Local to global economic and environmental trade-offs of the Food-energy-water-ecosystem nexus

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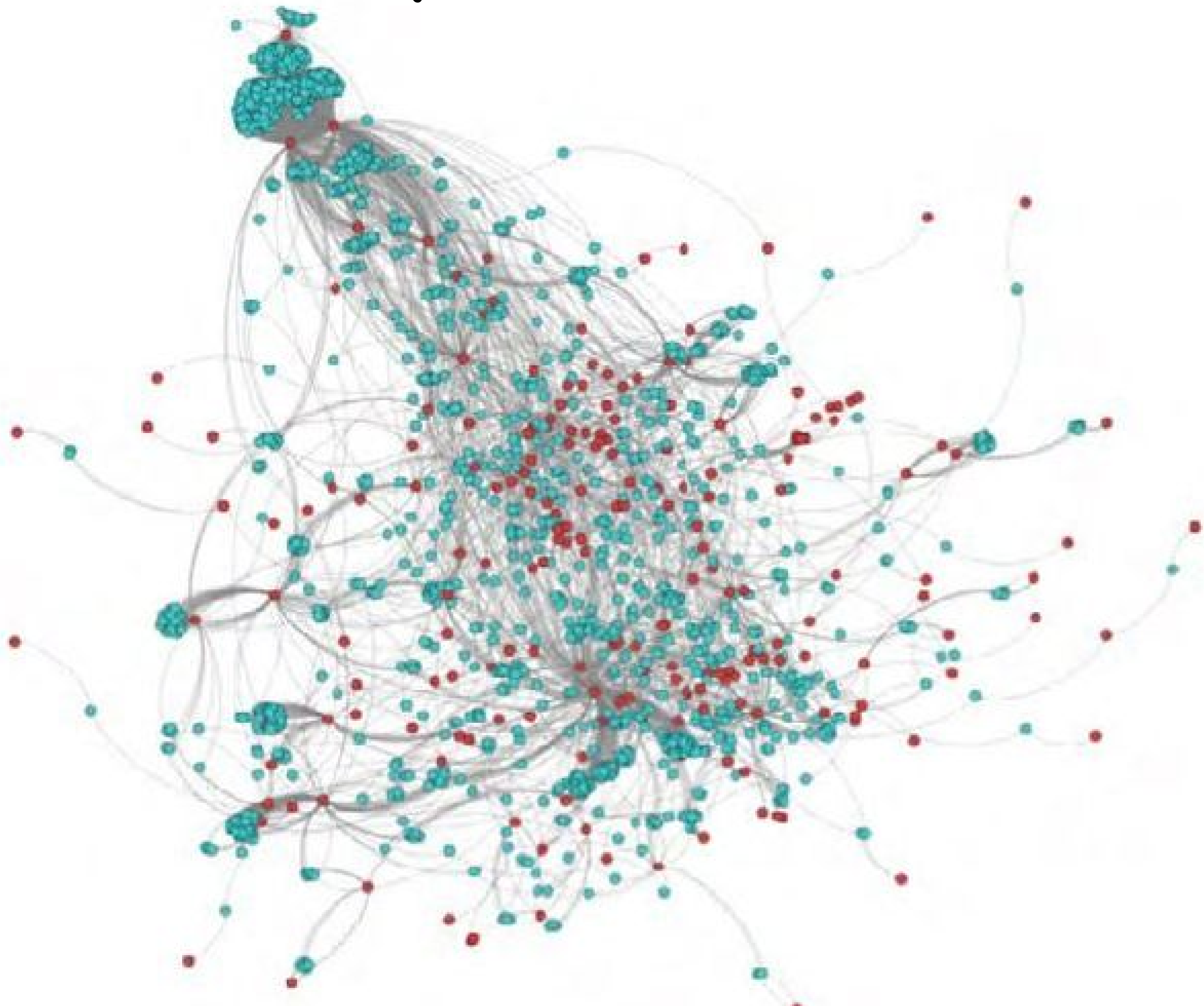
IIASA

Bibliometric Analysis



Dataset

- 755 Documents from ISI Web of Knowledge (as of 2-Dec-2017)
- Nexus (in Title, Abstract or Keywords)

h-index

31

Average citations per item

6.91

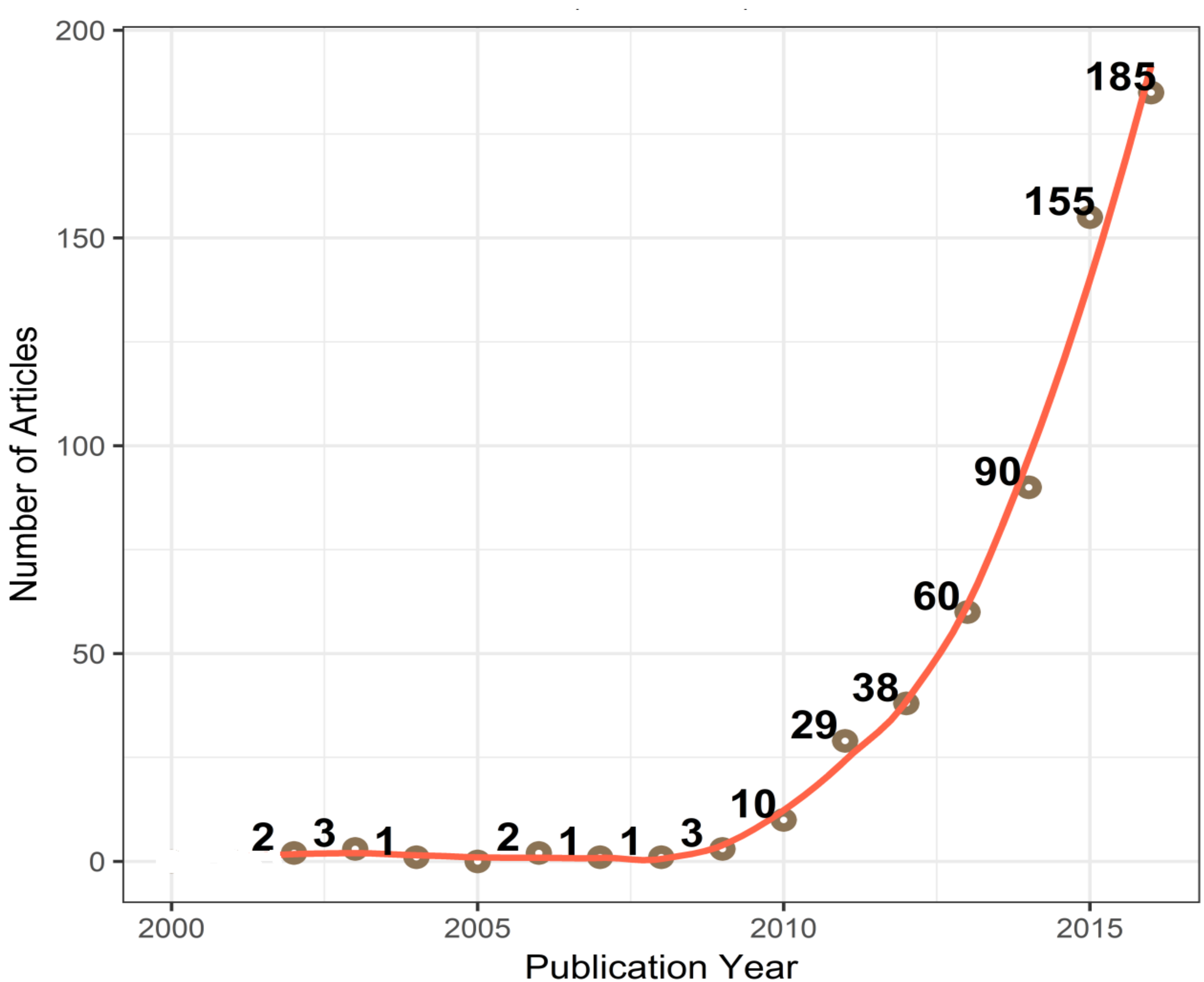
Sum of Times Cited

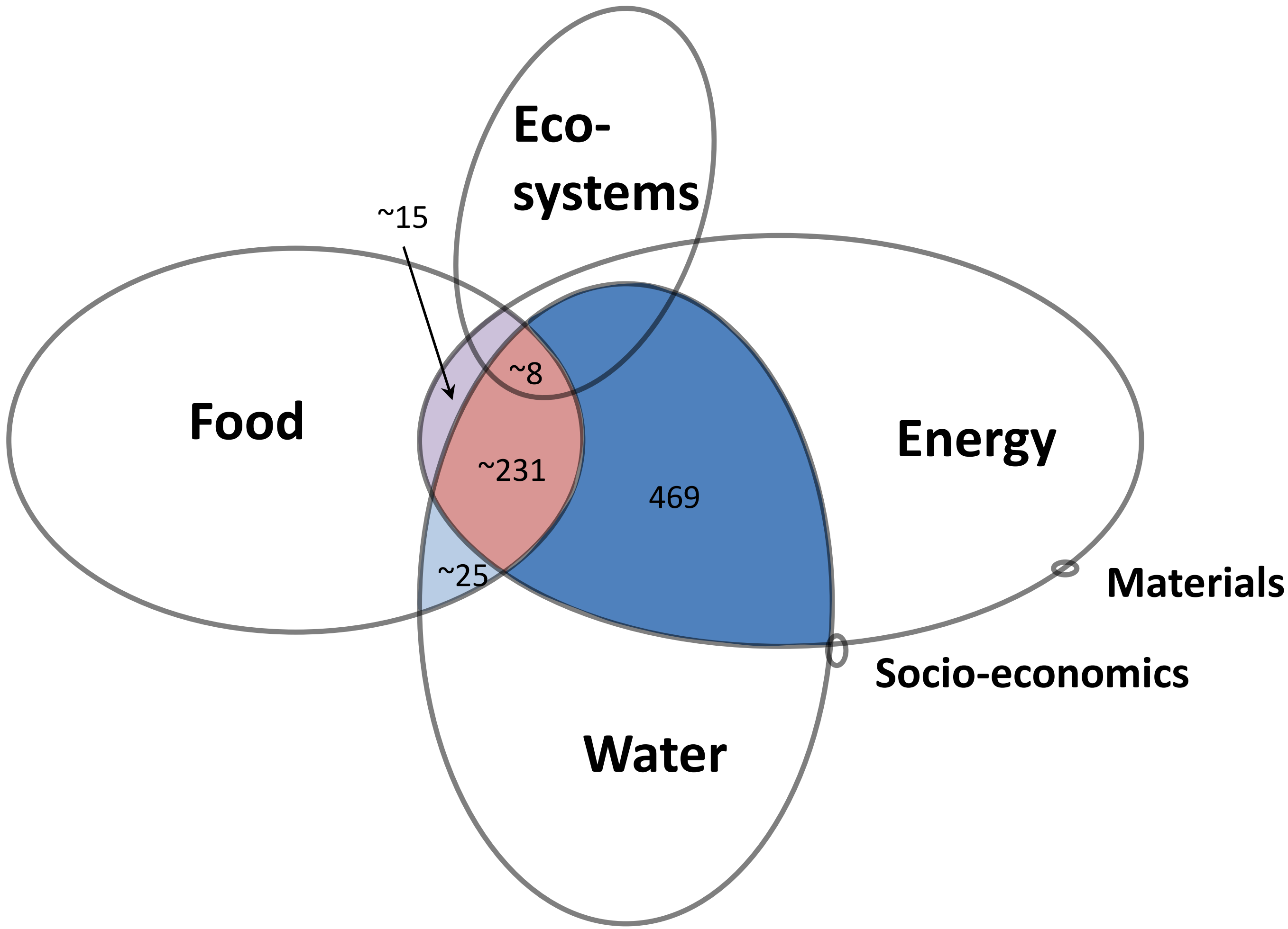
5,220

Without self citations

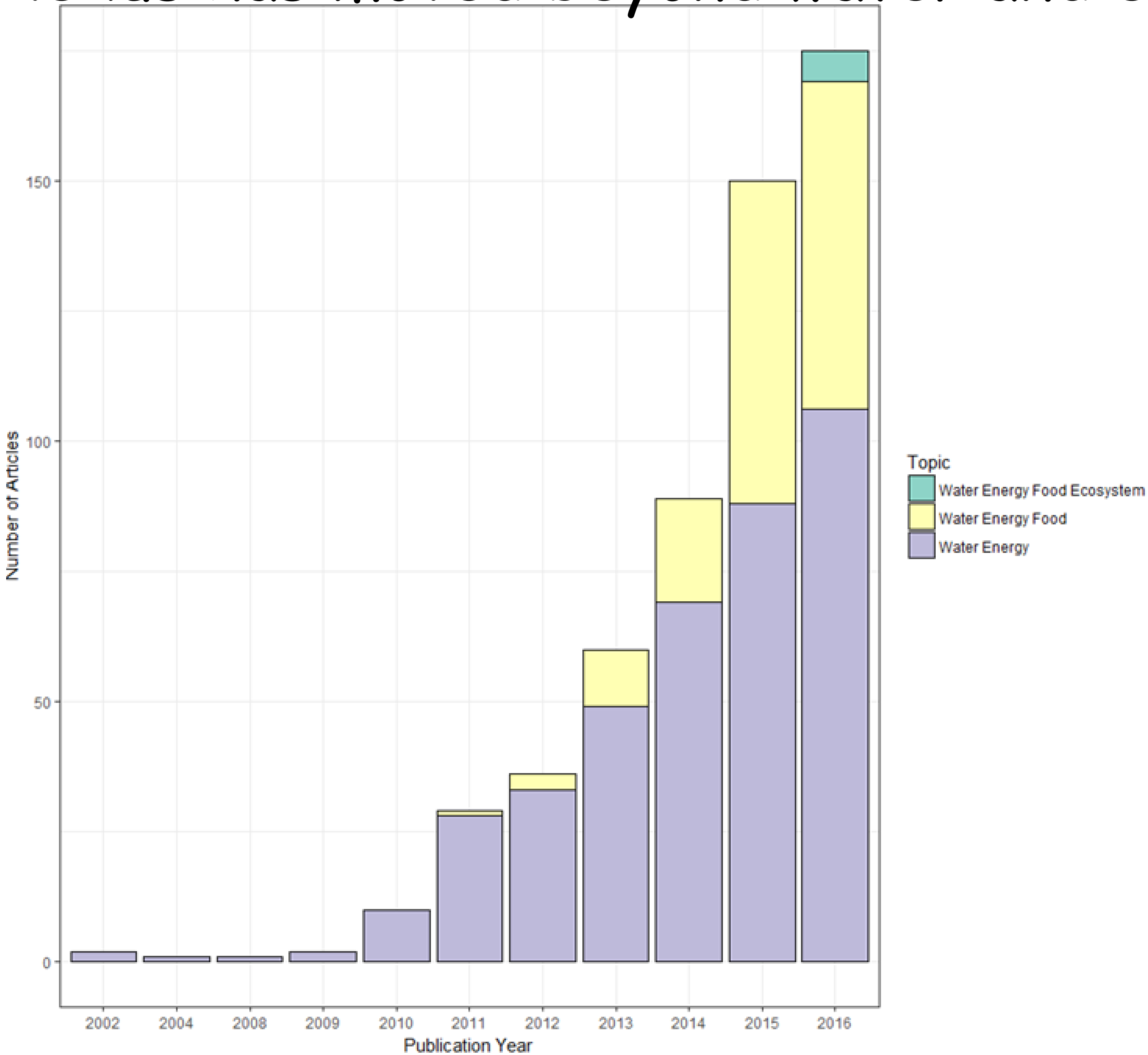
3,493

Numbers of nexus publications are on the rise




Eco-
systems
~15
~8
Food
~231
469
Energy
~25
Materials
Socio-economics
Water

Nexus has moved beyond water and energy



Articles by Selected Research Areas

- Environmental Sciences/Ecology (~300)
- Engineering (~280)
- Water Resources (~200)
- Energy Fuels (~160)
- Atmospheric Sciences (43)
- Thermodynamics (27)
- Agriculture (24)
- Geology (22)

Main outlets for nexus publications

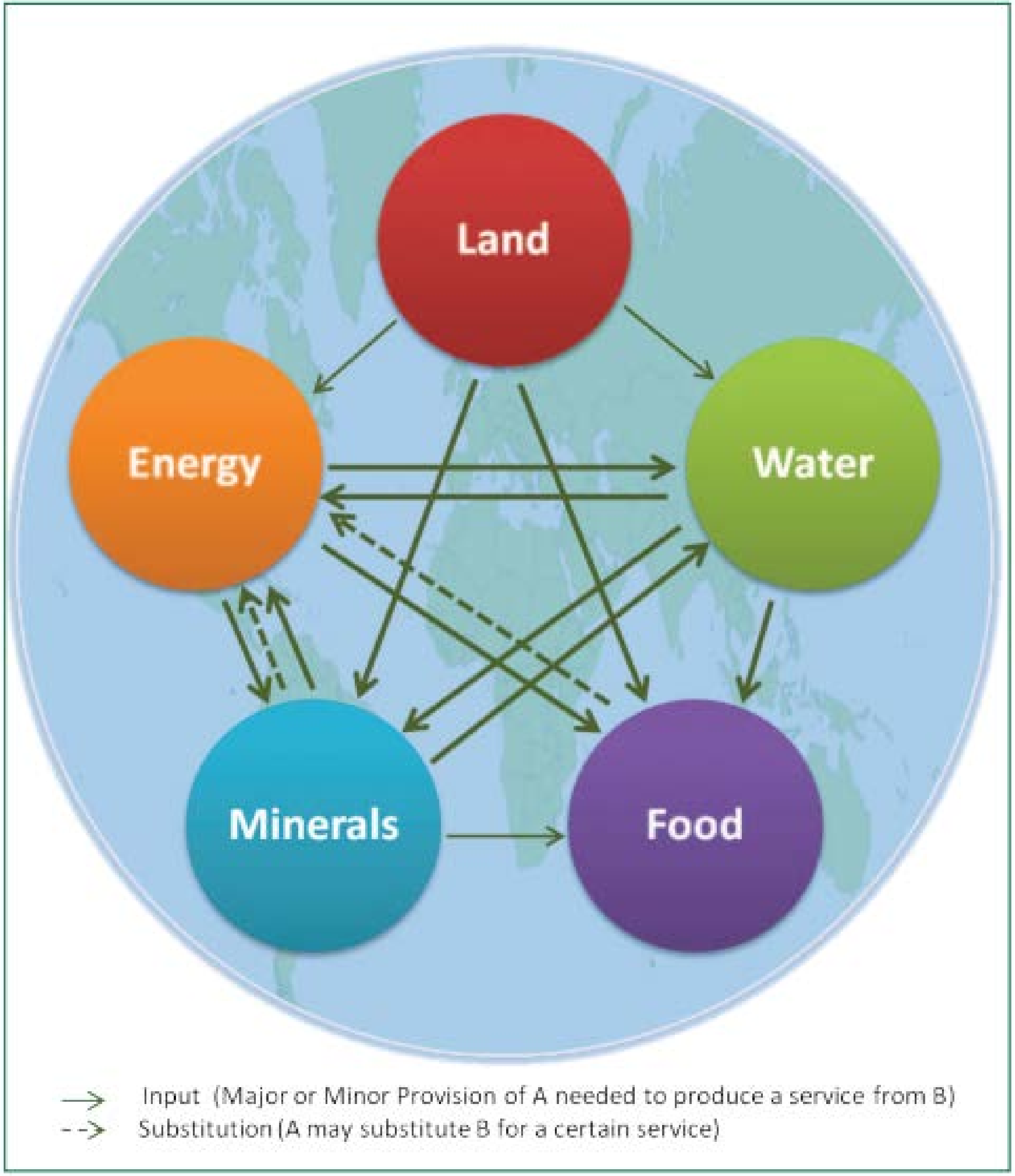
Total of 200 journals; 115 with only 1 publication

