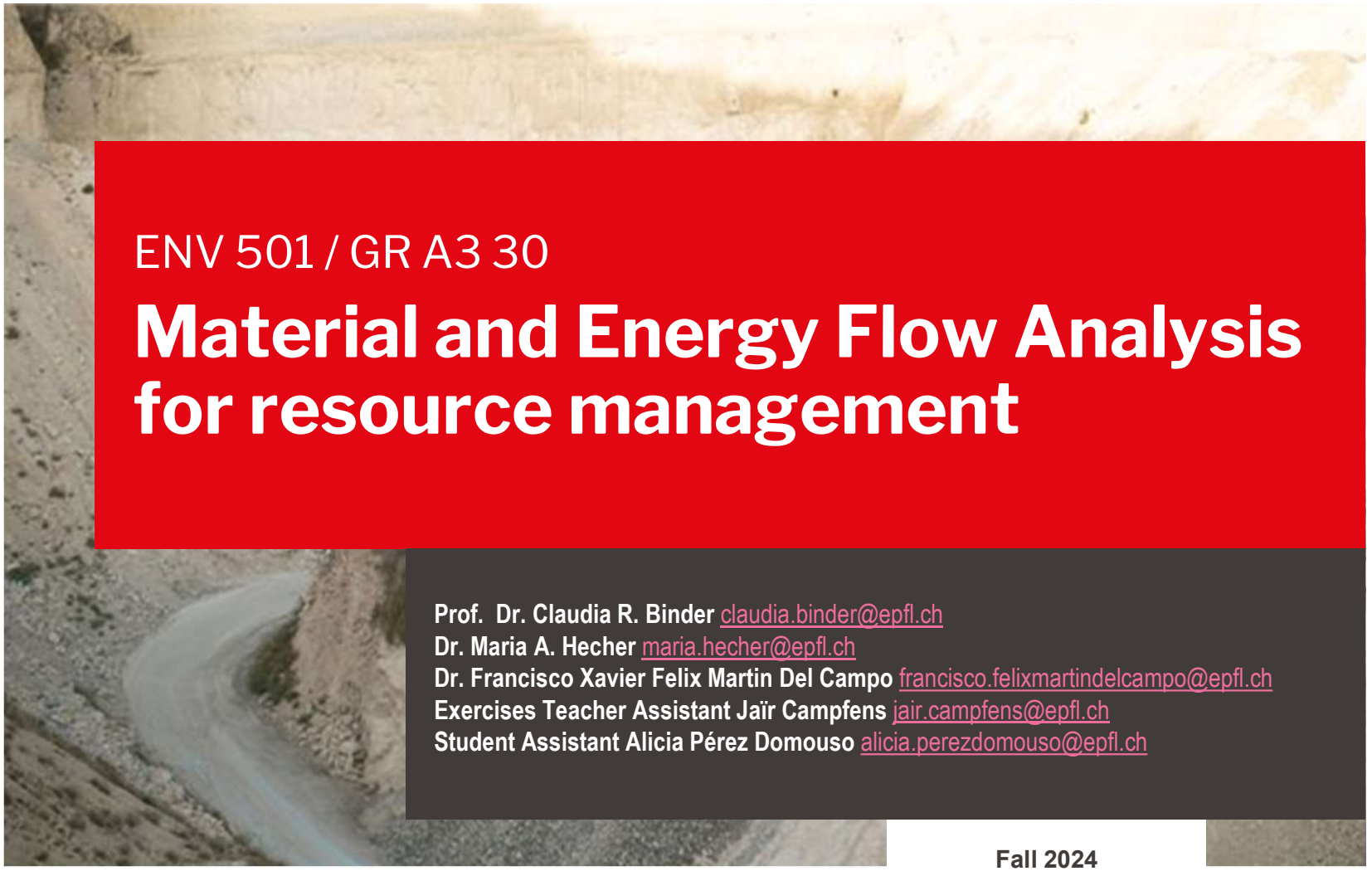

ENV 501 / GR A3 30

Material and Energy Flow Analysis for resource management

Prof. Dr. Claudia R. Binder claudia.binder@epfl.ch
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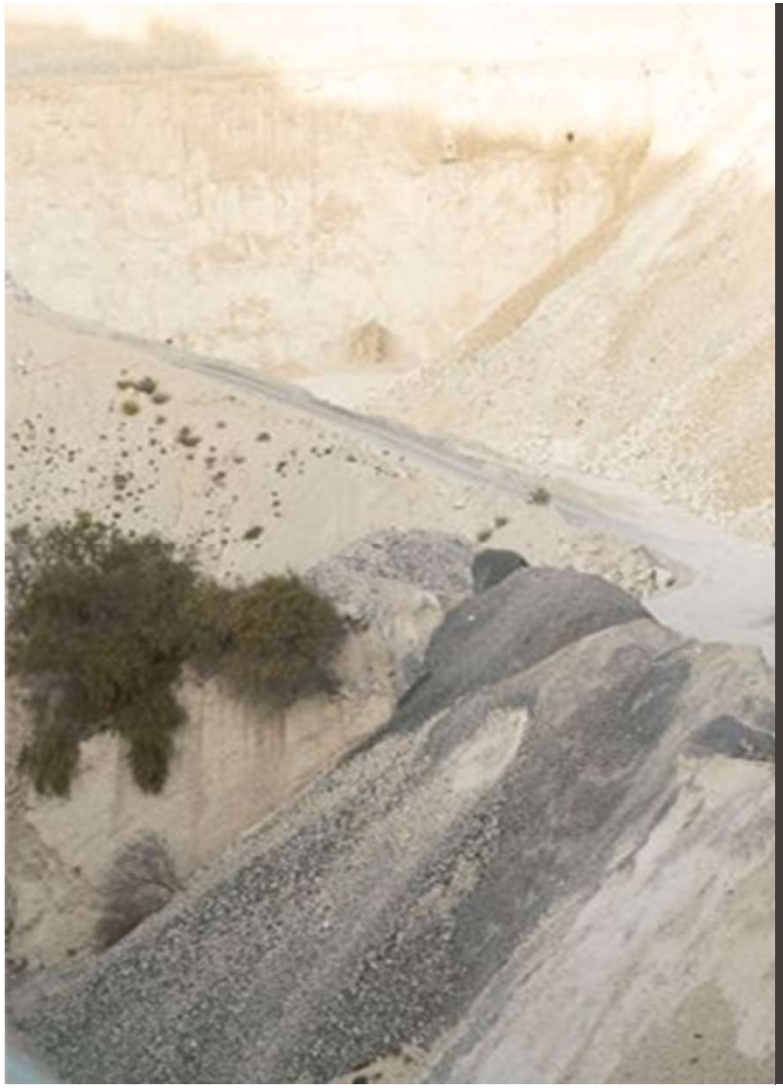
Fall 2024

Course outline

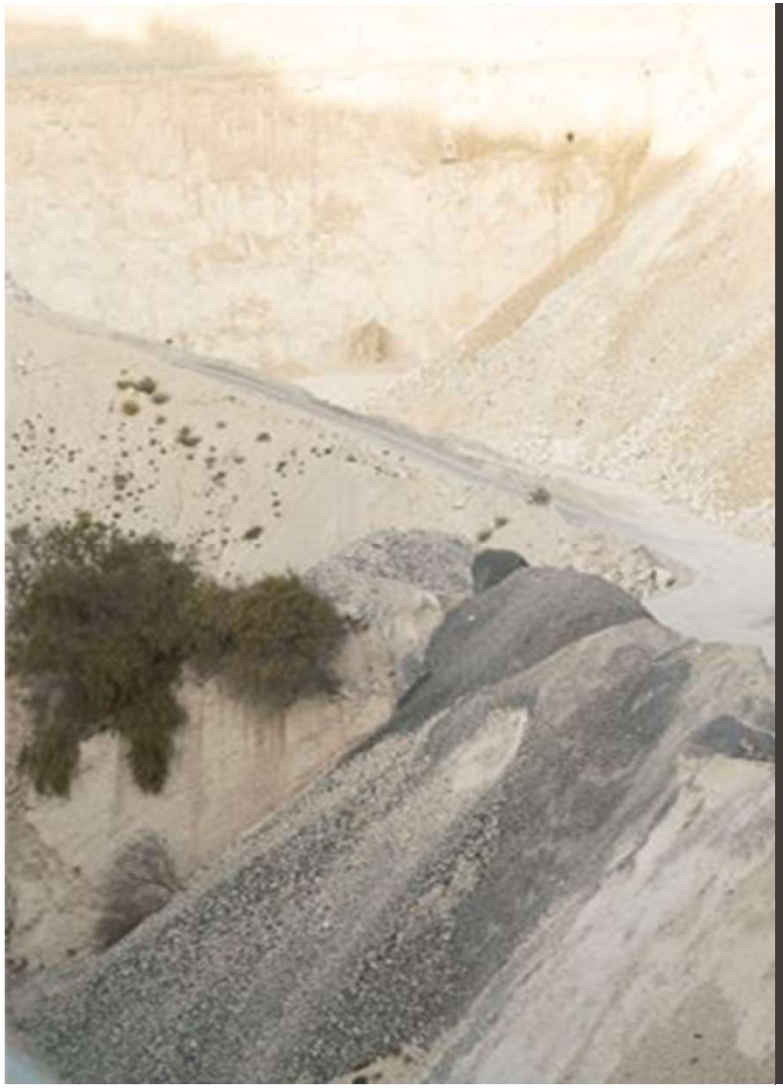
		8:15 - 9:00 and 9:15 - 10:00		13:15 - 14:00	14:15 - 15:00
Block I: EW-MFA global / national	W1 - Sep 12	Introduction to the course and general concepts	All	Exercise	Project
	W2 - Sep 19	EW – MFA and EW – MFA in different countries	FMC	Exercise	Project
	W3 – Sep 26	EW – MFA in the Swiss context, Urban Metabolism	External Guest – Florian Kohler	Exercise	Project
	W4 - Oct 03	EW – MFA in the Swiss context: Cantons and Circular Economy	FMC	Exercise	Project
Block II: MFA regional / urban	W5 - Oct 10	The Service-Stock-Flows Nexus	CRB	Exercise	Project
	W6 - Oct 17	Dynamic MFA	External Guest – Stefan Pauliuk	Exercise	Project
	Oct 24	Autumn break			
	W7 - Oct 31	Spatial MFA	FMC	Exercise	Project
	W8 - Nov 07	Input-Output Analysis and Material Flow Cost Accounting	External Guest – Vincent Moreau	Exercise	Project
	W9 - Nov 14	MFA and Uncertainty	External guest – Stefan Pauliuk	Exercise	Project
	W10 - Nov 21	Case studies: Waste management in Indonesia / Critical Raw Materials in the Swiss context	GF & FMC	Exercise	Project
Block III: Social sciences and public policy	W11 - Nov 28	Social Metabolism	CRB	Exercise	Project
	W12 - Dec 05	Agent-based model	CRB, FMC, MAH, SLC	Past exam	Project
	W13 - Dec 12	Group Project Presentation	CRB, FMC, MAH	Project	Project
	W14 - Dec 19	Group Project Presentation	CRB, FMC, MAH	Project	Project

Content of the lecture

- Understand the relationship between MFA, policy and the public
- Understand MFA as a tool for bridging disciplines
- From Material Flow Analysis to Material Flow Management
- The HES framework
- Know how MFA can be combined with social science approaches



Why do we need to engage with social science, policy or the public?



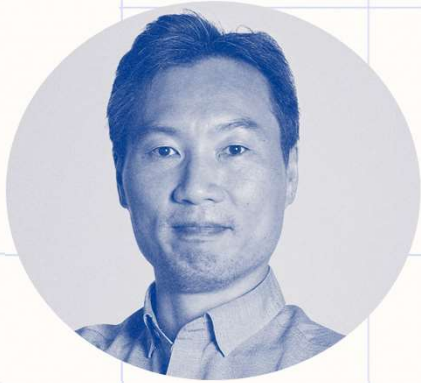
Solving climate change seems impossible

How did we suceed in earlier environmental crises?

The Role of Industrial Ecology in Empowering Corporates for Global Low-Carbon Transition

Sangwon Suh, PhD

Head of Scientists, Watershed Technology Inc.
Professor, University of California, Santa Barbara



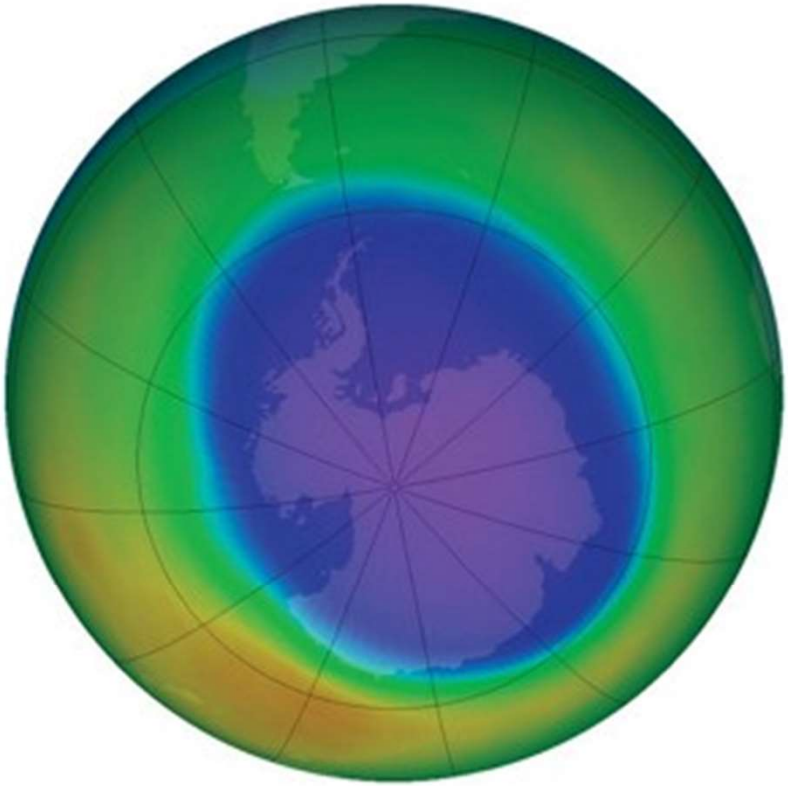
3°

tCO_2e

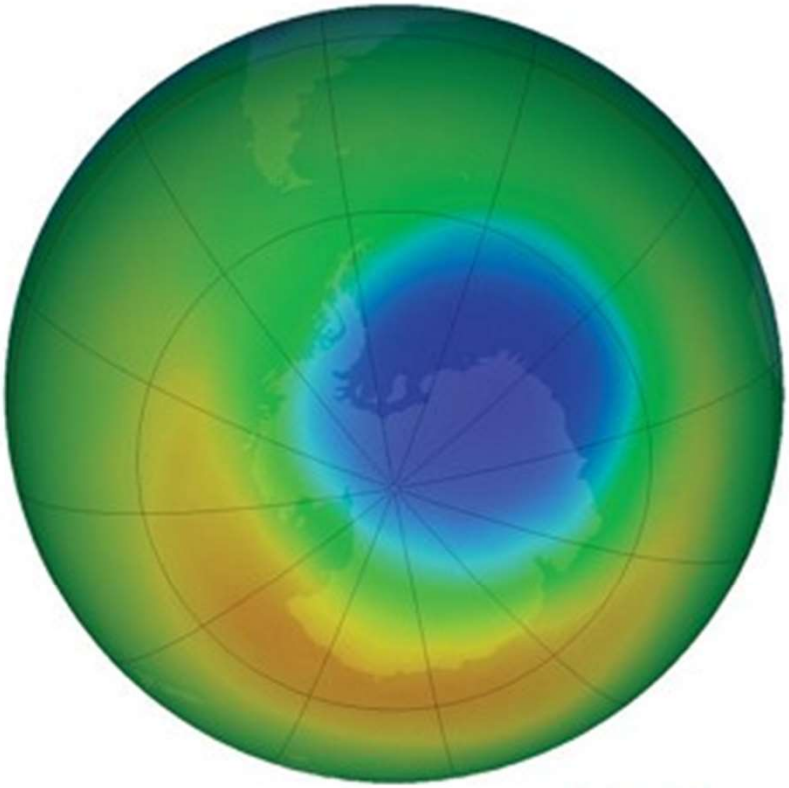
Have we ever solved any environmental problems? If so, how did we do it?

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024



Sept. 1994



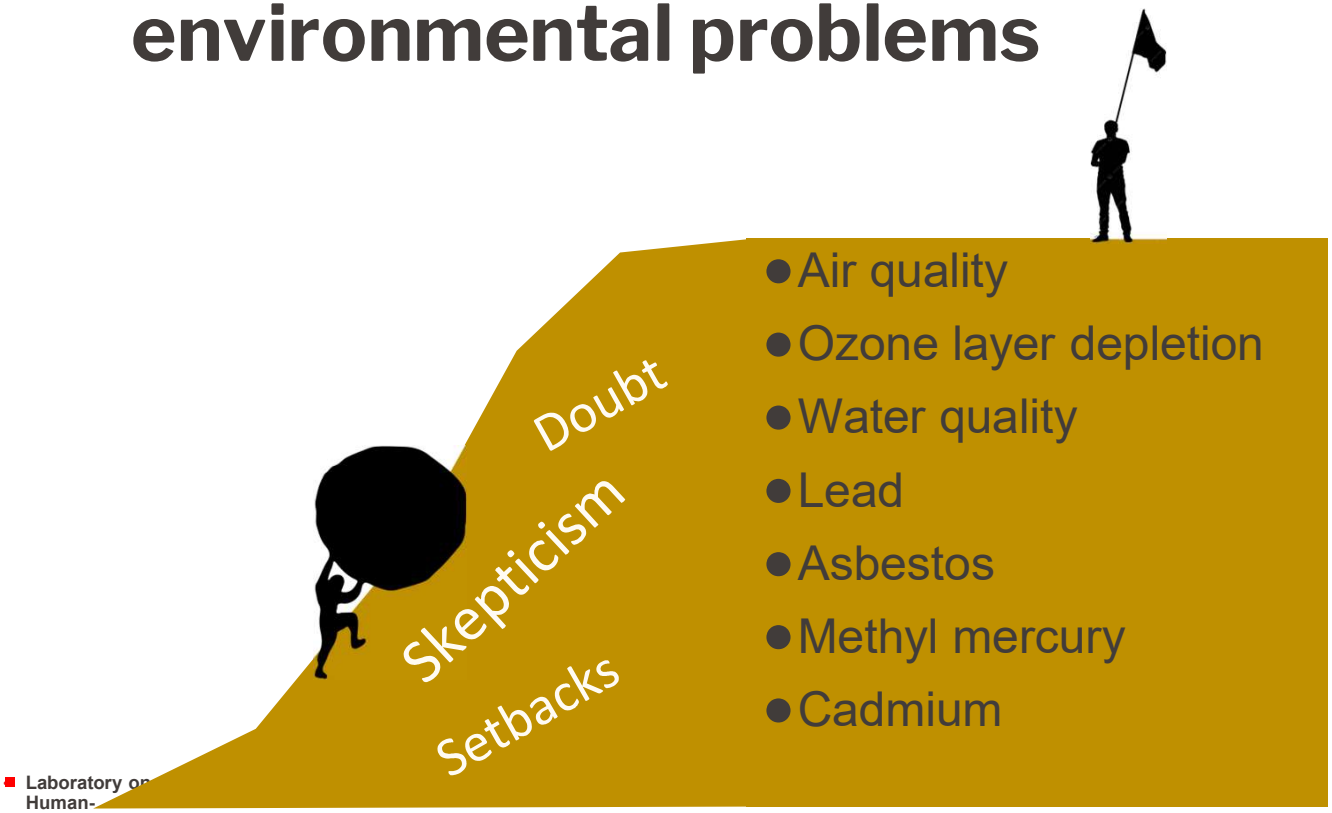
Oct. 2019

c&en's STEREO CHEMISTRY


Courtesy : Sangwon Suh, IIE Gordon Conference, 2024
1969 Cuyahoga river, Cleveland


Courtesy : Sangwon Suh, IIE Gordon Conference, 2024
2021 Cuyahoga river, Cleveland

Solving big environmental problems



What do these problems have in common?

