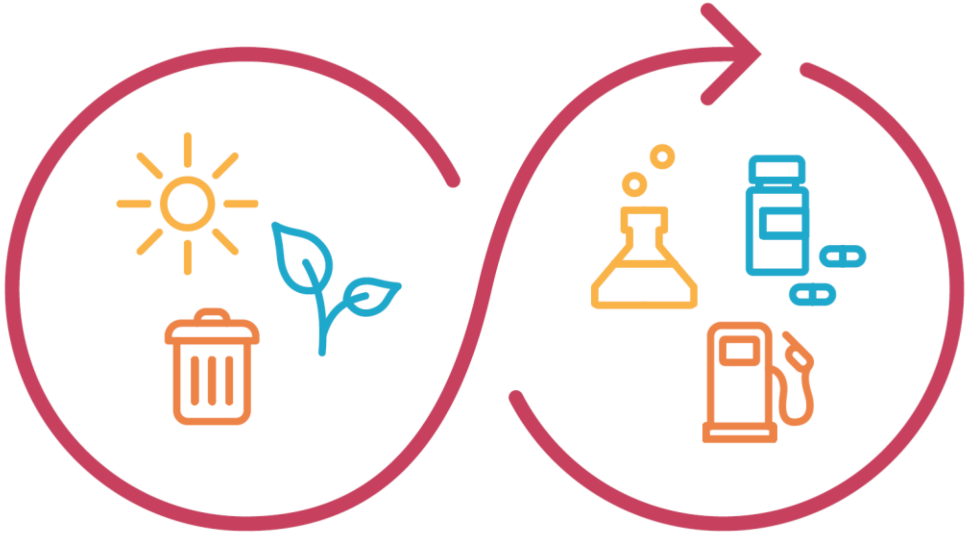
Concepts and Tools for Sustainable Chemicals Manufacture

Sustainability in the chemical sector

A social sciences perspective



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GAME PLAN

1. Science and Technology Studies (STS) as **analytical** lens
2. The multiple and evolving **dimensions** of sustainability:
   - → *A mixed social and technical challenge difficult to implement*
   - → *Questioning sustainability as progress: focusing on how and why it emerges*
3. How and why is sustainability a **« complex » matter**?
   - ⇢ *A social problem is a scientific and engineering problem, which is a social problem, which is a scientific and engineering problem, etc.*

1. Science and Technology Studies - STS

A brief look at an analytic perspective from the social sciences

Word map: https://sts.univie.ac.at/en/

3 typical STS questions

- Science and Technology are not asocial or impersonal or universal activities
- The facts derived from scientists' investigations are conditioned by and condition the context (historical, political, social, etc.) rather than just objective representations of nature.
- Three questions from Science and Technology Studies:
  - → The question "What does science do to construct its objects in society? What is the rationale for S&T in/with/for society?" (**Socio-Epistemic Perspective)**
  - → The question "What are the (new) objects, entities and elements of science? What do they tell us factually about ourselves, our common life, our relation to the world?" **(Ontological Perspective)**
  - → The question "How do science and its objects affect our experiences, relationships, identities, values, norms, policies, practices, etc.?" **(Socio-Political Perspective)**

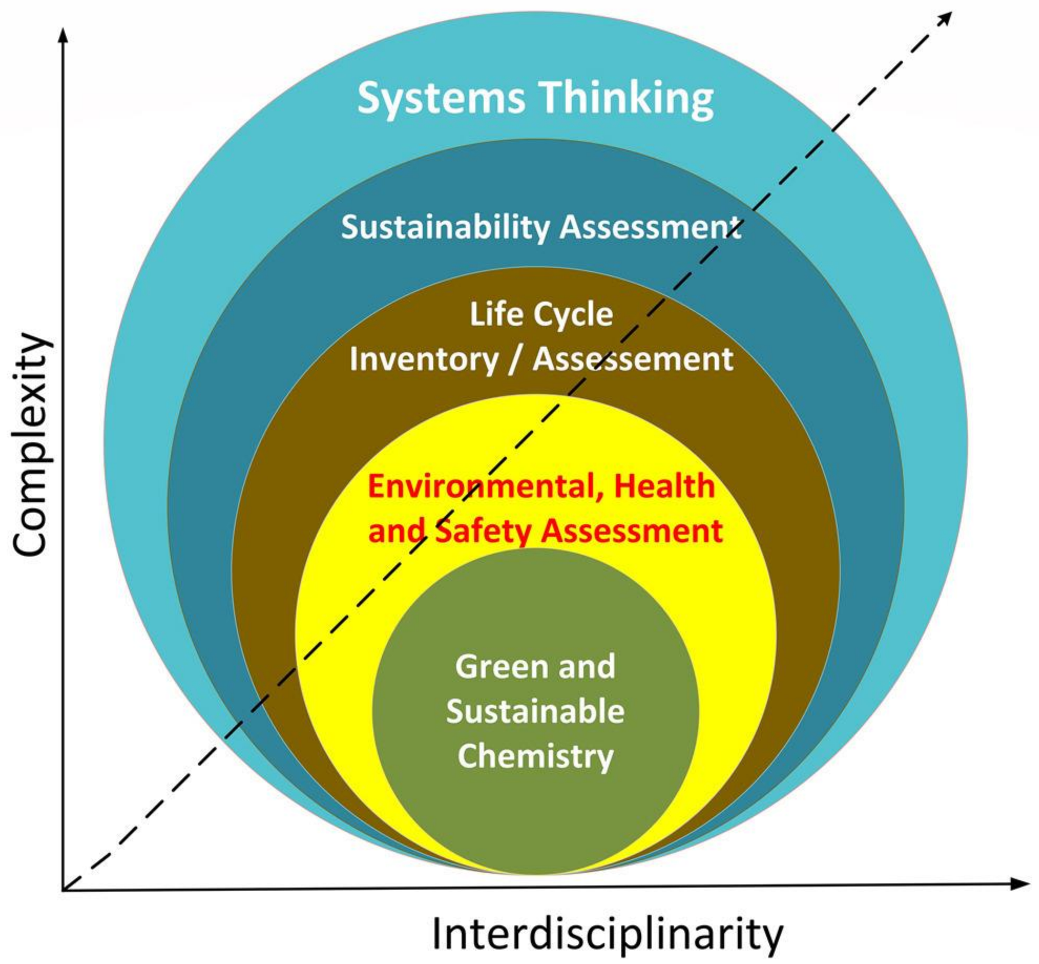
New Problem: "sustainability" for a novel chemistry in/with/for society?

"Sustainable chemistry is **a complex equation** which must ensure the **longevity of the human, animal, and vegetable species** whilst taking into consideration **issues** related to accessing different **resources** (carbon, water, metals), problems of access to **energy**, **global warming**, the exponential increase in the **human population**, for which chemistry must allow a serene development, the social and environmental impact of **the value chain**, and **the erosion of biodiversity**, while of course maintaining **economic competitiveness** to create profit and business."

Marion, P., et al. Sustainable chemistry: How to produce better and more from less? Green Chem. 19, 4973–4989 (2017)

Sustainable, environmental, green: what's in a name? A great deal!

https://doi.org/10.1016/j.isci.2021.103489



Multiple and intersecting dimensions?

OECD
BETTER POLICIES FOR BETTER LIVES

Defining Sustainable Chemistry

For purposes of theses activities, "Sustainable Chemistry" -- also sometimes known as Green Chemistry or Environmentally Benign Chemistry -- is defined as chemistry designed for pollution prevention as opposed to waste treatment and control or characterization of chemicals in the environment. Sustainable chemistry is the design, manufacture, and use of environmentally benign chemical products and processes that prevent pollution, reduce or eliminate the use and generation of hazardous waste, and reduce risk to human health and the environment. By way of example, the following lists some, but not all, types of sustainable chemistry activities:

OECD Workshop on Sustainable Chemistry – Venice, 15-17 October 1998

https://one.oecd.org/document/ENV/JM/MONO(99)19/PART1/en/pdf
https://one.oecd.org/document/ENV/JM/MONO(99)19/PART2/en/pdf
https://one.oecd.org/document/ENV/JM/MONO(99)19/PART3/en/pdf

Time-sensitive?

New configurations of expertise and decision-making?

https://doi.org/10.1016/j.isci.2021.103489

Requiring the collaboration of multiple actors (expert but also social ones)?

- Key actions in the Chemicals Strategy

- **Banning the most harmful chemicals** in consumer products - allowing their use only where essential
- **Account for the cocktail effect of chemicals** when assessing risks from chemicals
- **Phase out per - and polyfluoroalkyl substances (PFAS)** in the EU, unless their use is essential
- **Boost the investment and innovative capacity** for production and use of chemicals that are **safe and sustainable by design** throughout their life cycle
- **Promote EU's resilience of supply** and sustainability **of critical chemicals**
- Establish a simpler "**one substance one assessment**" **process** for the risk and hazard assessment of chemicals
- **Play a leading role globally** by championing and promoting high standards and not exporting chemicals banned in the EU

https://environment.ec.europa.eu/strategy/chemicals-strategy_en#documents

Sustainability in chemistry: a social sciences perspective

Expertise and contribution to the NCCR Catalysis community (WP5, Phase 2)

- Studying the mixed value-laden and factual negotiations that shape visions of sustainability in chemistry (holistic measurements as **social and epistemic matter**).
  - *Who does sustainability, under what circumstances, with what difficulties, configurations, etc.?*
- What visions of "sustainability" stem from this work for different actors (**ontologies** contested, unfinished, negotiated/negotiable, situated, etc.).
  - *How do they diverge/converge? How do they shape our understanding of nature, human-environment relations, etc.?*
- Document how science and governance of sustainable chemistry co-produce one another; with what consequences for multiple actors (influence over **socio-political** processes)
  - *How can these visions of sustainability converge in a shared social and/or political agenda?*

Benefit for NCCR Catalysis community

- Reinforce the consortium's knowledge of sustainable chemistry as social issue (beyond technical knowledge)
- Conditions for political change: what actors, with what values, with what discourses, ideologies and strategies likely succeed?

1. Multiple Evolving

Dimensions of 'sustainability' in chemistry

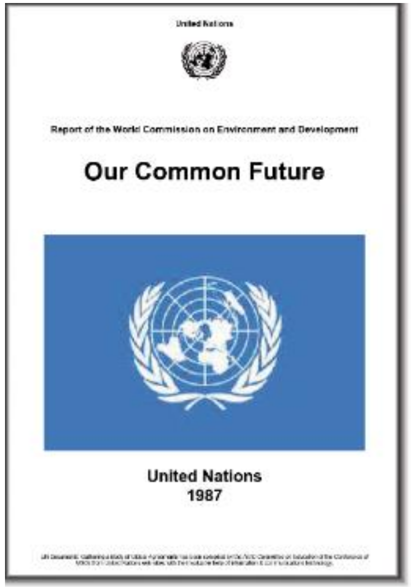
(A scientometric analysis)

The Brundtland Report

Ontological perspective

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
World Commission on Environment and Development, Our Common Future (1987)

- <u>Two built-in ideas</u>
  - *Needs* – overriding priority to the essential needs of the world's poor
  - *Limitations* – ecological & technological constraints on meeting needs



Socio-epistemic perspective

Why did this definition emerge? (late-1970s – mid-1980s backdrop)

1. *Global context:* oil shocks, debt crisis, widening North-South inequality & visible environmental degradation created pressure for an integrated vision of "economy + ecology".
2. *UN mandate:* WCED (1983) was asked to frame "a global agenda for change"; chaired by Gro Harlem Brundtland, it sought a concept broad enough to unite development and environment lobbies
3. *Intellectual lineage:* builds on 1972 Stockholm Conference & IUCN's 1980 *World Conservation Strategy*; shifts debate from "limits to growth" to "**conditions for development**".