	Title	Count	%
1	ENVIRONMENTAL RESEARCH LETTERS	33	6.1
2	JOURNAL OF CLEANER PRODUCTION	24	4.5
3	APPLIED ENERGY	21	3.9
4	WATER	20	3.7
5	INTERNATIONAL JOURNAL OF WATER RESOURCES DEVELOPMENT	19	3.5
6	ENERGY	15	2.8
7	ENERGY POLICY	14	2.6
8	ENVIRONMENTAL SCIENCE & TECHNOLOGY	14	2.6
9	ENVIRONMENTAL SCIENCE & POLICY	13	2.4
10	WATER INTERNATIONAL	13	2.4

Summary-bibliometrics

- 200 Sources
- Only 13 articles between 2002 to 2010.
- Top cited manuscript:
  - Considering the energy, water, and food nexus: Towards an integrated modelling approach by Bazilian, M. et al. (2011) *Energy Policy*. (>150 citations)
- High concentration of articles on energy/water; lack of ecosystems, materials, and socio-economic aspects

Definitions



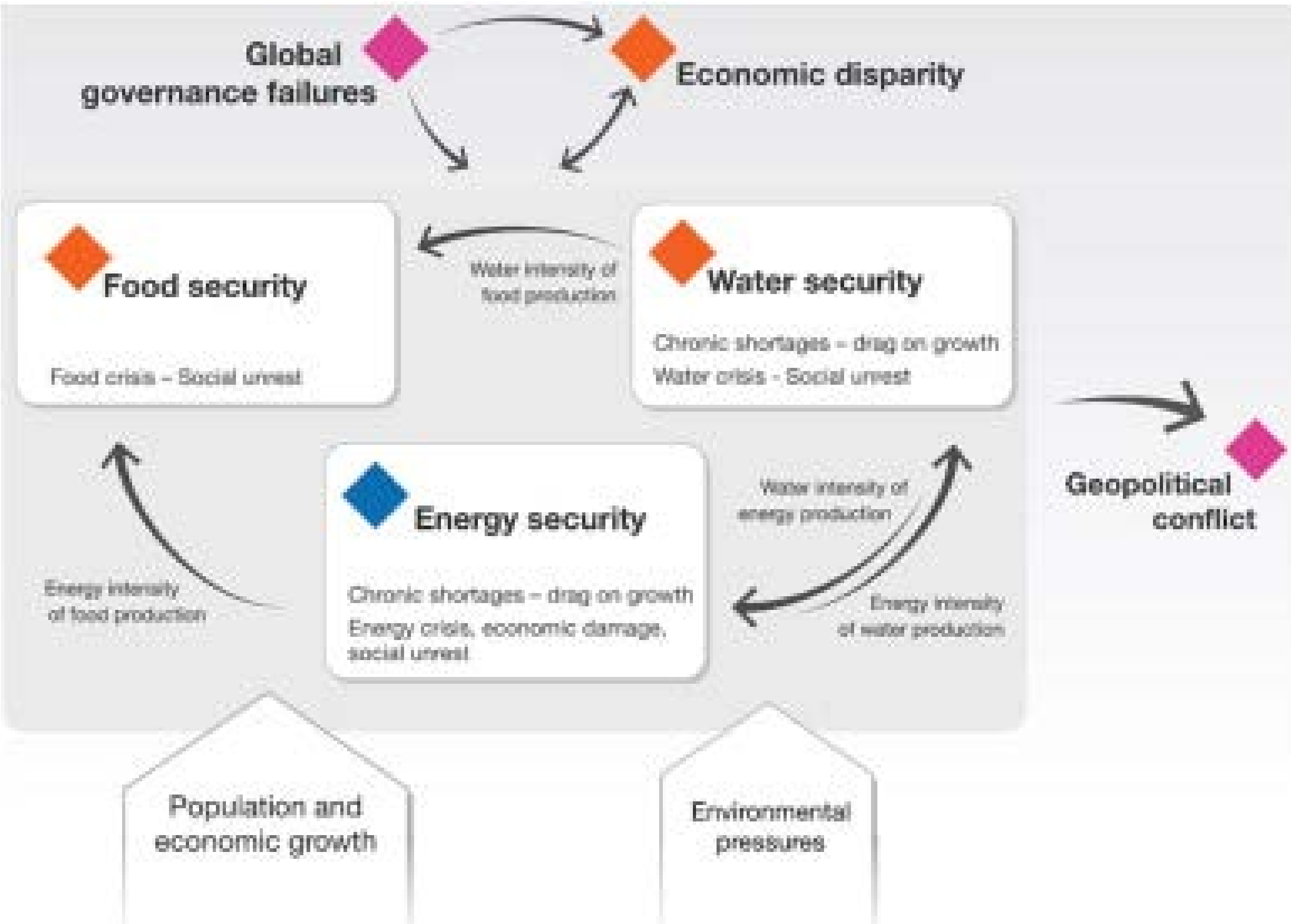
One resource being an input to produce another

or

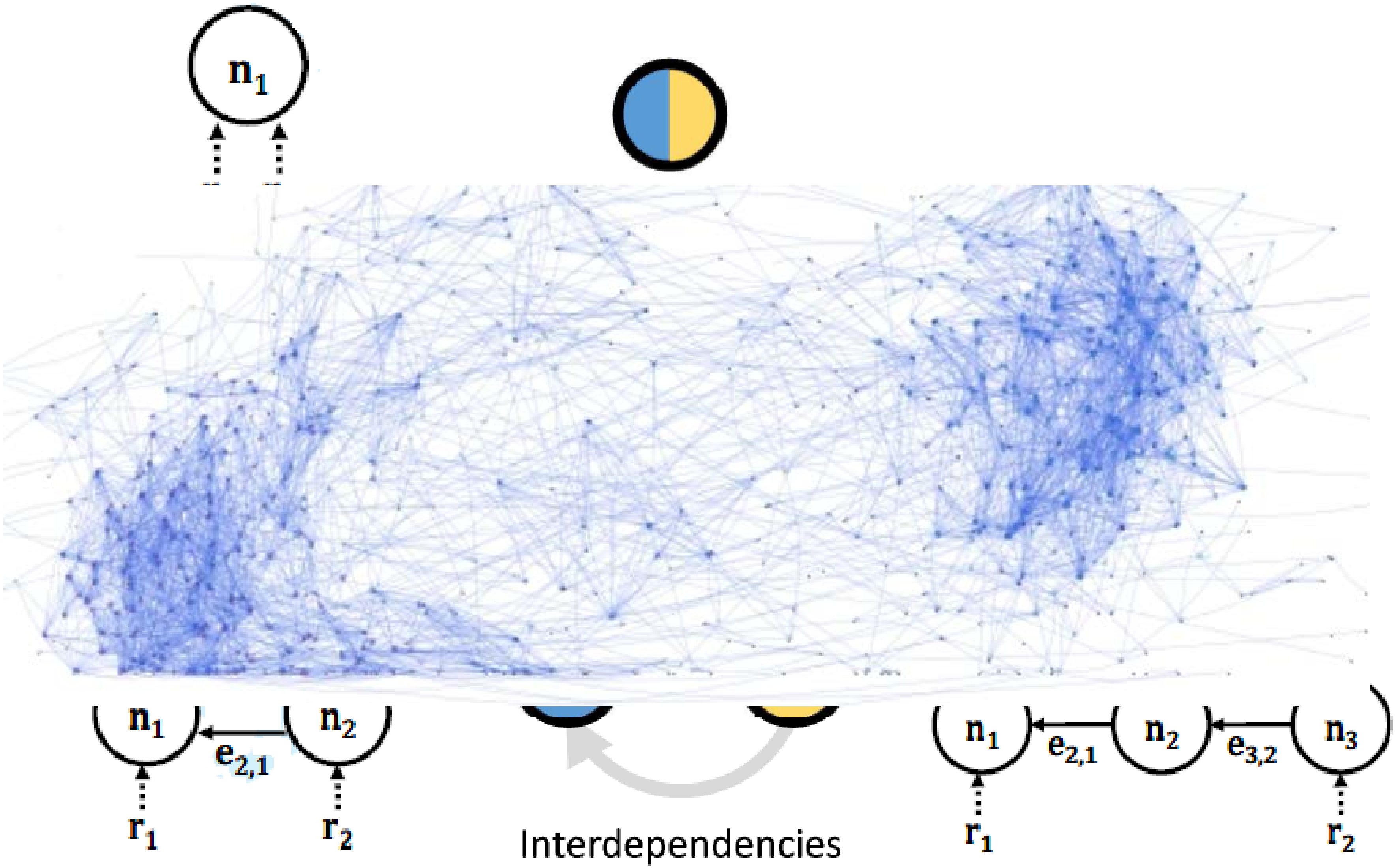
Substitutability of two or more resources.

Andrews-Speed, P, Bleischwitz, R, Boersma, T, Johnson, C, Kemp, G, VanDeveer, SD, 2012. "The global resourc
nexus : the struggles for land, energy, food, water, and minerals." Transatlantic Acad., Washington, DC..

Nexus as interdependencies between production systems



M Bazilian et al. 2011. “Considering the energy, water and food nexus: Towards an integrated modelling approach”. *Energy Policy*, Volume 39, Issue 12, 2011.



Font Vivanco, D., S. Deetman, R. Wang, E. Hertwich (forthcoming). "Unravelling the nexus: exploring the pathways to combined resource use. *Industrial Ecology*

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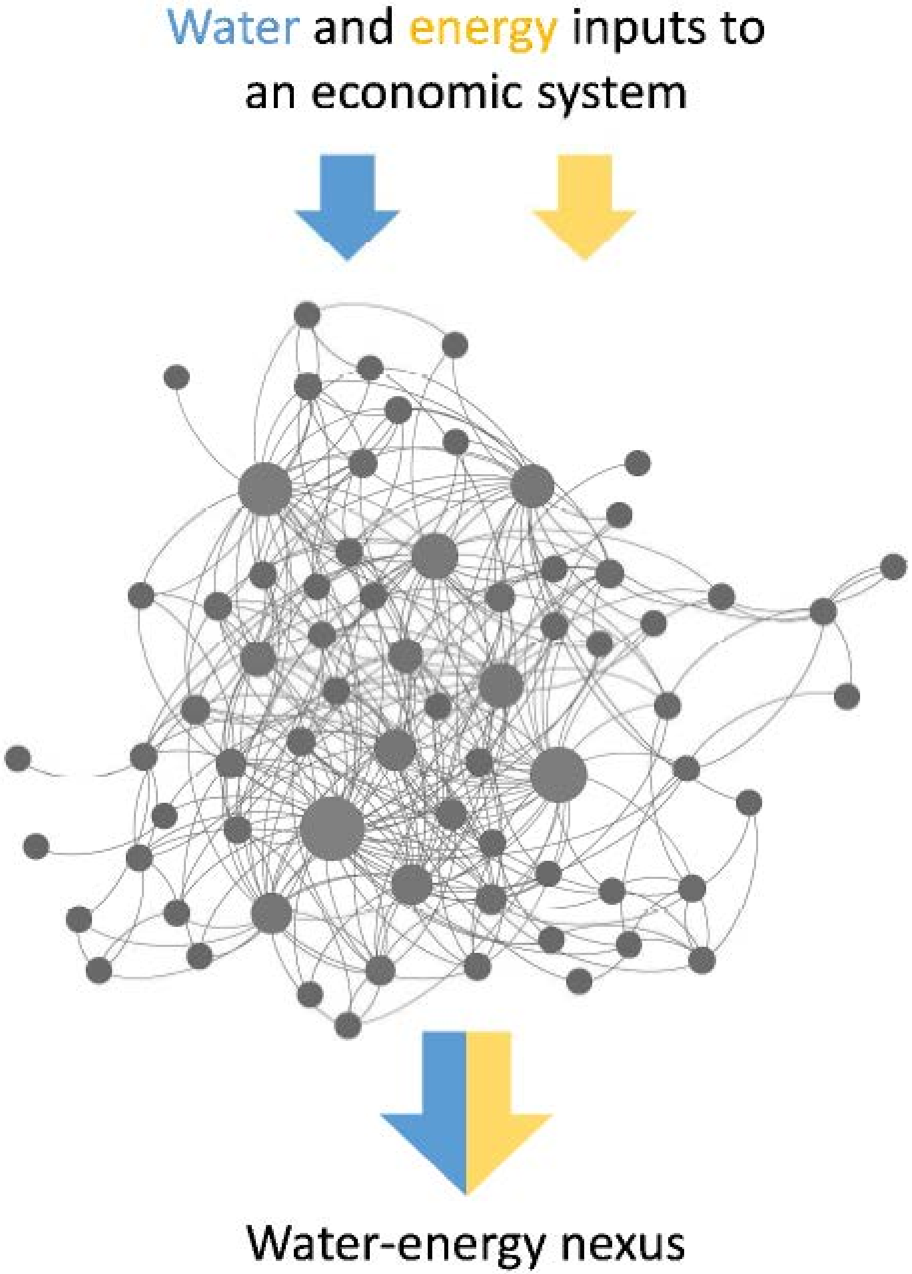

Resource Nexus, which refers to the combined use of two or more resources, is a result of resource flows along supply chains

Font Vivanco, D., S. Deetman, R. Wang, E. Hertwich (forthcoming). "Unravelling the nexus: exploring the pathways to combined resource use. *Industrial Ecology*

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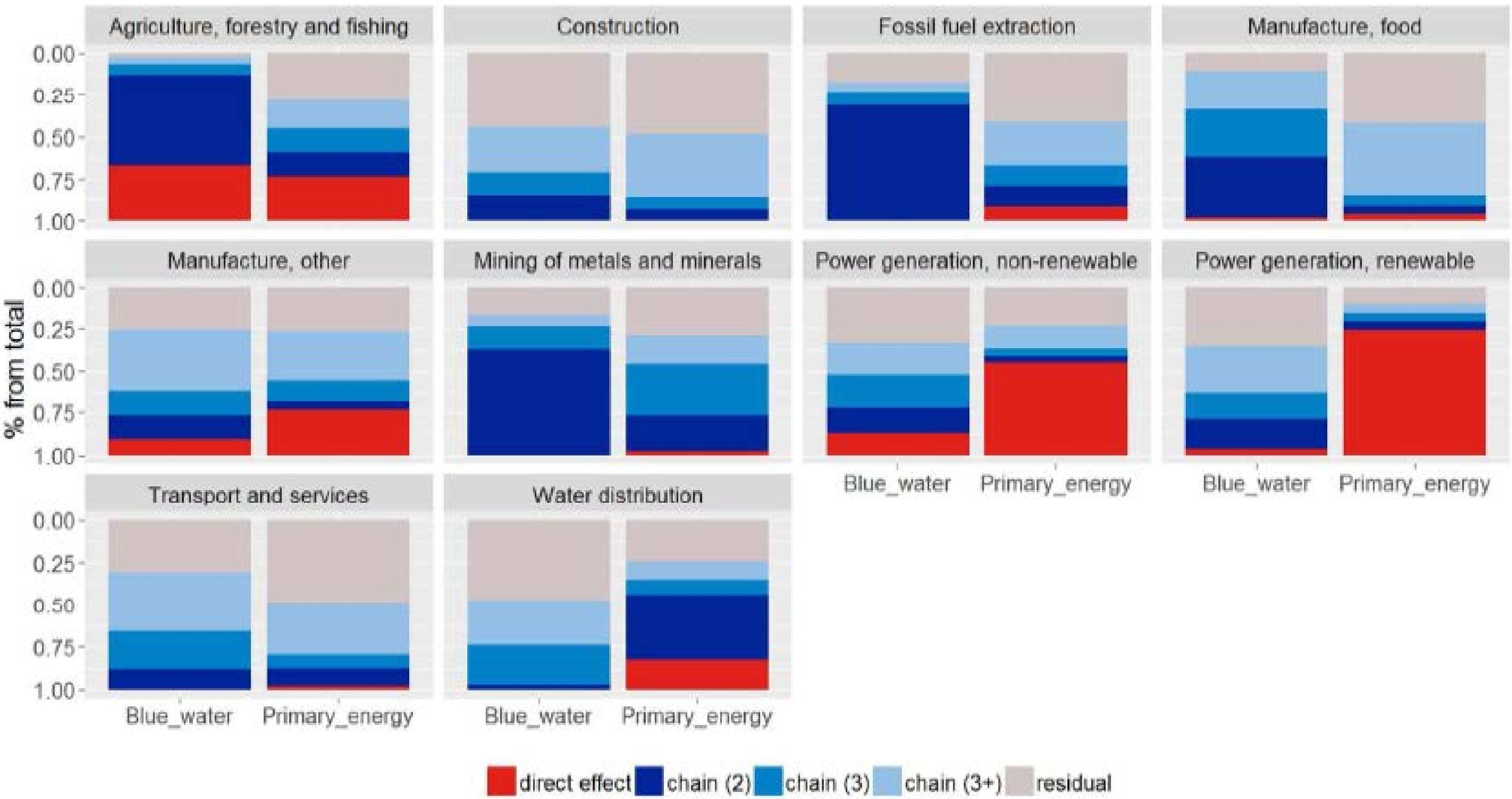
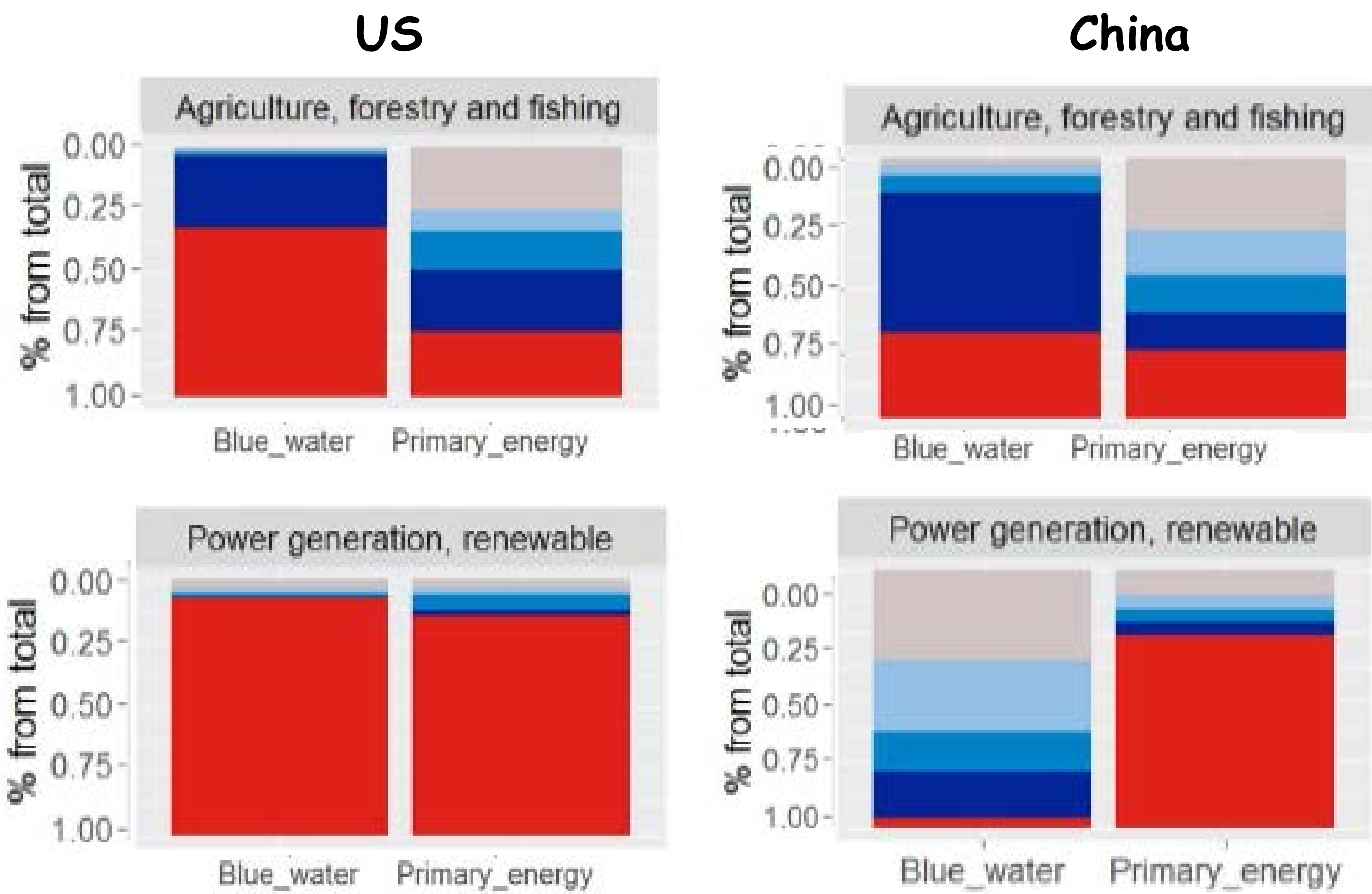
The E-W nexus is less evident in manufacturing and service sectors, where most of the resource use takes place several steps upstream in the supply chain



