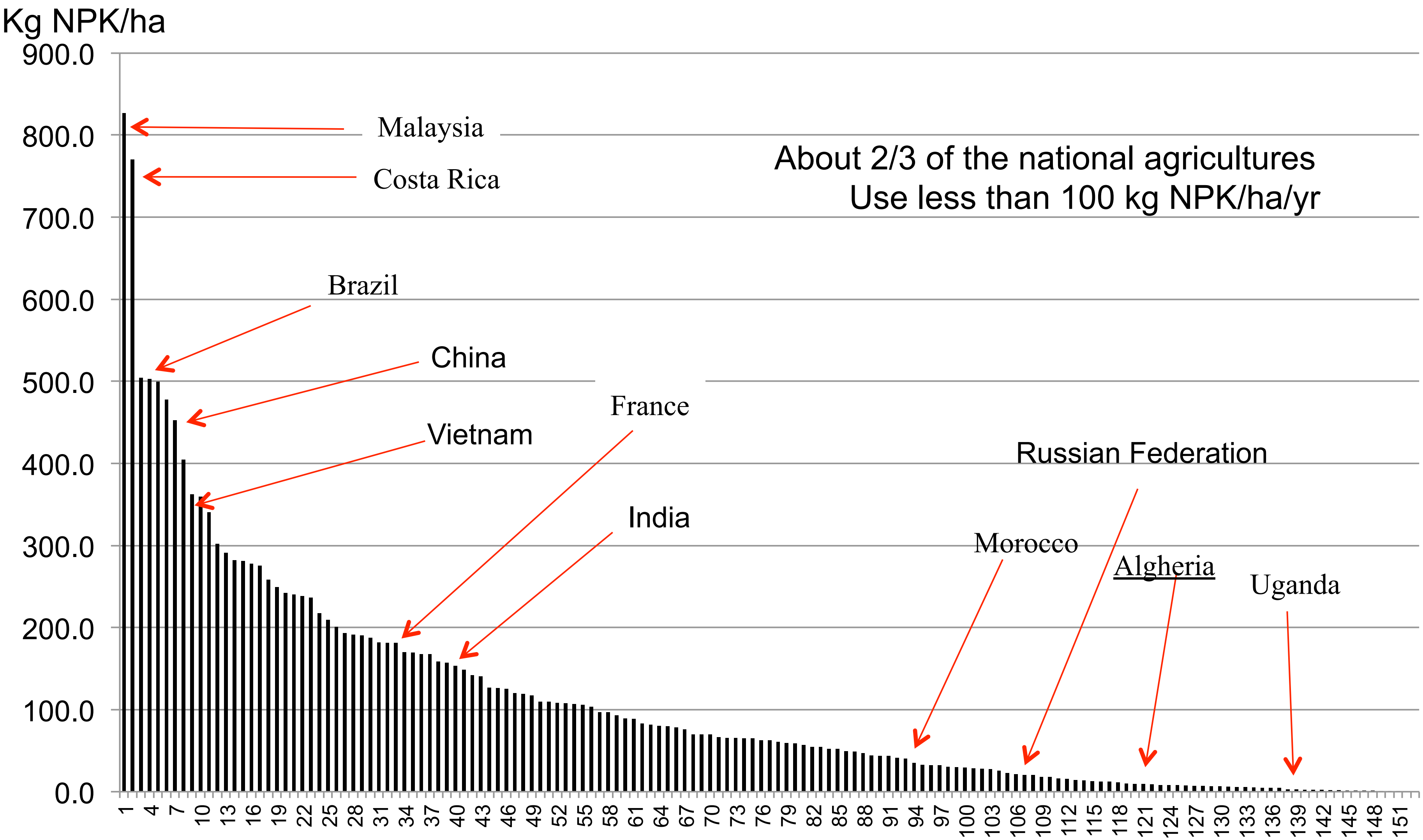

This includes geopolitical risks which have been excluded see:

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 phos-phorus? *Global Environmental Change*, *23*, 11-27.