The Sustainable Development Goals

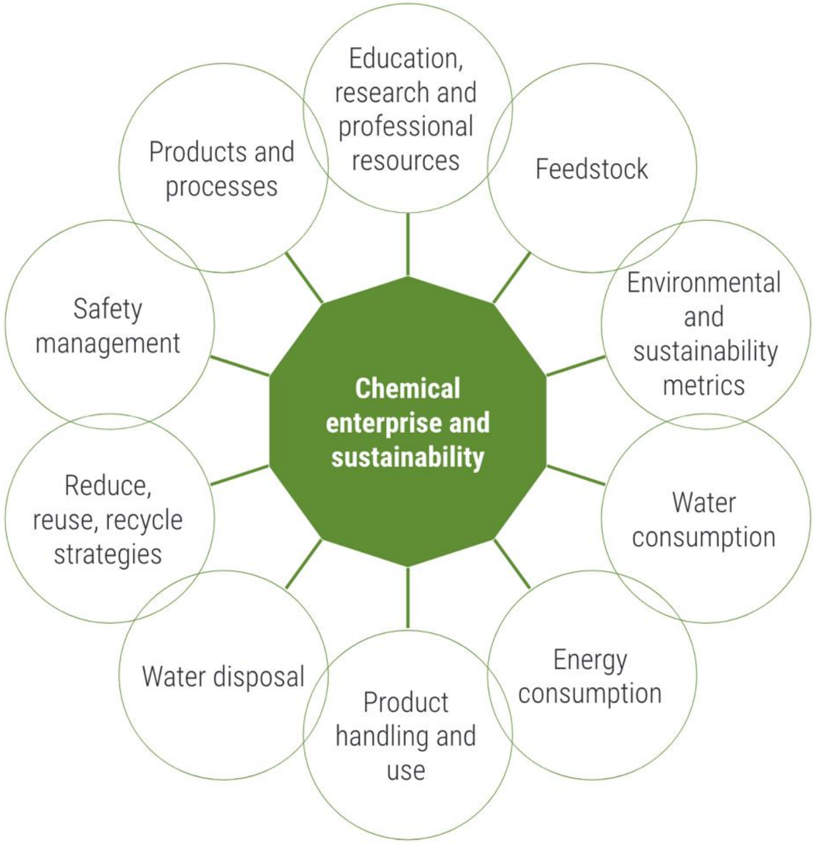
From concept to action? **Socio-political perspective**

- **1992 Rio Earth Summit** – *Agenda 21* operationalises Brundtland's ideas and anchors the three-pillar model (environmental-social-economic).
- **2000 MDGs** – poverty-centred goals echo Brundtland's "priority to needs". siev.org
- **2015 SDGs (2030 Agenda)** – 17 universal goals translate the qualitative Brundtland principles into quantitative targets:
  - "Leave no one behind" → the **needs** clause
  - Climate, oceans, biodiversity caps → the **limitations** clause
  - Integrated, indivisible goals mirror the three-pillar framework.

Mondini, G. "Sustainability Assessment: from Brundtland Report to SDGs", *Valori e Valutazioni* 23 (2019)
Hajian, M. & Kashani, S.J. "Evolution of the concept of sustainability: from Brundtland Report to SDGs", in *Sustainable Resource Management*

Ontological perspective

Typical view of sustainability in the chemical enterprise:
Beyond chemicals, processes and products



1. Broader focus beyond the intrinsic properties of chemicals
2. Minimize their hazard properties and potential
3. The entire **life-cycle** of chemicals and products (cradle to grave)
4. Contribute to broader **environmental** sustainability goals (e.g. sustainable chemical for a non-sustainable product)
5. Contribute to broader **economic** sustainability goals (e.g. circular economy)
6. Contribute to broader **social** sustainability goals (e.g. sustainable chemical, bad labor conditions)

…

1. United Nations Environment Programme. *GREEN AND SUSTAINABLE CHEMISTRY: FRAMEWORK MANUAL*, 2020.
2. Hill, J., Kumar, D.D. and Verma, R.K. (2013). Challenges for chemical education: engaging with green chemistry and environmental sustainability. Journal of the American Institute of Chemists 86(1), 24-31

1.Sustainability as systemic challenge

Technical, scientific, environmental, economic, social, etc.

"The 2030 Agenda emphasizes that development needs to be compatible with all three dimensions of sustainability: economic, social and environmental. Sustainable development **is integrated and indivisible**, meaning that it needs to be implemented as a whole, rather than through fragmented silos”

(UNEP, *Green and sustainable chemistry: framework manual*, p.15)

Let’s problematize it…

Approach and methods

Research approach

- Explorative and qualitative dive into the sustainability definitions in “sustainable chemistry” research
- Building on the scientometric analysis and literature review of UniL

Data collection

- **20+ semi-structured interviews with NCCR members & industry experts**
- Survey among NCCR Catalysis members
- Consensus workshops within NCCR Catalysis
- Feedback from NCCR Review Panel and International Advisory Board

Analysis

- Identifying points, determinants, roadblocks of convergence/divergence
- Identifying and clustering the common patterns between different expert opinions of sustainability (in chemistry)

→ conceptualizing them into a shared understanding (maybe definition)

Problem: effective technical trade-offs **across these multiple dimensions**

*"The Brundtland definition is **qualitative**—it's about meeting present needs without compromising future ones. But when it comes to assessing sustainability, especially in practice, we need something more precise. **Quantitative frameworks**, like planetary boundaries, offer clearer thresholds—say, CO_2 concentrations or land use limits—beyond which sustainability is compromised. The problem is that while these models help objectify environmental limits, **they often don't cover social and economic pillars.** Plus, also on the environmental side there's no global consensus yet. Without **a shared set of quantitative metrics**, everyone can claim they are moving toward sustainability—one actor might cut emissions, another reduces waste—but there's no agreed benchmark. This ambiguity opens the door to greenwashing. If we had a robust, agreed-upon quantitative definition, it would make sustainability claims more verifiable and harder to misuse. **It's not sufficient on its own, but it's a necessary step to make sustainability actionable and transparent**.*

(Scientist, Chemical Systems Engineering)

Socio-epistemic perspective

Problem: effective collaborations **across these multiple dimensions**

*"One of the key challenges to implementing sustainability systemically lies not just in technology, but in the way **disciplines and institutions are organized**. Take chemistry and chemical engineering: while chemists focus on discovery and fundamental understanding, engineers are trained to design real-world systems, asking whether a process will be scalable, profitable, or lower the carbon footprint. Yet, **these two worlds often work in parallel rather than in concert**. Even within companies, you see departments called 'process design' that only deal with the reactor—not the whole system. **But sustainability requires exactly that: systems thinking.** You have to integrate the single catalyst with all downstream processes. <u>**Institutional divisions—historical, educational, even cultural—can become roadblocks to this**</u>. And without collaboration, we risk overvaluing isolated innovations that may never work at scale or reduce environmental impact. We need frameworks and metrics that connect disciplines and help us collectively assess what truly makes a process sustainable.".*

(Scientist, Chemical Engineer)

Socio-epistemic perspective

Take home message #1 (tentative and preliminary)
Sustainability definitions for chemical sector: a curse and a blessing?

Critical yet elusive concept of sustainability

- **Sustainability** is the key concept to address the environmental, social, and economic balance meeting the needs of the present without compromising the ability of future generations to meet their own needs (UN, 1987)
- Yet, diverse definitions and conceptualizations blur what sustainability **implies in practice** for different sectors: how to implement it? Through what metrics?
- Sustainability remains **ambiguous** and **difficult to balance** from chemicals to processes, products, and systemic considerations (economic or social)
- **Not just a matter of operationalizing (from quality to quantity): misfits** between actors, interests, visions, institutional traditions; need to identify and reach consensus; translate a unified view of sustainability

Do we need a unified definition of sustainability or a roadmap to work together?

→ It is certainly hard to turn actors sustainable without a **shared understanding, but ask yourselves: is the definition, the implementation or its adoption the problem?**

2. Sustainability as progress?

"While green chemistry is characterized and guided by scientific principles that focus on chemistry innovation, **recent discussions** on sustainable chemistry suggest a **broader concept and more holistic** interpretation that takes into account economic, environmental and social dimensions."

(UNEP, *Green and sustainable chemistry: framework manual*, p.21)

Let's problematize it…

The contingent origins of Sustainability

Green Chemistry as Regulatory “Design” (Maxim 2023)

- **Historic trigger** – “The emergence of GC … is ***an expression of major political changes*** in the management of chemical risks”
- **Policy pivot** – After Toxic Substances Control Act (TSCA, 1976) setbacks or the 1991 asbestos case (Pollution Prevention Act, 1990), EPA moved from command-and-control to **voluntary co-management with industry**; GC became its flagship legitimation tool
- **Scientization & depoliticisation** – GC was stripped of overt politics so industry would adopt it, while civil-society voices were kept at bay

Take-home message #2: Sustainability concepts arise as **situated political technologies**, not universal ideals unfolding into history. Understanding their regulatory backstory is essential before treating them as neutral «milestones of progress».

Socio-epistemic perspective

Maxim, Laura. “The Birth of Green Chemistry: A Political History.” *Science, Technology, & Human Values* (2023).

Socio-epistemic perspective

Global Idiom, Local Trajectories

From Green to Sustainable Chemistry (Krasnodębski 2023)

- **Contingent evolution** – "There is ***nothing inevitable in the emergence of new disciplines*** … they are historically contingent" (pp. 464–465) .
- **Bifurcation** – Green & Sustainable Chemistry overlapped in the 1990s but "***slowly grew apart*** … largely due to developments within the German-speaking world" (p. 464)
  - «Green» being a politically charged notion as name of a party
- **Linguistic 'safe spaces'** – Diverse terminologies (sanfte Chemie, ökologische Chemie, etc.) nurtured alternative frameworks before entering global debate (p. 472)

Take-home message #3: Sustainability is **polyphonic and place-based**; linguistic and institutional contexts redirect its course, challenging any single, linear genealogy from Brundtland to SDGs.

Krasnodębski, Marcin. "An Unlikely Bifurcation: History of Sustainable (but Not Green) Chemistry." *Foundations of Chemistry* 25, no. 3 (October 1, 2023): 463–84. https://doi.org/10.1007/s10698-023-09474-x.

Myths, Detours & Reinventions

The Bumpy Road & the ‘Reinventing’ Debate (Krasnodębski 2024, 2022)

- Study of the influence of the **12 principles of Green Chemistry** (Anastas and Warner 1998)
- **Cracks in the canon** – Enthusiastic stories around the 12 Principles hide dissent; the paper seeks “to ***dismantle the myths*** surrounding the list” (p. 86)
- **False linearity** – Tree-of-progress visuals create “***a false sense of unity*** … not good history of science” (p. 90) .
- **Re-branding cycles** – New banners (one-world, circular chemistry) risk “***reinventing the wheel***” when they ignore earlier sustainability debates (p. 114)

Take-home message #4: The sustainability narrative advances through **contested, looping pathways**; reflexive socio-historical awareness is vital to avoid reductionist checklists and perpetual reinvention.

Krasnodębski, Marcin. “The Bumpy Road to Sustainability: Reassessing the History of the Twelve Principles of Green Chemistry.” *Studies in History and Philosophy of Science* 103 (2024): 85–94.

Two hypotheses

Networks that can be localized produce the emergence of green/sustainable chemistry (actors, policy contexts, etc.)

The bifurcation of green chemistry into sustainability; the latter taking over slowly in the 2000s (what factors?)