Font Vivanco, D., S. Deetman, R. Wang, E. Hertwich (forthcoming). "Unravelling the nexus: exploring the pathways to combined resource use. *Industrial Ecology*

Disparities in the relative contribution between the US and China can be largely explained by differences in economic structure, technology, and resource endowments



Font Vivanco, D., et al. (forthcoming). *Industrial Ecology*

Summary-definitions

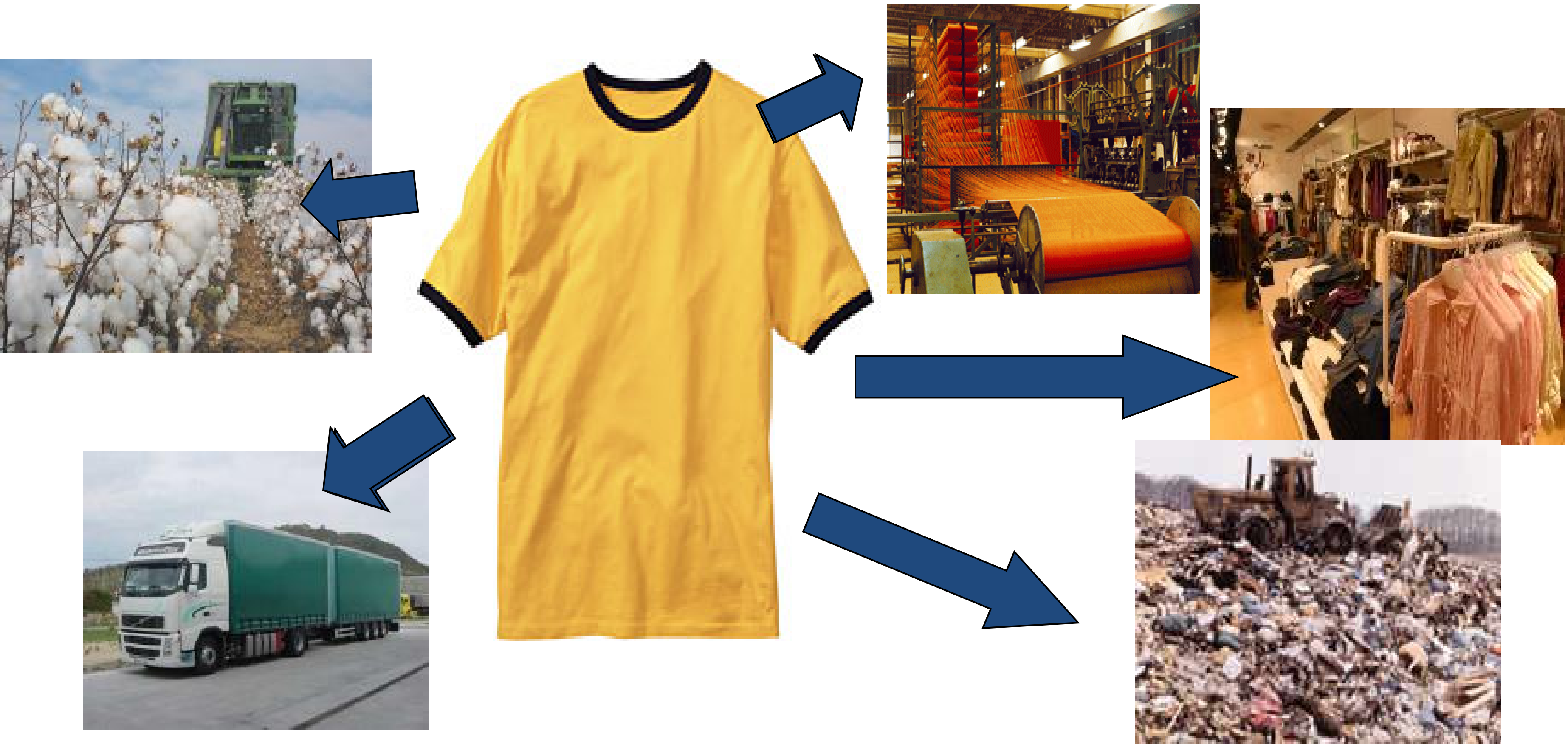
- **Many nexus studies are case studies within a specific area. While some nexus issues are location-dependent, there is a trans-regional or global dimension as local constraints can be mediated by trade.**
- **Moreover, most of the nexus literature focuses on particular industries, such as food and energy, where large quantities of natural resources are directly used.**
- **On the other hand, the water-energy nexus is less evident in manufacturing and service sectors, where most of the resource use takes place several steps upstream in their supply chain.**
- **As a consequence, those industries with no immediate resource implications or in which resource interdependencies reside across complex and global supply chains are overlooked.**

Conceptual and modeling Framework

Requirements/Ingredients

- Along the entire supply chains (from cradle to grave);
- across space (globally); and
- tracking multiple flows

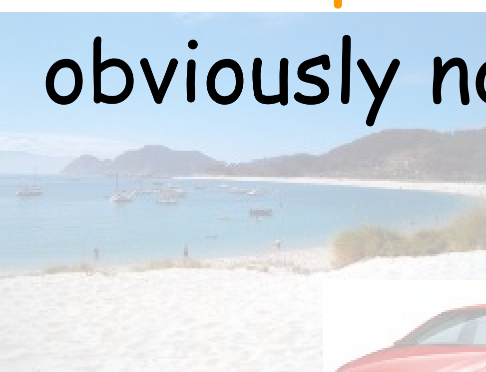
From cradle to the grave using Life-Cycle Analysis (LCA)



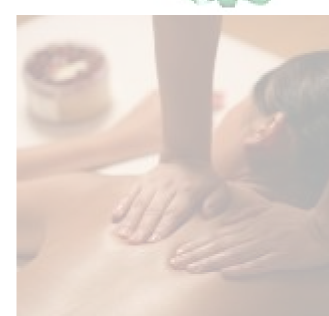


There are millions of products, each one is different from the other!

If we want to calculate emissions from all consumption of a given territory, we will obviously not be able to do that with LCA





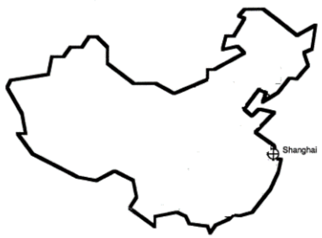



(modified from Santacana, 2008)

Hybrid approaches overcome the shortcomings of both top down and bottom up approaches

"TOP DOWN"

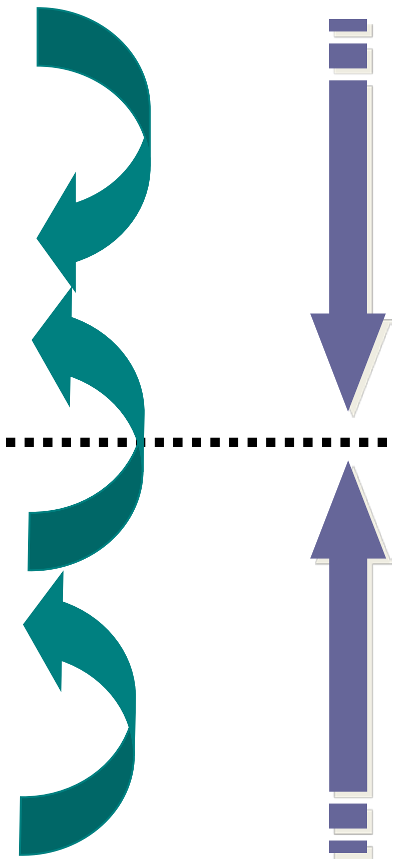
National accounts



Resource footprint of countries

Regional footprint

Local footprint



Footprint of companies and organizations

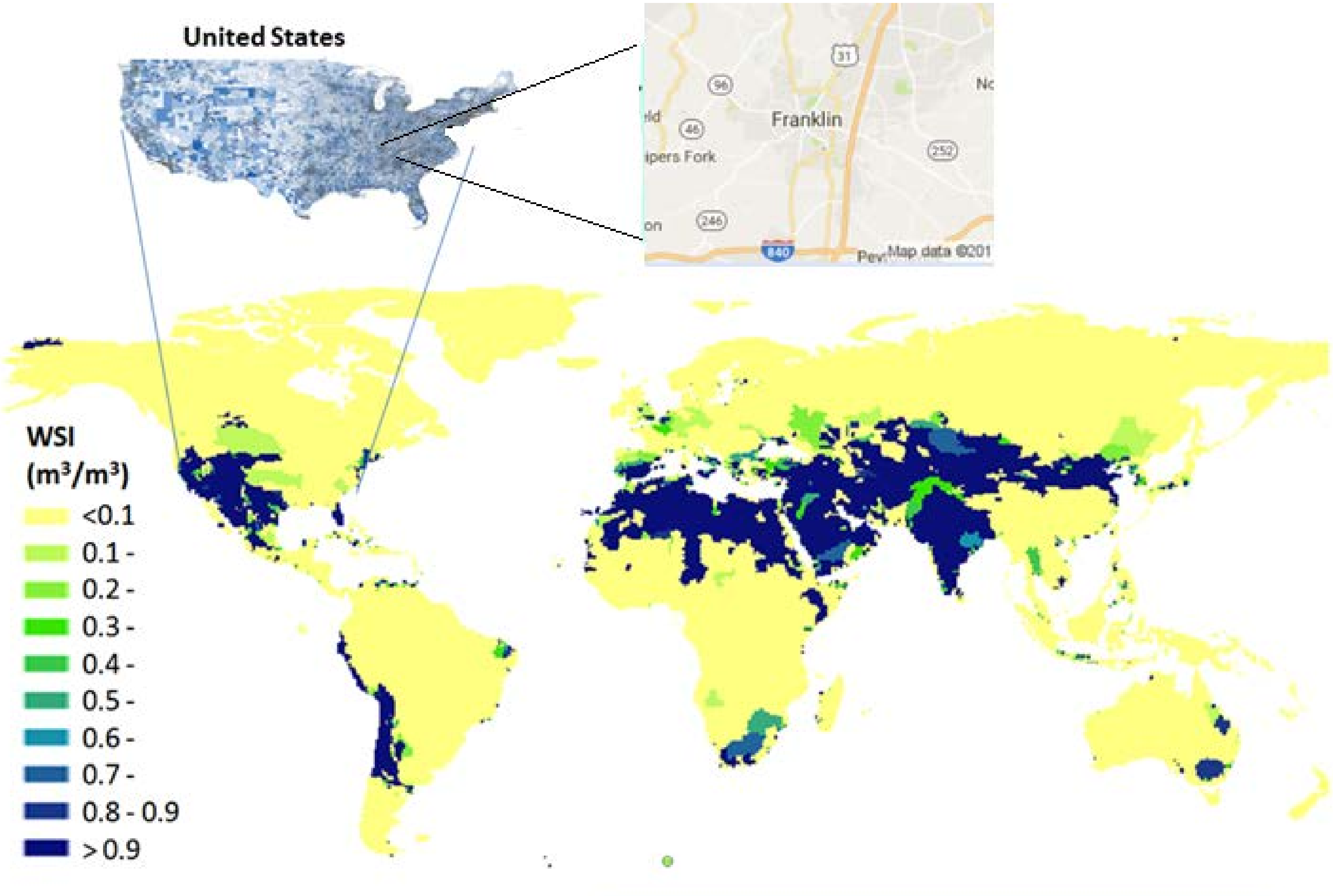
Citizen footprint

Footprint of products and activities

"BOTTOM-UP"

LCA & CES

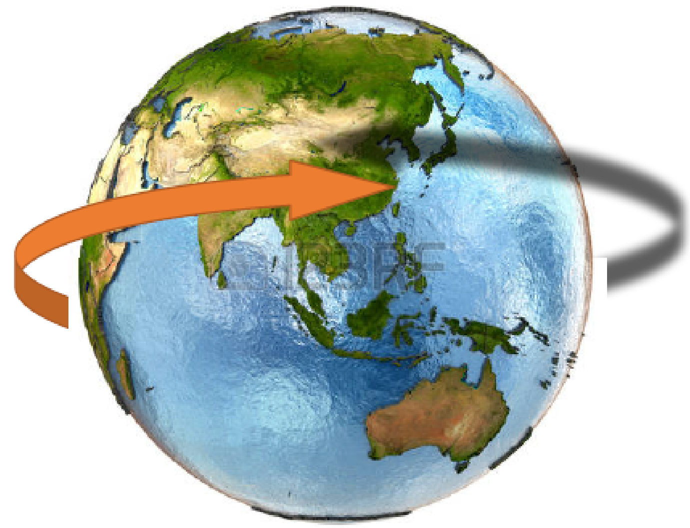
Linking local consumption to global impact



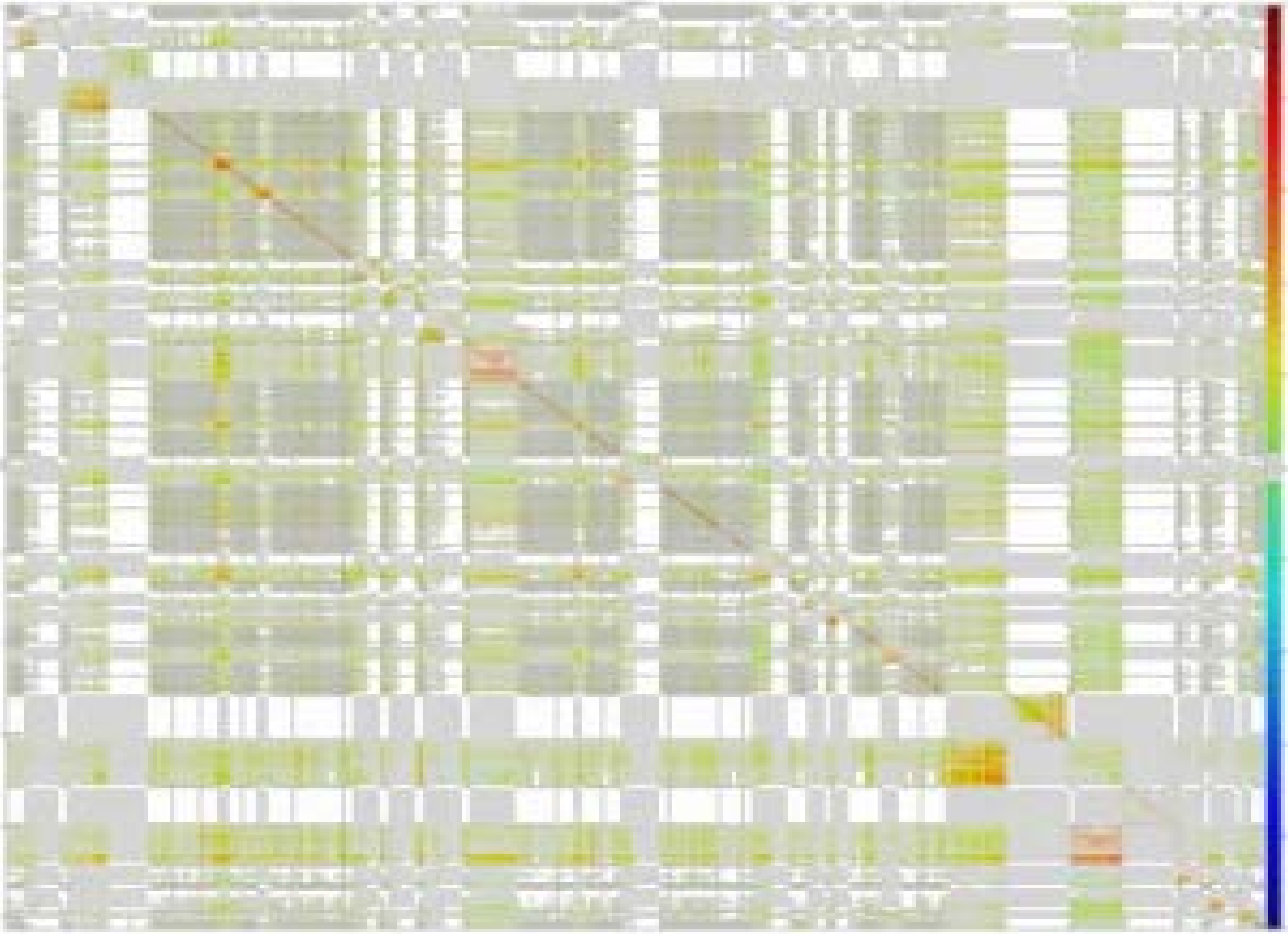
Hubacek et al. (2014). “Teleconnecting Consumption to Environmental Impacts at Multiple Spatial Scales. Research Frontiers in Environmental Footprinting. *Industrial Ecology.*