# The current trend of mineral P use

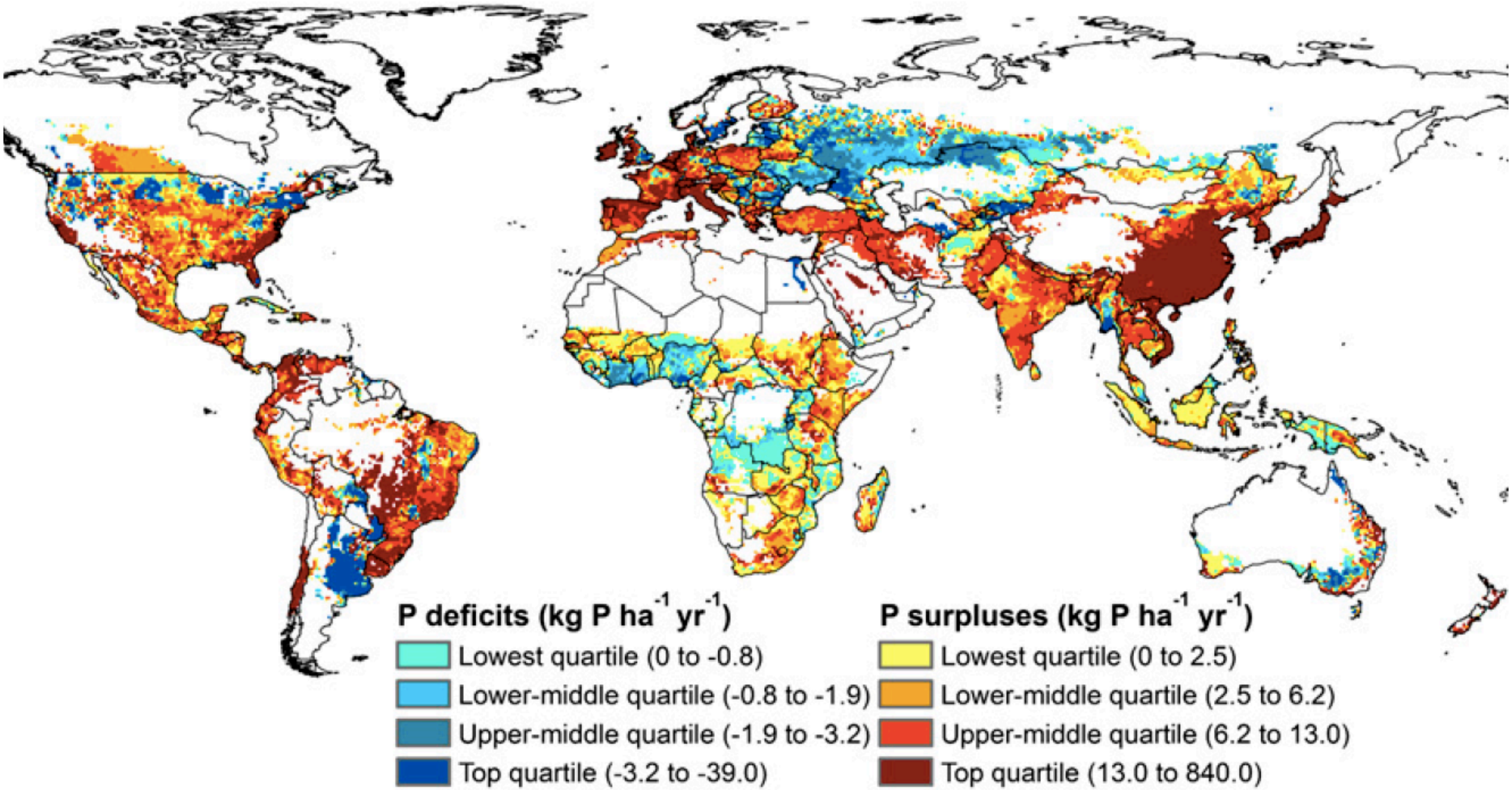


# There is the endangerment of economic scarcity: Providing access to phosphorus for the poor




The World Bank. (2012). Fertilizer consumption (kilograms per hectare of arable land), *N* = 153 countries with assessed annual NPK fertilizer consumption, without Bahrain, Quatar, Iceland and New Zealand (showing higher values)

# There is an unequal distribution of phosphorus use and access





MacDonald, G. K., Bennett, E. M., Potter, P. A., & Ramankutty, N. (2011). Agronomic phosphorus imbalances across the world's croplands. Supporting Information. *Proceedings of the National Academies of Sciences of the United States of America, 108(7), 1-9.*

# Five Conclusions

- The phosphorus cycle is complex, anthropogenically shaped. There is a huge potential for increasing use efficiency along the supply chain (Conclusion 1) and for becoming more efficient with P-NUE in some parts of the world (Conclusion 2). Not only efficiency but the interplay between efficiency and efficacy matters.
- Phosphorus use is Janus-faced. Some environmental impacts are evident (e.g. some Chinese lakes), but not all environmental vulnerabilities cause by excessive use may have been identified (Conclusion 3).
- There will be no necessary physical scarcity in the next decades/ century and no supply driven Peak P. There are many reasons for working towards a supply driven peak Phosphorus. (Conclusion 4)
- Getting access to phosphorus for the poor and closing the phosphorus cycle is the challenge. This asks for a multi-stakeholder discourse and for the integration of knowledge science and society as it is done in Global TraPs. (Conclusion 5)

GLOBAL TraPs

TRANSDISCIPLINARY PROCESSES FOR SUSTAINABLE PHOSPHORUS MANAGEMENT

Fraunhofer ISC

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# Thank you for your attention!