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we do it?

Smog

- In 1302, King Edward I banned the use of coal in London.
- In 1952-1953, the Great London Smog caused 12,000 excess casualty.

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

PALL OVER L.A.—Smog blanket hangs over downtown, dimming the setting sun. The bout of smog was called the worst here in 24 years.
Times photo by George Rose

Smog Siege Grips Area for 7th Day

Expected to Last Into the Weekend; Ailments Increase

BY RICHARD E. MEYER
Times Staff Writer

Eye-searing, throat-burning smog smothered the Los Angeles area in a bourbon-colored blanket Thursday, sending scores of persons to hospitals with respiratory trouble and forcing school children to stay indoors, out of the noxious air.

Meteorologists predicted that the yellow-brown bilge would wash over the Southland into the weekend. Doctors advised even healthy adults to stay indoors. The South Coast Air Quality Management District urged motorists to stay off the streets.

Too few did. The California Department of Transportation said traffic on Los Angeles freeways increased Thursday over the day before—by .005%.

The smog control district declared a Stage 2 alert for the seventh

WEATHER SHIFT OVER THE PACIFIC SEEN AS CAUSE

BY ROBERT GILLETTE
Times Science Writer

An unusual shift in summertime weather patterns over the northwestern Pacific appears to be the dominant cause of Los Angeles' worst siege of smog in more than two decades, meteorologists said Thursday.

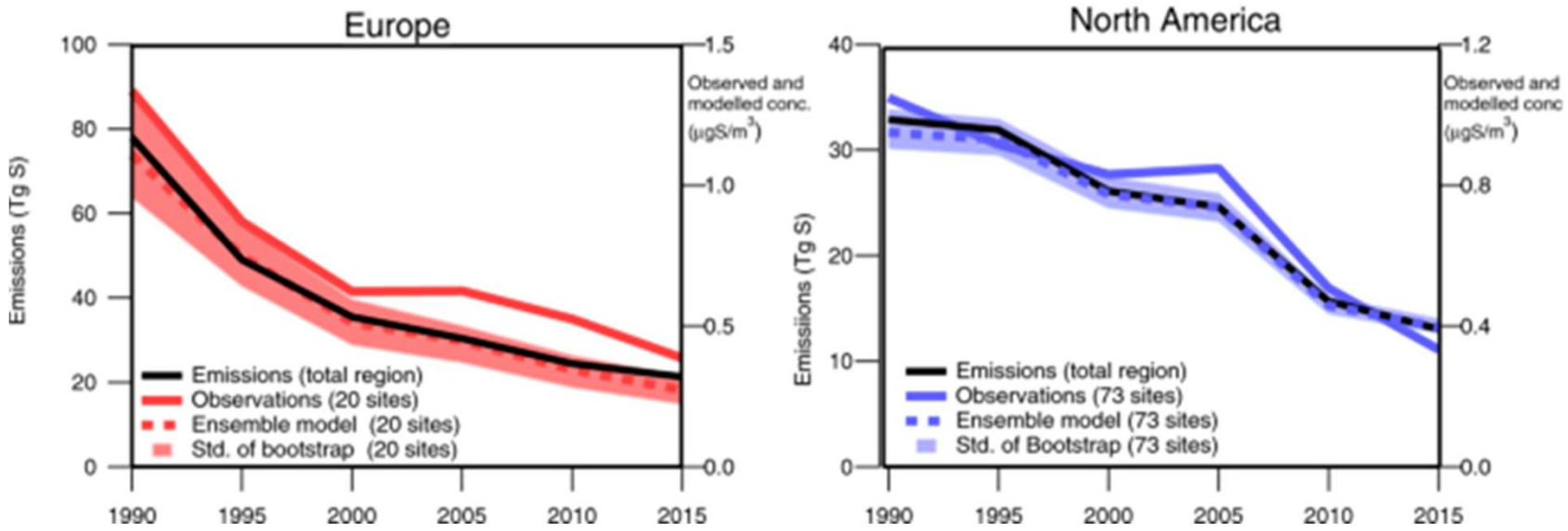
Dr. Jerome Namias, a research meteorologist at UC San Diego, said that the persistent inversion layer—a blanket of warm air—that has trapped pollutants in the Los Angeles Basin for more than a week stems from a major westward shift of the Pacific high-pressure area that normally dominates summertime weather patterns over a vast area of the North Pacific and coastal United States.

The Pacific high is also significantly weaker than usual.

L.A. Times, Friday, Sept. 14, 1979 (Los Angeles Times)

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

SOx emissions and concentrations



Aas, W., Mortier, A., Bowersox, V., Cherian, R., Faluvegi, G., Fagerli, H., Hand, J., Klimont, Z., Galy-Lacaux, C., Lehmann, C.M. and Myhre, C.L., 2019. Global and regional trends of atmospheric sulfur. *Scientific reports*, *9*(1), p.953.

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we solve it?

Scientific underpinnings

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we solve it?

Scientific underpinnings

Arie Haagen-Smit
Professor at CalTech

Chemistry and Physiology of Los Angeles Smog

A. J. HAAGEN-SMIT
California Institute of Technology, Pasadena, Calif., and
Los Angeles County Air Pollution Control District, Los Angeles, Calif.

Air pollution in the Los Angeles area is characterized by a decrease in visibility, crop damage, eye irritation, objectionable odor, and rubber deterioration. These effects are attributed to the release of large quantities of hydrocarbons and nitrogen oxides to the atmosphere. The photochemical action of nitrogen oxides oxidizes the hydrocarbons and thereby forms ozone, responsible for rubber cracking. Under experimental conditions, organic peroxides formed in the vapor phase oxidation of hydrocarbons have been shown to give eye irritation and crop damage resembling closely that observed on smog days. The aerosols formed in these oxidations are contributors to the decrease in visibility. The odors observed in oxidation of gasoline fractions are similar to those associated with smog. Hydrocarbons present in cracked petroleum products, harmless in themselves, are transformed in the atmosphere into compounds highly irritating to both plants and animals, and should therefore be considered as potentially toxic materials. A proper evaluation of the contribution of air pollutants to the smog nuisance must include not only the time and place of their emission, but also their fate in the air.

AIR pollution in the Los Angeles area is characterized by a decrease in visibility, crop damage, eye irritation, objection- damage in this area. It has long been known that ozone has a characteristic cracking action on raw or vulcanized rubber when

How did we solve it?

Scientific underpinnings

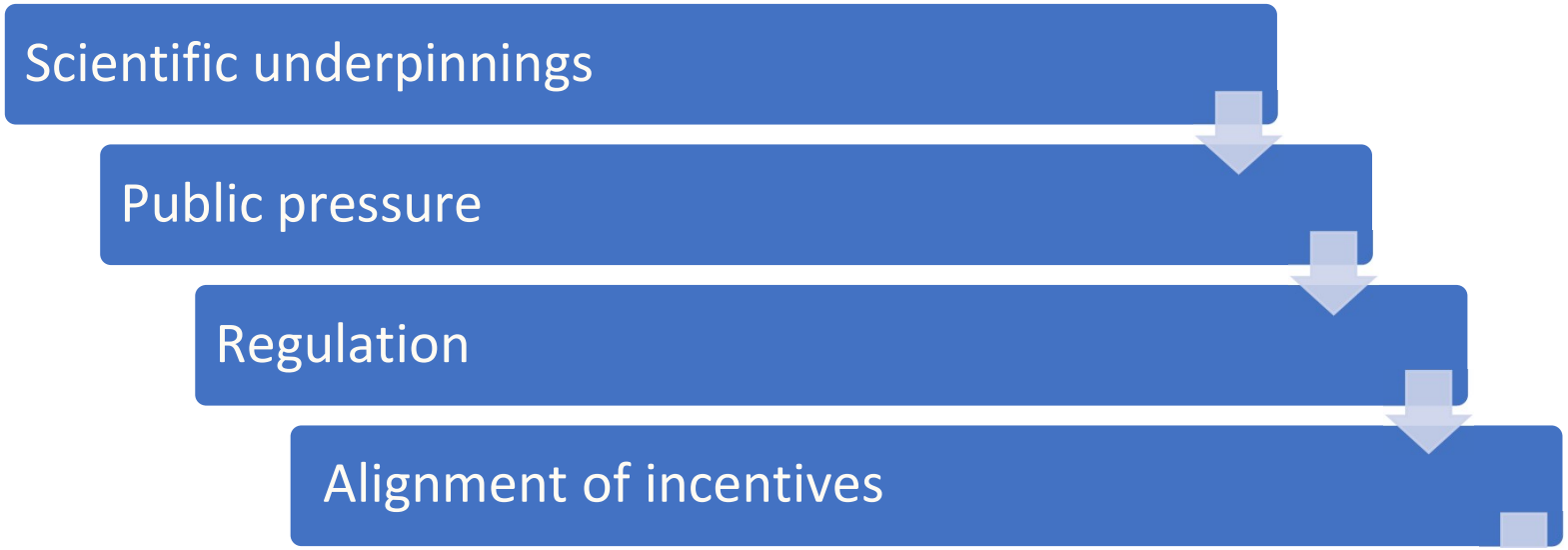
Public pressure

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we solve it?

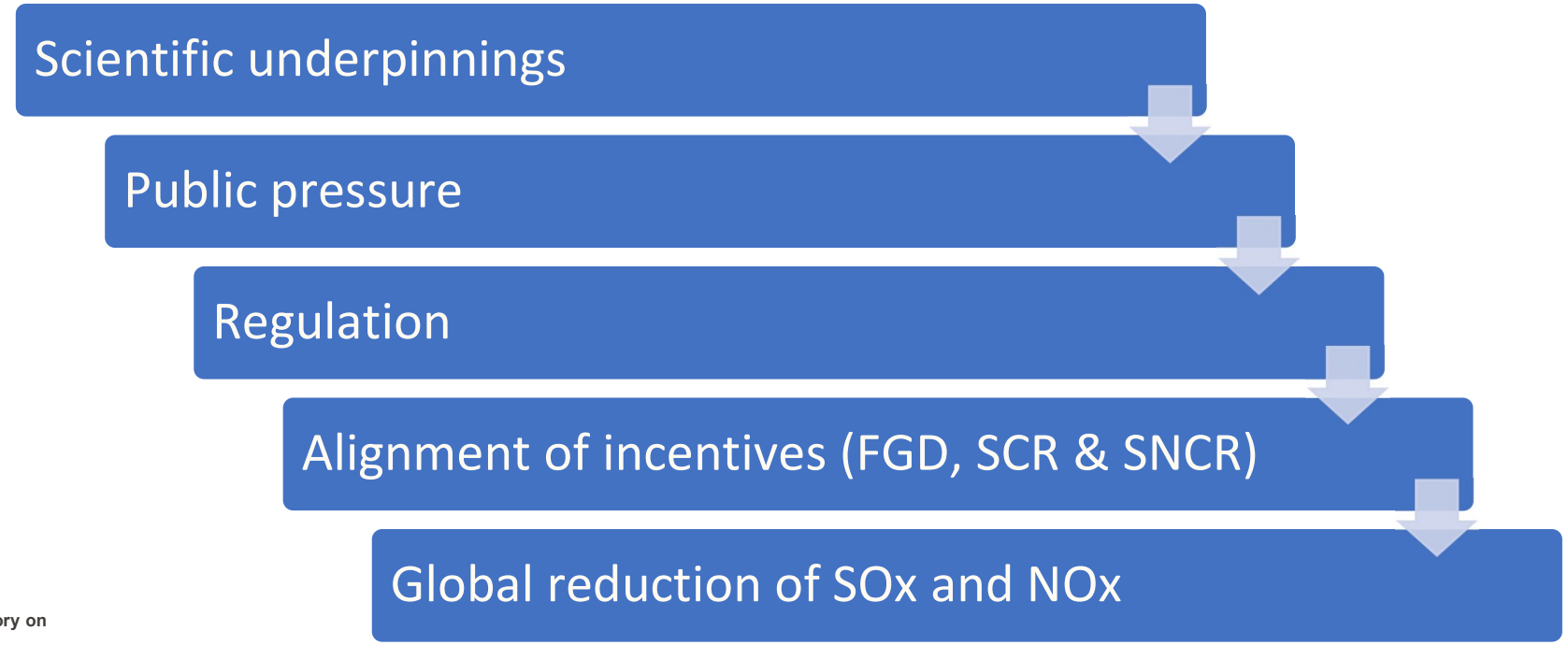
Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we solve it?



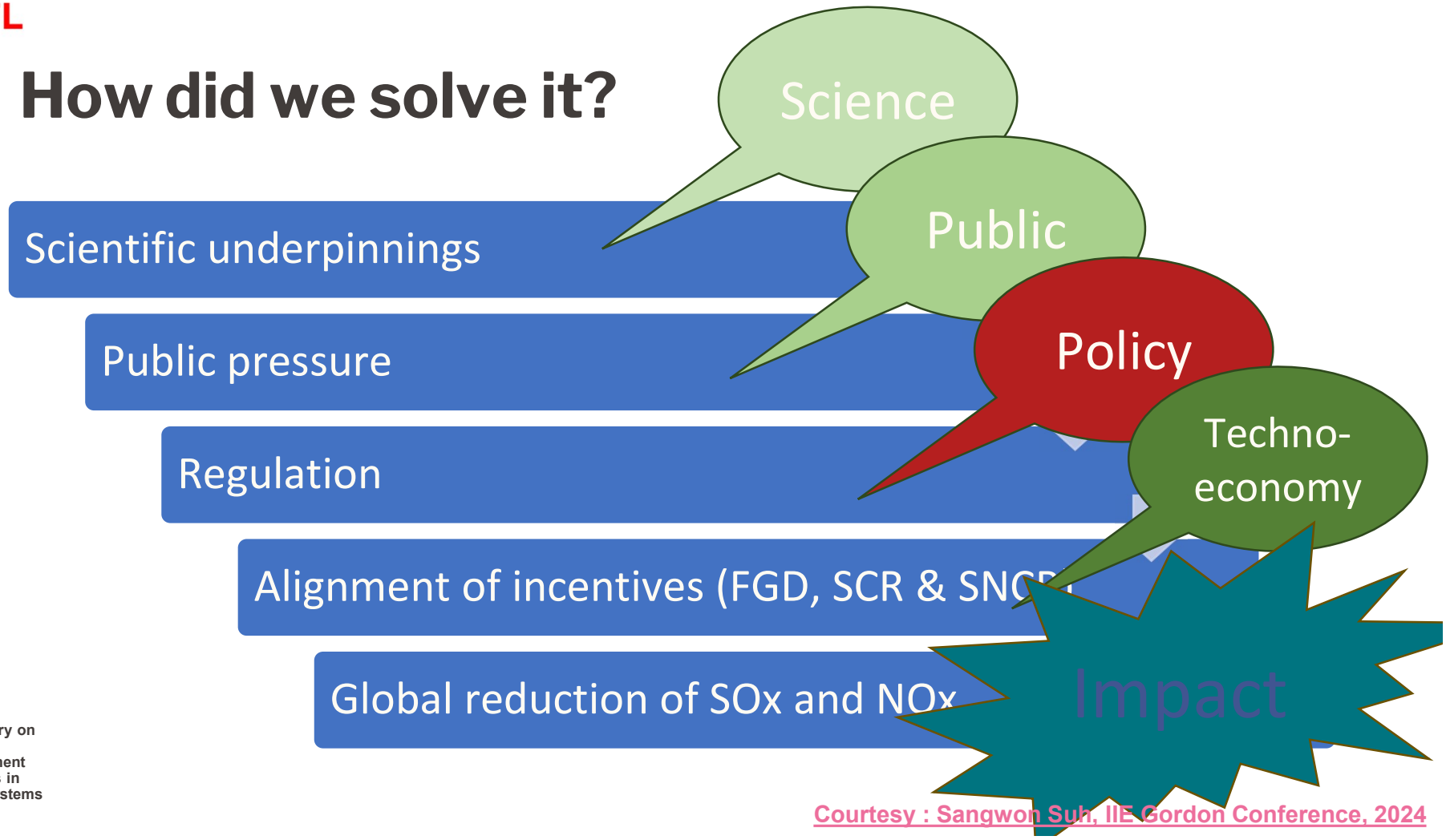
Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we solve it?



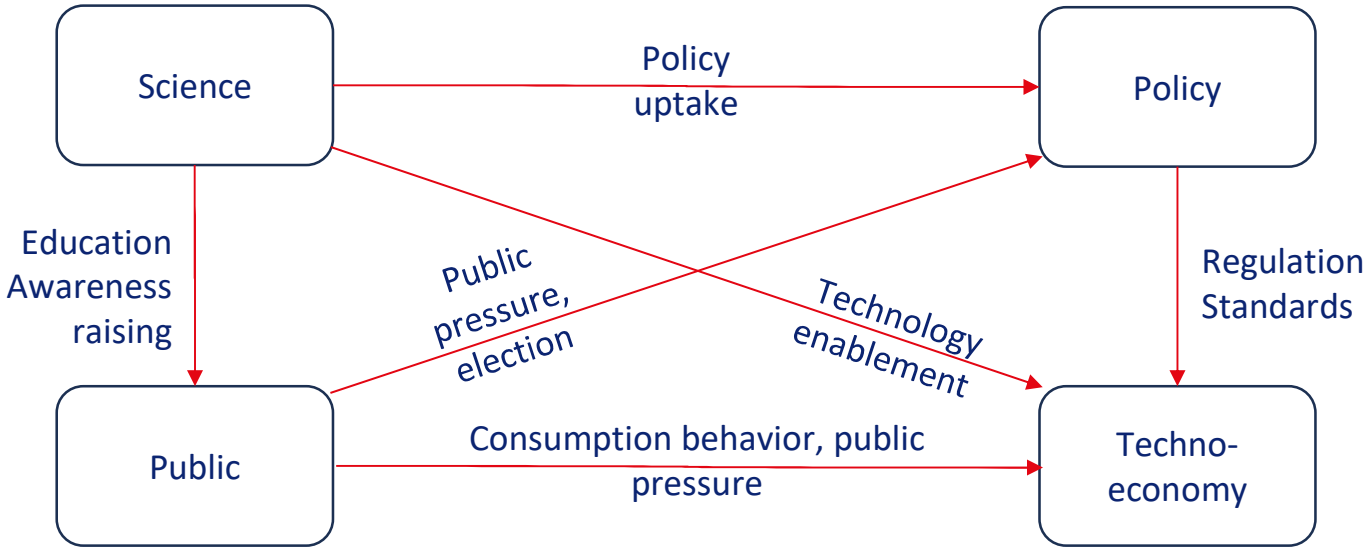
Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

How did we solve it?