For your perusal

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KP=(CHEMICALS) AND KP=(SUSTAINABILITY) OR ((ALL=("green chemistry") OR TS=(chem* OR petrochem* OR plastic*) AND (TS=(Sustainab*) OR AK=(Sustainability) OR TS=(precautionary) OR KP=(GREEN) OR AK=(green) OR TI=(Green) OR WC=(Green & Sustainable Science & Technology))) AND (KP=(“POLICY”) OR KP=(“POLICIES”) OR KP=(“POLITICS”) OR KP=(“GOVERNANCE”) OR KP=(“ENVIRONMENTAL GOVERNANCE”) OR TS=(“regulatory science”) OR TS=(“policy makers”) OR WC=(Social Issues) OR KP=(“SOCIAL IMPACTS”) OR WC=(Social Sciences, Interdisciplinary) OR WC=(History & Philosophy Of Science) OR SU=("Business & Economics") OR WC=(Management) OR KP=(“DEVELOPMENT STRATEGIES”) OR KP=(“OPPORTUNITIES”) OR KP=(“ENVIRONMENTAL-MANAGEMENT”) OR TS=(“CHEMICALS MANAGEMENT”) OR WC=(Business) OR TS=(“BIO-BASED ECONOMY”) OR TS=(“BIOBASED ECONOMY”) OR SU=(“Government & Law”) OR WC=(“Law”) OR KP=(“ENVIRONMENTAL JUSTICE”) OR KP=(“METRICS”) OR TS=(“process metrics”) OR KP=(“CONTEXT-BASED CHEMISTRY”) OR TS=(“LIFE-CYCLE ASSESSMENT”) OR KP=(“SUSTAINABILITY INDICATORS”) OR KP=(“SUSTAINABILITY ASSESSMENT”) OR KP=(“ENVIRONMENTAL IMPACTS”) OR KP=(“ENVIRONMENTAL-IMPACTS”) OR TS=(“Planetary boundaries”) OR TS=(“Multicriteria Decision Analysis”)) NOT (KP=("AGRICULTURE" OR "SOIL" OR "CHEMICAL FERTILIZER" OR "CHEMICAL FERTILIZERS" OR "YIELD" OR "YIELDS") OR WC=("Energy & Fuels" OR "Agriculture, Multidisciplinary" OR "Water Resources" OR "Plant Sciences" OR "Soil Science") OR SU=("Energy & Fuels" OR "Agriculture" OR "Plant Sciences" OR "Water Resources" OR "Computer Science")))

Step 2. Data extraction and corpus enrichment (most cited references)

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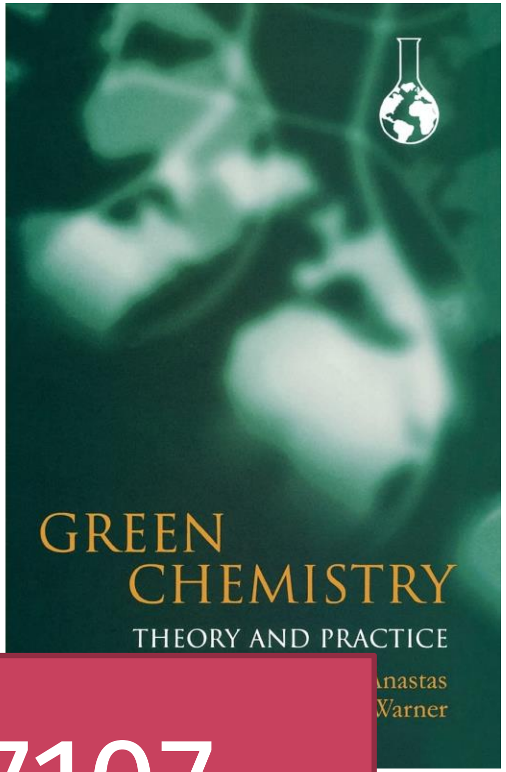
Matus K.J.M., 2007, OVERCOMING CHALLENGE
Matus KJM, 2012, ENVIRON SCI TECHNOL, V46, P10892, DOI 10.1021/es3021777
Matus KJM, 2010, ENVIRON SCI TECHNOL, V44, P6022, DOI 10.1021/es102149j

No pain no gain...



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Preliminary results: *Top AU*, *Top AU Keywords* and *Top Wos Keywords*

Top AU	*count*	Top AU Keywords	*count*	Top Wos Keywords	*count*
Moreira, MT	*34*	Life cycle assessment	*1130*	LIFE-CYCLE ASSESSMENT	*1644*
Guillén-Gosálbez, G	*33*	sustainability	*675*	SUSTAINABILITY	*479*
Feijoo, G	*29*	Circular economy	*366*	ENERGY	*478*
Tobiszewski, M	*24*	LCA	*242*	MANAGEMENT	*445*
Dewulf, J	*22*	Life Cycle Assessment (LCA)	*212*	PERFORMANCE	*380*
Azapagic, A	*21*	Green chemistry	*203*	IMPACT	*354*
González-Garcia, S	*21*	Recycling	*202*	LCA	*296*
Bardow, A	*20*	Environmental impact	*189*	DESIGN	*271*
Sonnemann, G	*20*	Sustainable Development	*159*	OPPORTUNITIES	*259*
Clark, JH	*19*	Waste management	*112*	WASTE	*258*
Gheewala, SH	*18*	environmental impacts	*100*	SYSTEMS	*245*
Hauschild, MZ	*18*	Industrial ecology	*97*	FRAMEWORK	*244*
Hessel, V	*18*	Carbon footprint	*91*	EMISSIONS	*214*
Eckelman, MJ	*17*	biorefinery	*85*	POLICY	*206*
Irabien, A	*17*	biomass	*78*	BIOMASS	*199*
You, FQ	*17*	Climate change	*78*	MODEL	*193*
Gani, R	*16*	Life-cycle assessment	*73*	ENVIRONMENTAL IMPACTS	*192*
Cespi, D	*15*	Environment	*72*	CHALLENGES	*189*
Hellweg, S	*15*	Plastic waste	*63*	METRICS	*185*
Kralisch, D	*15*	Bioeconomy	*60*	GREEN	*169*
Namiesnik, J	*15*	plastics	*60*	IMPACTS	*169*

Legenda: ID= WoS keywords, DE= Authors' keywords; WC= WoS journal category; SC= Research domain; Au= Author

Preliminary results: Top Research Areas, SDG, WoS Index...

Top Research Areas	count
Environmental Sciences & Ecology	3082
Science & Technology - Other Topics	2879
Engineering	2532
Chemistry	1091
Business & Economics	744
Materials Science	268
Operations Research & Management Science	215
Biotechnology & Applied Microbiology	161
Social Sciences - Other Topics	151
Polymer Science	112
Education & Educational Research	92
Construction & Building Technology	80
Public Administration	75
History & Philosophy of Science	74
Government & Law	70
Food Science & Technology	69
Public, Environmental & Occupational Health	69
Physics	65
Biochemistry & Molecular Biology	57
Toxicology	39
Metallurgy & Metallurgical Engineering	36
International Relations	29
Forestry	26
Transportation	25
Development Studies	21

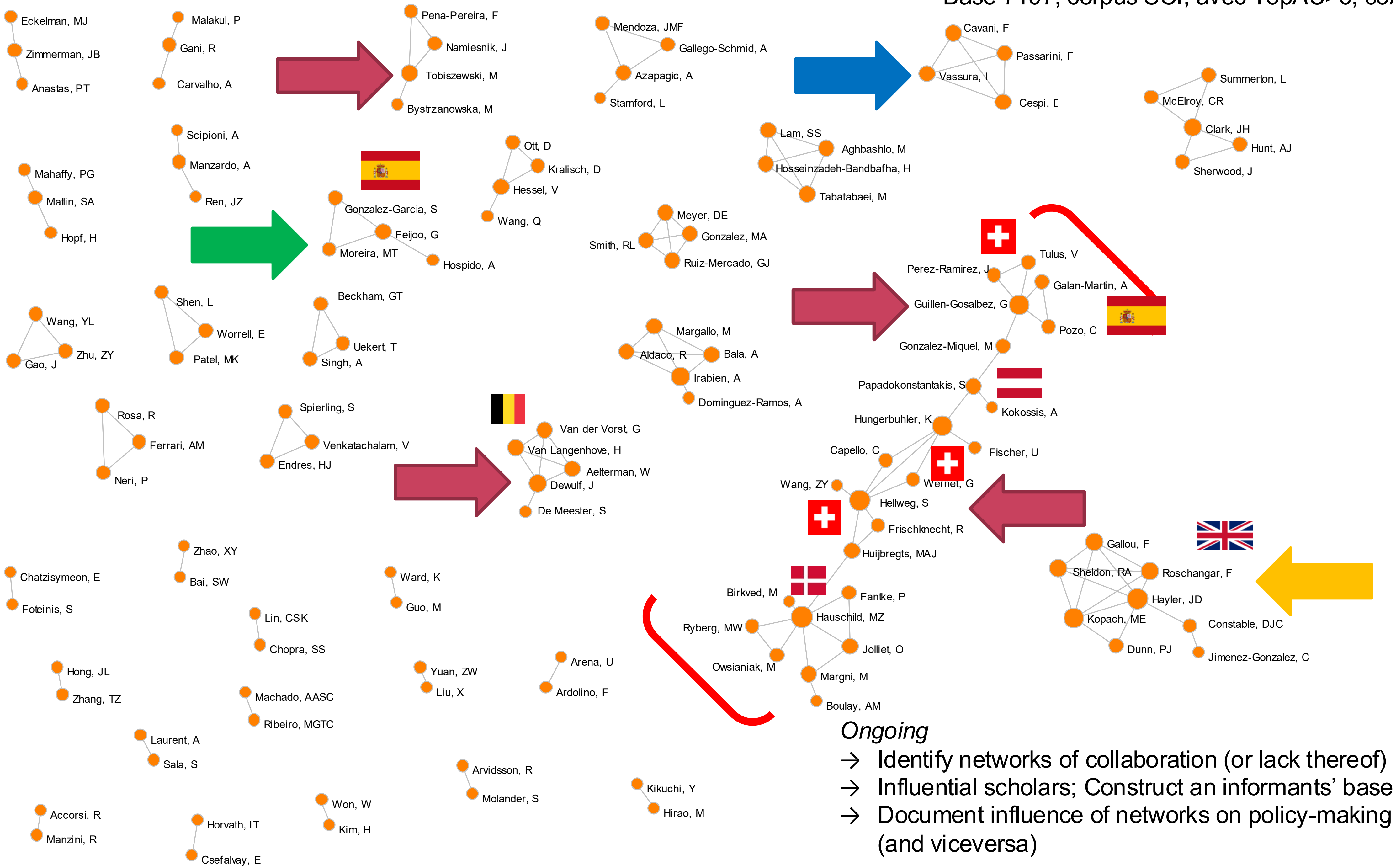
Top WoS Categories	count
Green & Sustainable Science & Technology	2735
Environmental Sciences	2530
Engineering, Environmental	1676
Environmental Studies	961
Chemistry, Multidisciplinary	905
Engineering, Chemical	719
Management	353
Business	313
Economics	267
Operations Research & Management Science	215
Materials Science, Multidisciplinary	203
Biotechnology & Applied Microbiology	161
Engineering, Industrial	125
Social Sciences, Interdisciplinary	120
Polymer Science	112
Multidisciplinary Sciences	98
Engineering, Civil	93
Engineering, Manufacturing	90
Chemistry, Physical	84
Construction & Building Technology	80
History & Philosophy Of Science	74
Food Science & Technology	69
Public, Environmental & Occupational Health	69
Ecology	62
Physics, Applied	59

Sustainable Development Goals (SDG)	count
01 No Poverty	42
02 Zero Hunger	340
03 Good Health and Well-being	408
04 Quality Education	61
05 Gender Equality	8
06 Clean Water and Sanitation	386
07 Affordable and Clean Energy	476
08 Decent Work and Economic Growth	21
09 Industry, Innovation and Infrastructure	142
10 Reduced Inequality	6
11 Sustainable Cities and Communities	450
12 Responsible Consumption and Production	2113
13 Climate Action	1381
14 Life Below Water	303
15 Life on Land	157
16 Peace and Justice Strong Institutions	5

WoS Index	count	
Science Citation Index Expanded (SCI-EXPANDED)	4798	4798
Book Citation Index – Science (BKCI-S)	132	
Conference Proceedings Citation Index – Science (CPCI-S)	319	
Social Sciences Citation Index (SSCI)	1650	1650
Arts & Humanities Citation Index (A&HCI)	52	
Book Citation Index – Social Sciences & Humanities (BKCI-SSH)	74	
Conference Proceedings – Social Science & Humanities (CPCI-SSH)	240	