Burden shifting

10-30% of global surface and rainwater use
11% of global groundwater use
13% of global polluted water
15-38% of global labor
17-30% of global biodiversity loss
20-24% of global land use
22% of global $PM_{2.5}$-related deaths
22-30% of global air pollution
22-33% of global CO_2 emissions
23-30% of global GHG emissions
24-68% of global raw material extractions
26% of global reactive nitrogen emissions
32% of global scarce water use
35% of global energy use
62-64% of global metal ore extractions
67% of global mercury emissions

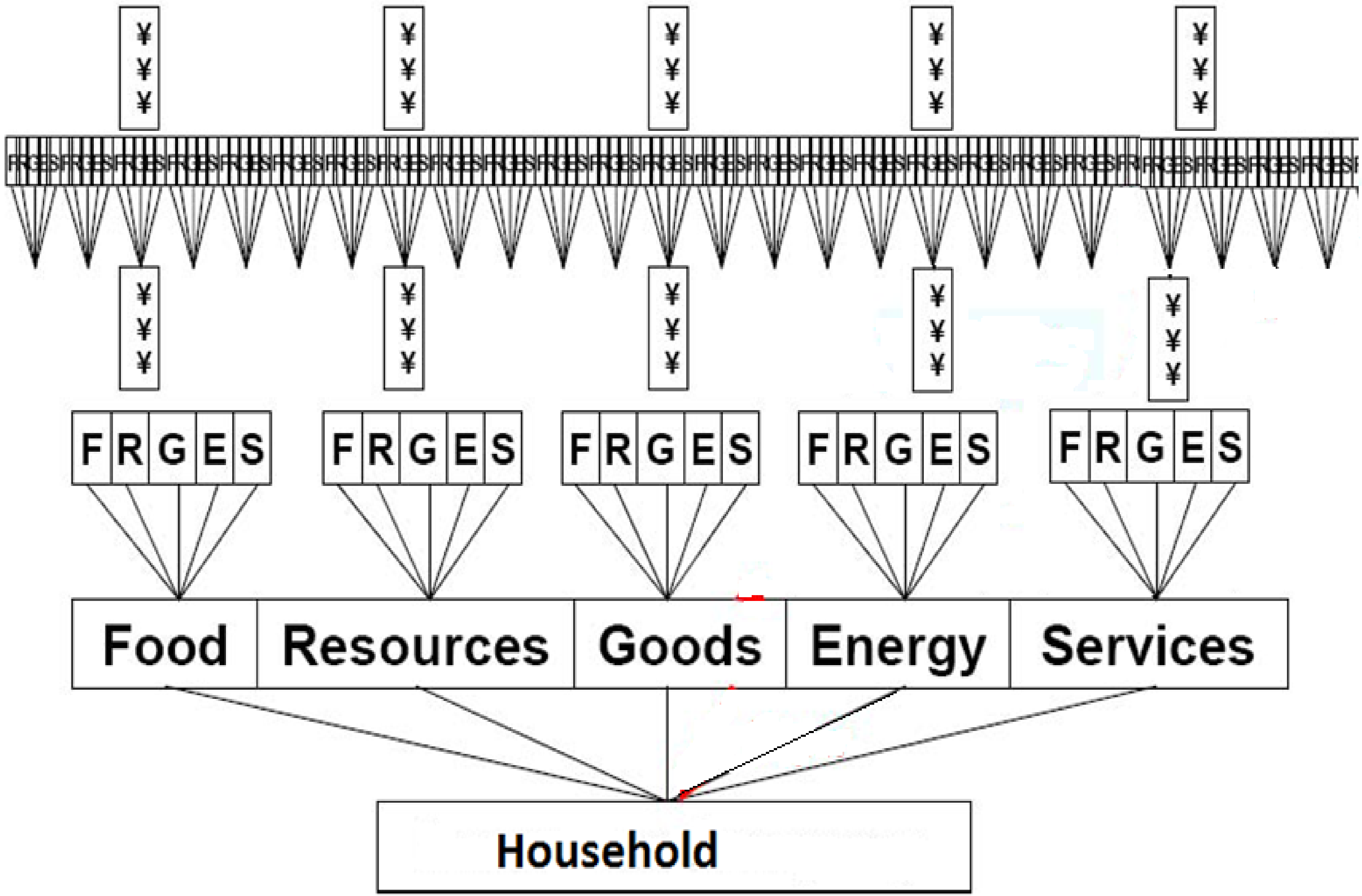


are embodied in international trade



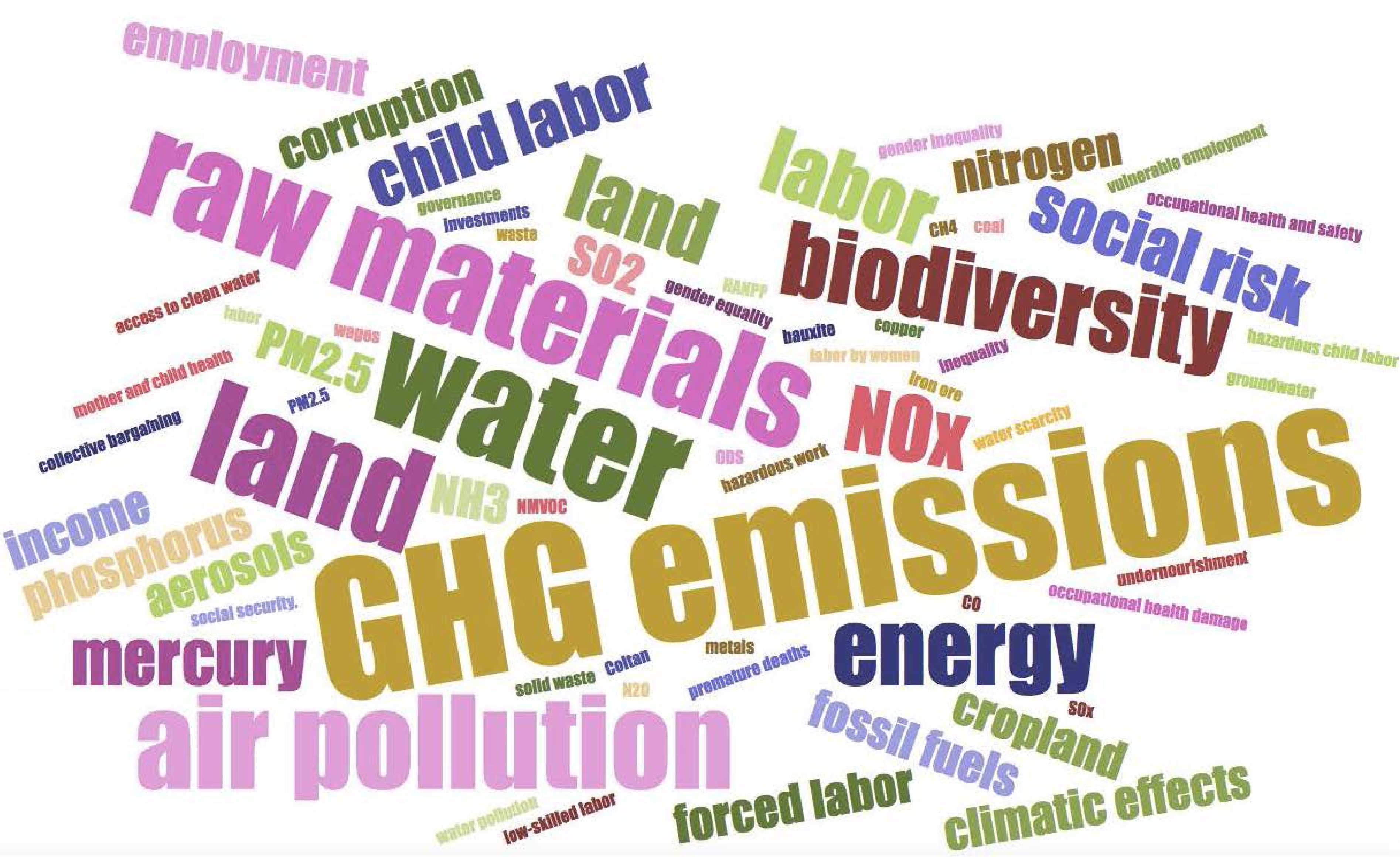
A 160-country 10,000×10,000-sector balanced World MRIO for the year 2000; by Lenzen et al.

Taking care of upstream emissions



Source: Foran, Lenzen et al. 2005. "Integrating Sustainable Chain Management… *Ecological Economics*.

GMRIO-calculated footprints of…



Summary-approach

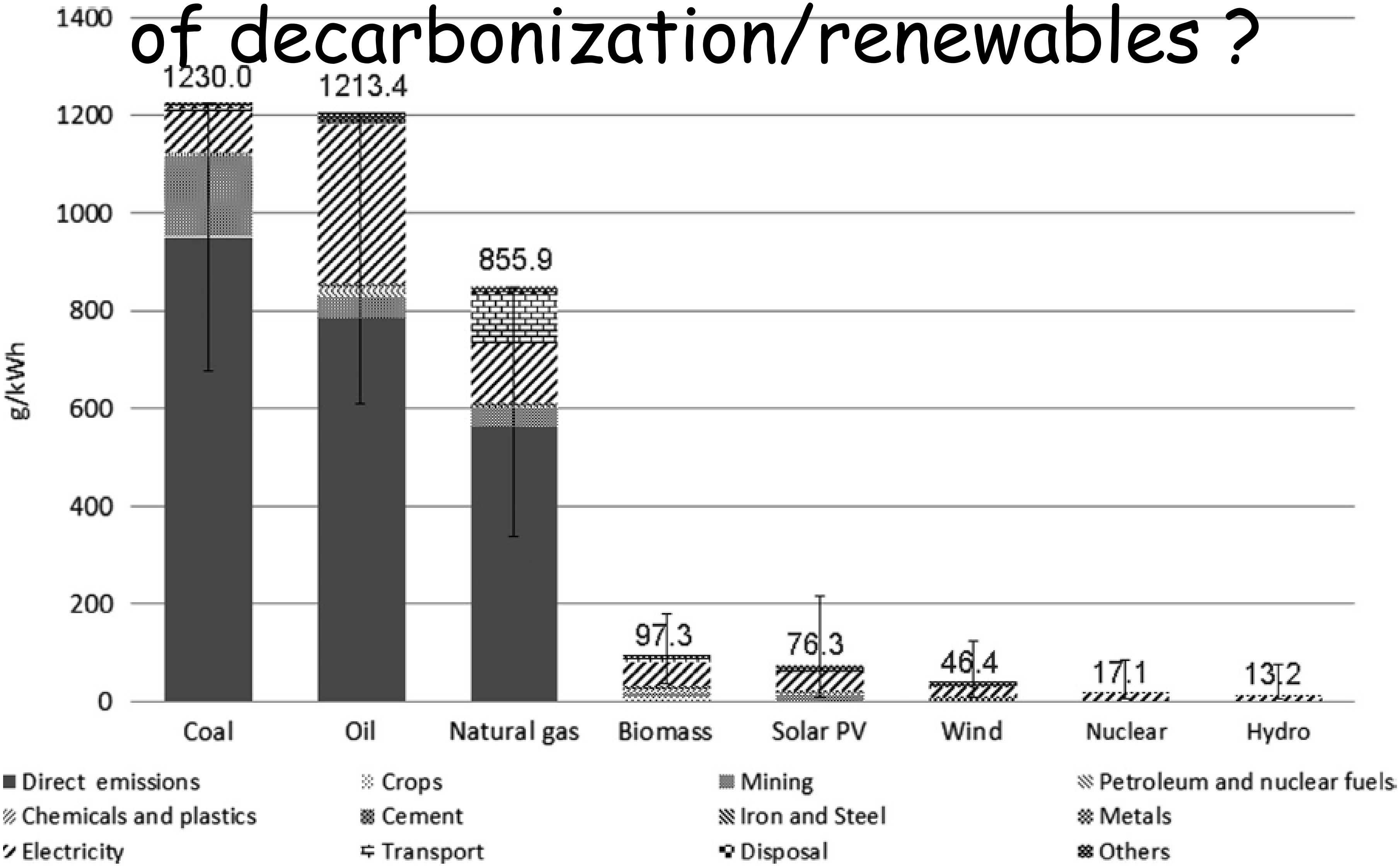
- **Input-output (IO) analysis allows:**
  - **to model all sectors of the economy that use 'Nexus' resources**
  - **to add socio-economic aspects, value added, jobs,…**
  - **to investigate resource flows along global supply chains ('teleconnecting') to other economic systems.**
  - **to identify intervention points along the entire supply chain as well as for demand-side management**

Some applications

Hybrid LCA-IO approach for nexus to assess the carbon and hydrological consequences for electricity production in China

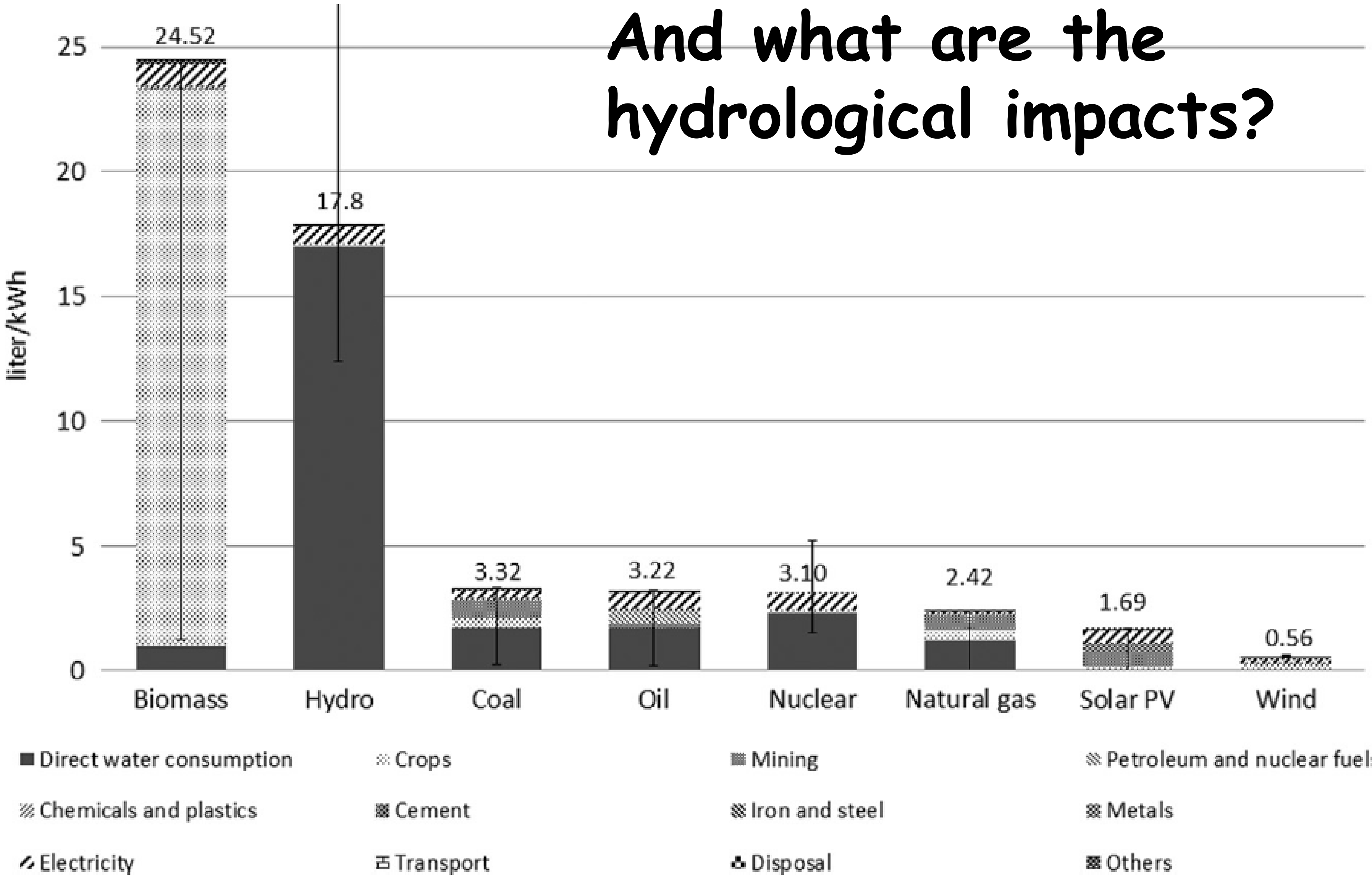
Feng, Li, Siu, Hubacek (2014). "The energy and water nexus in Chinese electricity production: A hybrid life cycle analysis." ***Renewable & Sustainable Energy Reviews***. Volume 39, Pages 342–355.

What are the carbon and water costs of decarbonization/renewables ?



Feng, Li, Siu, Hubacek (2014). "The energy and water nexus in Chinese electricity production: A hybrid life cy analysis." *Renewable & Sustainable Energy Reviews*. Volume 39, Pages 342–355.

And what are the hydrological impacts?



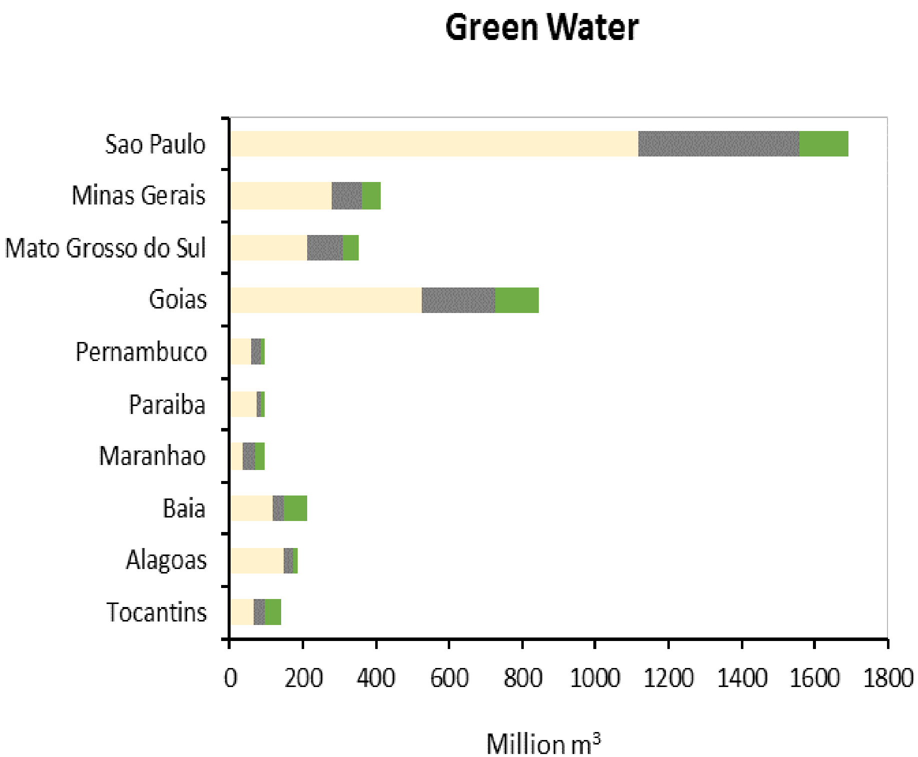
Feng, Li, Siu, Hubacek (2014). "The energy and water nexus in Chinese electricity production: A hybrid life cyc
analysis." Renewable & Sustainable Energy Reviews. Volume 39, Pages 342–355.