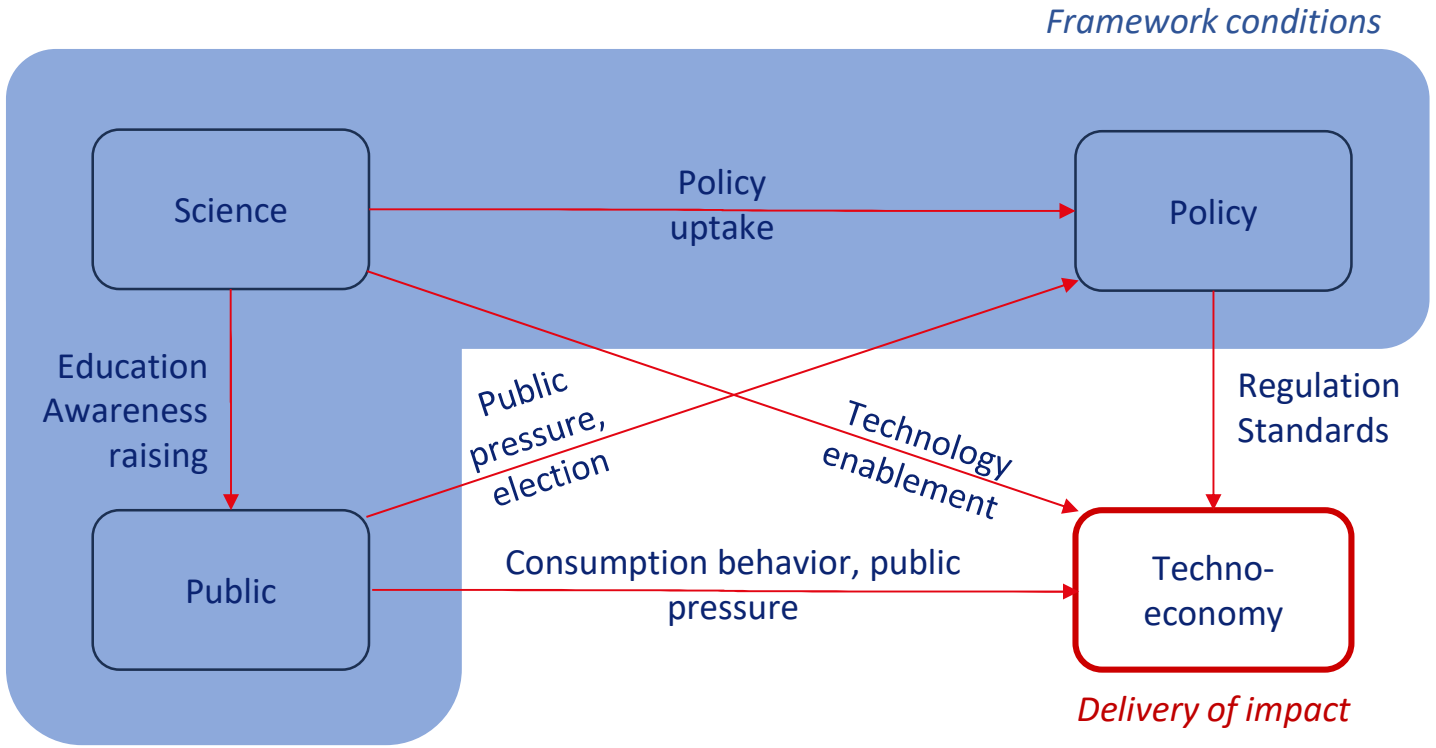
Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

Interplay between key actors



Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

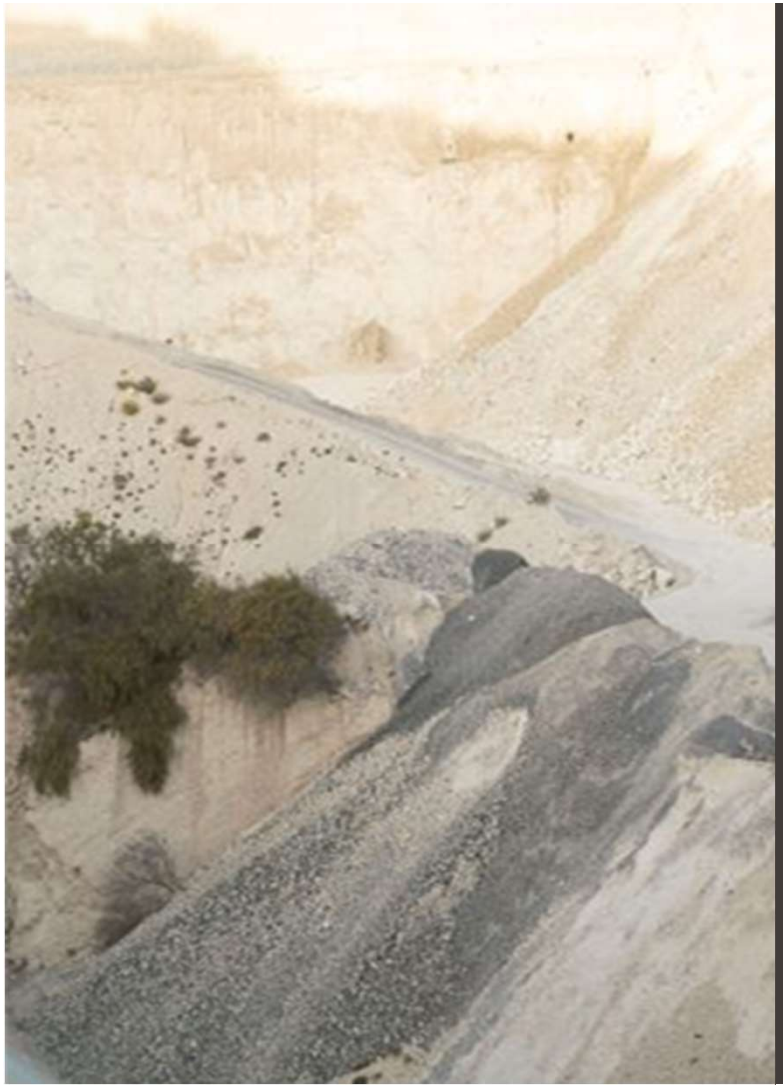
Interplay between key actors



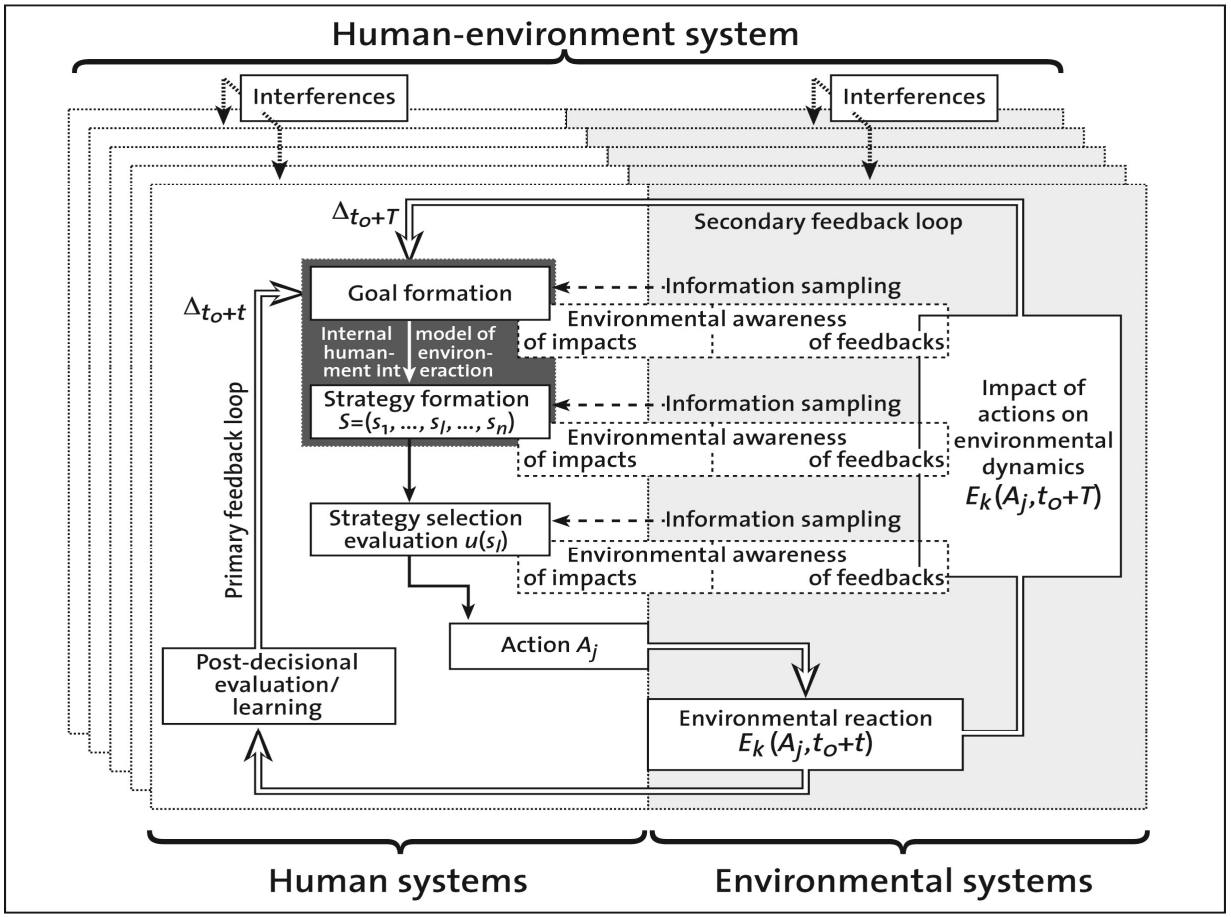
Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

Once incentive systems are aligned, private sector has demonstrated its remarkable power of delivering solutions to big environmental problems.

Courtesy : Sangwon Suh, IIE Gordon Conference, 2024

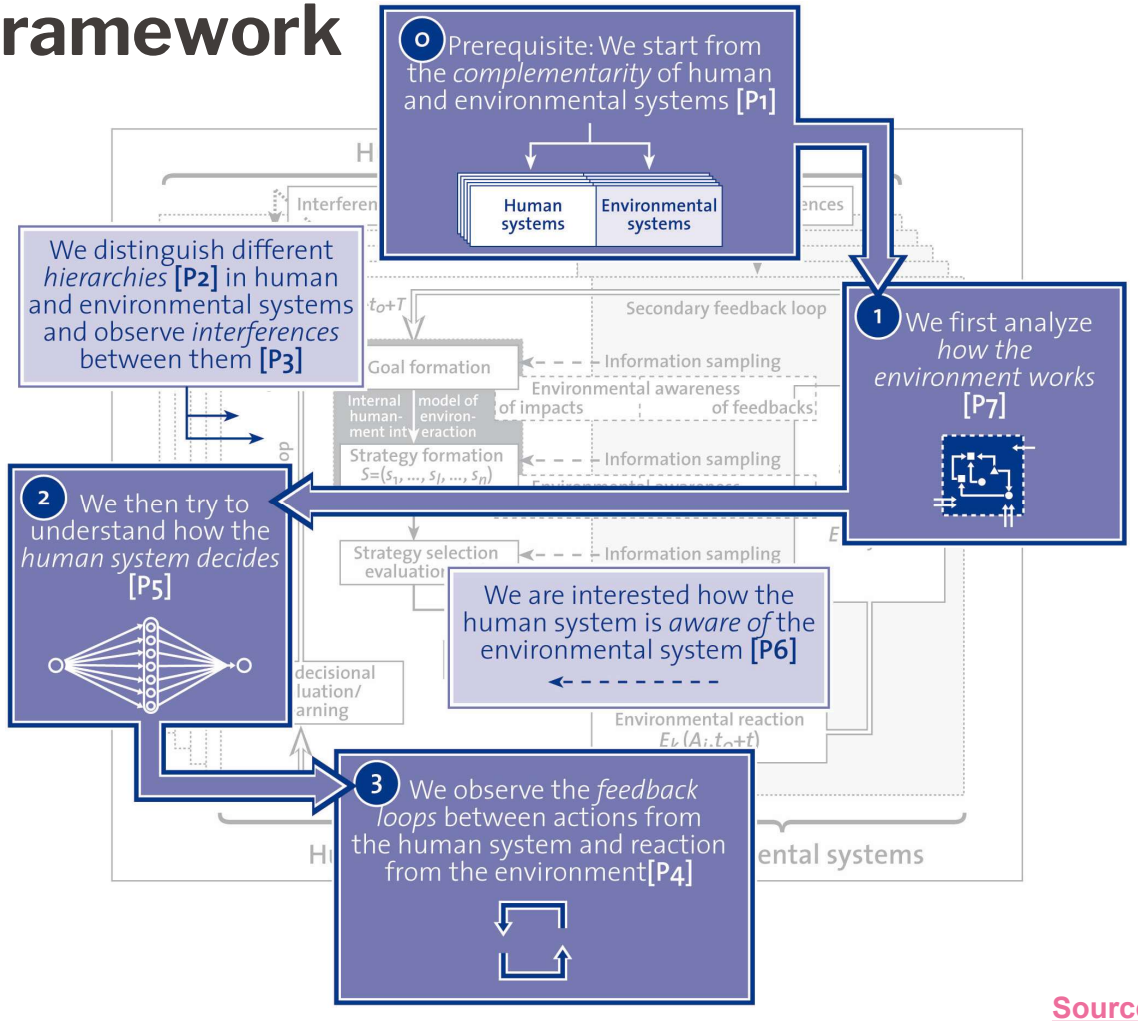


The HES (Human-Environment System) framework



Source : Scholz & Binder, 2011

HES Framework



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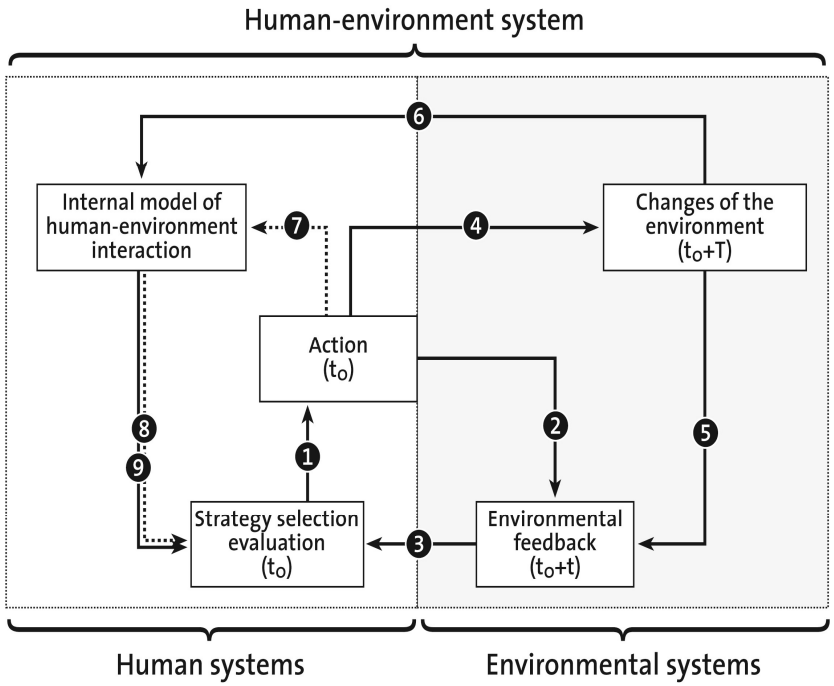
Source : Scholz & Binder, 2011

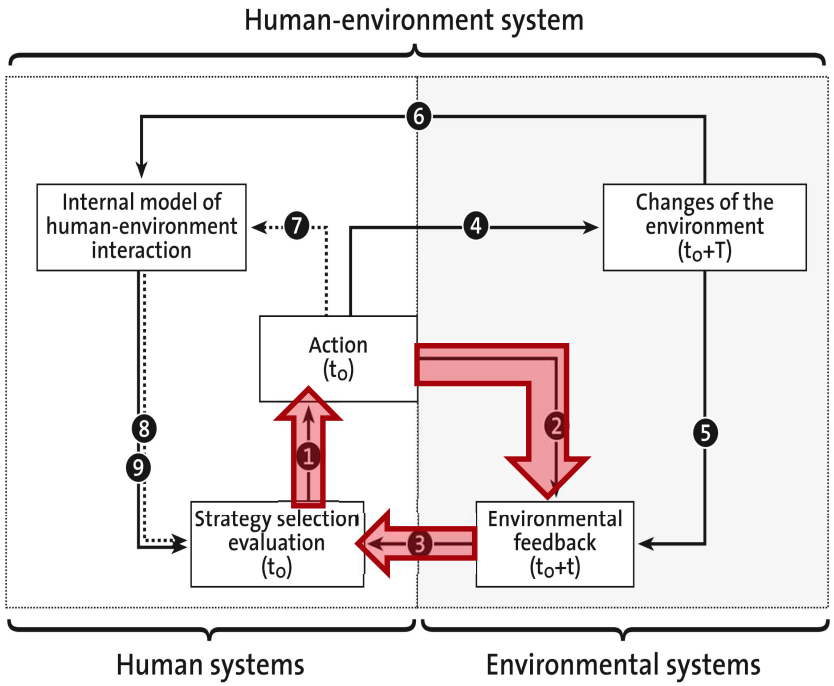
Feedback types in HES



Source : Scholz & Binder, 2011

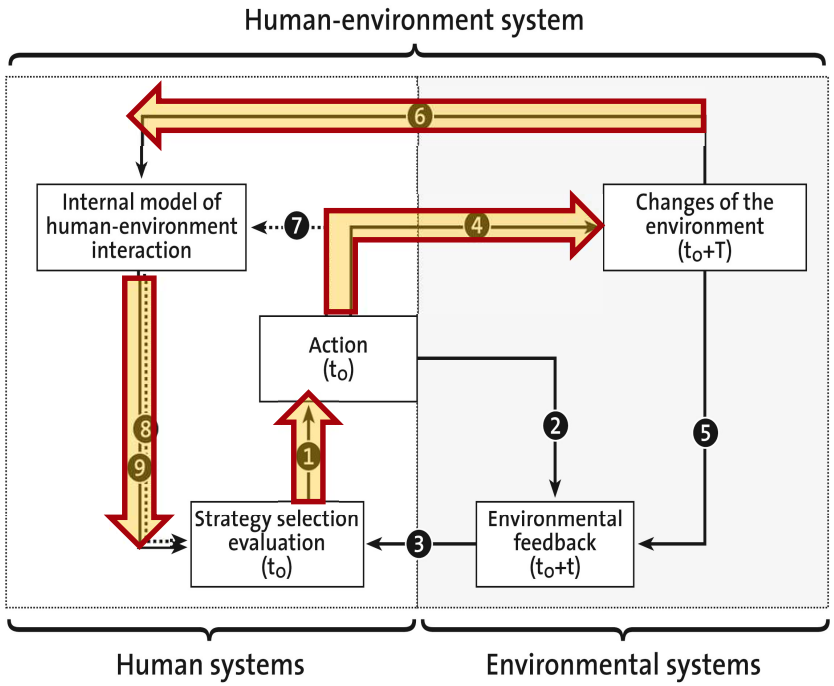
Feedback types in HES

Primary feedback loop
(F_1 =1-2-3): human reaction to environmental changes in short-term (t_0+t). Decision rules are fixed.