Legenda: ID= WoS keywords, DE= Authors' keywords; WC= WoS journal category; SC= Research domain; Au= Author

Base 7107, corpus SCI; avec TopAU>6, coAu>2



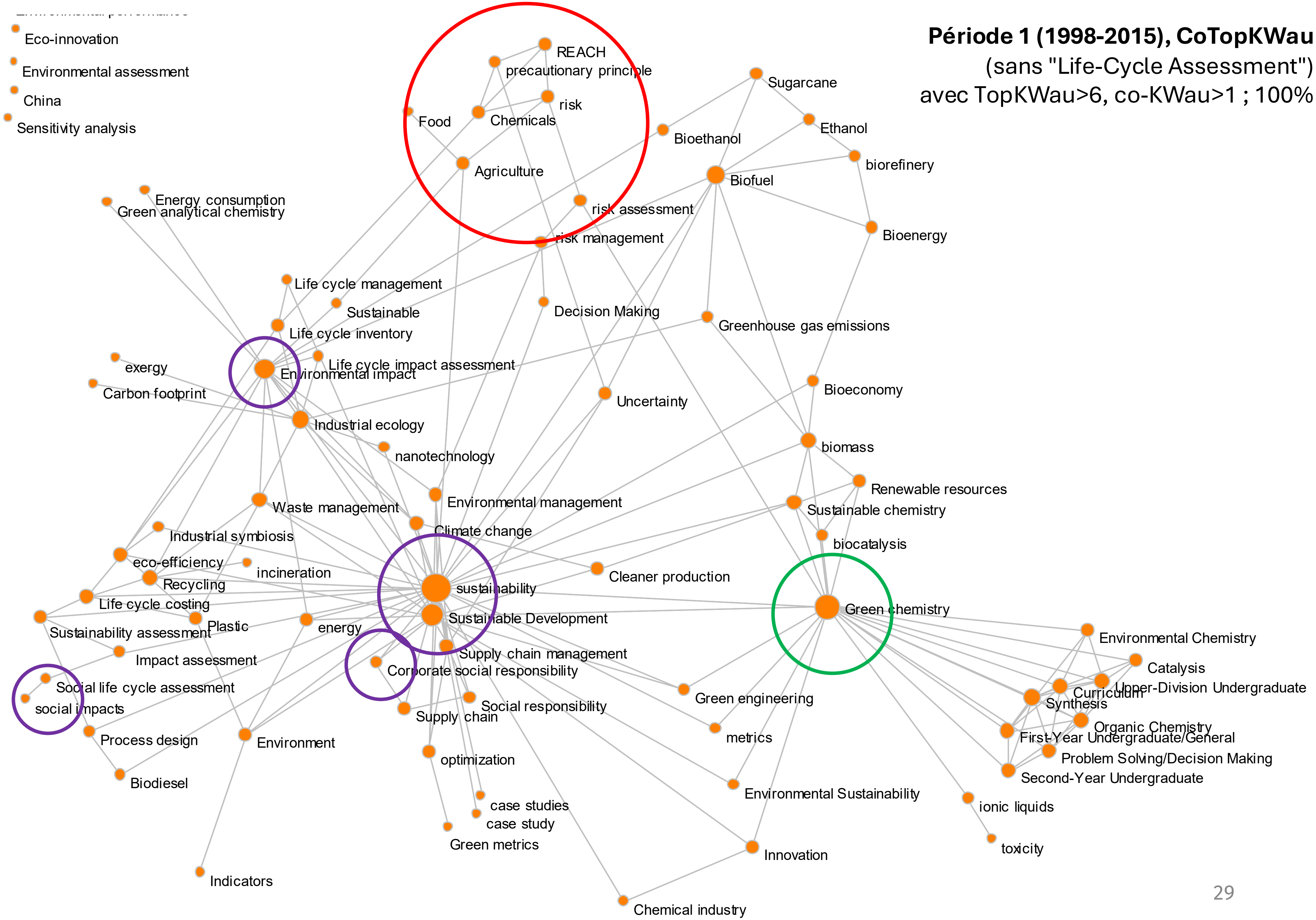
Ongoing

→ Identify networks of collaboration (or lack thereof)
→ Influential scholars; Construct an informants' base
→ Document influence of networks on policy-making (and viceversa)

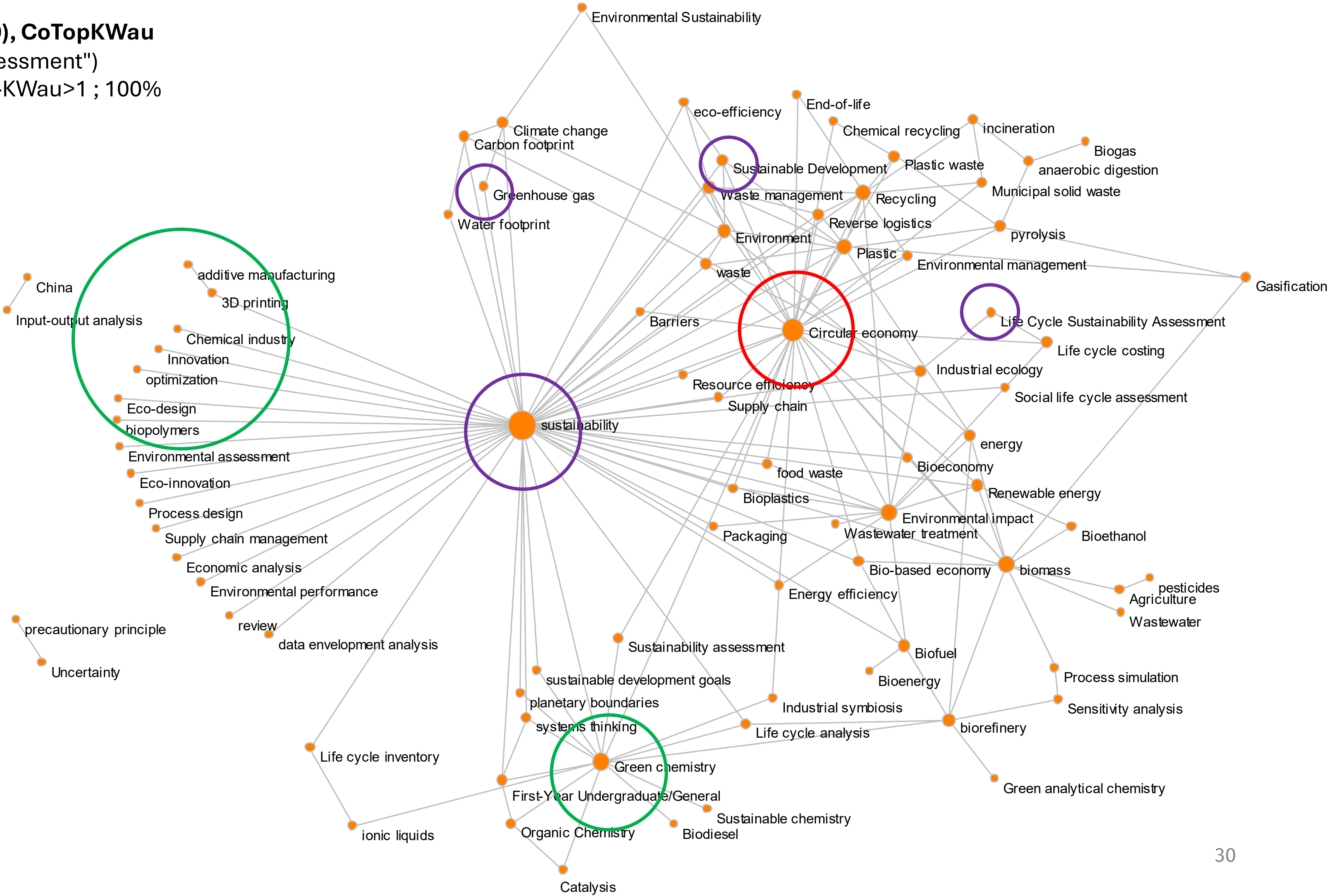
Période 1 (1998-2015), CoTopKWau

(sans "Life-Cycle Assessment")

avec TopKWau>6, co-KWau>1 ; 100%



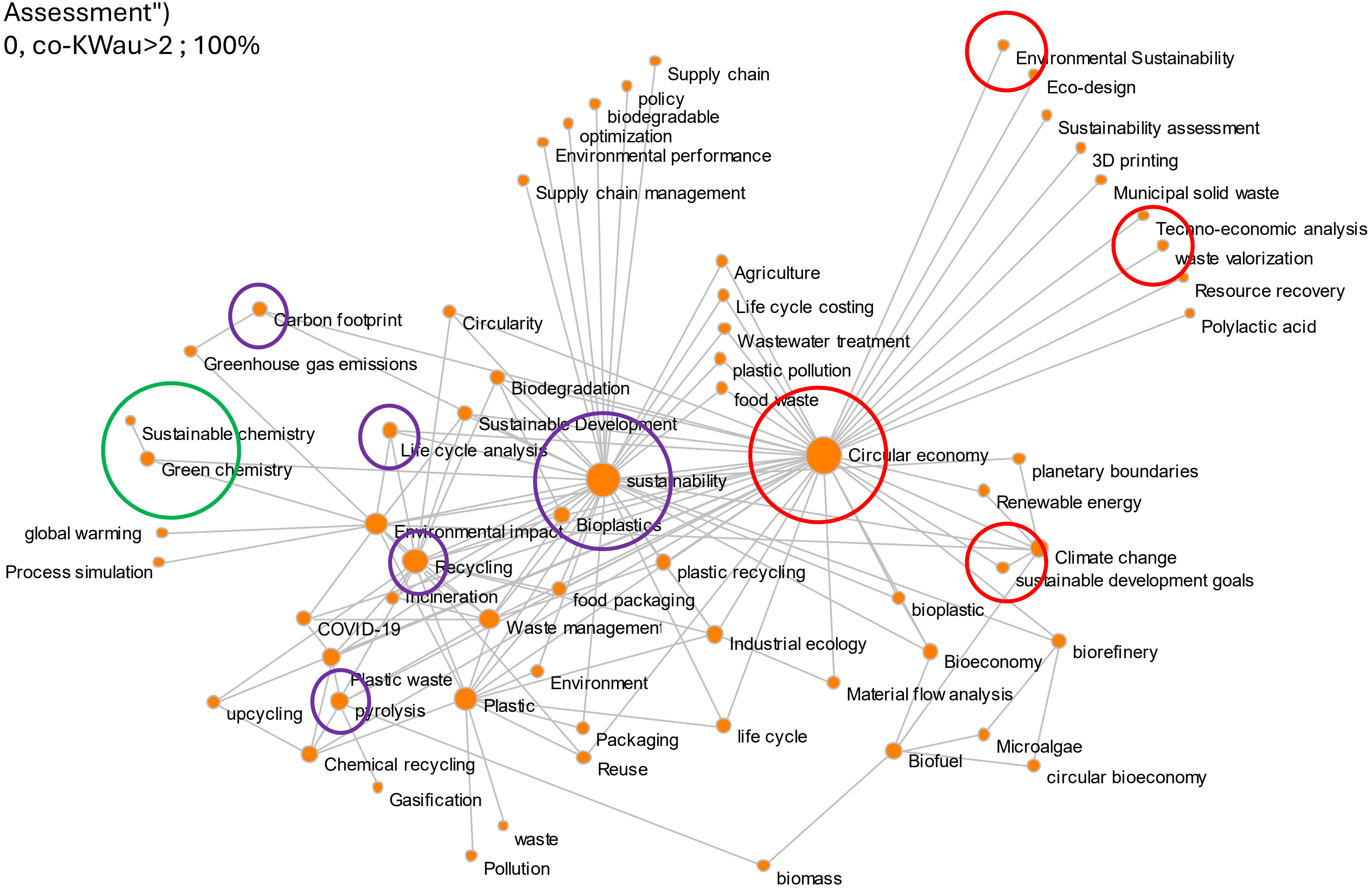
Période 2 (2015-2020), CoTopKWau
(sans "Life-Cycle Assessment")
avec TopKWau>8, co-KWau>1 ; 100%