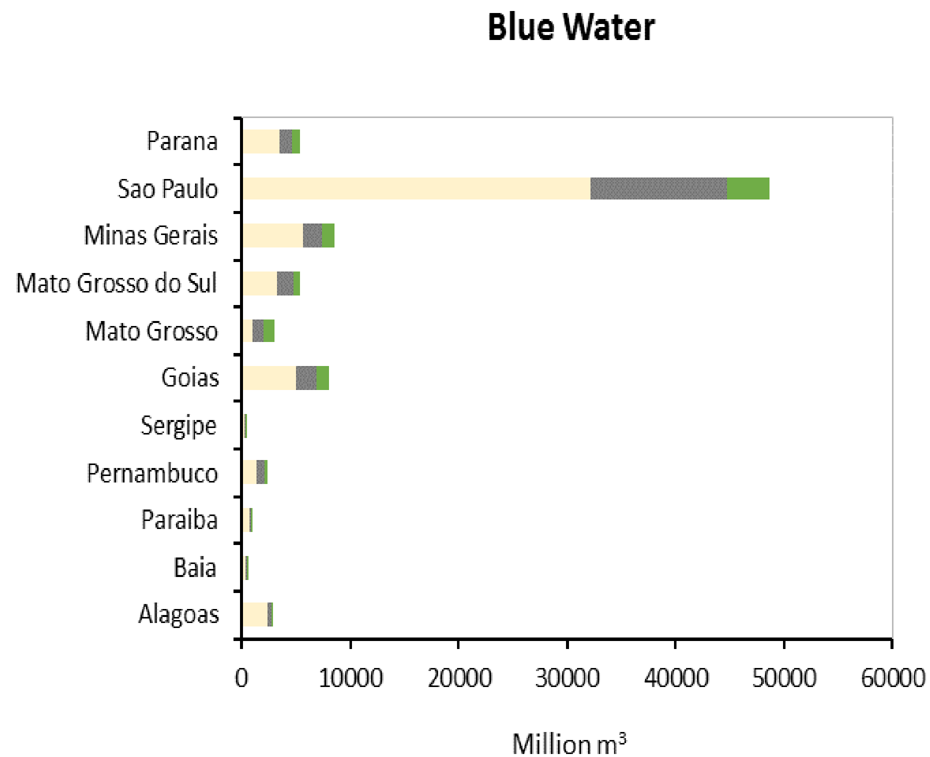
MRIO to calculate water footprints of biofuel production in Brazil

- **Brazil is a water abundant country**
- **Bioethanol might create water pressure**
- **The Paris agreement might amplify the problem**

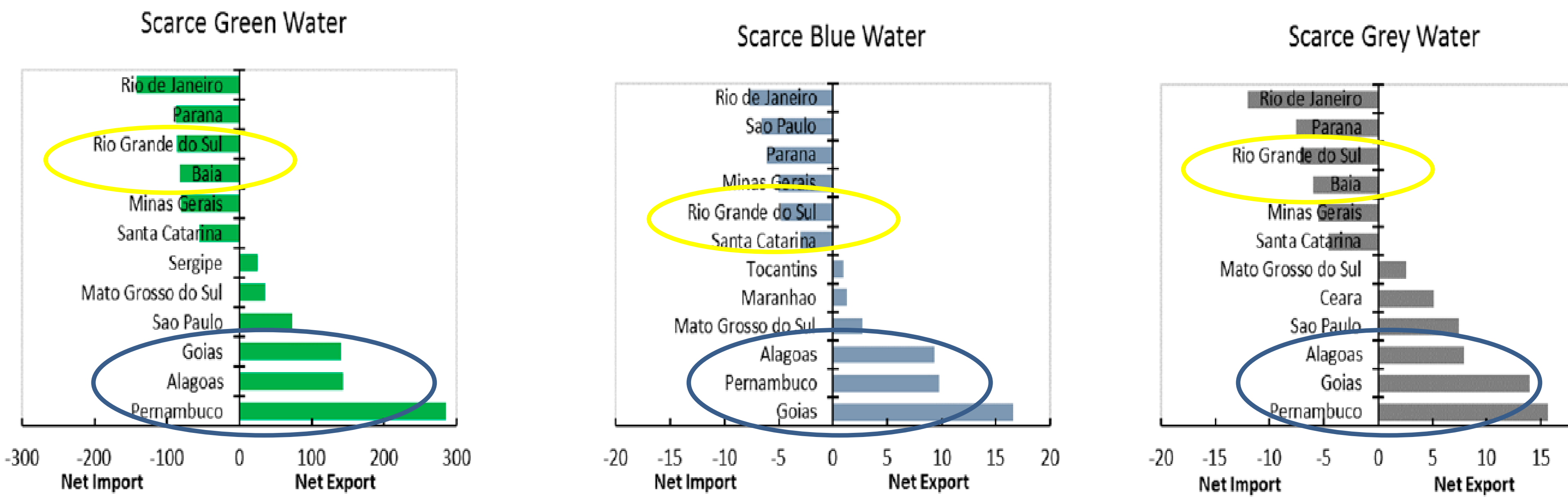
Munoz Castillo, R., K. Feng, K. Hubacek*, L. Sun, J. Guilhoto, F. Miralles-Wilhelm (2017). " Uncovering the Green, Blue and Grey Water Footprint and Virtual Water of Biofuel Production in Brazil, a Nexus perspective." ***Sustainability***. 9, 2049.

Sugar is the biggest contributor to the water footprint



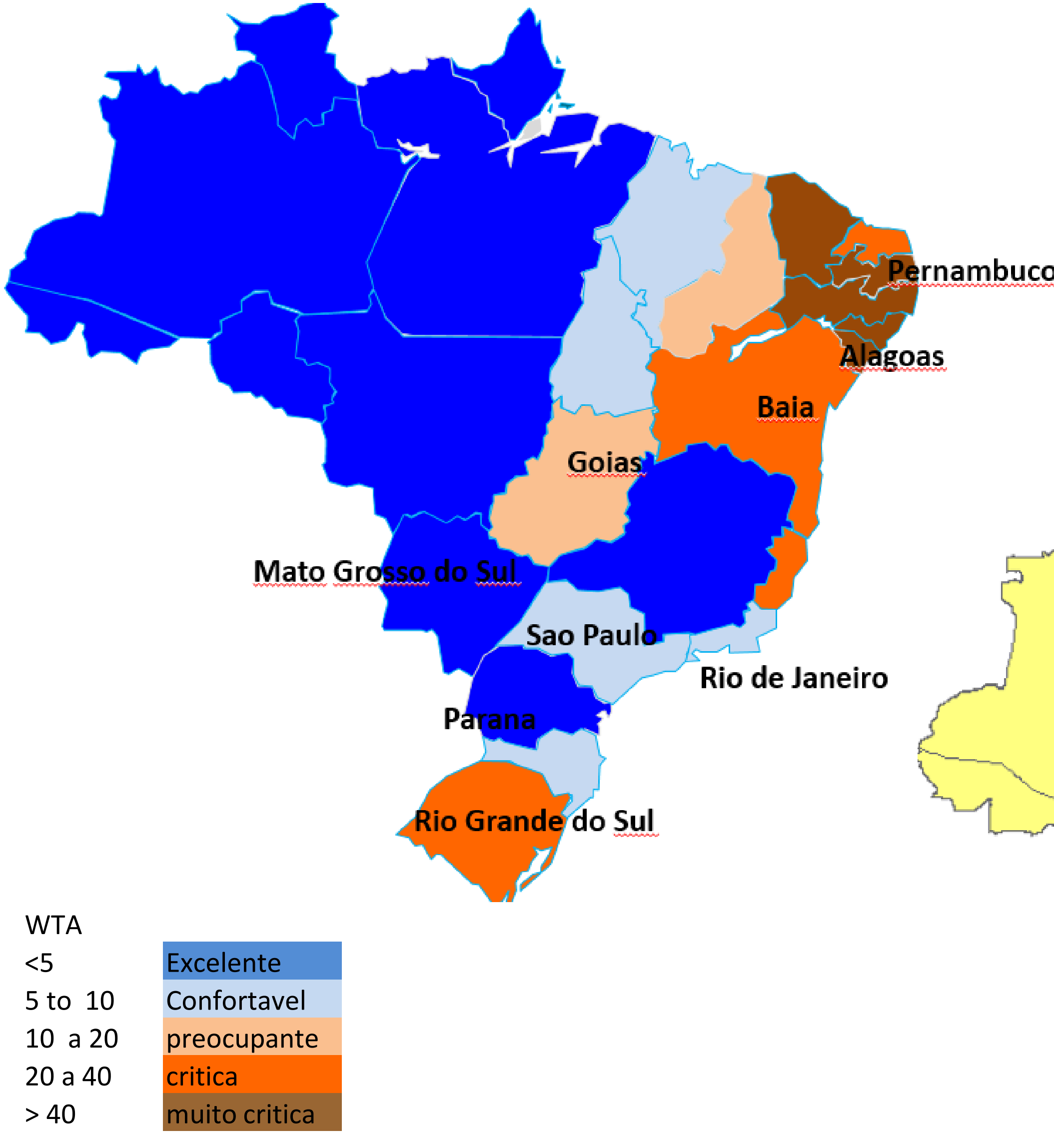


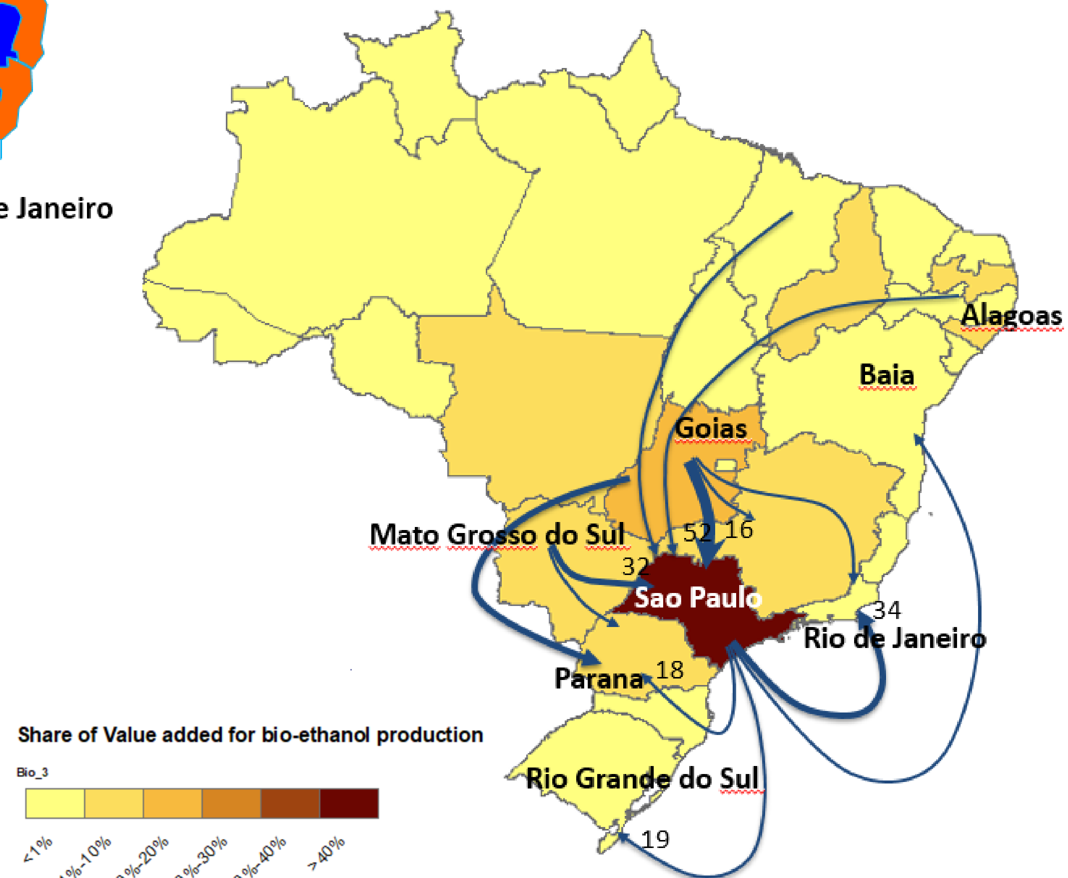
Some states facing severe to critical water scarcity conditions are benefitting from importing virtual water, …



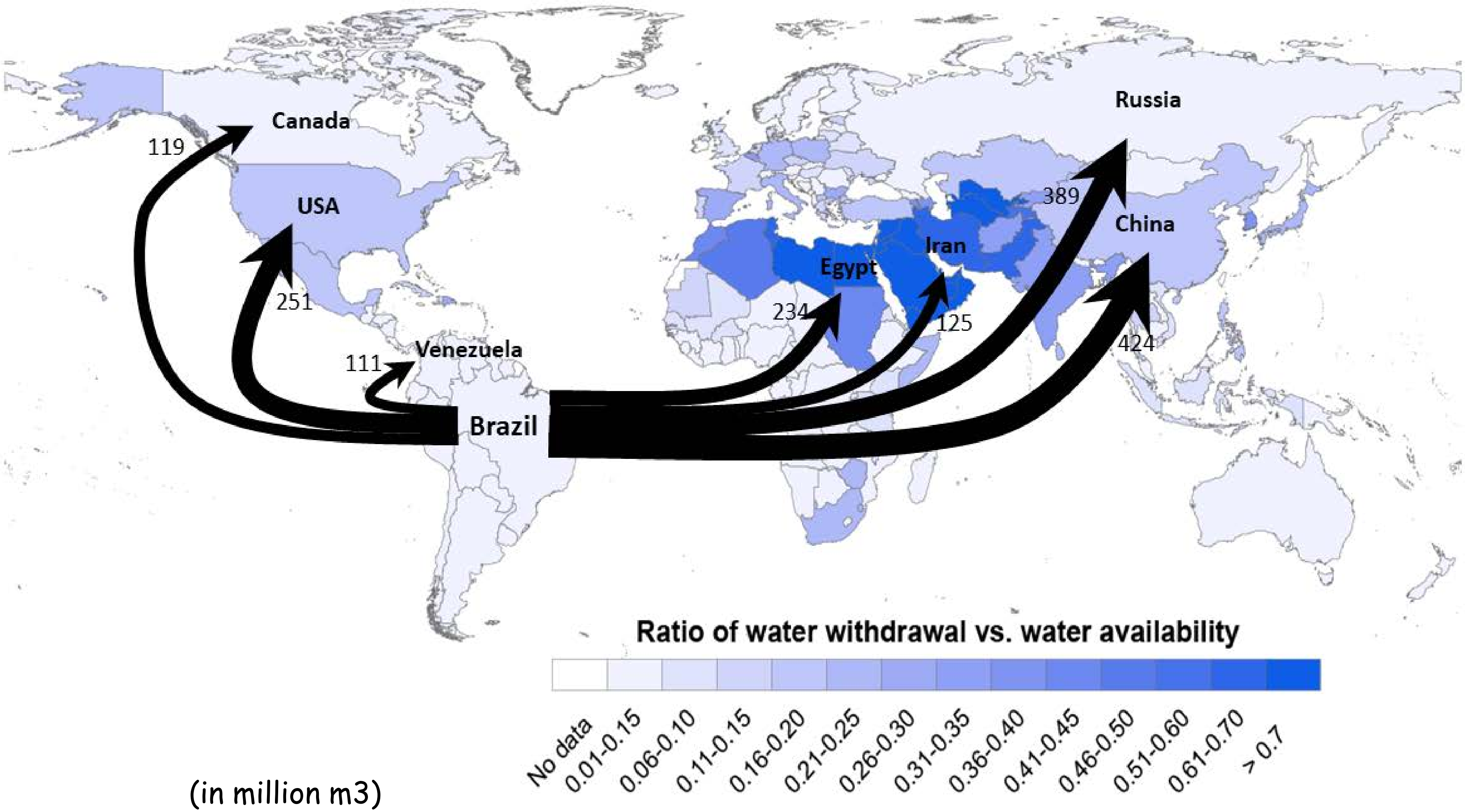
but predominantly, water-rich states outsource water pressure to water-scarce states

Water-rich states tend to also have higher value added along national supply chains