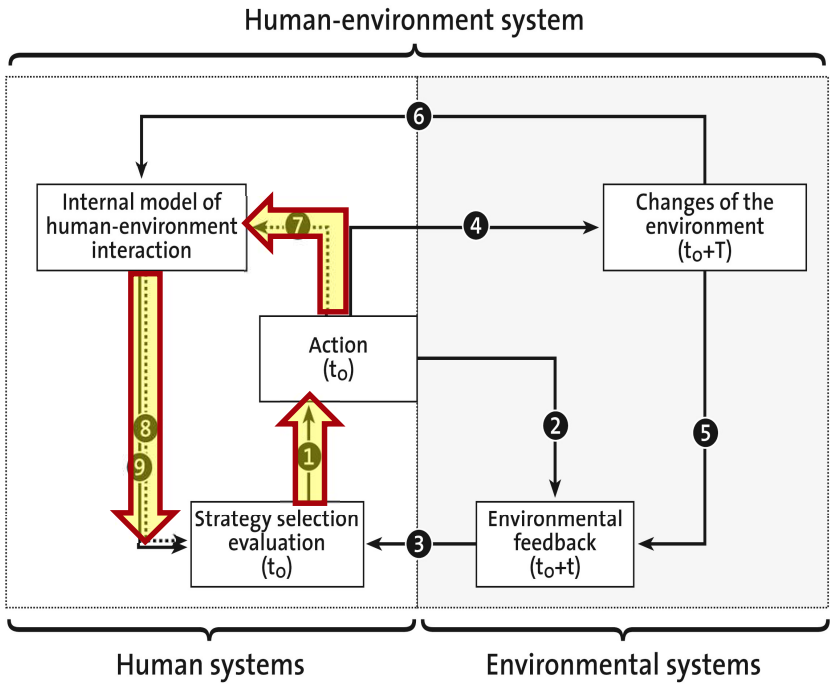
Feedback types in HES

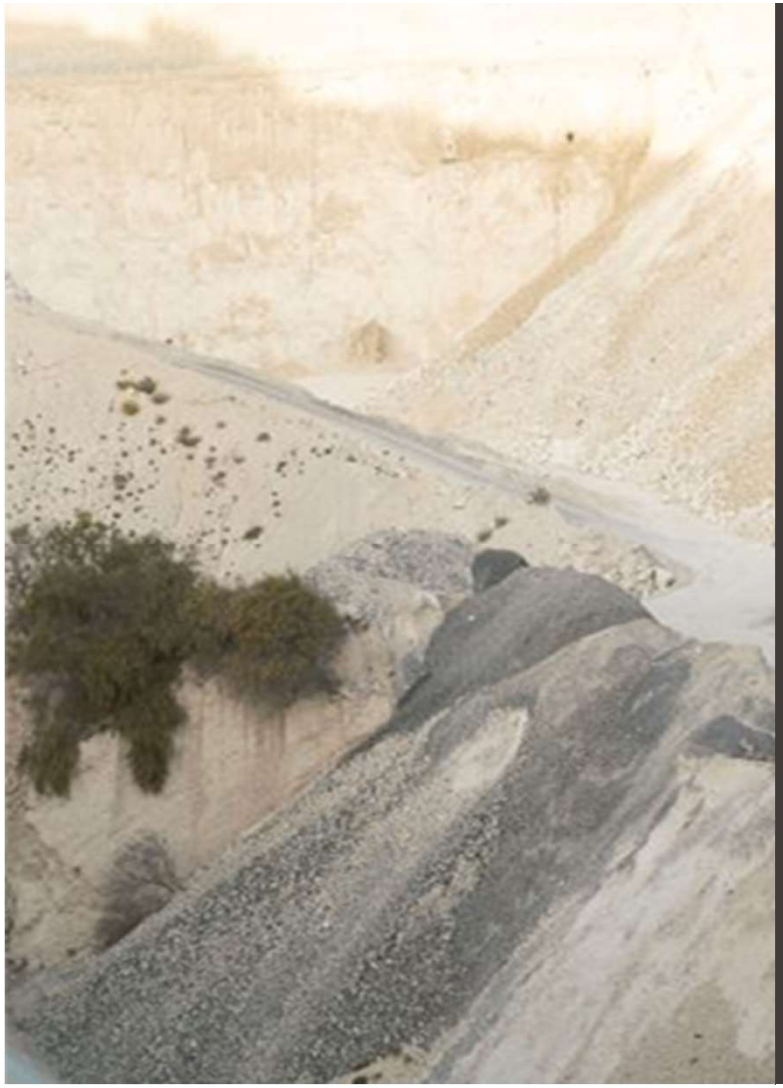
- Secondary feedback loop learning (F_2 = 1-4-6-9): human coping to long-term environmental changes. Decision rules can be changed based on becoming aware of long-term environmental changes (t_0+T).



Feedback types in HES

- *Reframing:* feedback loop (anticipation of environmental feedback; F_3 =7-8-1): self-reflection; can redefine goals and behavioral programs.





Utility of linking MFA results with social science methods

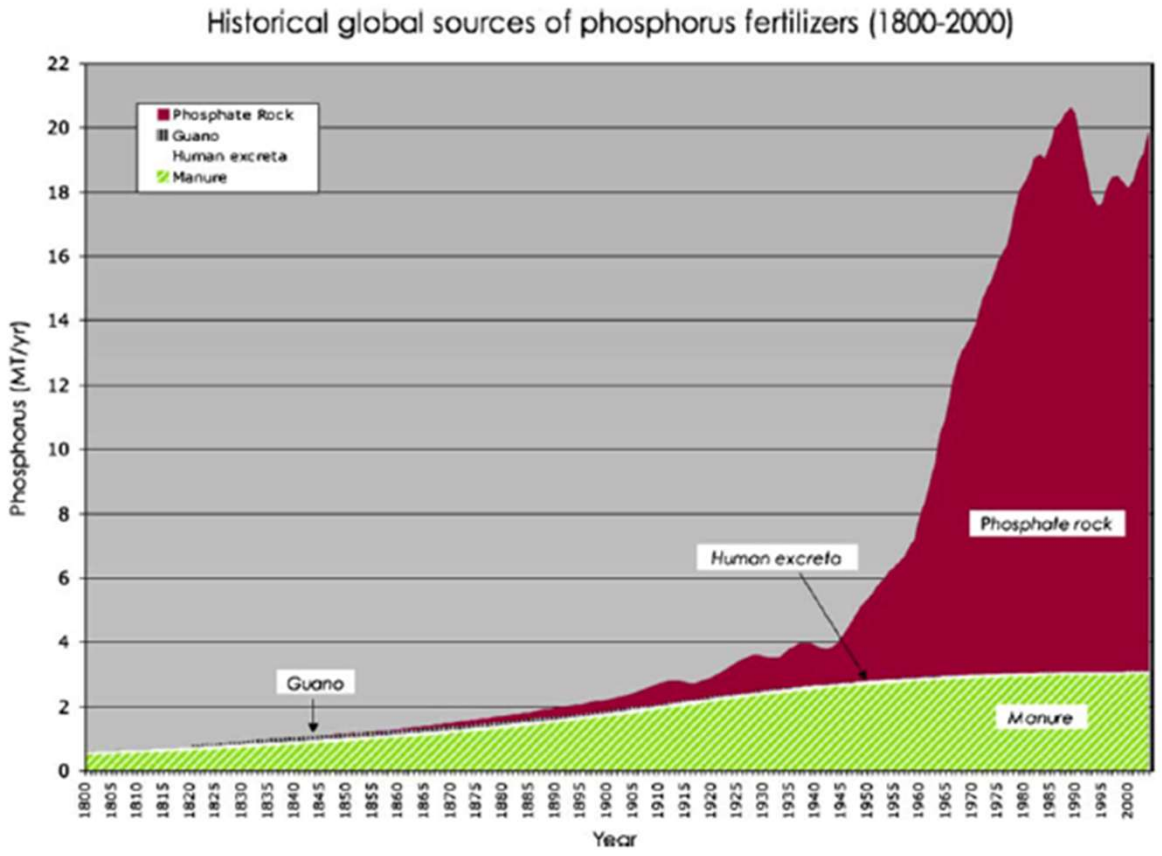
Phosphorus management in Switzerland

Laboratory on Human-Environment Relations in Urban Systems

Relevance of phosphorus

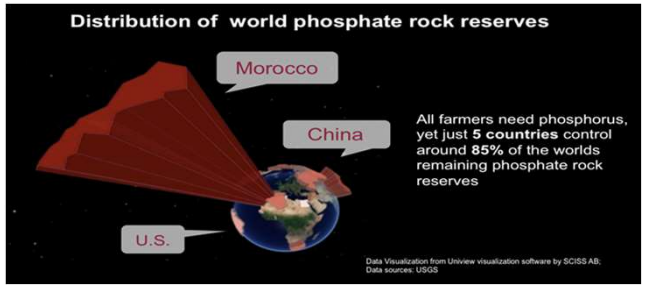
- Phosphorus cannot be substituted for in its principal domains of application - Availability becomes increasingly important!
- In 2033, the max. yearly production will have been reached (peak)
- The most important phosphate mineral is apatite ($Ca_{10}F_2(PO_4)_6$).
- Phosphorus availability
  - ⅗ ocean sediments
  - > ⅕ volcanic origin
  - Small rest: Guano (fossil bird excrements)
- Phosphorous causes eutrophication

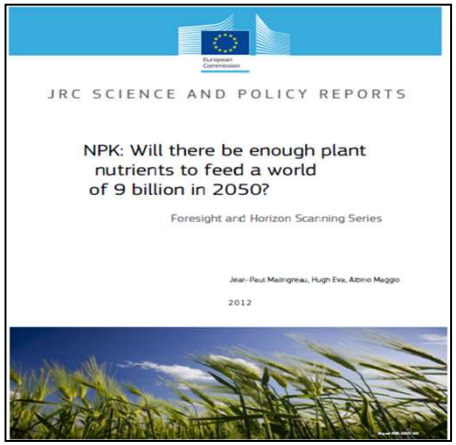
Relevance of phosphorus



Source : Cordell et al., 2009

Global deposits: A reason of concern?





- P-reserves of increasingly bad quality (Uranium, Cadmium)
- Potential geopolitical shortage
- → Increasing need for a sustainable P-management

Methods: Material flow analysis [1]

- **Spatial boundary:** Switzerland
- **Temporal boundary:** years 2006 / 2011 / 2015
- **System**
  - **6 processes (subsystems):**
    Agriculture animals / husbandry
    Agriculture plants / cultivation
    Chemical industry
    Household and industry
    Waste management
    Water bodies
  - **5 stocks**
  - **84 flows**

Methods: Material flow analysis [2]

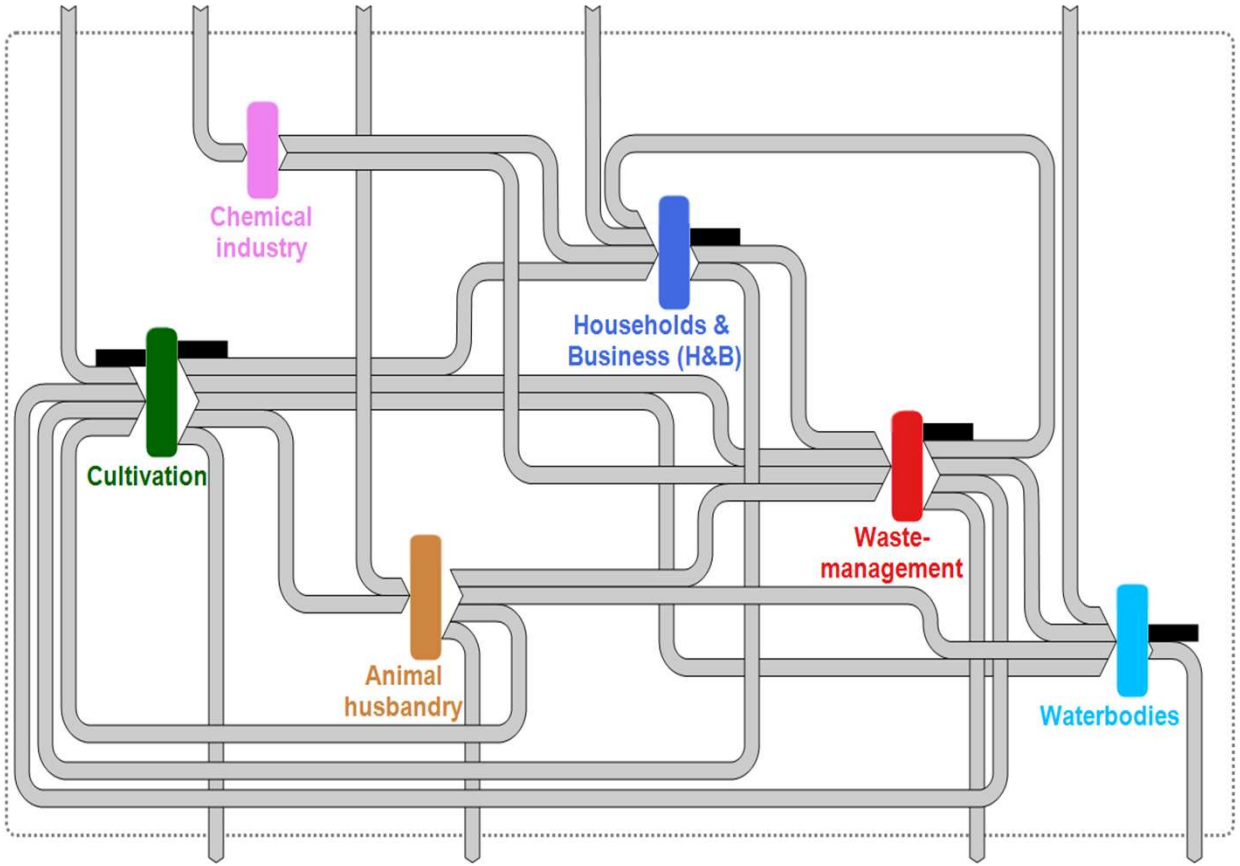
Data sources

- Literature / expert interviews
- Uncertainty ranges

Calculations & software

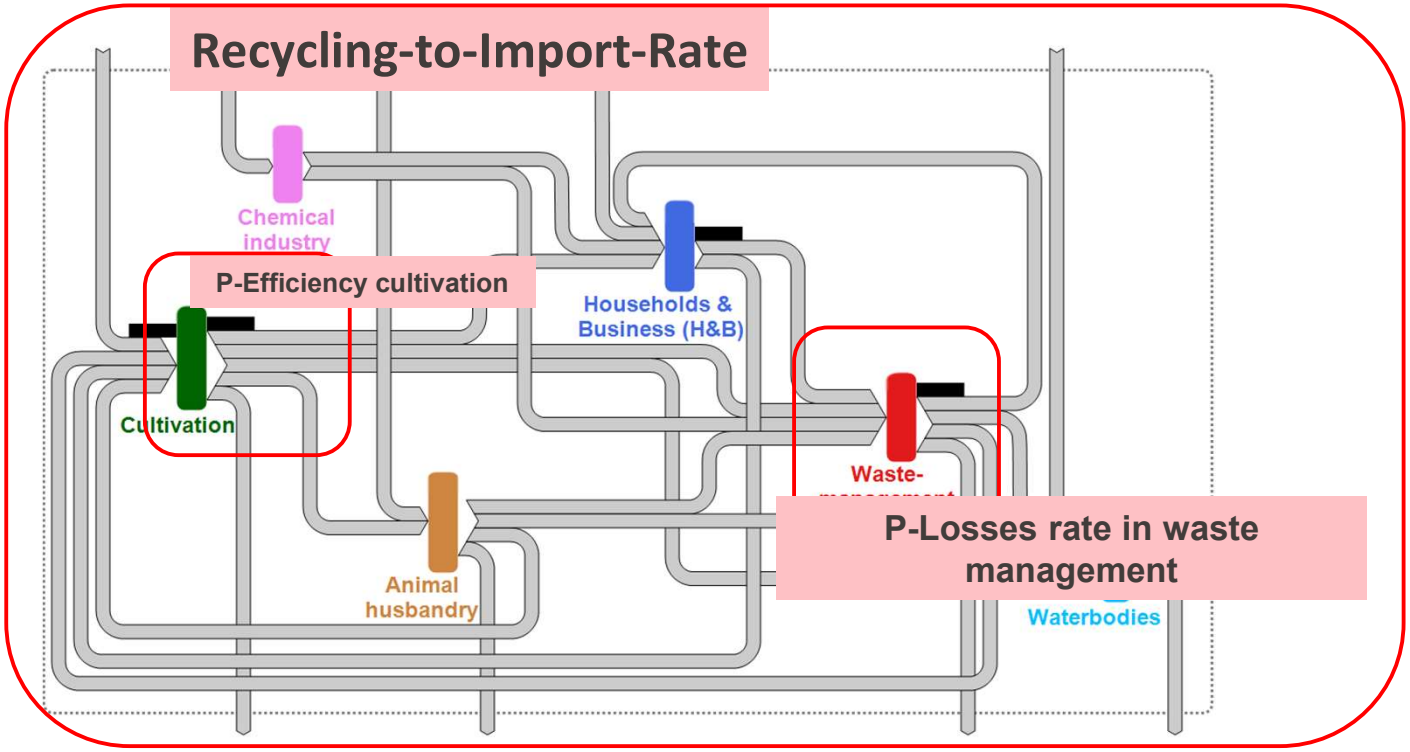
- Error propagation for flows
- STAN

System analysis: Sankey diagram



Source : Binder & Mehr, 2017

Processes and indicators



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Source : Binder & Mehr, 2017

How efficient is the P-system in CH?

Indicators

- Overall system — **TID:** Total Import Dependency
- Cultivation — **PEP:** P-Efficiency Plant Production
- Waste management — **PLW:** P-Losses Waste Management

Phosphor: Historical overview in CH

Original issue: Eutrophication

1986: Phosphate ban in textile detergents

1990: Improvements of P-Elimination at waste water treatment plant WWTP

1990: BSE: Ban meat and bone meal as animal feed

1993: Ordinance of direct payments

1999: Proof of ecological performance (ÖLN)

2001: Ban of animal by-products for fertilizer use

2006: Ban of sewage sludge fertilization

2007: Abrupt rise of P-price

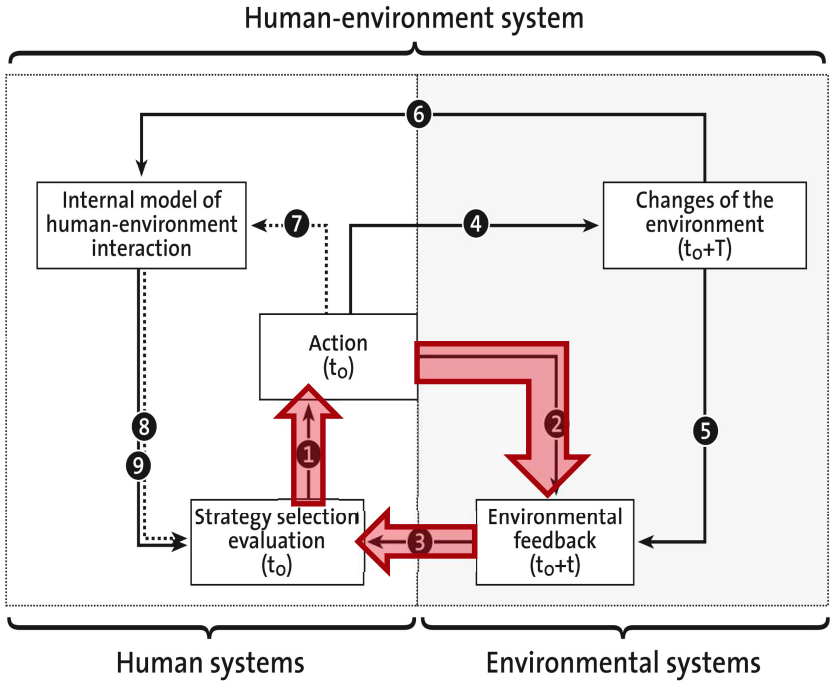
2016: VVEA Ordinance on Avoidance and Disposal of Waste

Eutrophication, algae bloom, fish death

Source : US geological survey, 2022

Action to environmental problem

Federal Water Protection Act, (1972): treatment of industrial and household wastewater



Oxygenation of lakes doubtful

"*We are convinced that the priority should be shifted to external measures: improvements in fertilising practices, restricted use of artificial fertilizers, adaptation of livestock holdings, improvements in the treatment of household wastewater, promotion of phosphate-free washing powders etc.*" (WWF statement, quoted in Knoepfel, 1995; 109).