Période 3 (2020-2024), CoTopKWau

(sans "Life-Cycle Assessment")

avec TopKWau>10, co-KWau>2 ; 100%



Socio-epistemic perspective | Ontological perspective

Take home message #5

Influential actors-networks of «sustainability» and/or «green» chemistry are *always* moving

- Two kinds of processes: things go up/down, appear/disappear; networks change (tables)
- Against linearity: does not simply move from brown to green to sustainable chemistry
- Actors co-produce different impacts of 'sustainability': Who cites what? Ask yourself: who's winning at talking 'sustainability'? Where? And why?
- Do we observe the disappearance of «green chemistry» (as restricted technical focus; e.g. carbon footprint) and its replacement by sustainability (multi-dimensional; see 2 to 3)? **Yes and no**

Does it really matter?Different factors intervene in this process

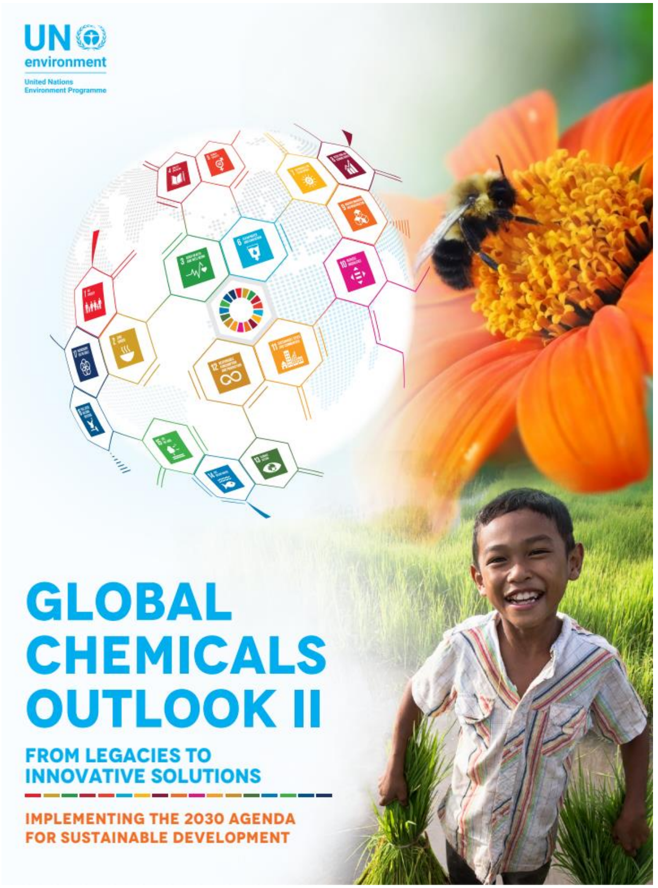
- How do policy debates evolve from an independent network (no relation to sust/green in 1) to a network embedded in either design/production or management/circular economy?
- What is the role of debates in management/circular economy in operating this change?

2. Complex Issue

Social sciences for systems thinking?

Alternatives assessment-UNEP 2019

*“Alternatives assessment provides a **systematic approach** to the evaluation of chemical, process and design alternatives to chemicals of concern. By being systematic, it guides the transition to safer, more sustainable chemicals, materials, and products and minimizes the potential for unintended consequences (UNEP 2019b). The knowledge and skillsets needed in alternatives assessment – toxicology, engineering, health and safety – are **complementary** to those needed for green and sustainable chemistry and can **be built into new chemical design**.”* *(UNEP 2020, p.60)*



Why AA? Example: regrettable substitutions

Table 5.3 Examples in the literature referring to potential regrettable substitution (Siddiqi, Laessig and Reed 2003; US CDC 2008; Birnbaum and Bergman 2010; US NTP 2011; Ichihara *et al.* 2012; ECHA 2013; Tomar, Budroe and Cendak 2013; Eladak *et al.* 2015; Rochester and Bolden 2015; Canadian Centre for Occupational Health and Safety 2017; Anastas, Constable and Jiménez-González 2018; Jamarani *et al.* 2018; Sackmann *et al.* 2018)

Chemical of concern (function)	Hazard of chemical of concern	Substitute	Hazard of substitute
BPA (used in production of plastics)	Endocrine disruption	BPS, Bisphenol F	Endocrine activity
DEHP (plasticizer)	Endocrine disruption	Diisononyl phthalate	Carcinogenicity, possible endocrine disruption
Methylene chloride (solvent carrier in adhesives)	Acute toxicity, carcinogenicity	1-Bromopropane (nPB)	Carcinogenicity, neurotoxicity
Methylene chloride (brake cleaners)	Acute toxicity, carcinogenicity	n-Hexane	Neurotoxicity
Polybrominated diphenyl ethers (flame retardant)	Persistence, neurotoxicity, reproductive toxicity, carcinogenicity (penta and deca)	Tris (2,3-dibromopropyl) phosphate	Carcinogenicity, aquatic toxicity
TCE (metal degreasing)	Carcinogenicity	nPB	Neurotoxicity, carcinogenicity

Sustainability and Health

The safe and sustainable by design (SSbD) framework

SSbD is a framework applicable to chemicals and materials and established by the European Commission in the recent Commission Recommendation (EU) 2022/2510 (EU, 2022c). It aims to:

- steer the innovation process towards green and sustainable industrial transition;
- substitute or minimise the production and use of substances of concern, in line with and beyond existing and upcoming regulatory obligations;
- minimise the impact on health, climate and the environment during sourcing, production, use and end-of-life of chemicals, materials and products.

Objective	Number of indicators supporting assessment	
Protect health and the environment: Use of safe chemicals while preventing harm to humans and the environment by avoiding substances of concern for non-essential uses	3	Data on the occurrence of substances of concern in articles (products) on the EU market
Encourage innovation: Promote the development of safe and sustainable chemicals and materials, clean production processes and technologies	2	Data on the uptake of the SSbD framework by the EU chemical industry for the (re-design of chemicals and materials (including information gaps in cases of substitution to SSbD alternatives) Data on the use of resources by the EU chemical industry, including both feedstock for energy use (fossil fuels or renewable energy) and processes (raw materials and by-products of petrochemical processes)
Encourage innovation: Promote the development of innovative tools for testing and risk assessments	2	Data to assess the regulatory acceptance of non-animal test data

https://www.eea.europa.eu/publications/eu-indicator-framework-for-chemicals/

https://www.eea.europa.eu/publications/eu-indicator-framework-for-chemicals/

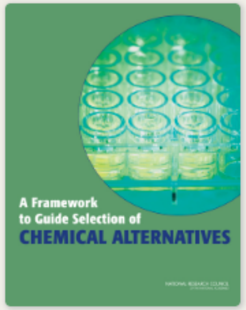
Sustainability and Health

Human biomonitoring offers the opportunity to understand human exposure to chemicals from multiple sources and thus health risks associated with chemical pollution.

- The bodies of EU citizens are contaminated by a range of chemicals. For some substances, such as bisphenol A and perfluorooctanesulfonic acid (PFOS), internal concentrations exceed safe levels, posing a potential risk to health.
- The monitoring of chemicals in the human body and in the environment remains key to maintaining visibility on pollution levels and impacts, identifying emerging risks and for tracking the effectiveness of policy interventions over time.
- Under the European partnership for the assessment of risks from chemicals (PARC), ongoing research projects will help provide further data on the occurrence of chemicals in the European population and associated risks.

«**Knowledge is lacking on human exposure** to and the impacts of many substances and materials, including how the combined exposure to many different substances can **impact our health** (the cocktail effect). (p.10)

The dependence of chemical alternatives (SSbD) from novel testing and risk assessment standards



A Framework to Guide Selection of Chemical Alternatives

(2014)

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The Evolving Landscape: Addressing Today's Challenges in Chemical Engineering Operations

Dr. Joel Shertok

perational Excellence by Optimizing Chemical

| Maximize Profits 🔹Boost Efficiency 🔹Ensure...

The Impact of Novel Assessment Methodologies in Toxicology on Green Chemistry and Chemical Alternatives FREE

Ivan Rusyn ✉, Nigel Greene

Toxicological Sciences, Volume 161, Issue 2, February 2018, Pages 276–284, https://doi.org/10.1093/toxsci/kfx196

Published: 18 September 2017

Research Paper

The Green toxicology approach: Insight towards the eco-toxicologically safe development of benign catalysts

Carina Lackmann [a b], Julia Brendt [b], Thomas-Benjamin Seiler [b c], Alina Hermann [d], Angela Metz [d], Pascal M. Schäfer [d], Sonja Herres-Pawlis [d], Henner Hollert [a b e] ✉

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https://doi.org/10.1016/j.jhazmat.2021.125889 ↗