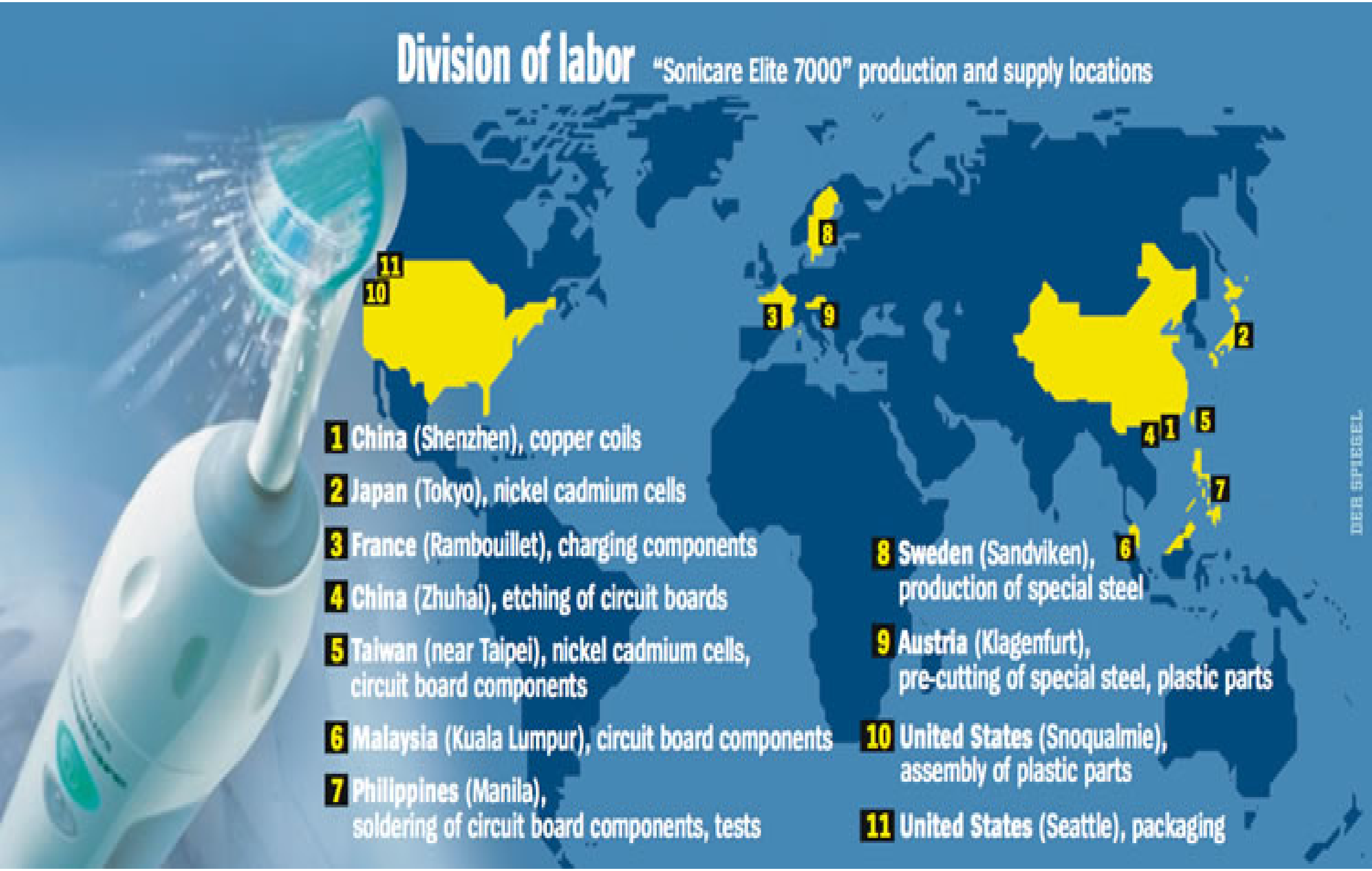


Brazil's water used for bioethanol is exported globally



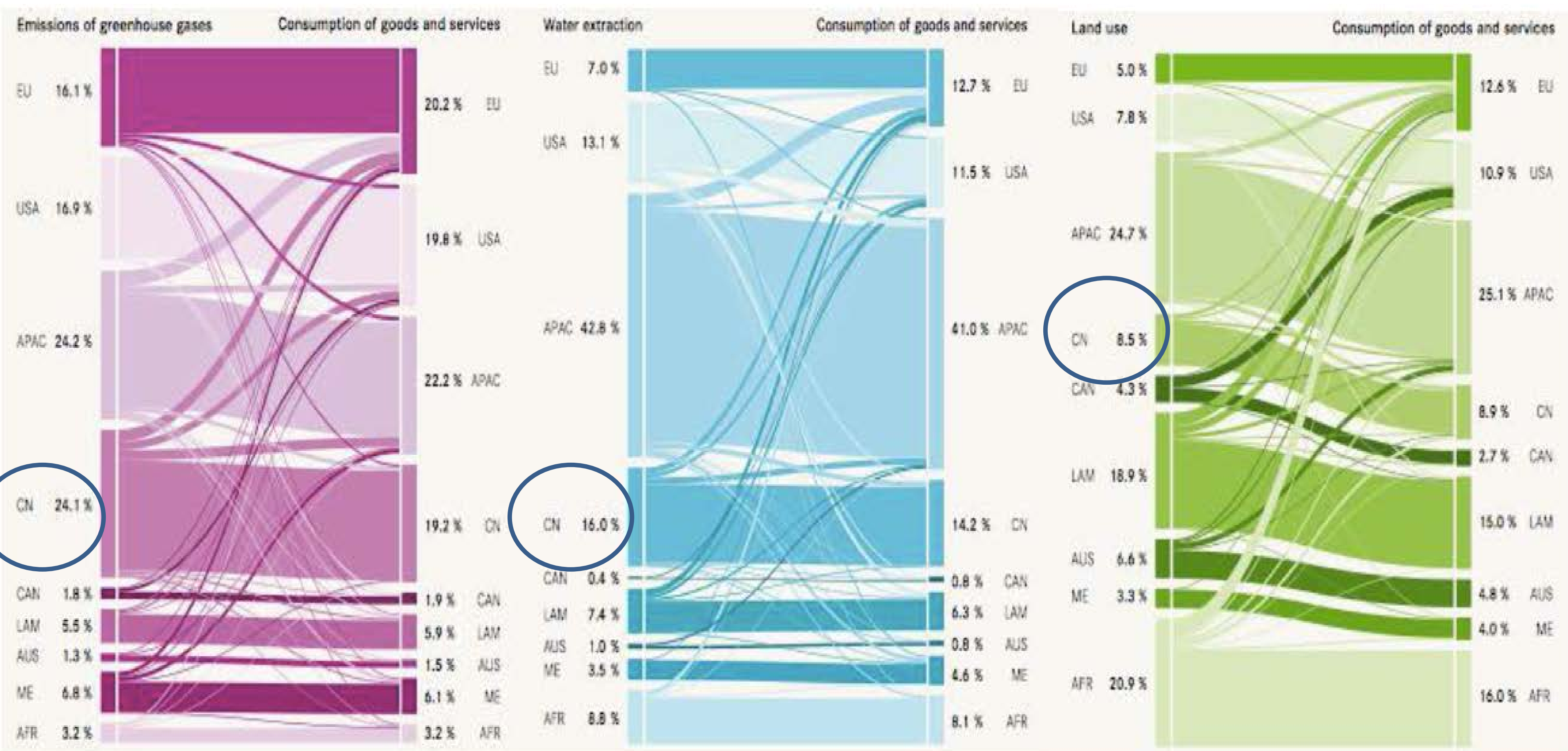
(in million m3)

Utilizing and modeling global supply chains



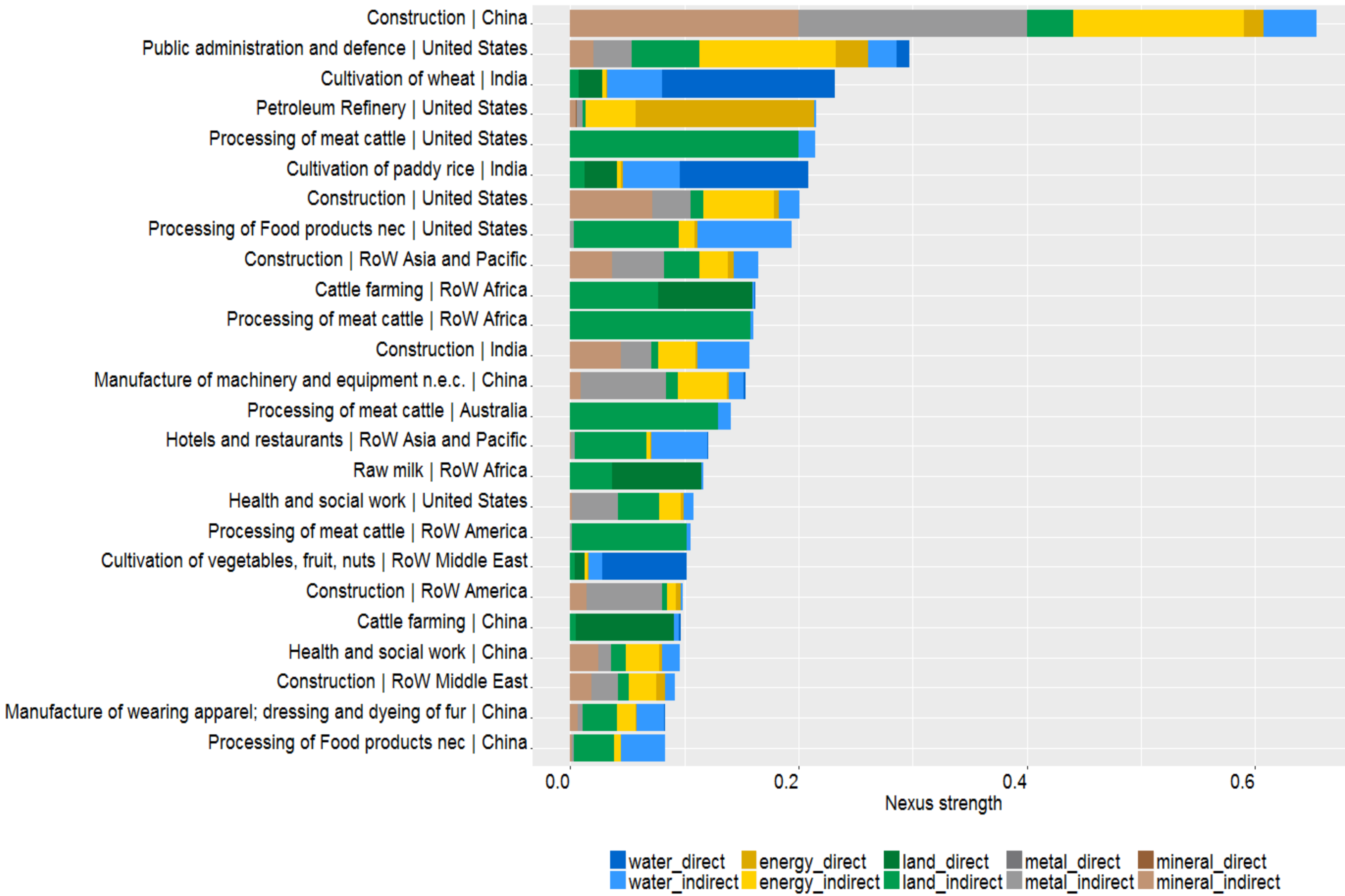
GMRIO can show how production and consumption are linked across the globe

GHGs Water Land



Tukker et al. (2014) The Global Resource Footprint of Nations. Report from the EU FP7 Project CREEA

Top 25 product nexuses identified through consumption-based accounting



Font Vivanco, D., R. Wang, E. Hertwich (forthcoming). "Nexus strength: a novel metric for assessing the global resource nexus. . *Industrial Ecology*

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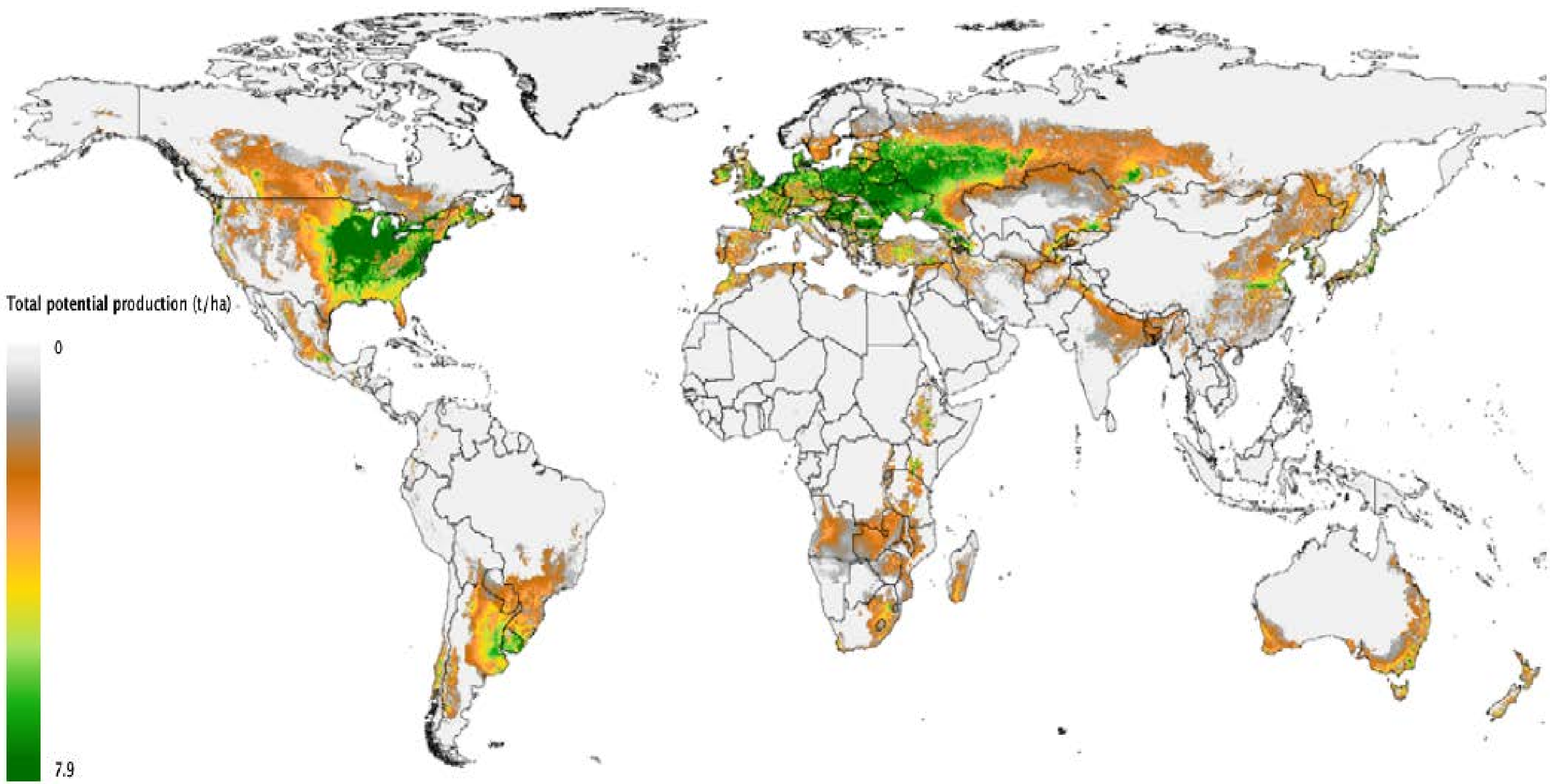
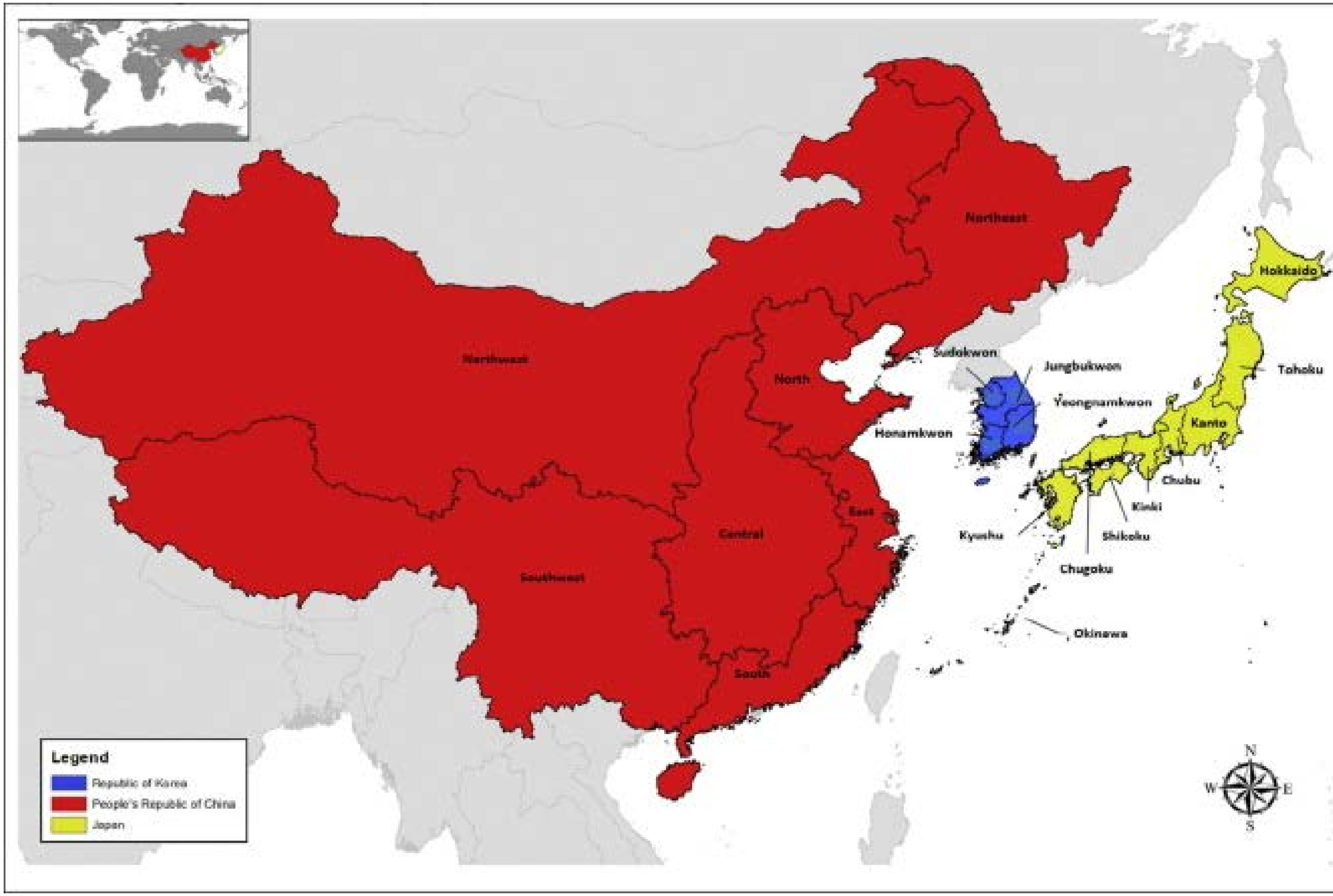
Spatial mismatch economic and biophysical data