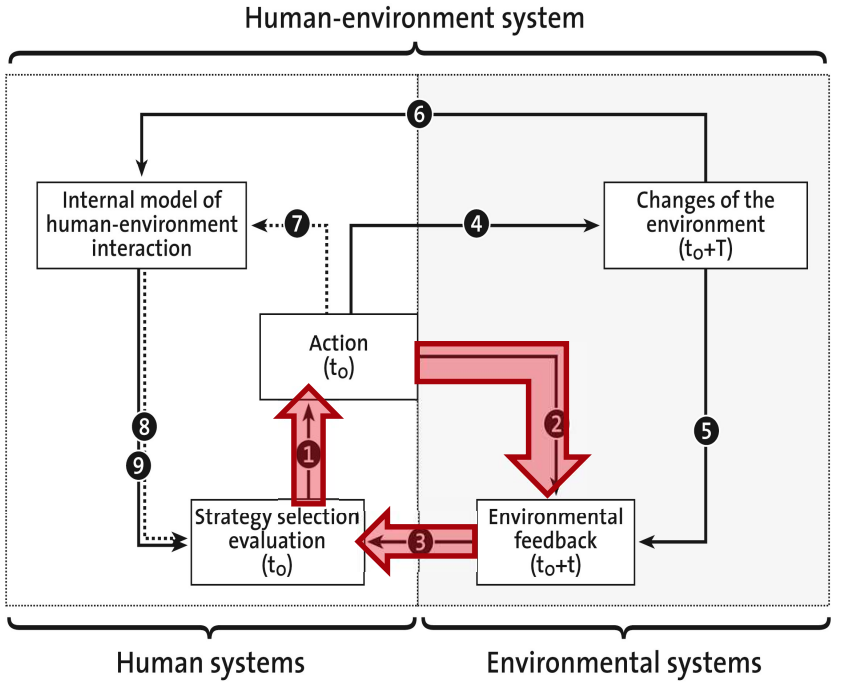
Source : WWF, 1995

Feedbacks

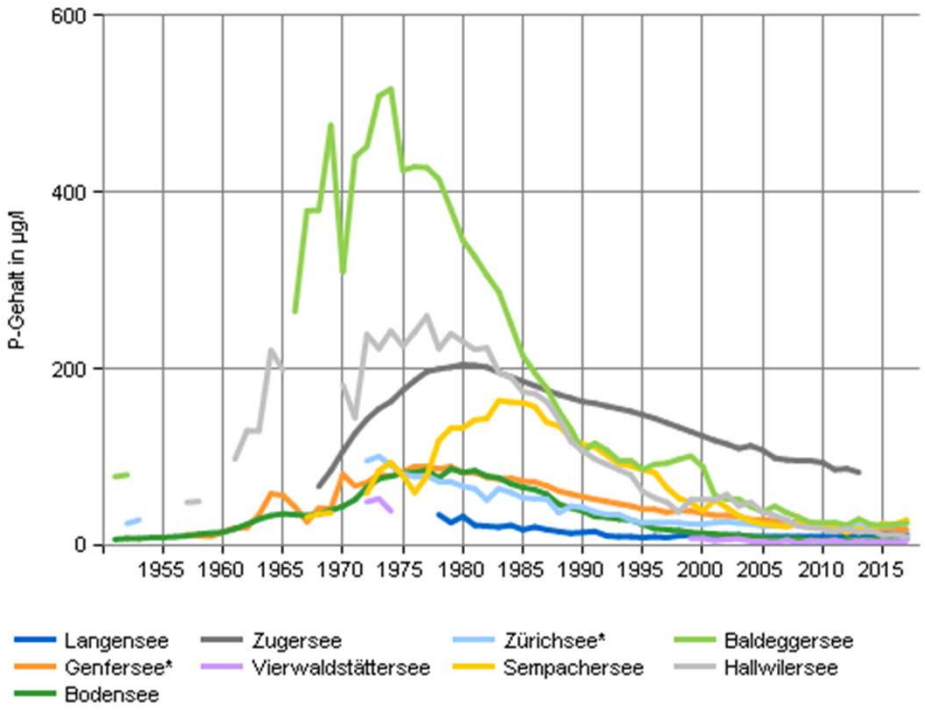
7/8 August 1984:
325'000 fish died in Lake Sempach.

Public uproar

- ban of P in detergents;
- integration of a fourth level for P filtration in the WWTP
- severe restrictions in the use of fertilisers in agriculture, close to rivers and lakes



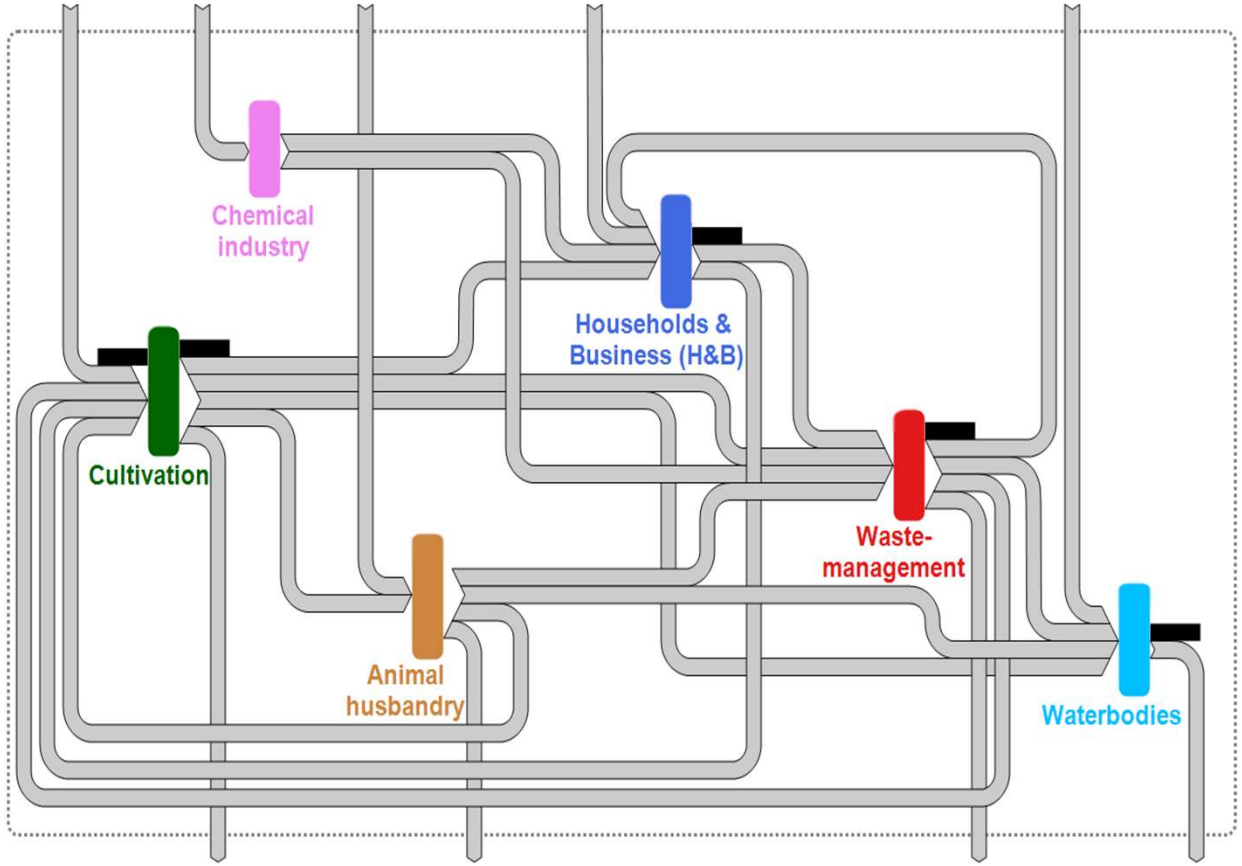
P in Swiss lakes 1950-2017



Baldeggersee *(Canton of Luzern)*

Source : FSOE, Swiss Federal Office for the Environment

Where did we intervene?



Source : Binder & Mehr, 2017

Phosphor: Historical overview in CH

1986: Phosphate ban in textile detergents

1990: Improvements of P-Elimination at WWTPs

Issue: Human Health

1990: BSE: Ban meat and bone meal as animal feed

1993: Ordinance of direct payments

1999: Proof of ecological performance (ÖLN)

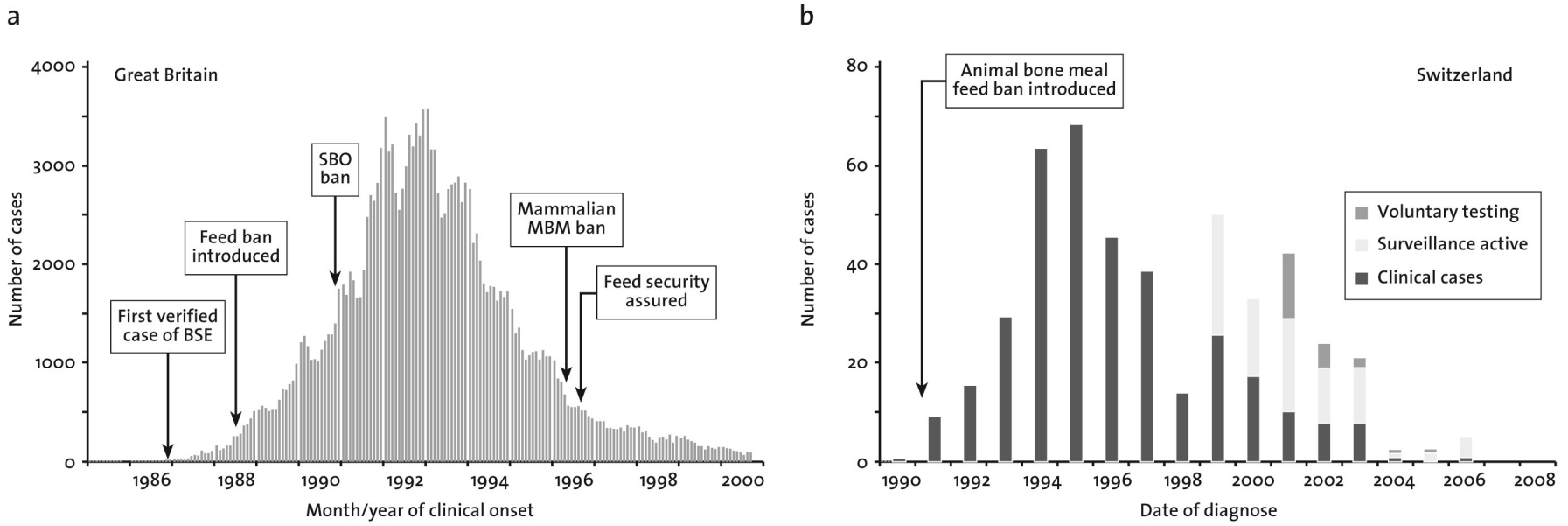
2001: Ban of animal by-products for fertilizer use

2006: Ban of sewage sludge fertilization

2007: Abrupt rise of P-price

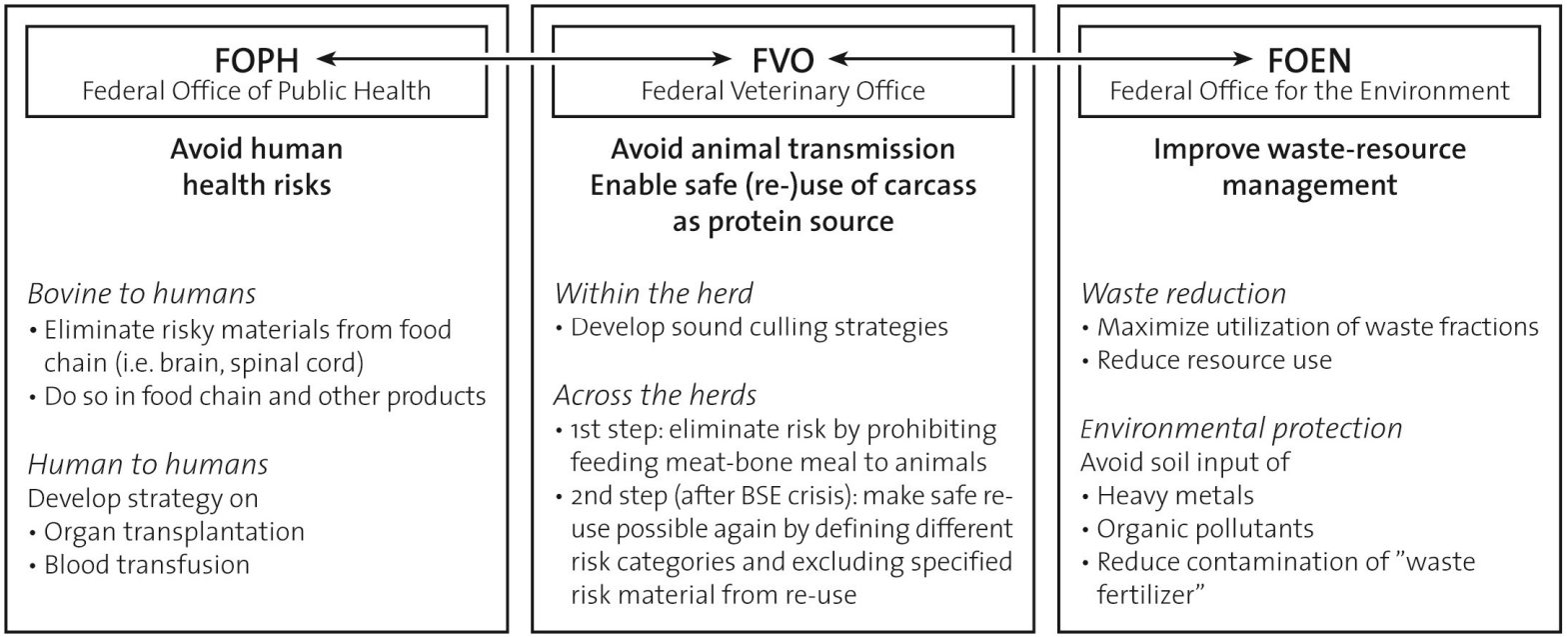
2016: VVEA Ordinance on Avoidance and Disposal of Waste

Problem dynamic of BSE

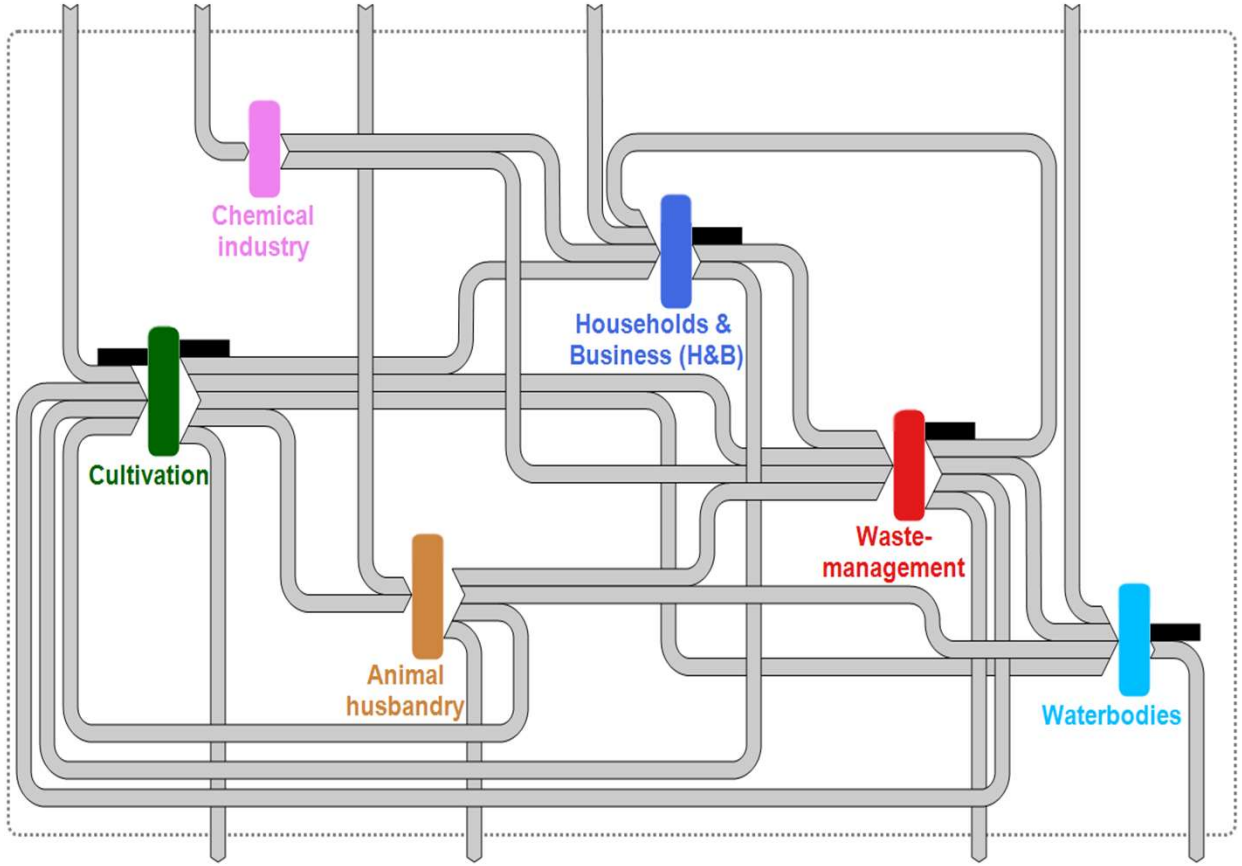


Source : Scholz & Binder, 2011

Conflict of interest



Where did we intervene?