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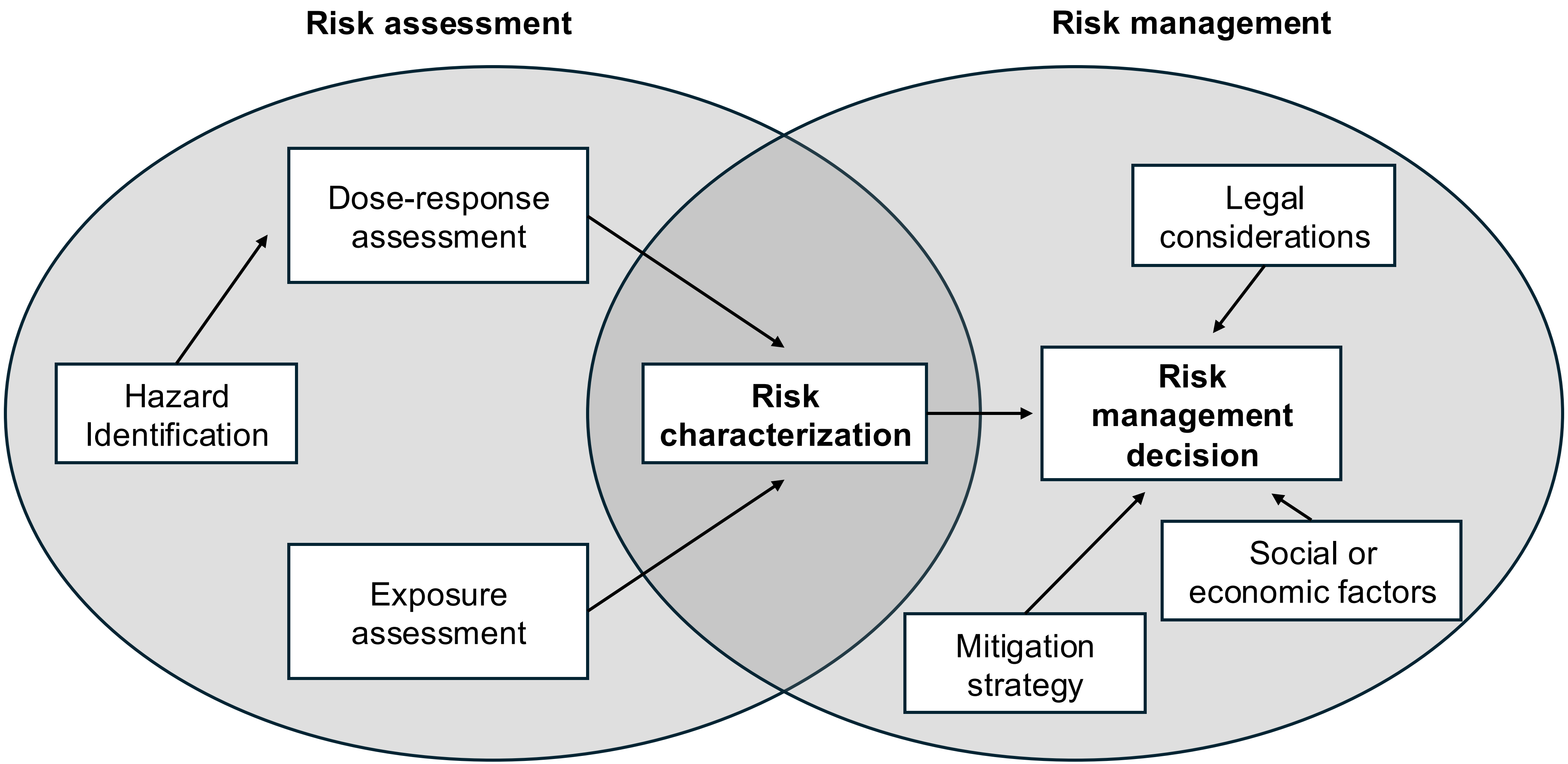
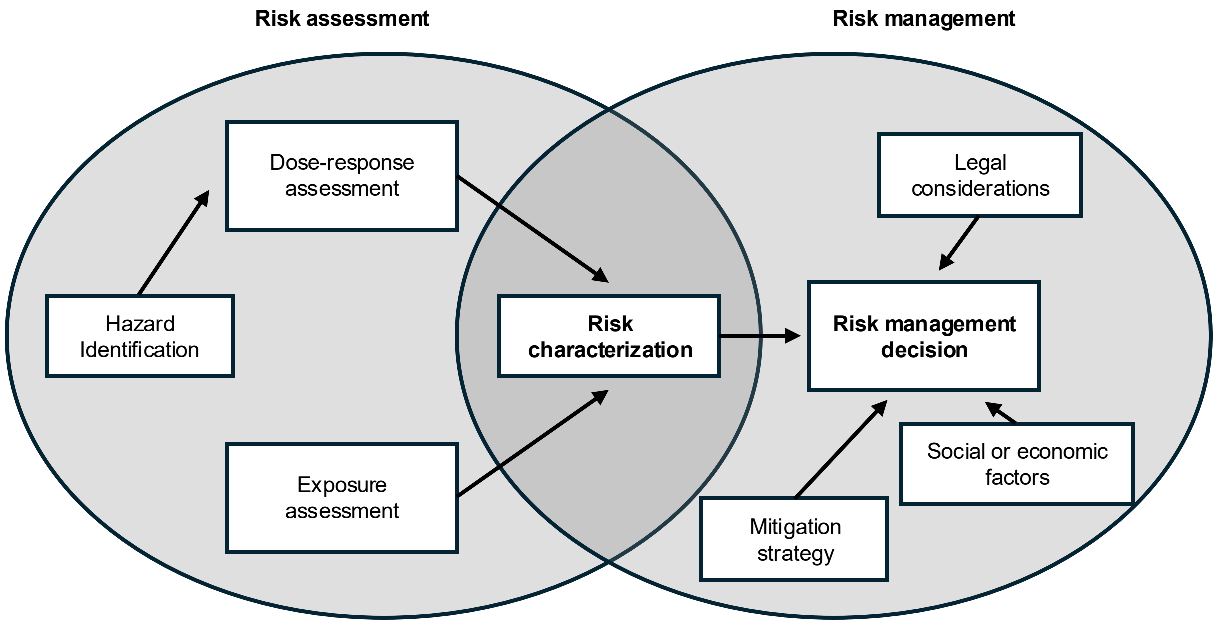
What can a social science perspective offer to the understanding of the challenges of alternatives assessments?

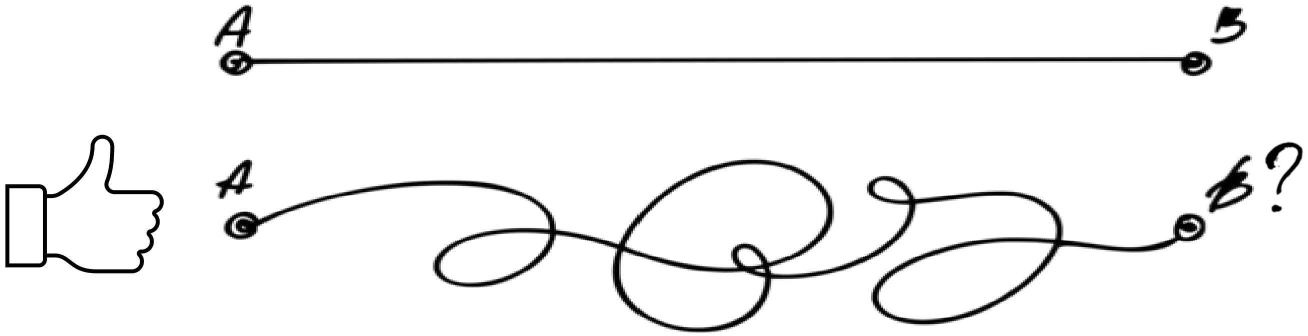
TRADITIONAL ENVIRONMENTAL HEALTH RISK ASSESSMENT: Ready to deliver on alternatives assessment?

Figure from here



TRADITIONAL ENVIRONMENTAL HEALTH RISK ASSESSMENT





DOCUMENTING A MULTI-FACETED CHALLENGE

A NEW KIND OF ENVIRONMENTAL HEALTH RISK ASSESSMENT?

Key Science and Technology Studies questions

NOVEL TOOLS AND EVIDENCE STANDARDS 1

How do these practices construct exposures, risks and their effects?

MEANINGS AND FIGURATIONS OF RISK 2

What goes in and what is left out?

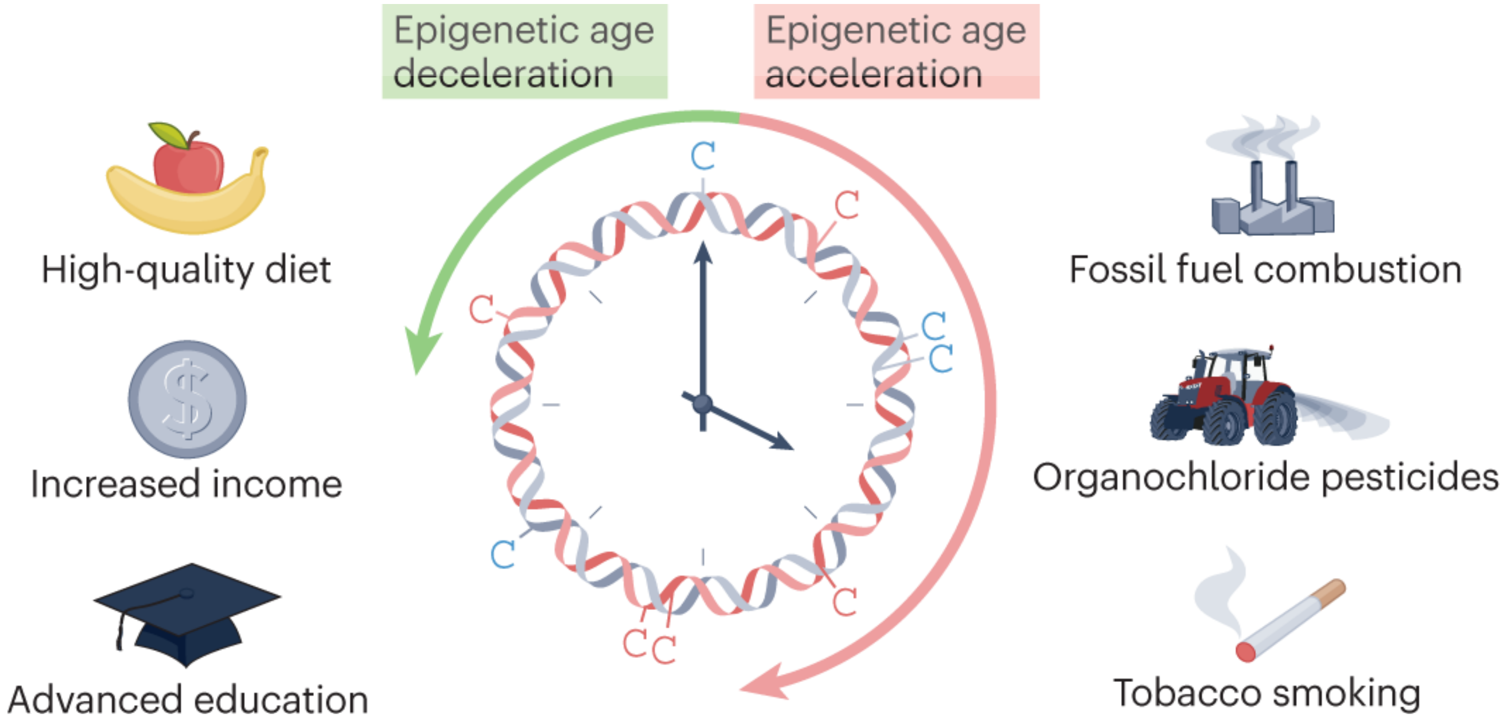
DECISION-MAKING IN RISK MANAGEMENT 3

What responsibilities? How to govern the politics of risk?

1 Evidence: the example of toxicoepigenetics

▷ How do these practices construct exposures, risks and their effects?

EXAMPLE: AN EPIGENETIC MODEL OF RISK



Bottom line:
Epigenetic ***technologies enable a representation*** of exposures and their effects over health that is not afforded by traditional approaches and could complement regulatory standards (e.g., OECD test protocols).

Wu, H., Eckhardt, C.M. & Baccarelli, A.A. Molecular mechanisms of environmental exposures and human disease. Nat Rev Genet (2023). (Here)

Problematizing Toxicoepigenetics

Novel technologies of risk assessment are socially constructed

1

(cf. Latour 1983)

Making issues amenable to experts, tools (some, but not others).

Translation

History of technicity

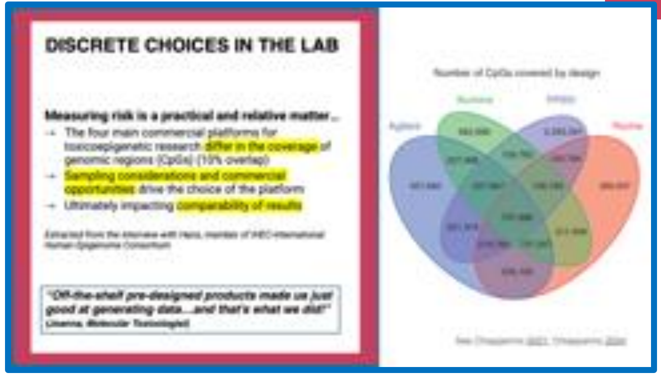
Technical changes re-shape questions asked.

(Creager 2018; 2021)

(Rheinberger 2010; Fujimura 1987)

Modularity, standards, opportunity make research problems relevant.