Biophysical accounts are available at fine spatial scale



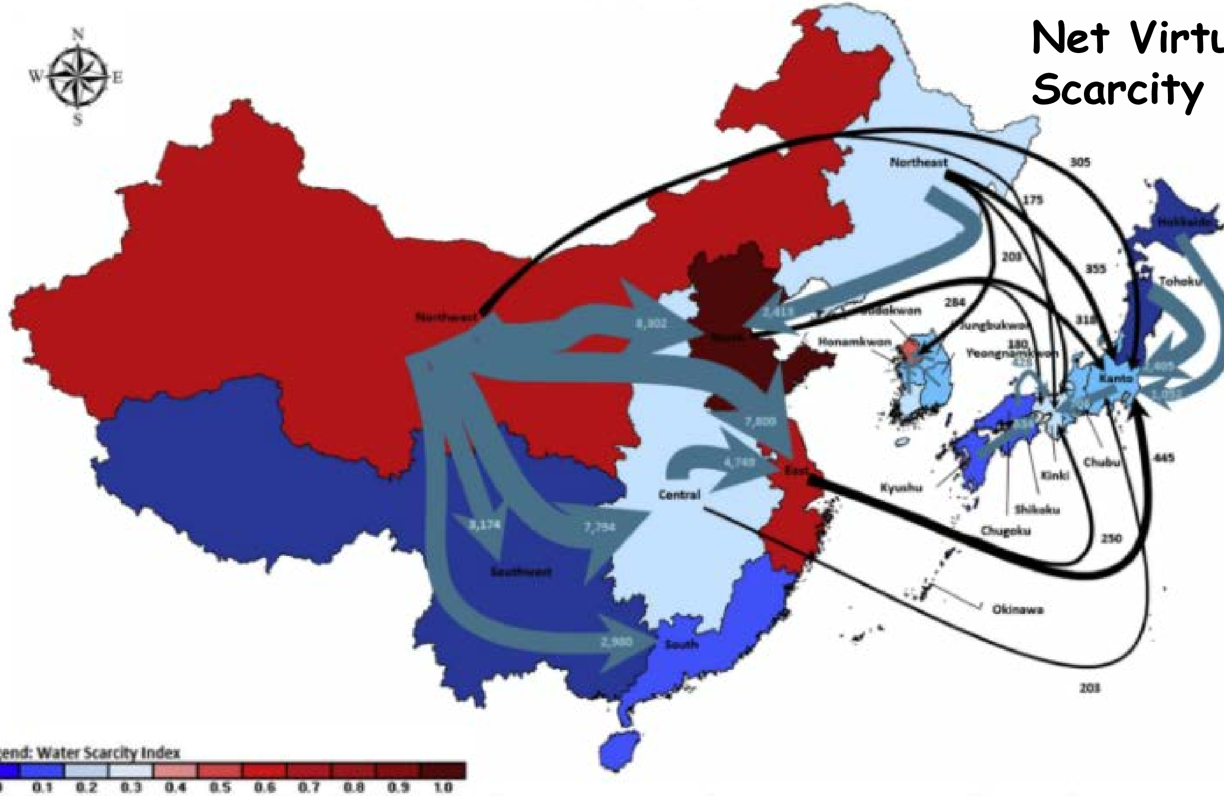
IIASA/FAO Land suitability and land productivity potential

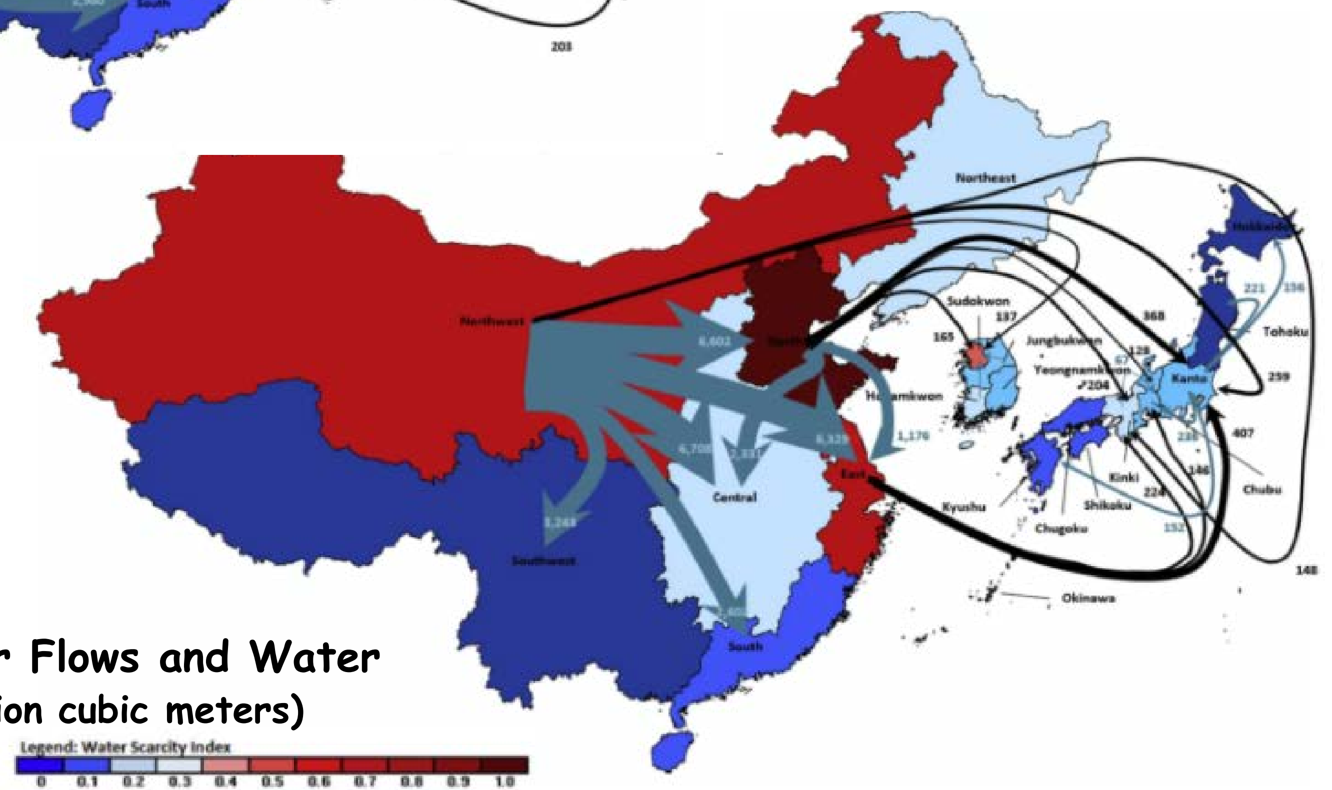
MRIO for subnational water, energy, food, GHG, SO_x flows



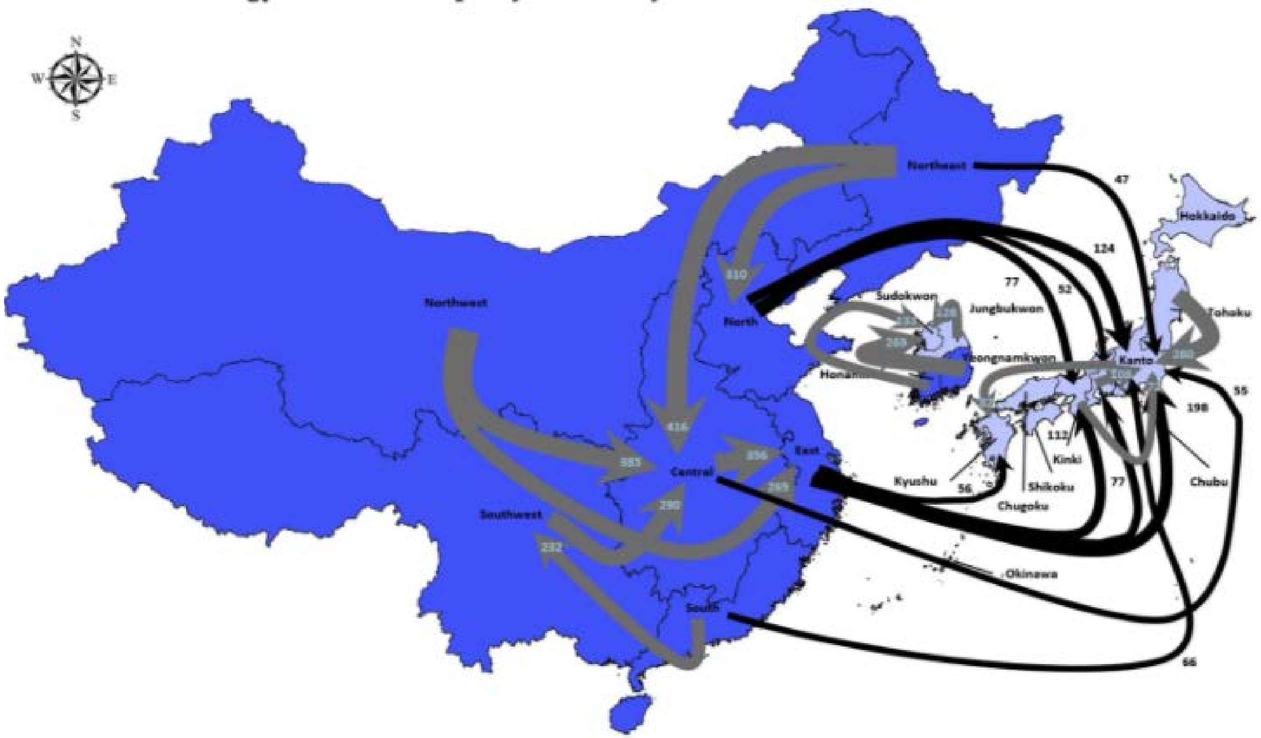
White, David and Klaus Hubacek*, Kuishuang Feng, Laixiang Sun, Bo Meng (In Press). The Water-Energy-Food Nexus in East Asia: A Tele-connected Value Chain Analysis Using Inter-Regional Input-Output Analysis. ***Applied Energy***.

Net Virtual Water Flows and Water Scarcity by Region (in million cubic meters)





Net Virtual Scarce Water Flows and Water Scarcity by Region (in million cubic meters)



Net Virtual Energy Flows
(in petajoules)

Net Virtual Agriculture Land Flows
(in thousand hectares)

Net Virtual Green House Gases Flows
(in ten thousand metric tons)

We see outsourcing of pollution and environmental pressure to China: E.g., Japan's consumption of textiles depends to 74% water, 79% energy, and 100% agriculture land from China.

In other words, Japan and South Korea externalize environmental impacts by importing low value added and pollution intensive commodities produced in China.

We see a similar pattern of outsourcing from rich to poor regions within China.

The nexus approach provides entry points in a defined economy to identify and manage tradeoffs between the (three) subsystems and across various spatial scales.

Net Virtual SO_x Flows
(in ten thousand metric tons)

Main scientific de… recent y…

New indicators

* many more environmental and social indicators
* pressure > impact > damage

Coupling of models

* physical/chemical process/transport models
* exposure / fate / life-cycle impact coupled with flows

Big data

linking models with novel data

Spatial resolution and crossing scales

spatial mapping and sub-national analysis linked within nested GMRIO

谢谢！

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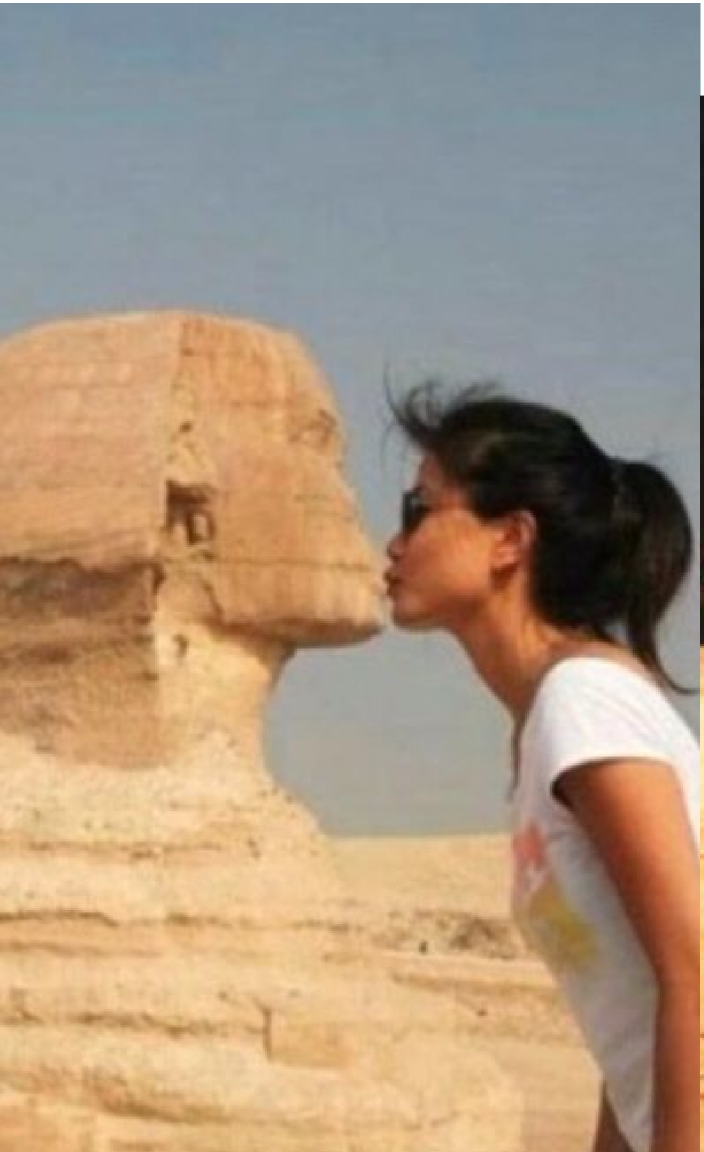
DEPARTMENT OF GEOGRAPHICAL SCIENCES

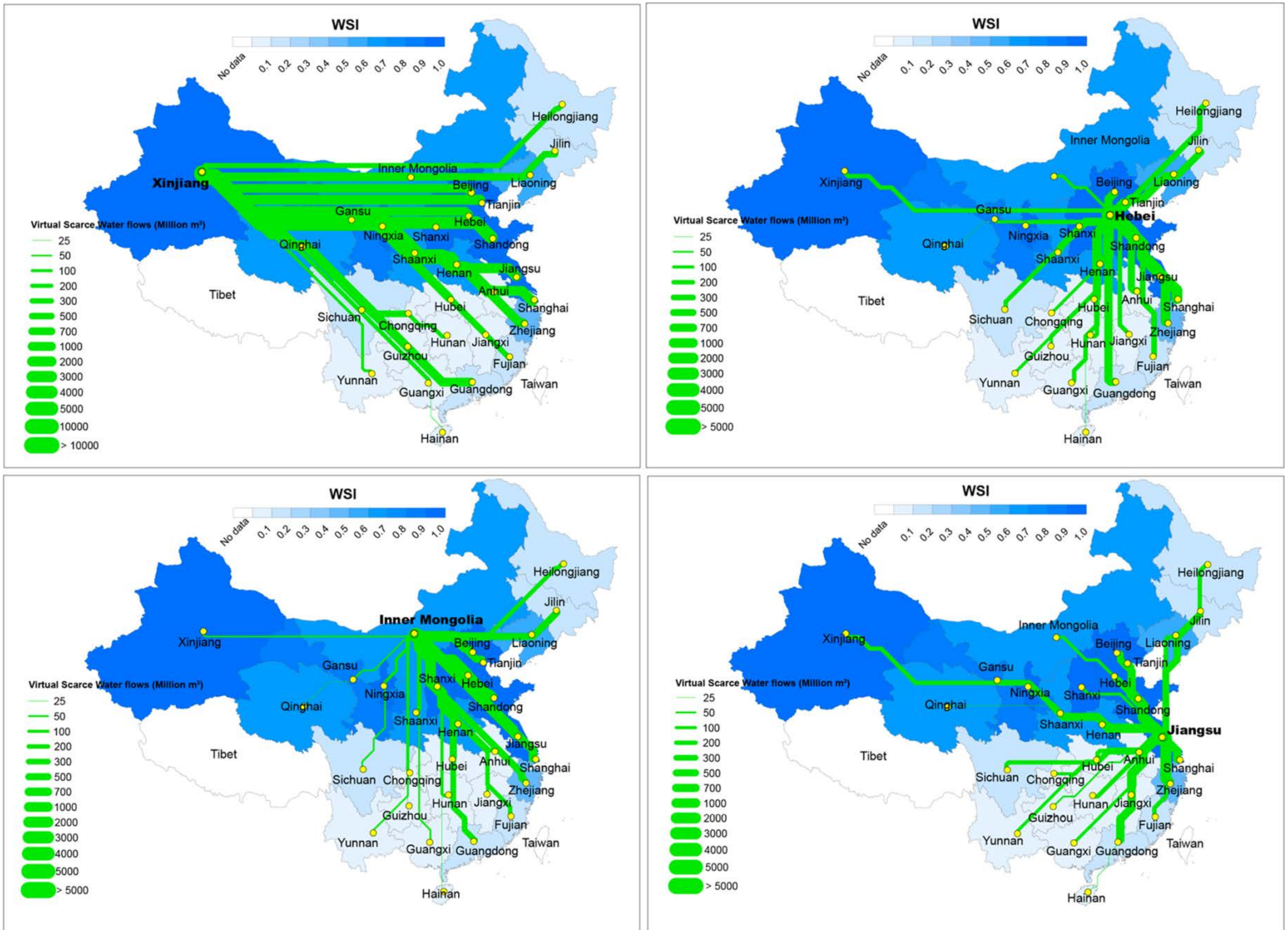
Additional Slides

Spatial mismatch – going subnational



Accounting for impacts

Virtual Scarce Water in China

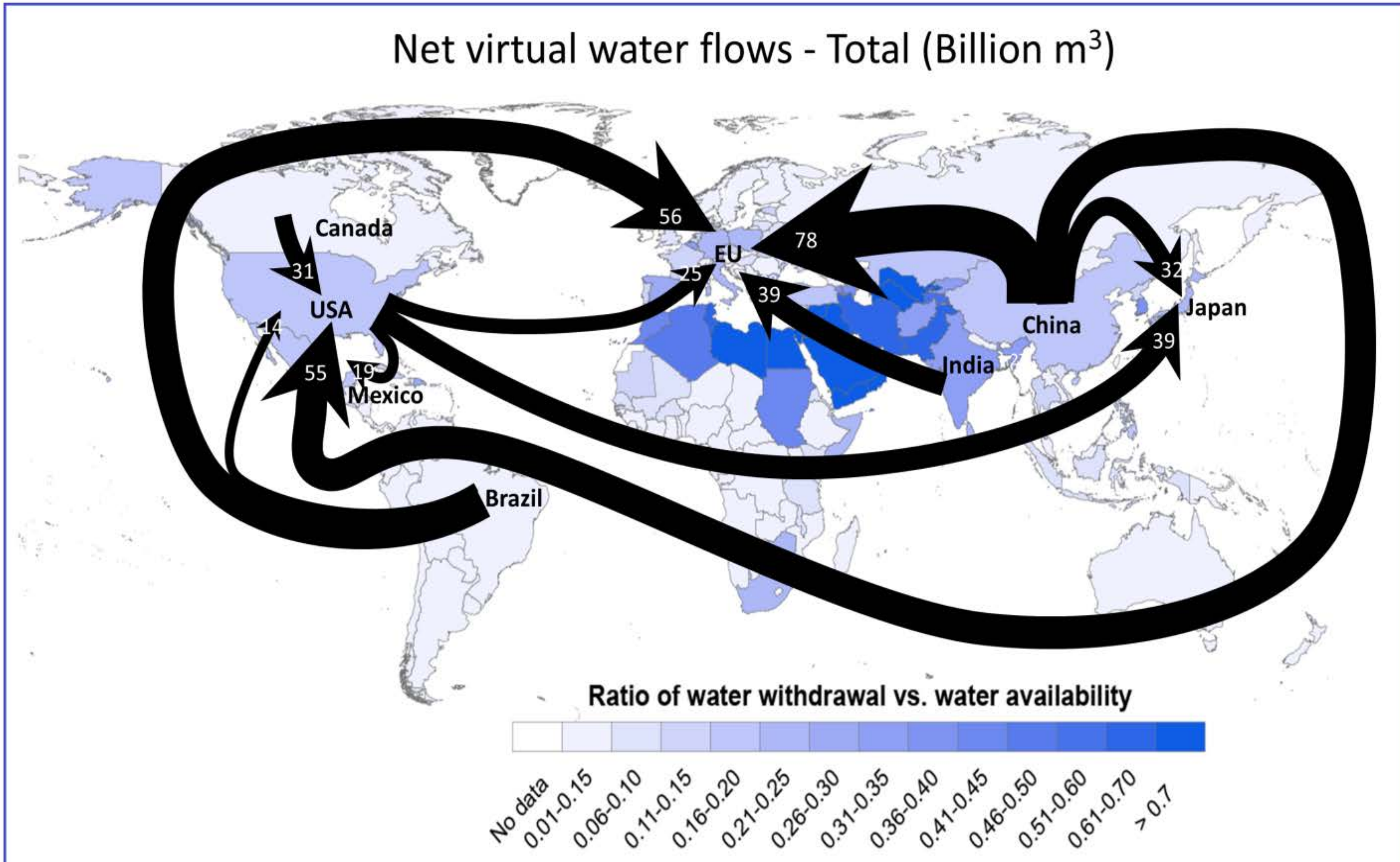


- Line 454: Our approach differs from the mainstream resource nexus literature in that we first quantify the economy-wide use of two resources, and then trace back their individual pathways through supply chains to quantify and categorize them. This contrasts with more traditional case study-based approaches which identify specific (inter)dependencies (e.g. water consumption in an energy-intensive sector) in a given context of resource scarcity, supply risk, etc. The value of our approach is that it helps to better understand the pathways leading to the simultaneous use of two or more resources from any given sector. For instance, whether such pathways relate to the use of resources on-site, through supply-chain dependencies or via reinforcing feedback loops.
- **(abstract): Interdependencies or feedbacks are generally thought to be relevant for the WEN, especially between water and energy sectors. Our economy-wide analysis for both countries indicates, however, that feedbacks neither play an important role in the WEN nor substantially take place between water and energy sectors. The most important feedbacks contribute to less than 1% of total resource use, and these take place mostly between manufacturing sectors. Overall, the studied WEN is mostly driven by dependent pathways and, to a lesser degree, direct resource use**.