Source : Binder & Mehr, 2017

Increased P-Efficiency / P-Losses in waste management

Source : Mehr et al, 2018

Phosphor: Historical overview in CH

1986: Phosphate ban in textile detergents

1990: Improvements of P-Elimination at WWTPs

1990: BSE: Ban meat and bone meal as animal feed

Environmental issue: Eutrophication and soil overfertilization

1993: Ordinance of direct payments

1999: Proof of ecological performance (ÖLN)

2001: Ban of animal by-products for fertilizer use

2006: Ban of sewage sludge fertilization

2007: Abrupt rise of P-price

2016: VVEA Ordinance on Avoidance and Disposal of Waste

Restrictions to Swiss farmers

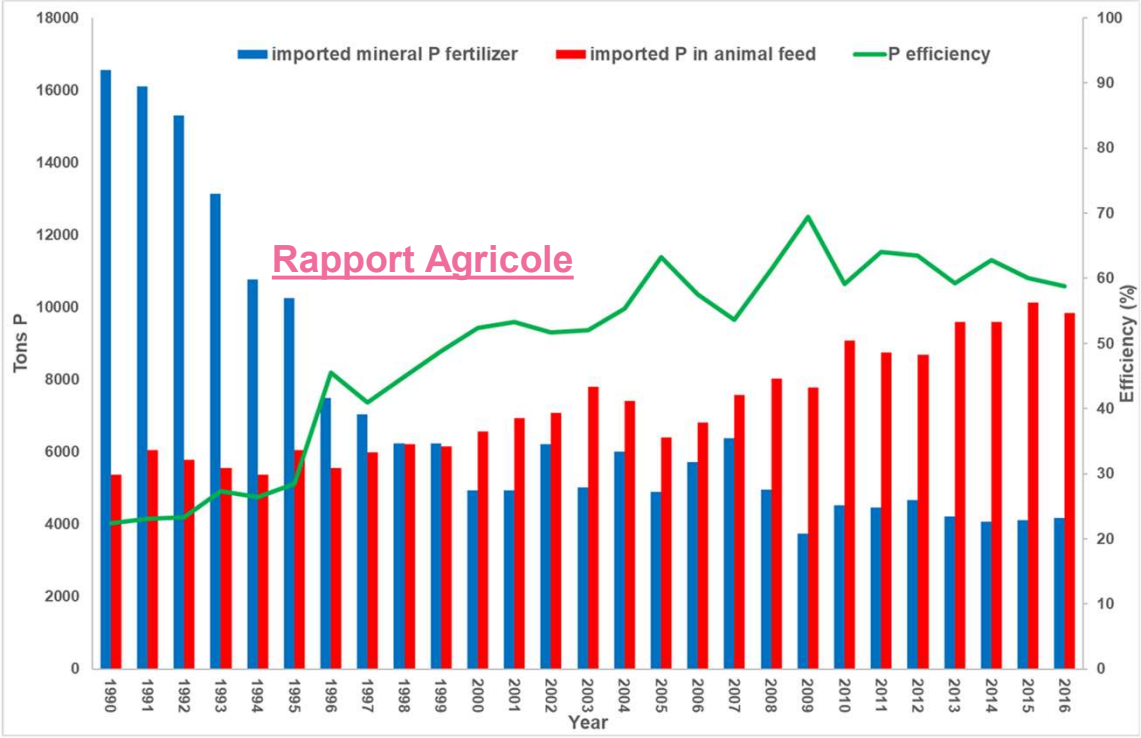
Direct Payments Ordinance

Balanced fertilizer budget and soil analysis

According to Article 13 of the Direct Payments Ordinance (DZV, SR 910.13), the nutrient cycles must be closed as far as possible and the number of livestock adapted to the location in order to fulfil the ecological performance certificate.

The permissible amount of P and N is calculated on the basis of the plant requirement and the operational management potential. The P and N balance may each show an error range of no more than +10 % of the crop requirement on the farm as a whole.

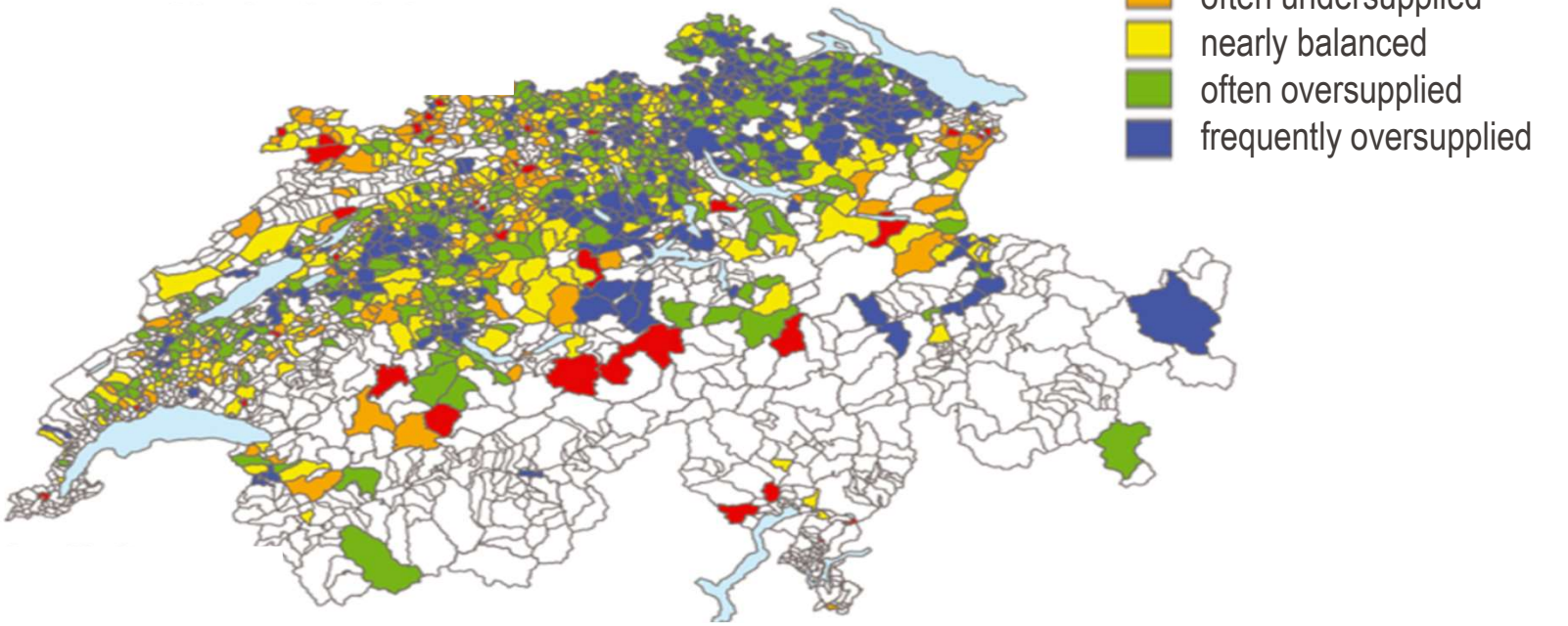
Phosphorus imports in Swiss agriculture 1990-2016



Source : Rapport Agricole, 2024

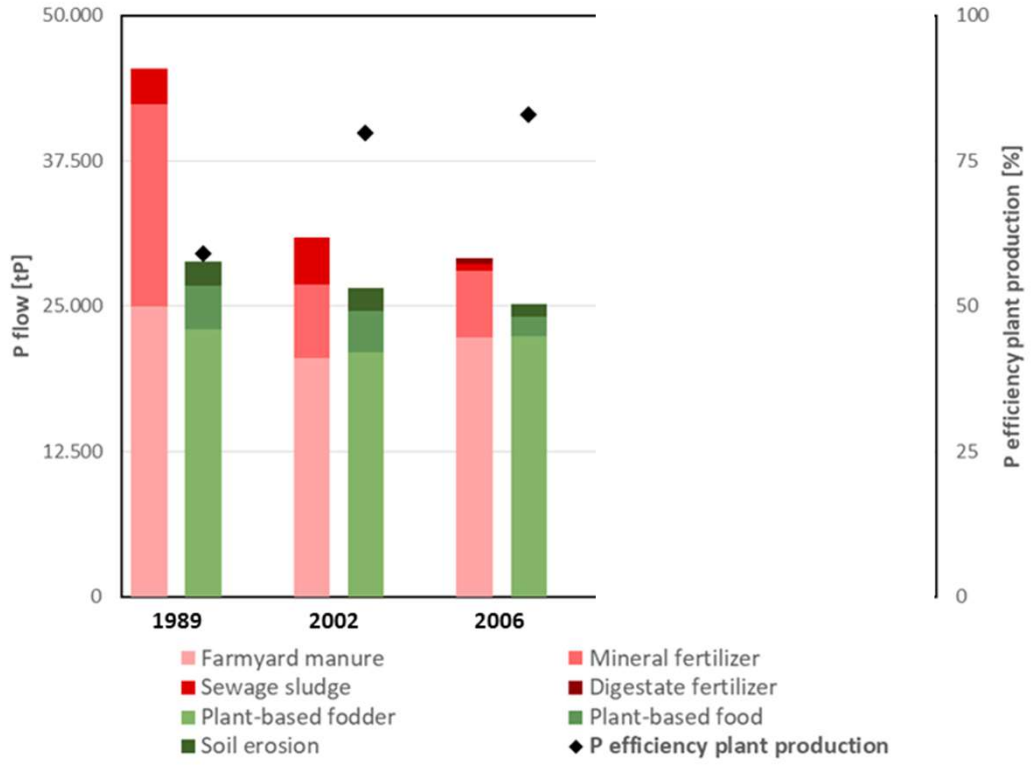
Phosphorus in Swiss soils 2010-2016

Soil samples from crop production sites
n = 56’202



Source : Rapport Agricole, 2024

P-flows agriculture: Temporal dynamics



Based on own research; Binder et al. 2009; Binder & Jedelhauser 2014; Lamprecht et al. 2011

Phosphor: Historical overview in CH

1986: Phosphate ban in textile detergents

1990: Improvements of P-Elimination at WWTPs

1990: BSE: Ban meat and bone meal as animal feed

1993: Ordinance of direct payments

1999: Proof of ecological performance (ÖLN)

2001: Ban of animal by-products for fertilizer use

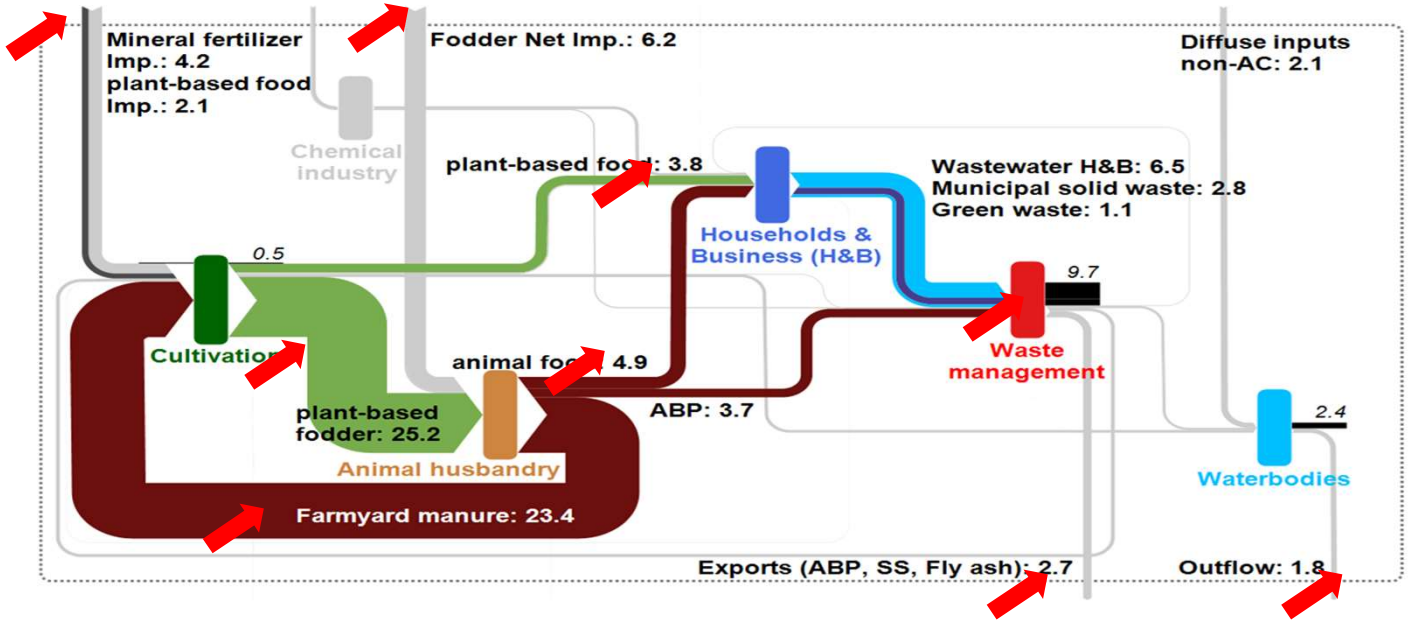
Environmental issue: P-scarcity and loss of resource

2006: Ban of sewage sludge fertilization

2007: Abrupt rise of P-price

2016: VVEA Ordinance on Avoidance and Disposal of Waste

P-flows in CH 2015

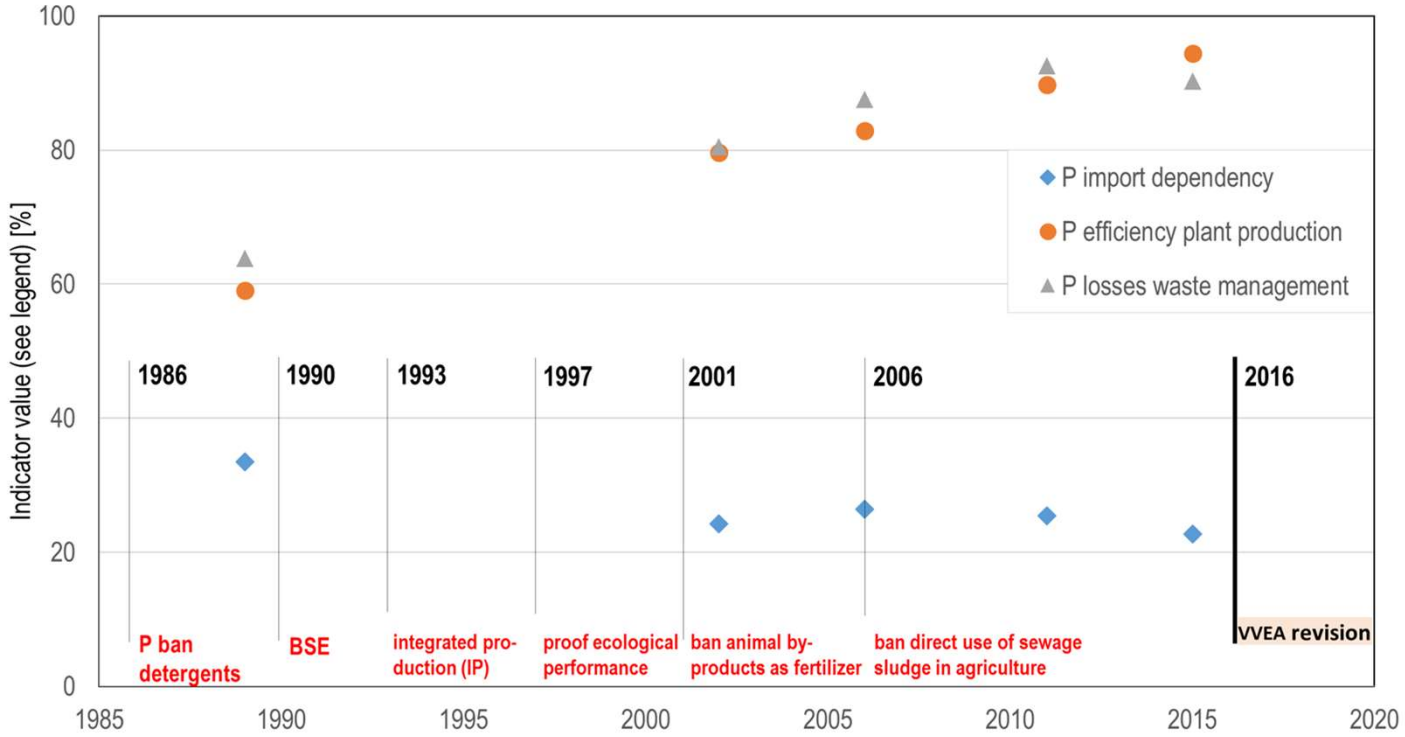


Import ~ 14'000 t P/year (90% agriculture)
Export ~ 4'500 t P/year

→ «**Losses** in deposit» ~10'000 t P/year (93% in landfills and cement industry)