Doable experiments



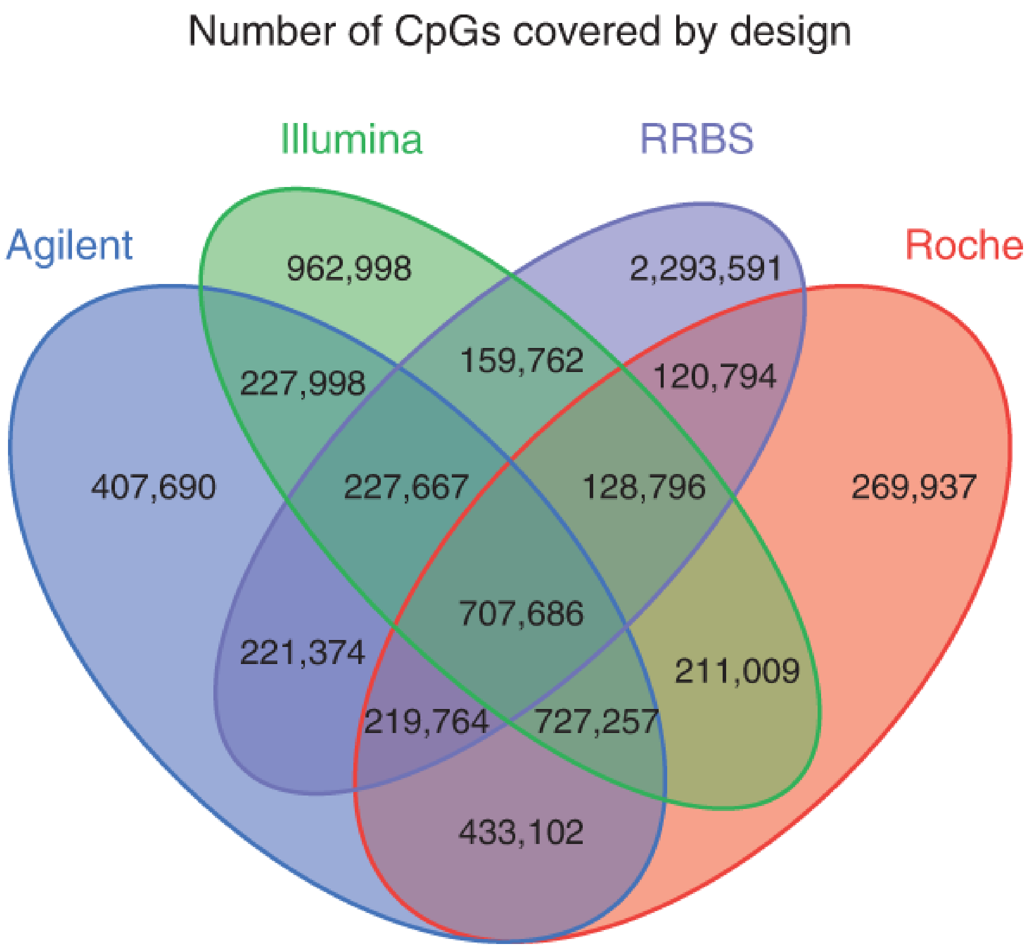
DISCRETE CHOICES IN THE LAB

Measuring risk is a practical and relative matter…

- The four main commercial platforms for toxicoepigenetic research differ in the coverage of genomic regions (CpGs) (10% overlap)
- Sampling considerations and commercial opportunities drive the choice of the platform
- Ultimately impacting comparability of results

Extracted from the interview with Hans, member of IHEC-International Human Epigenome Consortium

> ***"Off-the-shelf pre-designed products made us just good at generating data…and that's what we did!"***
> ***(Joanna, Molecular Toxicologist)***



See Chiapperino 2021; Chiapperino 2024

Problematizing Toxicoepigenetics

Novel technologies of risk assessment are socially constructed

1

Translation

History of technicity

Doable problems

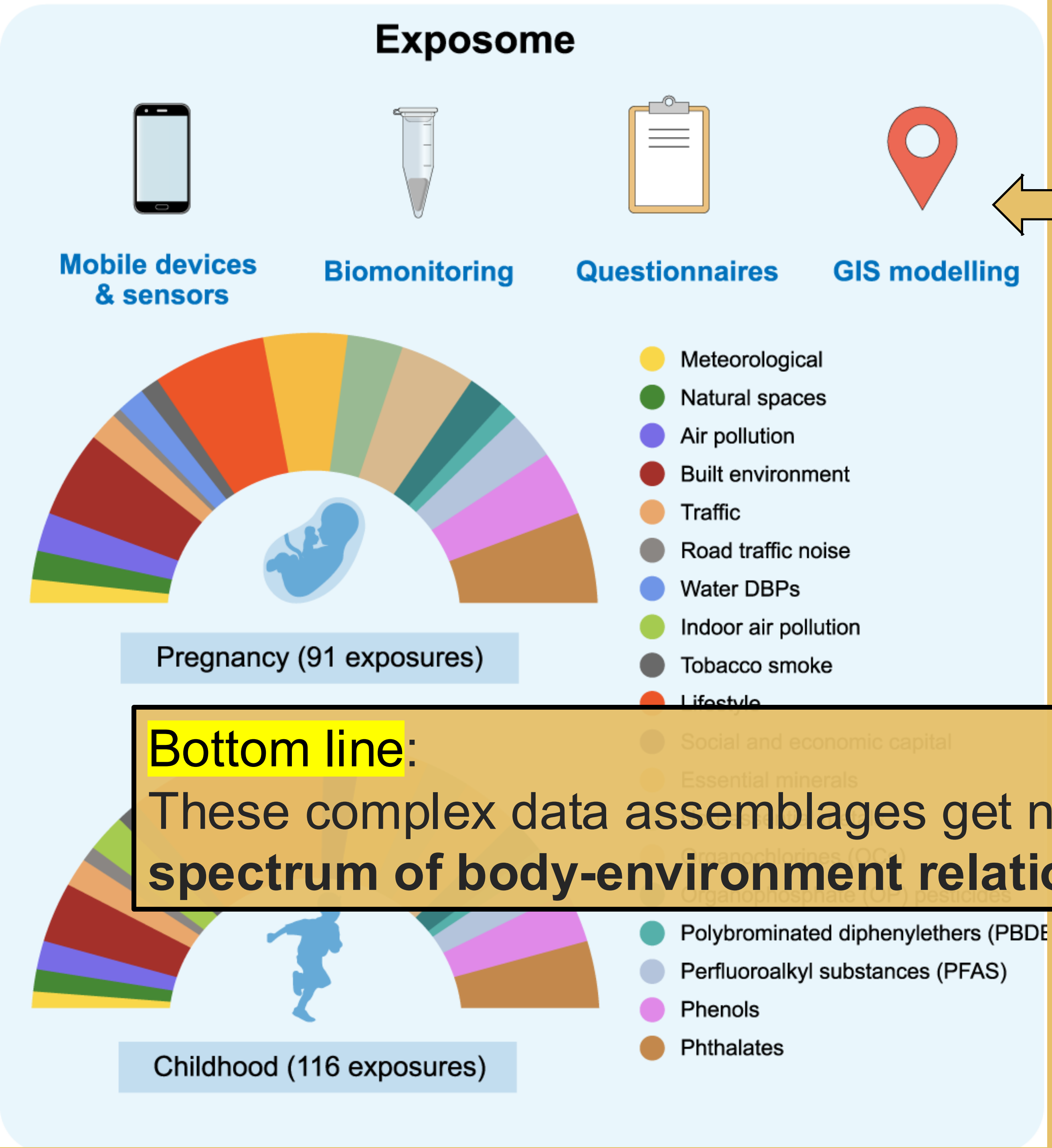
Take home message #6

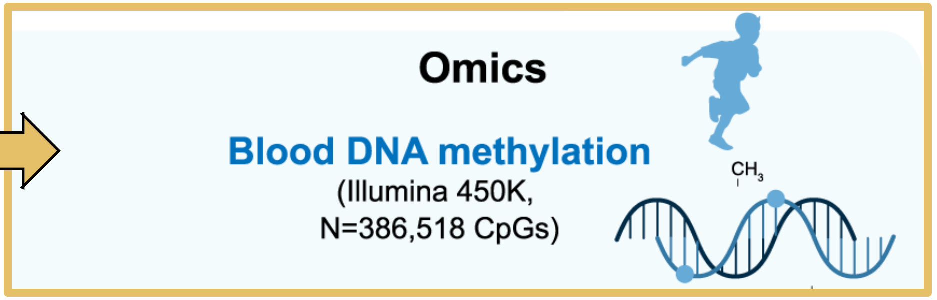
The evidence standards of environmental health risk assessment can be re-conceptualized as:

1. ***A mixed social and technical process intervening into methodological limitations***
2. ***A matter of technical opportunities and choices: cheap technologies making experiments doable, pragmatic considerations in the lab, etc.***

2 New meanings and figurations of risk

- What goes in and what is left out?





«**The entire result catalogue** is publicly available (https://helixomics.isglobal.org/), **enabling exploration of the complete [sic!] list of exposomic relationships**».

Bottom line:
These complex data assemblages get narrated as grasping **the full spectrum of body-environment relations**.

Maitre, L., Bustamante, M., Hernández-Ferrer, C. et al. Multi-omics signatures of the human early life exposome. Nat Commun 13, 7024 (2022). (Here)

Questioning data assemblages on exposures

What goes in and what is left out in these figurations of risk?

2

(Henry 2021; 2024)

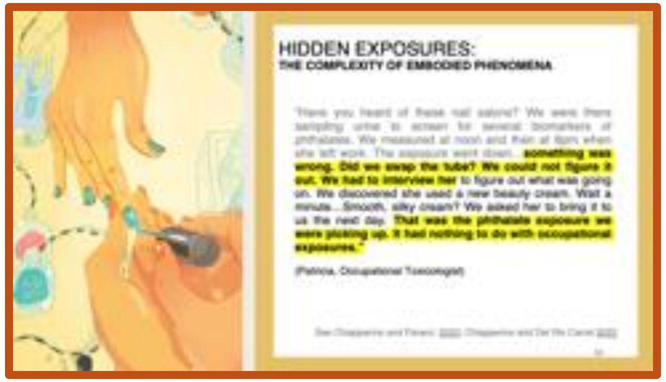
Knowledge is ignorance?!?

(Murphy 2006)

Uncertain correlations?

(Rossmann and Müller 2024)

Risks and toxicity are socially patterned



HIDDEN EXPOSURES:
THE COMPLEXITY OF EMBODIED PHENOMENA

"Have you heard of these nail salons? We were there sampling urine to screen for several biomarkers of phthalates. We measured at noon and then at 6pm when she left work. The exposure went down…**something was wrong. Did we swap the tube? We could not figure it out. We had to interview her** to figure out what was going on. We discovered she used a new beauty cream. Wait a minute…Smooth, silky cream? We asked her to bring it to us the next day. **That was the phthalate exposure we were picking up. It had nothing to do with occupational exposures."**

(Patricia, Occupational Toxicologist)

See Chiapperino and Paneni. 2022; Chiapperino and Del Rio Carral 2022

Questioning data assemblages on exposures

What goes in and what is left out in these figurations of risk?

2

Knowledge is ignorance?!?

Uncertain correlations?

Risks and toxicity are socially patterned

Take home message #7

Novel truth discourses offer a new meaning of risk that is not neutral:

1. ***While magnifying some harms, they may be blind to others***
2. ***Sidelining the mixed social and biological patterns of risk***

Exposures as "Riskscapes"

01 **The interaction of social and environmental inequalities (e.g., racialized)** creates a '**riskscape**' (Morello-Frosch & Pastor, 2001)

02 Maternal and child health disparities (Morello-Frosch et al., 2011)

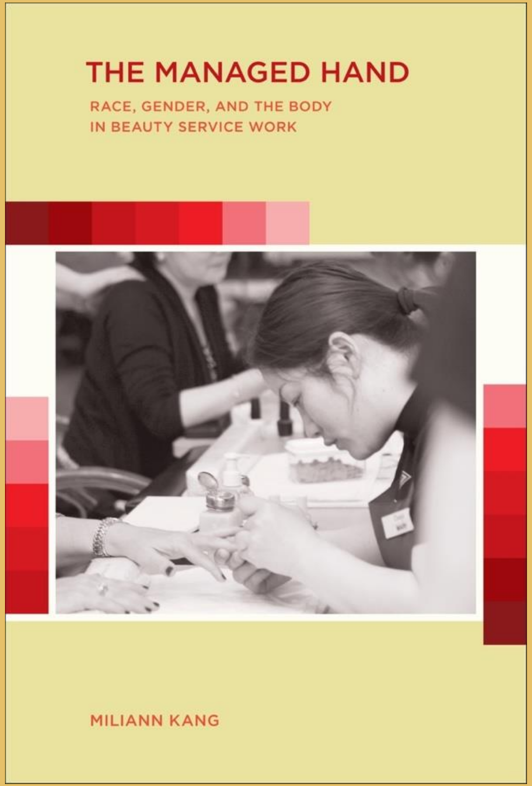
03 Neighborhood poverty and inadequate housing (racialized differences) (Morello-Frosch & Shenassa, 2006)

04 Psychosocial stress increasing vulnerability (Lewis et al., 2011)

05 Policies should address both chemical and non-chemical stressors in risk assessment (Clougherty & Rider, 2020)

Resources to explore this topic

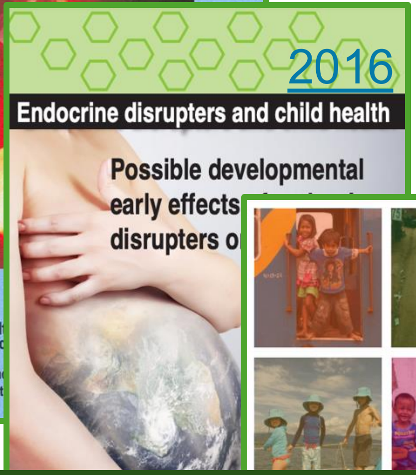
Milian Kang 2010



❸ Decision-making in risk management

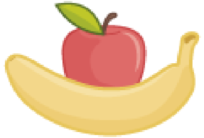
▷ What individual responsibilities? How to govern the politics of risk?