Line 339: We find a generally consistent pattern across industries: pathways leading to the water-energy nexus become longer and more intertwined as supply chains grow in complexity. The water-energy nexus is often more evident in primary industries that require natural resources as factors of production, as resource use occurs on-site or in immediate suppliers. On the other hand, the water-energy nexus is less evident in manufacturing and service sectors, where most of the resource use takes place several steps upstream in their supply chain. This finding supports the conclusion of Li et al. (2012) and Okadera et al. (2015), who find supply chain effects to be important in the study of the water-energy nexus. In these cases, the residual accounts for a large share of the resource use, meaning that an important part of resource use is unknown as it takes place either in paths longer than ten steps and/or in multiple paths with little individual contribution (see section ‘Structural Path Analysis’).

- Line 362: Moreover, manufacturing, transport and service sectors in China describe longer paths for blue water with respect to the US. This can be explained by the relatively more intensive use of fertilizer in China (Li et al., 2013), which creates relevant water pathways in the manufacturing of a variety of food and clothing products, as well as services.

Global virtual water flows



Coupling MRIO model and GAEZ model

- Inputs from MRIO model to GAEZ

  -- future land requirement for food production and economic development

  -- future biofuel demand

  -- future water demand fro industrial production and services

- Inputs from GAEZ to MRIO

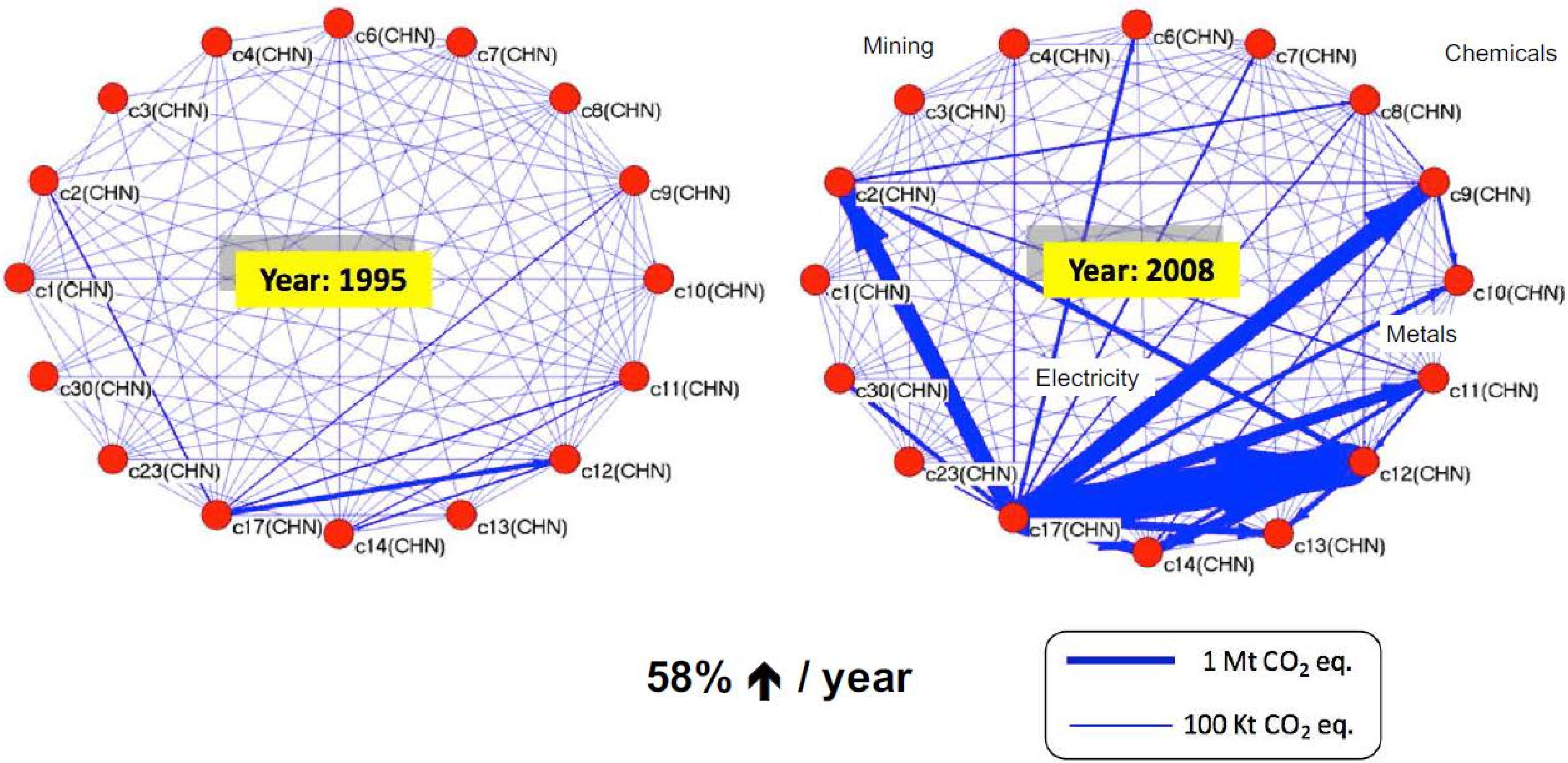
  -- sectoral land use

Moving from environmental accounts to environmental impacts

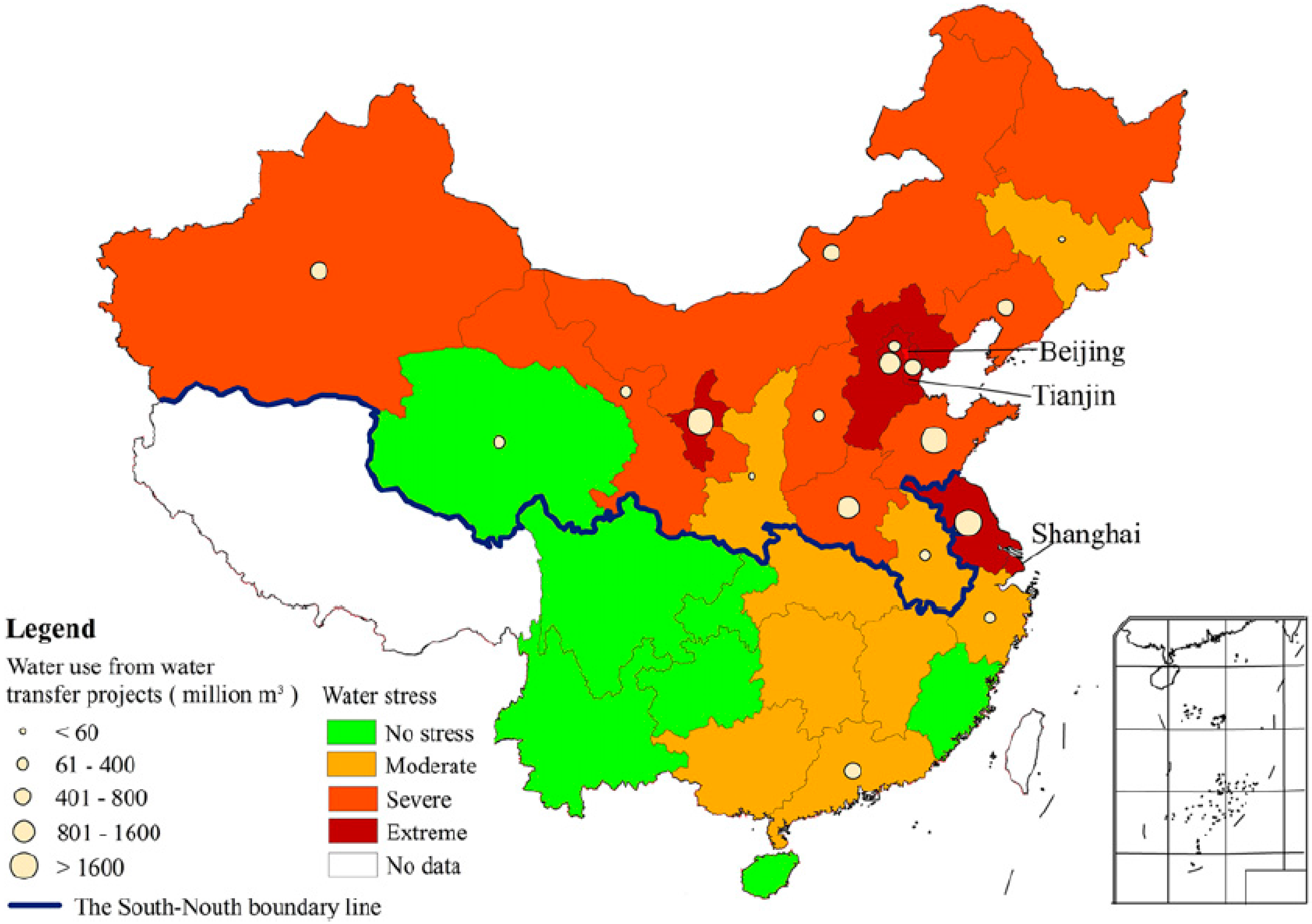
- Environmental footprints for countries, regions, and cities have been calculated for greenhouse gases, land, water, and a growing number of other environmental stressors, but often without quantifying the environmental impacts on local and regional ecosystems.
- Environmental indicators, such as water consumption and land use, can be weighted by a resource scarcity index, as well as emissions that can be characterized concerning their potential environmental or health damage.
- This is standard procedure in life cycle assessment but rarely seen in footprinting studies.

Interconnectivity

GHG emissions cluster in China induced by US demand in construction



Kagawa S, Suh S, Hubacek K et al (2015) CO2 emission clusters within global supply chain networks: Implications for climate change mitigation. *Global Environmental Change*, **35**, 486-496


Beijing
Tianjin
Shanghai
Legend
Water use from water transfer projects (million m³)
< 60
61 - 400
401 - 800
801 - 1600
> 1600
Water stress
No stress
Moderate
Severe
Extreme
No data
The South-Nouth boundary line

PNAS 2014

Environment vs. Economy

Global Agro-Ecological Zones (GAEZ) model

- GAEZ model is an integrated global assessment model for food security and sustainable agricultural resource use and development.
- It provides an integrated agro-ecological methodology.
- As well as a comprehensive global database for the characterization of climate, soil, and terrain conditions relevant to agricultural production
- It can be used to for assessing the regional and global land potential productivity in terms of net primary production (NPP), carbon sequestration bio-capacity, crop water requirements, and supply of food, feed, and fibers.

Integrated Impact Assessment

- **Food security**

-- future food demand and potential food shortage based on land suitability for land expansion

-- Impact of future biofuel production on food security

- **Energy Security**

-- water scarcity impact on electricity production

-- water scarcity and climate change impact on biofuel production

- **Water security**

-- Water stress from over-withdrawal water for economic development

-- Impact of future food production on water demand and local water scarcity.

-- Water consumption for electricity use and associated impact on scarcity

Most productive authors

Webber, ME (17 articles)	• Mechanical Engineering • The University of Texas at Austin
Chen, B (15)	• School of Environment • Beijing Normal University
Farid, AM (14)	• Mechanical Engineering • Dartmouth College
Stillwell, AS (11)	• Civil and Environmental Engineering • University of Illinois
Ringler, C (9)	• Agricultural Economics • International Food Policy Research Institute (IFPRI), Washington D.C.

Top manuscripts (>90 citations)

Considering the energy, water and food nexus: Towards an integrated modelling approach (2011)

- M Bazilian et al.
- Energy Policy, Volume 39, Issue 12, 2011.

The water–energy nexus in Middle East and North Africa (2011)

- A Siddiqi & L Diaz Anadon
- Energy Policy, Volume 39, Issue 8, 2011.

The water implications of generating electricity: water use across the United States based on different electricity pathways through 2050 (2012)

- J Macknick et al.
- Environmental Research Letters, Volume 7, Number 4, 2012.

Policy and Institutional Dimensions of the Water-Energy Nexus (2011)

- CA Scott et al.
- Energy Policy, Volume 39, Issue 10, 2011.

Sources

Environmental Research Letters

Impact factor: 4.404

5-Year Impact: 5.221

JCR® Category	Rank in Category	Quartile in Category
ENVIRONMENTAL SCIENCES	25 of 229	Q1
METEOROLOGY & ATMOSPHERIC SCIENCES	8 of 85	Q1

Journal of Cleaner Production

Impact factor: 5.715

5-Year Impact: 6.207

JCR® Category	Rank in Category	Quartile in Category
ENGINEERING, ENVIRONMENTAL	6 of 49	Q1
ENVIRONMENTAL SCIENCES	17 of 229	Q1
GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY	5 of 31	Q1

Water

Impact factor: 1.832

5-Year Impact: 2.056

JCR® Category	Rank in Category	Quartile in Category
WATER RESOURCES	34 of 88	Q2

International Journal of Water Resources Development

Impact factor : 2.088

5-Year Impact: 1.944

JCR® Category	Rank in Category	Quartile in Category
WATER RESOURCES	27 of 88	Q2

Applied Energy

Impact factor: 7.182

5-Year Impact: 7.500

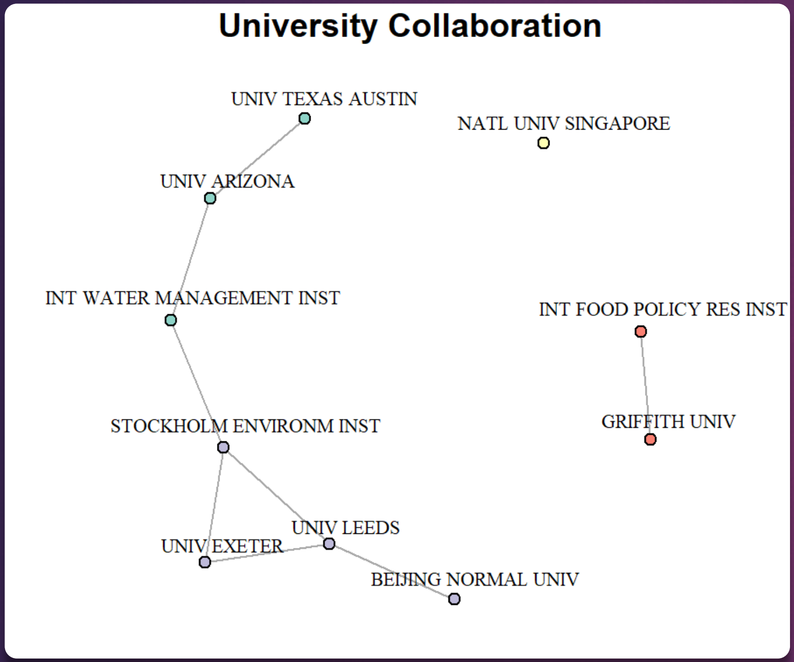
JCR® Category	Rank in Category	Quartile in Category
ENERGY & FUELS	6 of 92	Q1
ENGINEERING, CHEMICAL	4 of 135	Q1

Universities (top 10)

1. University of Texas at Austin, US (26)
2. Beijing Normal University, China (19)
3. Griffith University, Australia (12)
4. University of Arizona, US (12)
5. National University of Singapore (11)
6. University of Illinois, US (11)
7. University of Queensland, Australia (10)
8. Masdar Institute of Science and Technology, UAE (10)
9. University of Oxford, UK (10)
10. International Water Management Institute, Sri Lanka (10)

Summary-bibliometrics

- 200 Sources
- Only 13 articles between 2002 to 2010.
- Annual Percentage Growth rate up to 2016: 42%
- Authors per article: 2.6
- Top cited manuscript:
  - Considering the energy, water, and food nexus: Towards an integrated modelling approach by Bazilian, M. et al. (2011) *Energy Policy*. (>150 citations)
- While some nexus issues are mostly location-dependent (e.g. water use from constrained reservoirs), there is an explicitly global dimension as local constraints can be mediated by trade, as illustrated by virtual water trade and land use displacement. Moreover, most of the nexus literature focuses on particular industries, such as food and energy, where large quantities of natural resources are directly used. In consequence, those industries with no immediate resource implications or in which resource interdependencies reside across complex and global supply chains are overlooked.



University Collaboration

Summary-definitions

- Previously these systems have been dealt with in separation.
- The Nexus framework enables integrated approaches focusing on the linkages between socio-ecological systems and seeks comprehensive solutions (Liu et al., 2015).
- This framework allows to anticipate unforeseen consequences, identify trade-offs and co-benefits and find optimal solutions between competing interests.
- The water-energy nexus is often more evident in primary industries that require natural resources as inputs, such as agriculture, fuel extraction, and power generation, as resource use occurs on-site. On the other hand, the water-energy nexus is less evident in manufacturing and service sectors, where most of the resource use takes place several steps upstream in their supply chain.