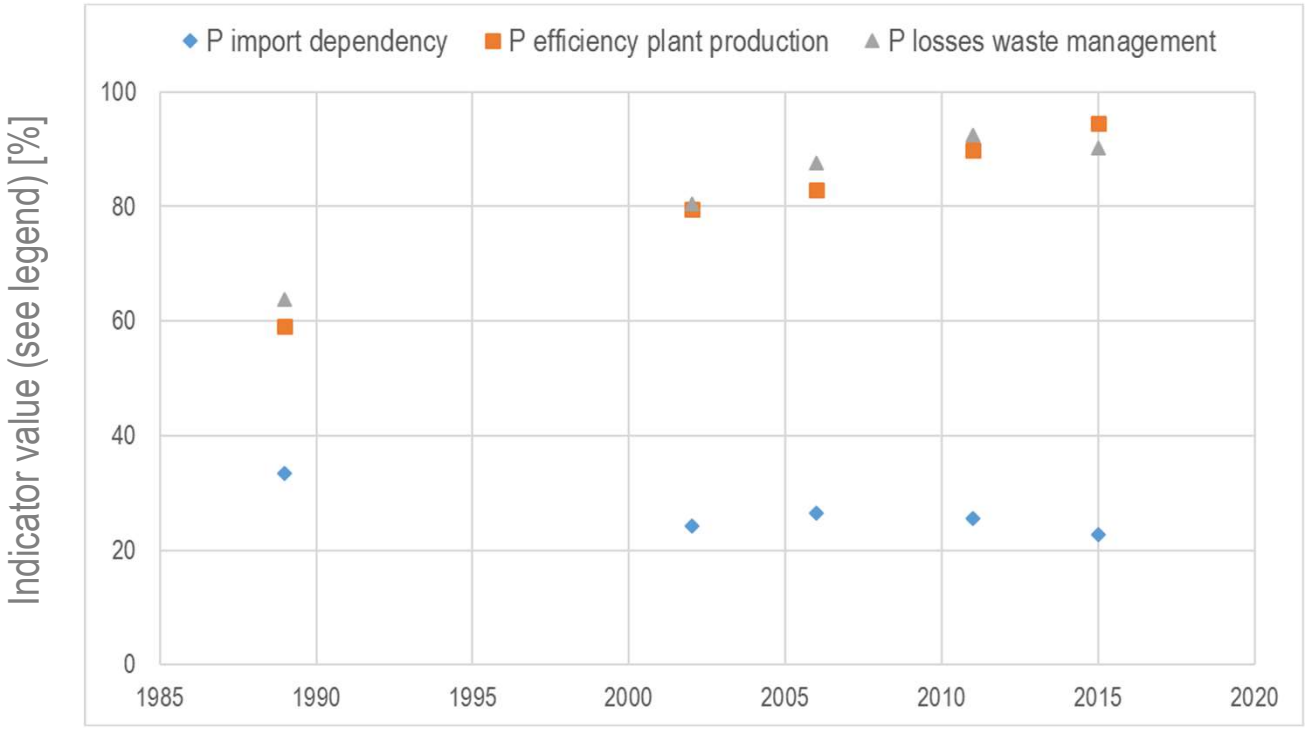
Source : Mehr et al, 2018

Summary: Effect of drivers on the Swiss P-system



Source : Mehr et al, 2018

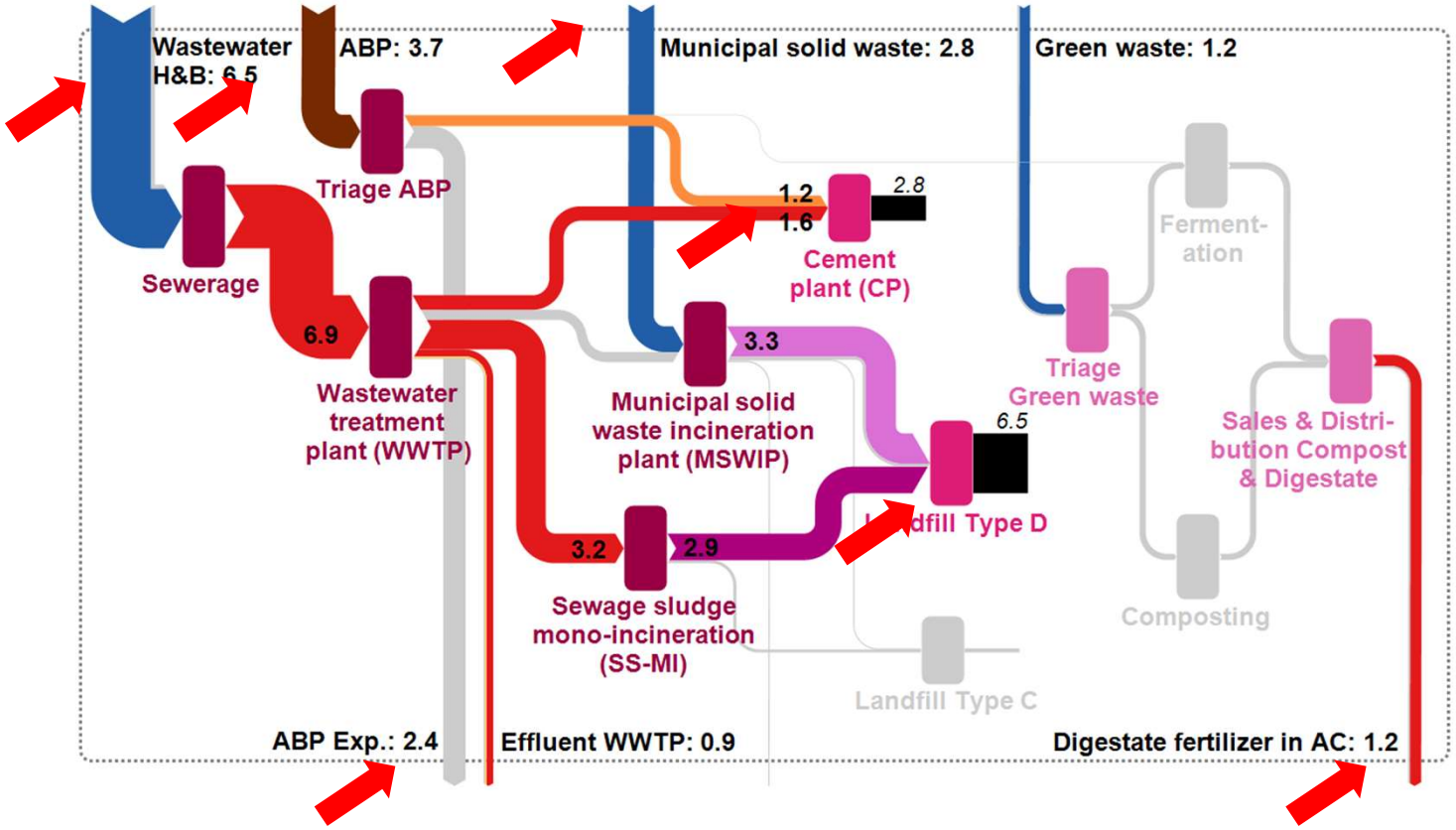
Increased P-Efficiency / P-Losses in waste management



Source : Mehr et al, 2018

Laboratory on Human-Environment Relations in Urban Systems

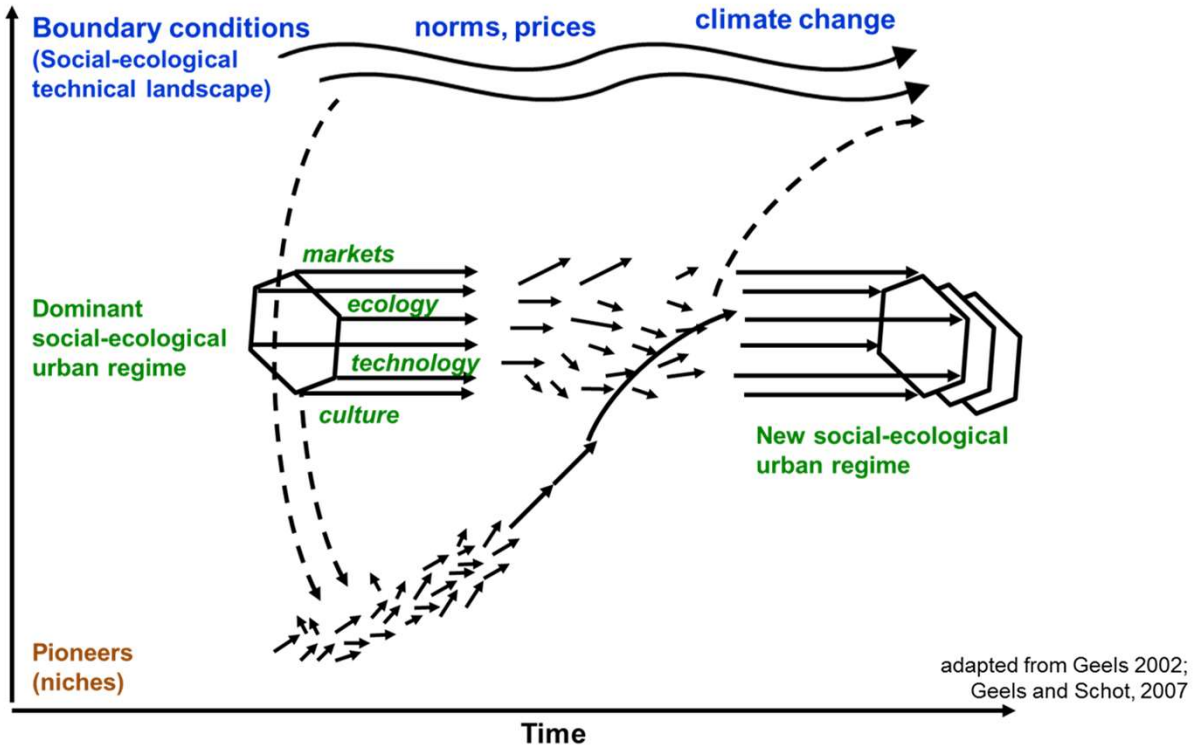
P-fows waste management 2015



Source : Binder and Mehr, 2017

How will the P flows develop over time?

Transitions occur at different levels



Scenarios

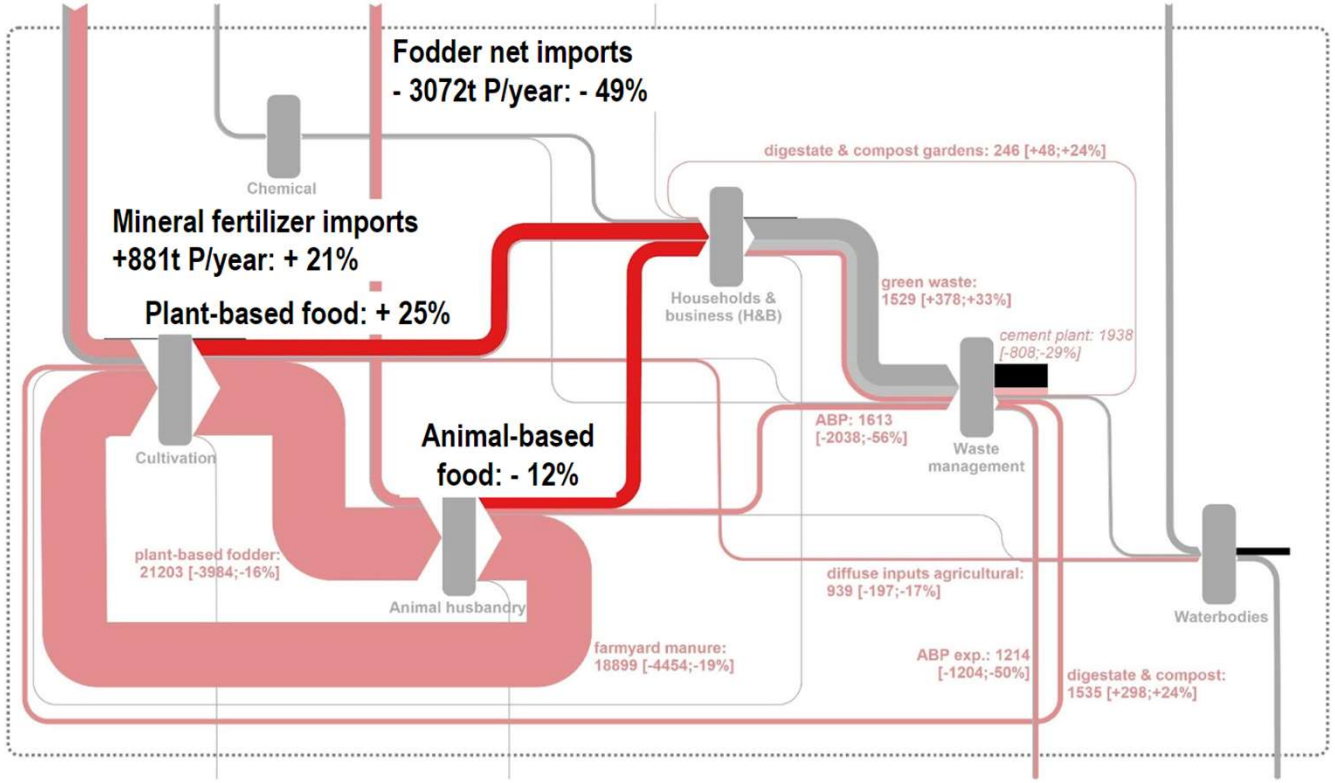
Scenario	Level	Context	Assumptions
Balanced and healthy human diet	**Landscape**	Government initiative: Swiss Nutrition Strategy 2017-2024	Food recommendations according to FSVO
Implementation of VVEA	**Regime**	Legislative intervention: VVEA	Full implementation of VVEA, i.e. P recovery from wastewater, sewage sludge or sewage sludge ashes and utilization of P in meat and bone meal
Urine separation	**Niche**	Research & pilot projects	Separate collection and recycling of 20% of total urine on the household & businesses level

Scenario I: Balanced and healthy diets (landscape)

Recommended food consumption compared to consumption in 2014/15 according to FSVO

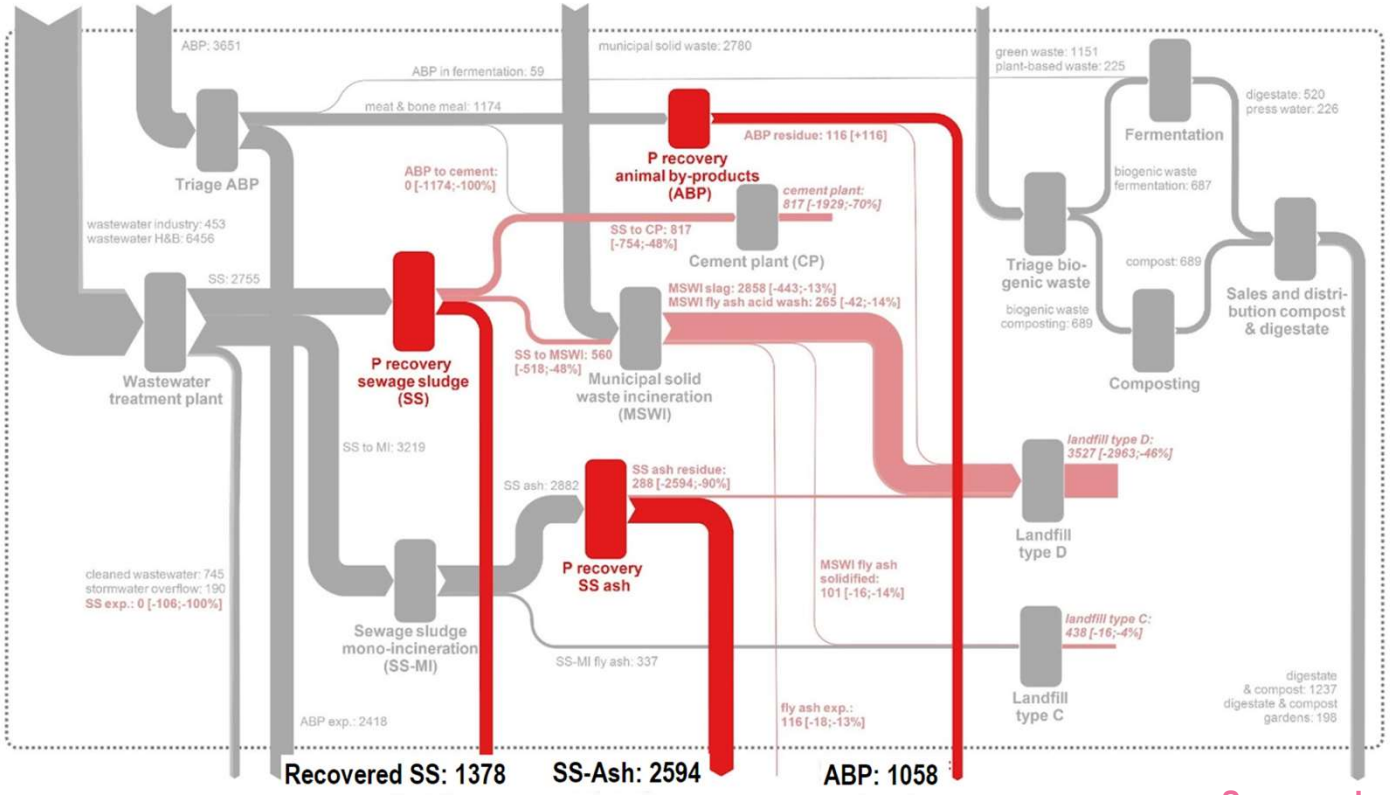
	%
Meat and fish	-68.5
Eggs	-19.5
Milk and dairy products	+50.0
Grain/rice/potatoes	+25.0
Vegetables	+76.5
Fruits	+5.3
Vegetable oils/fats	-34.0
Animal fats	-74.4
Nuts/seeds	+100.0
Sugar	-75.0

Scenario I: Balanced and healthy diets (landscape)



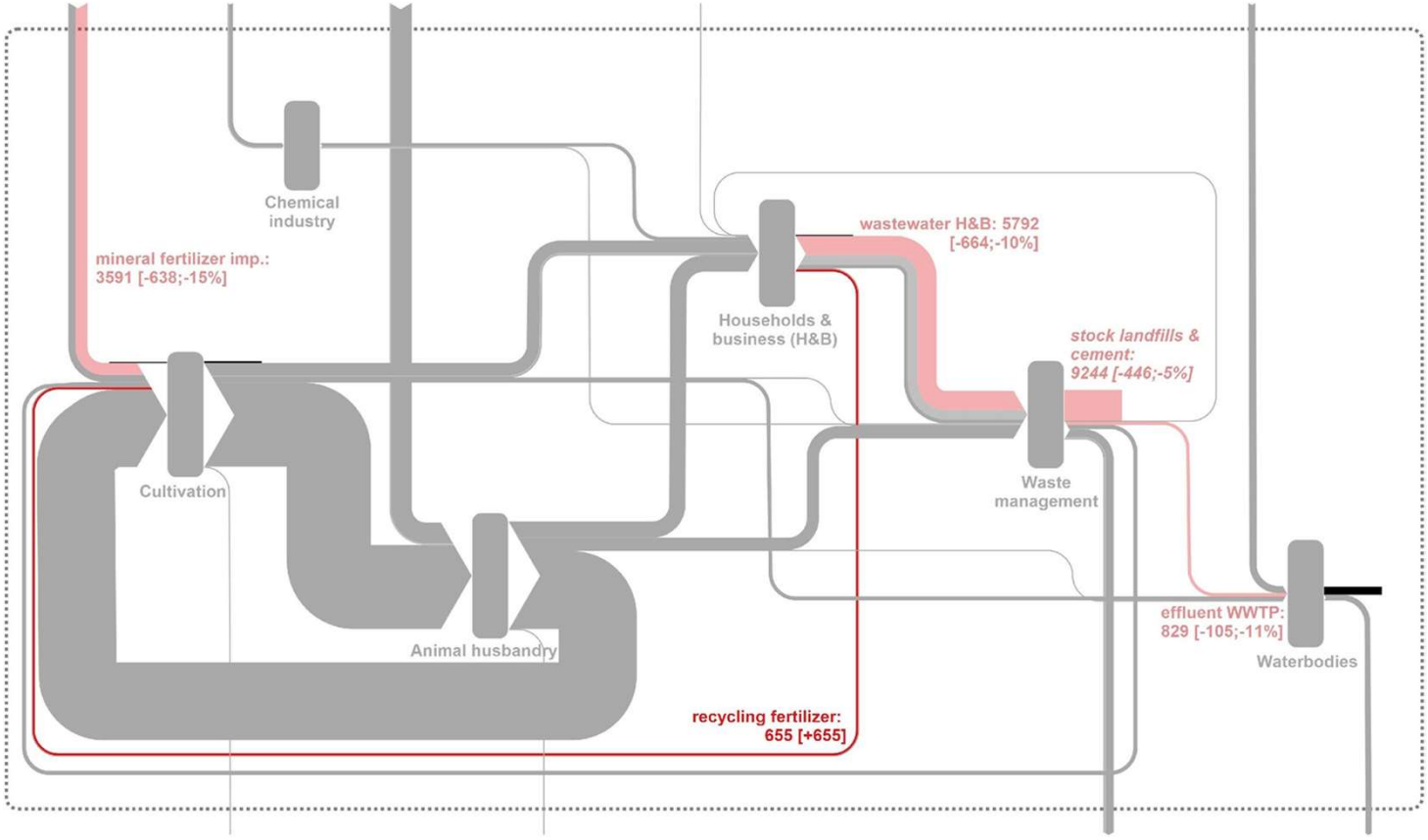
Source : Jedelhauser et al., 2018

Scenario II: VVEA implementation (regime)



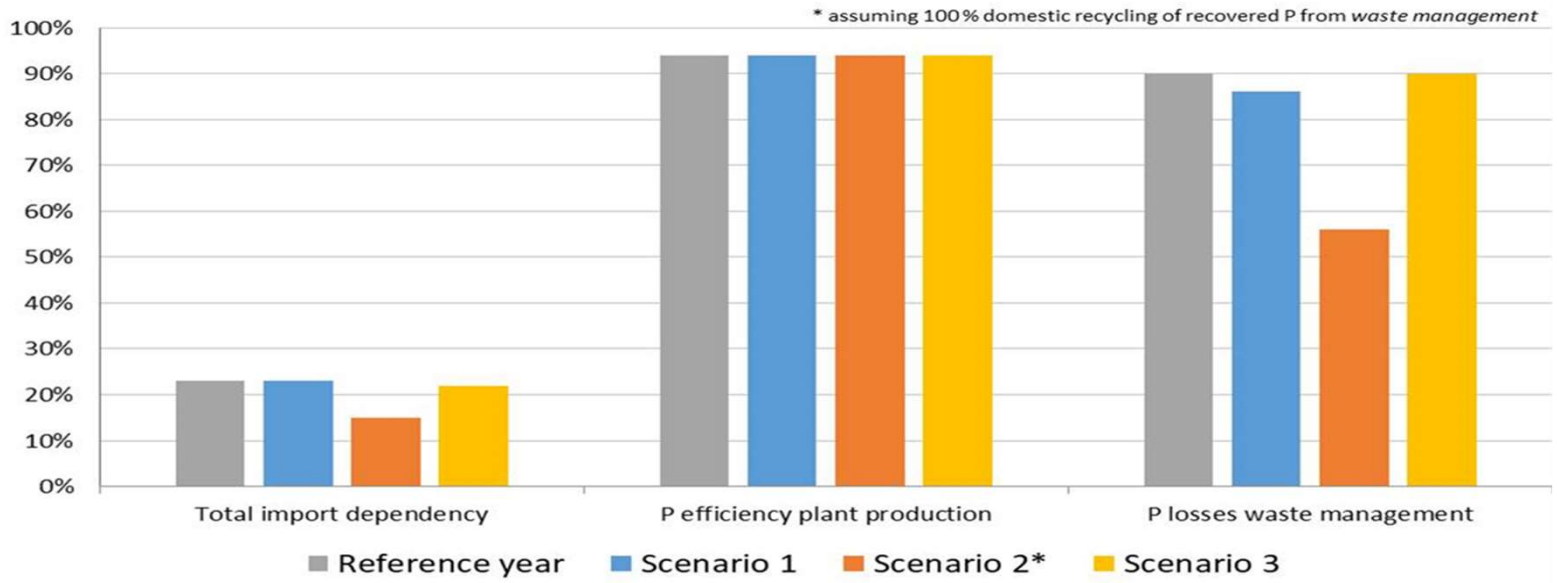
Source : Jedelhauser et al., 2018

Scenario III: Urine separation (niche)