POLICY DISCOURSES



SUBJECTIVE PRACTICES

Epigenetic age deceleration



High-quality diet

Bottom line:
Knowledge practices, meanings of “risk” are also **political matters**, in the sense of: (i) the subject of individual and collective action; (ii) the rationale for interventions, (iii) or a challenge at the science-policy interface.

CITIZEN INITIATIVES

Analysing the politics of environmental health risk
Dissecting its multiple levels and feedback loops

3

(e.g., Lappé, Fahey and Jeffreys-Hein 2022; Lamoreux 2023)

An economy of individual responsibilities

Micro

Meso

Scientists' discourses of policy and risk characterization

(e.g., Chiapperino and Panese 2018; Chiapperino et al. 2024)

(Jasanoff 1990; Le Goff et al. 2022; Demortain 2023)

Demarcating knowledge for policy; inconclusive governance

Macro

https://doi.org/10.1289/EHP13812

Bisphenol A (BPA): when testing methods drive opposite risk verdicts

Classical toxicology verdict (pre-2020)

- High-dose animal studies → NOAEL ≈ 5 mg kg^{-1} day^{-1} → regulators (FDA, BfR, others) concluded "BPA is safe at typical exposures."

21^{th}-century evidence overturns consensus

- Cell-based, endocrine-mechanistic & -omics assays detect neuro-, immune- and reproductive effects at µg–ng doses.
- Academic low-dose studies challenge high NOAELs and highlight *endocrine-disrupting* potential.

EFSA's 2023 reassessment

- Systematic review of >1 000 studies (many molecular endpoints) → new **TDI = 0.2 ng kg^{-1} day^{-1}** (↓ 20 000-fold).
- Concludes current European dietary exposure **exceeds safe levels for all age groups**.

Regulatory split

- **EFSA:** weight-of-evidence embraces molecular data → "unsafe."
- **FDA & BfR:** rely on guideline GLP studies → still "safe," argue EFSA over-interprets uncertain endpoints.

Choice of **measurement method** (classical apical vs. molecular mechanistic) can flip a chemical from "low risk" to "high concern." Harmonised criteria are needed to judge what counts as an *adverse* low-dose effect and avoid future **method wars**.

Analysing the politics of environmental health risk
Dissecting its multiple levels and feedback loops

3

Micro
(subjective practices)

Meso
(Risk characterization)

Macro
(Policy and governance)

Take home message #8

The science-politics relation is a complicated and messy one:

1. **More than just rolling out facts about risk**
2. **Governance gets made and remade through partial, limited evidence**
3. **Indecisiveness baked into the "expert" knowledge**

TAKE HOME MESSAGE#9

ENVIRONMENTAL HEALTH: MULTIPLE DIMENSIONS OF A COMPLEX SOCIOTECHNICAL CHALLENGE

1. ***Evidence***: *new technological repertoires, new evidentiary regimes (e.g., toxicoepigenetics) get socially constructed to objectivize risk, overcome uncertainty.*

2. ***Meaning***: *what is left out, with what consequences in these novel approaches (e.g., environmental justice concerns, riskscapes)?*

3. ***Decision***: *a demand for societal change (e.g., responsibilities, advocacy, policy); but also challenge to bring limited knowledge into collective action.*

Think systemically, collaborate (w/ social sciences): how is the pursuit of chemical alternatives (e.g. SSbD, alternatives assessment) dependent, affected by, shaped, or even **potentially jeopardized** by the controversies surrounding novel testing and risk assessment standards?

GENERAL CONCLUSIONS

1. **Sustainability is a moving target, not a fixed recipe**
   Diverse, sometimes competing definitions—"green", "sustainable", "systemic"—co-exist but the point is asking how they shift with politics, science, technological and institutional agendas
2. **Historical and social contexts matters**
   Concepts such as "Green Chemistry" were forged as regulatory inventions in 1990s U.S. policy and later re-branded elsewhere; they contributed or not to the emergence of sustainability; they disappeared or not; beware of linear origin stories (Brundtland → Rio → SDGs) that hide messy detours
3. **The struggle to enact qualitative ideals as quantitative trade-offs**
   Qualitative definitions are everywhere but difficult to implement; Planetary-boundary metrics promise objectivity yet leave social and economic pillars unaddressed; absent consensus, actors cherry-pick indicators and risk "reducing" or worse "greenwashing"
4. **Systems thinking as challenge *per se*: learning others' challenges and collaborating across silos**
   Chemistry, chemical engineering, toxicology and social science may better align; disciplinary and organizational boundaries may block extended life-cycle or holistic views
5. **Social sciences' role: bringing in reflexivity, preventing reinvention**
   With historical and socio-political self-scrutiny these systemic challenges can be documented (and prevented?); deconstruc new slogans (e.g., "circular" or "one-world" chemistry); avoid blind spots

Thanks for your attention.

And questions!

Luca.Chiapperino@unil.ch

What are the conditions for the emergence of this knowledge?
How do novel tools construct exposures, risks and their effects?

1

- *Are these novel approaches* ***a translation of the risk assessment problem*** *in the repertoire (of practices, technologies, expertise) of specific lab sciences* (cf. Latour 1983)
  - *Technical repertoires have given access to* ***novel possibilities of seizing risk****: blood pictures 1920, Dow's Karyotypes 1960s, Ames test 1970s, DNA adducts 1980s…* *(Creager 2018; 2021; Creager and Landecker 2009)*
    - *…2010s: In vitro, Metabolomics, Epigenetics, Exposomics*
- *Do novel technical repertoires* ***constrain the questions*** *that can be posed? How and what grounds?*
- *Are these just technologies for* ***doable experiments?*** *(cf. Rheinberger 2010; Fujimura 1987)*
  - *Describe how (e.g.) epigenetic technologies* ***construct environmental health problems****?* *(Chiapperino 2024; Rossmann and Müller 2024)*
- *How is innovation in biomonitoring for toxicity a* ***factual and value-laden controversy*** *that changes standards, communities of expert practice?* *(Demortain 2023)*

What goes in and what is left out in these novel figurations of risk? How could it be otherwise?

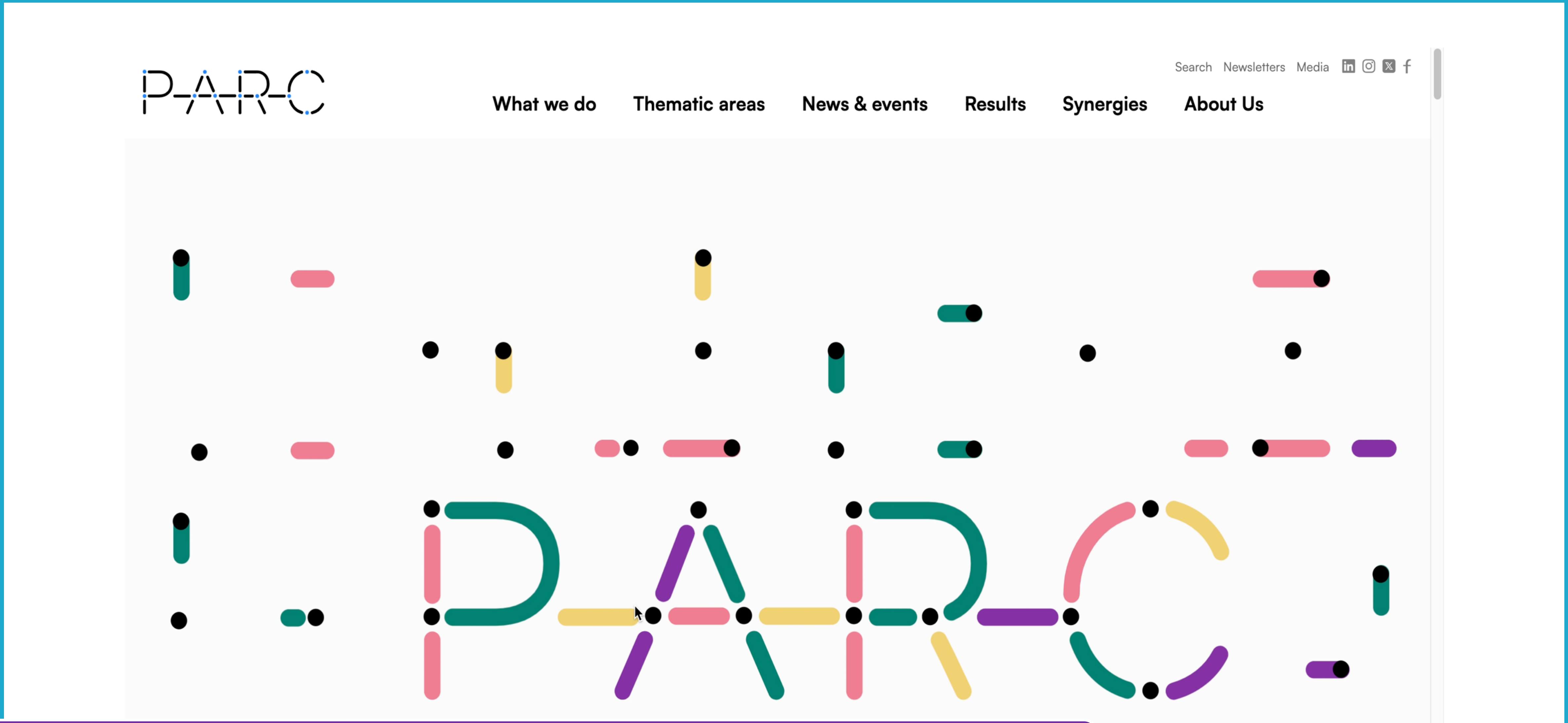
2

- *Novel assemblages of risk assessment produce novel figurations of risk, uncertainty and toxicity:*
  - *How do they end up **reinvigorating uncertainty and/or institutionalized ignorance** (Henry 2021; 2024)?*
  - *How do they **displace risk from environmental to bodily problem** (Murphy 2006; Rossmann and Müller 2024)*
    - *How are **social differences (gendered, racialized, socio-economic)** patterning exposure evacuated from these representations of risk? (Chiapperino and Del Rio Carral 2022; Chiapperino et al. In preparation)*

How does knowledge of environmental risks turn into agency, responsibility, governance of risk?

3

- *Knowledge practices in environmental health risk assessment are transformative of* ***(micro) subjective practices:*** *citizenship, "lifestyles", parentality, health, etc.* *(cf. Rabinow 1996; Rose 2007)*
  - *Responsibilities that are gendered (Chiapperino and Panese 2018; Lappé, Fahey and Jeffreys-Hein 2022), racialized (Chellappo 2023), entangled with national imaginaries (Lamoreux 2023)?*
- *Investigate* ***discourses of policy by scientists****: open up the (****meso****) black-box of "risk characterization" (Chiapperino et al. 2024)*
- *Demarcating (some) knowledge* ***for (macro) regulatory or policy action*** *(Jasanoff 1990; Le Goff et al. 2022; Demortain 2023)?*
  - *Making and re-making the governance of risk (and the legitimacy of its outcomes) (Jasanoff 1990)?*



Beyond incremental change: **is a new model governance of environmental health risk policy at stake in PARC**?