Source : Jedelhauser et al., 2018

Scenario comparison

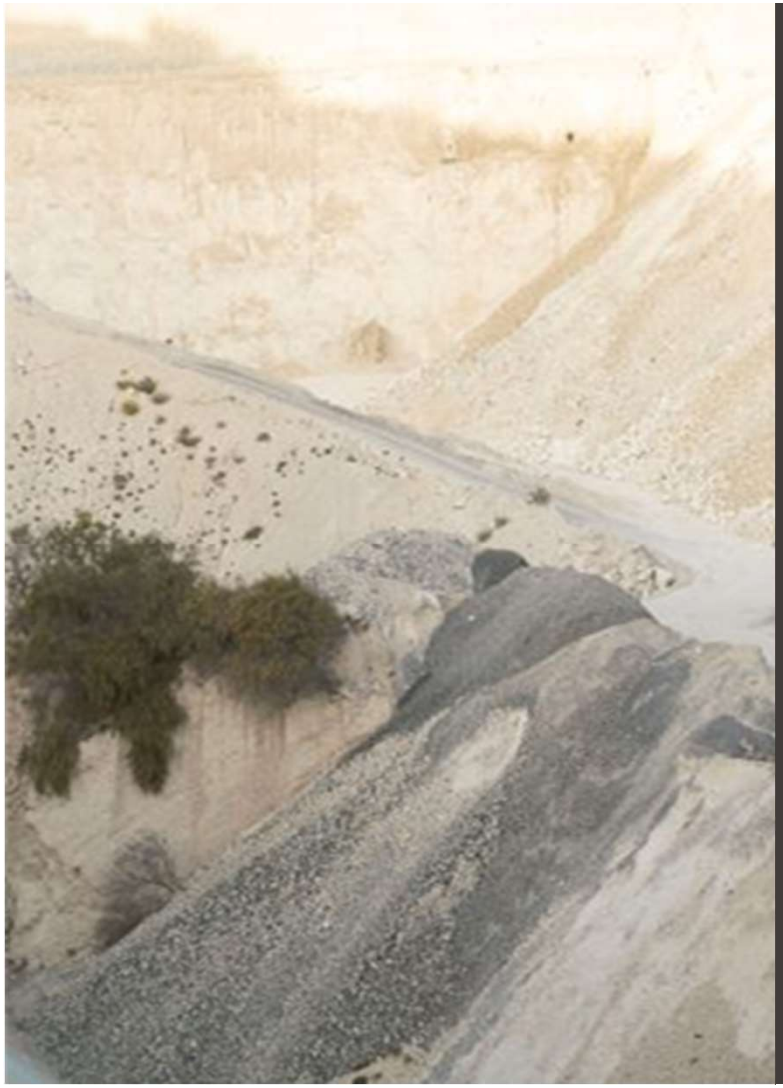


Scenario I: Balanced and healthy diets (landscape level)
Scenario II: VVEA implementation (regime level)
Scenario III: Urine separation (niche level)

Source : Jedelhauser et al., 2018

Summary

- Reduction of environmental impact is not only a technical fix
- It requires (several iterations of)
  - Scientific evidence
  - Public awareness
  - Policy
  - Technological innovation
- MFA can be a tool for:
  - Providing scientific evidence
  - Creating awareness
  - Monitoring



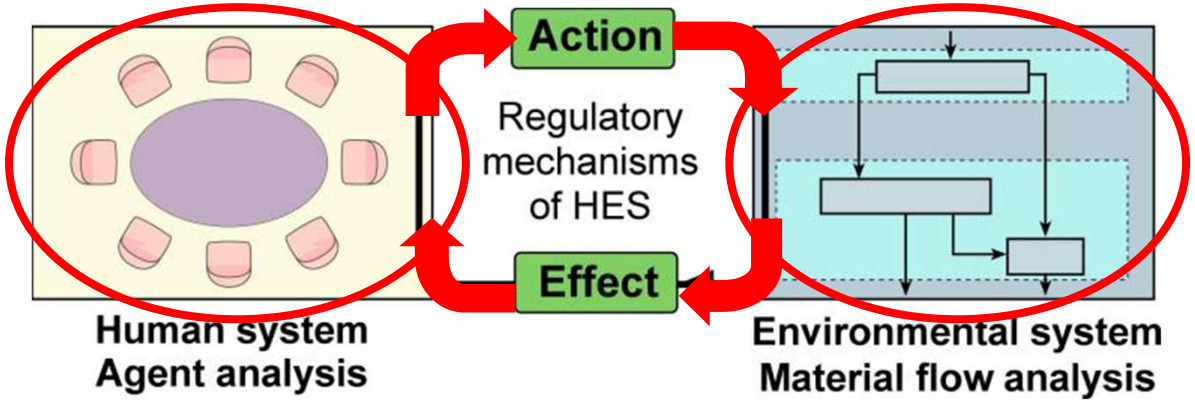
From Material Flow Analysis to Material Flow Management

MFA for policy-making: Material Flow Management

Policy makers have rarely included MFA results in their decision-making at a regional level:

- there is a need to improve the structure for interpreting MFA results, i.e. the goals of material management are not always clearly defined.
- the number of stakeholders involved increases with increasing levels of aggregation and it becomes unclear who is responsible for taking action.
- the uncertainty of the data increases.

Linking MFA results with the social system [1]

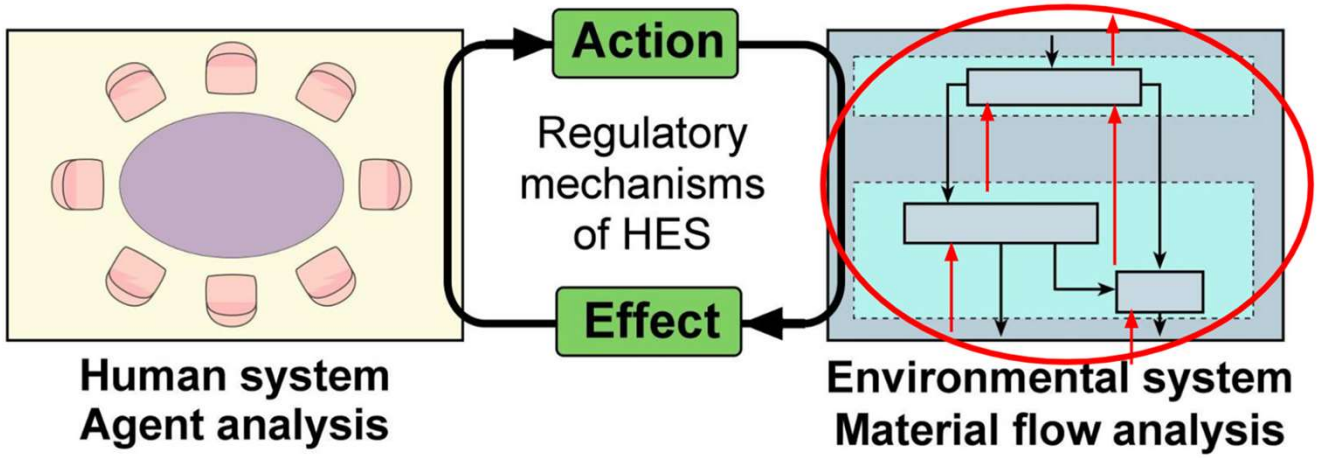


Key questions:

- What are the key problems in the environmental system?
- Which actions of humans affect or are related to these environmental problems?
- Which parameters do drive these actions?
- How can we monitor the effect of these actions?

Source : Binder, 2005

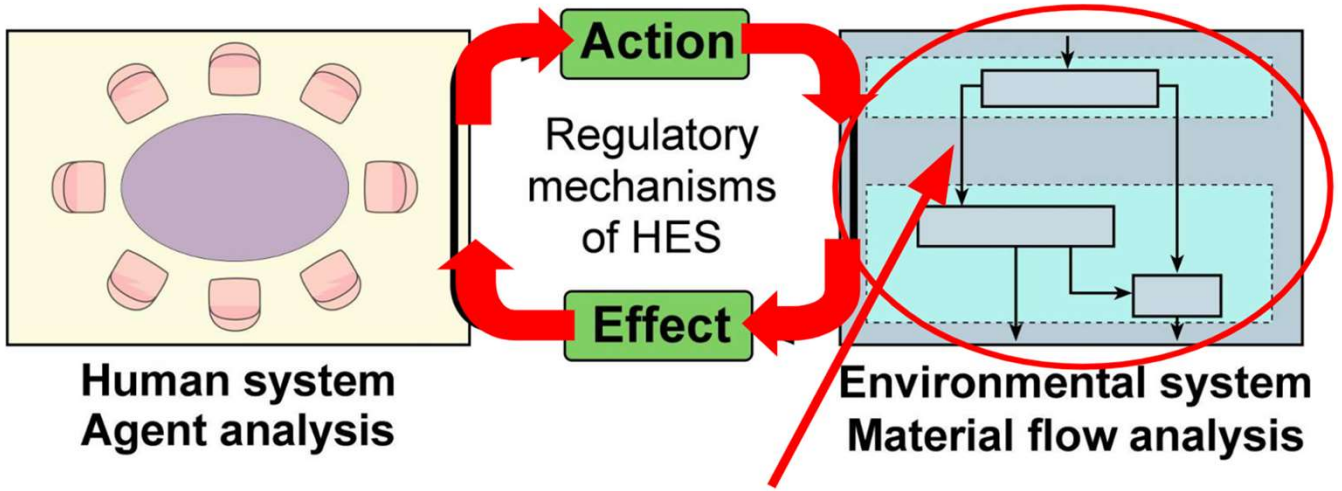
Linking MFA results with the social system [2]



What are the economic flows associated with the material flows?
⇒ Input/*Output Analysis*

Source : Binder, 2005

Linking MFA results with the social system [3]

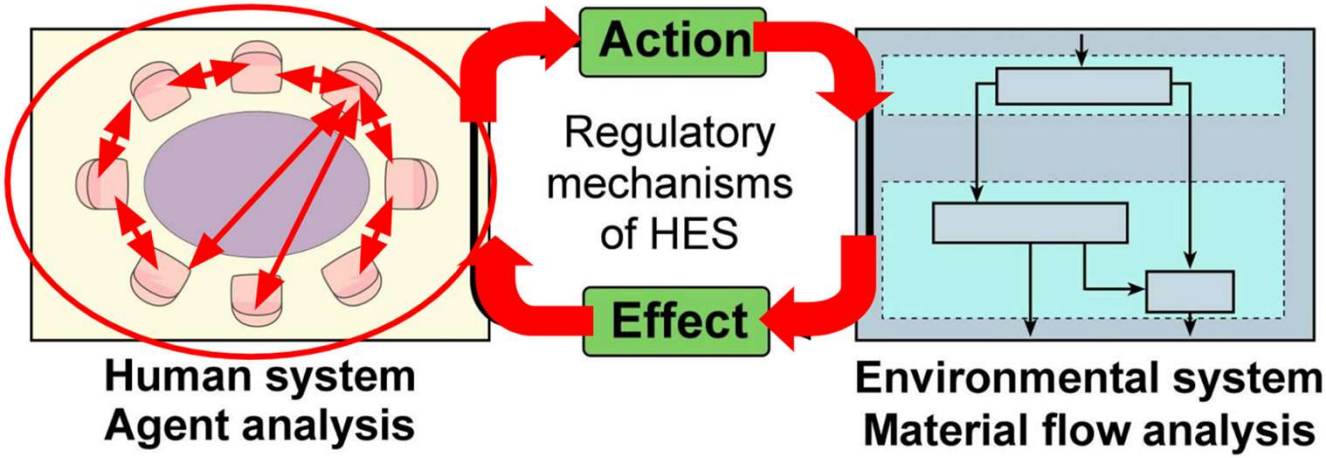


Which parameters affect the decision-making process relevant for specific material flows?

⇒ *Statistics / decision-making models / econometrics*

Source : Binder, 2005

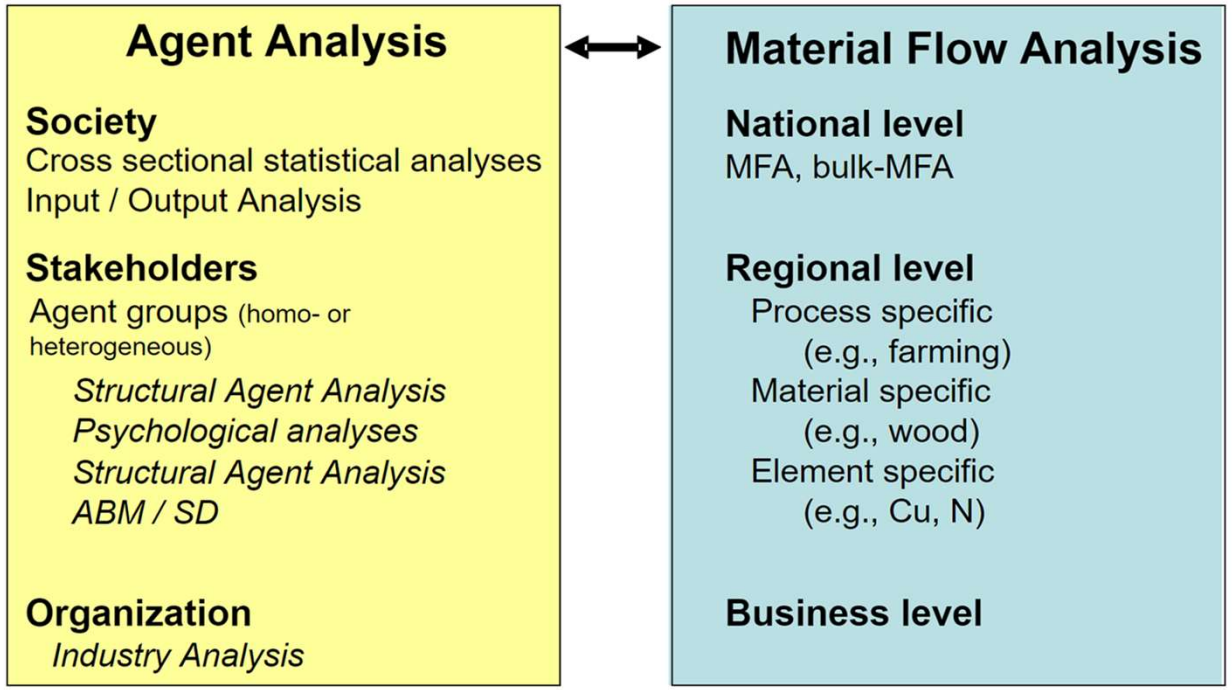
Linking MFA results with the social system [4]



What hinders / promotes the implementation of sustainable measures?
What is the role of interaction of stakeholders?
⇒ *Agent Analysis / Modeling techniques (SD, ABM)*

Source : Binder, 2005

Steering MFA systems: The necessity of analyzing actors



Source : Binder, 2005

Conclusion [1]

Linking MFA with social science methods can significantly support:

- the development of adequate measures considering human behavior.
- the analysis if implementation of best policies is possible.

MFA can bridge to other disciplines through:

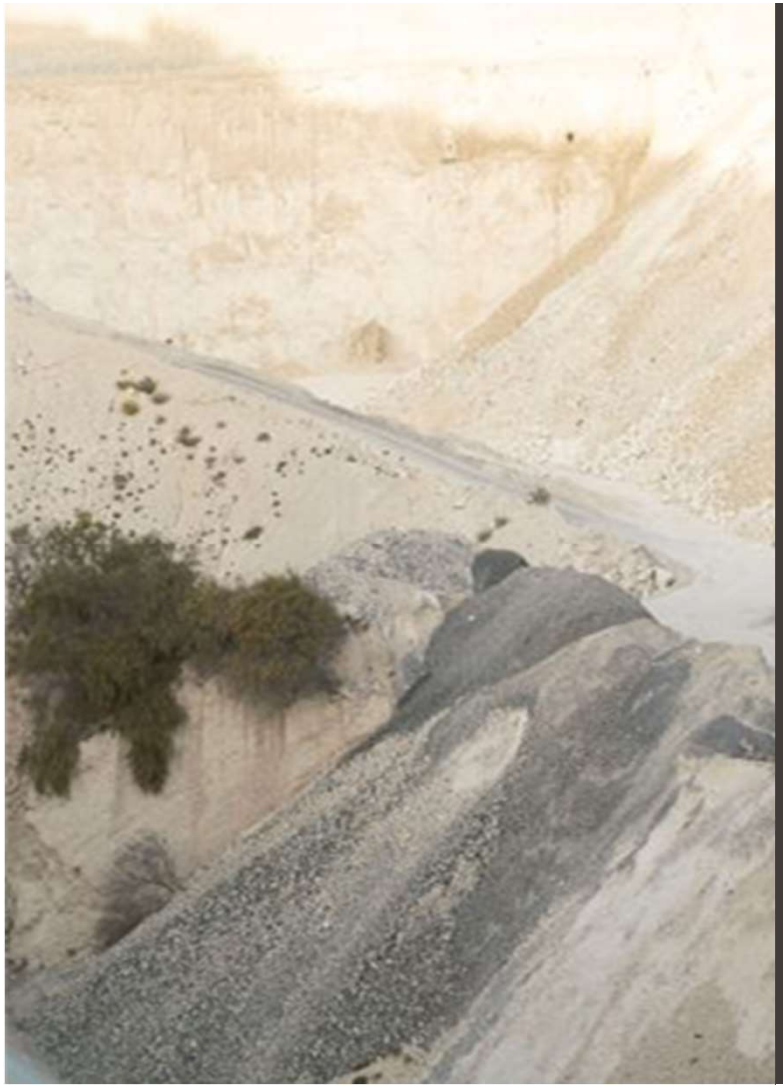
- a specific flow (behavior affecting a specific flow).
- aiming at changing the system (behaviors of several actors affecting the stocks and flows).

Conclusion [2]

It is crucial to consider scale and agent composition when selecting the social science method to be used:

- Homogenous agent group ⇒ statistical, econometric analysis, SD
- Heterogeneous agent groups ⇒ interaction analysis ABM, SD (quantitative approaches)

Structural Agent Analysis (qualitative approach)



Thank you for your time and attention!