

From *Analyzing* to *Forming* Agent Networks for Sustainability

Arnim Wiek

School of Sustainability, Arizona State University

Center for Complex Networks and Systems Research
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Understanding Complex Interactions

SCIENCE'S COMPASS • POLICY FORUM

POLICY FORUM: ENVIRONMENT AND DEVELOPMENT

Sustainability Science

Robert W. Kates, William C. Clark, Robert Corell, J. Michael Hall, Carlo C. Jaeger, Ian Lowe, James J. McCarthy, Hans Joachim Schellnhuber, Bert Bolin, Nancy M. Dickinson, Sylvie Fauchoux, Gilberto C. Gallopín, Arnulf Grubler, Brian Huntley, Jill Jäger, Narpat S. Jodha, Roger E. Kasperson, Akiko Mabuyuki, Pamela Matson, Harold Mooney, Berrien Moore III, Timothy O'Riordan, Uno Svedin

Merging fundamental human needs while preserving the life-support systems of planet Earth is the essence of sustainable development, an idea that emerged in the early 1980s from scientific perspectives on the relation between nature and society (1). During the late '80s and early '90s, however, much of the science and technology community became increasingly estranged from the preponderantly societal and political processes that were shaping the sustainable development agenda. This is now changing as efforts to promote a sustainability transition emerge from international scientific programs, the world's scientific academies, and independent networks of scientists (2).

Core Questions
A new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society. Such an understanding must encompass the interaction of global processes with the ecological and social characteristics of particular places and sectors (3). The regional character of much of what sustainability science is trying to explain means that relevant research will have to integrate the effects of key processes across the full range of scales from local to global (4). It will also require fundamental advances in our ability to address such issues as the behavior of complex self-organizing systems as well as the responses, some irreversible, of the nature-society system to multiple and interacting stresses. Combining different ways of knowing and learning will permit different social actors to work in concert, even with much uncertainty and limited information. With a view toward promoting the research necessary to achieve such advances, we propose an initial set of core questions for sustainability science (see the table on page 642). These are meant to focus research attention on both the fundamental character of interactions between nature and society and on society's capacity to guide those interactions along more sustainable trajectories.

Research Strategies
The sustainability science that is necessary to address these questions differs to a considerable degree in structure, methods, and content from science as we know it. In particular, sustainability science will need to do the following: (i) span the range of spatial scales between such diverse phenomena as economic globalization and local farming practices, (ii) account for both the temporal inertia and urgency of processes like ozone depletion, (iii) deal with functional complexity such as is evident in recent analyses of environmental degradation resulting from multiple stresses, and

(iv) recognize the wide range of outlooks regarding what makes knowledge usable within both science and society. Pertinent actions are not ordered linearly in the familiar sequence of scientific inquiry, where action lies outside the research domain. In areas like climate change, scientific exploration, and practical application must occur simultaneously. They tend to influence and become entangled with each other (5).

In each phase of sustainability science research, novel schemes and techniques have to be used, extended, or invented. These include observational methods that blend remote sensing with fieldwork in conceptually rigorous ways, integrated place-based models that are based on semiquantitative representations of entire classes of dynamic behavior, and inverse approaches that start from outcomes to be avoided and work backward to identify relatively safe corridors for a sustainability transition. New methodological approaches for decisions under a wide range of uncertainties in natural and socioeconomic systems are becoming available and need to be more widely exploited, as does the systematic use of networks for the utilization of expertise and the promotion of social learning (6). Finally, in a world put at risk by the unintended consequences of scientific progress, participatory procedures involving scientists, stakeholders, advocates, active citizens, and users of knowledge are critically needed (7).

Institutions and Infrastructure
Progress in sustainability science will require fostering problem-driven, interdisciplinary research, building capacity for this research, creating coherent systems of research planning, operational monitoring, assessment, and application, and providing reliable, long-term financial support. Institutions for sustainability science must foster the development of capacities ranging from rapid appraisal of knowledge and ex-

Global issues
Local issues

North
Old, rich nations
Affluence
"Global issues"
Resource surplus
Global climate change
Technological knowledge
Theoretical research

One divide
Young, poor nations
Poverty
"Local people"
Resource shortages
Impacts of climate change
Reduced knowledge
Action-driven research
South

Sustainability science within a divided world.

E. W. Kates, 33 Popple Point, Trenton, NJ 08605, USA; W. C. Clark and R. W. Kates, Kennedy School of Government, Harvard University, Cambridge, MA 02138, USA; C. Jaeger, American Meteorological Society, Washington, DC 20005, USA; J. M. Hall, National Oceanic and Atmospheric Administration, Silver Spring, MD 20910, USA; C. C. Jaeger and H. J. Schellnhuber, Potsdam Institute for Climate Impact Research, Potsdam, D-14473, Germany; I. Lowe, Griffith University, Nathan, QLD 4111, Australia; J. McCarthy, Harvard University, Cambridge, MA 02138, USA; B. Bolin, Stockholm University, Stockholm, S-14045, Sweden; S. Fauchoux, Centre d'Économie et d'Éthique de Versailles, Guyancourt 78047, France; G. C. Gallopín, Comisión Nacional para el Desarrollo de los Recursos Humanos, Santiago, Chile; A. Grubler, International Institute for Applied Systems Analysis, Vienna 2361, Austria; B. Huntley, National Botanical Institute, Cape Town 7701, South Africa; J. Jäger, International Human Dimensions Programme on Global Environmental Change, Bonn D-53115, Germany; N. S. Jodha, International Centre for Integrated Mountain Development, Kathmandu, Nepal; R. E. Kasperson, Stockholm Environment Institute, Stockholm 103 14, Sweden; A. Mabuyuki, Development Policy Centre, Sydney, Australia; P. Matson and H. Mooney, Stanford University, Stanford, CA 94305, USA; B. Moore III, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH 03824, USA; T. O'Riordan, Centre for Social and Environmental Research on the Global Environment, University of East Anglia, Norwich NR4 7TU, UK; Uno Svedin, Swedish Council for Planning and Coordination of Research (PNC), Stockholm, S-10037, Sweden.

*To whom correspondence should be sent. E-mail: william_kates@harvard.edu

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Pushing Networks to the Limit

New model army, janjawed fighters interact with many other groups in a model of the Darfur conflict.

complex-systems researchers have made solid contributions in the study of traffic, epidemiology, and economics. Some are now tackling more daunting problems, such as the emergence of social norms.

"The problems are more complicated than most natural scientists assume, but less hopeless than most social scientists think," says Dirk Helbing, a physicist turned sociologist at the Swiss Federal Institute of Technology Zurich (ETHZ). Overcomplication is a risk. "In some fields, physicists have a bad reputation for applying the laws of physics directly to cases in which it may not fit the facts," says Stephen Eubank, a physicist at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg who models epidemics.

Nevertheless, physicists and social scientists are working together on increasingly nuanced and realistic models. Helbing says. The complex-systems approach could help avert—or at least explain—systemic crises such as the current global economic meltdown, he says. "We spend billions of dollars trying to understand the origins of the universe," Helbing says, "while we still don't understand the conditions for a stable society, a functioning economy, or peace."

Complex is as complex does. Scientists can't say exactly what a complex system is in the same way they can define an atom or a gene. Rather, they tend to describe how a complex system looks and behaves. "If you ask a biologist, 'What is life?'" he will give you a list of characteristics. He probably won't give you a strict definition," says Inge Simonsen, a physicist at the Norwegian University of Science and Technology in Trondheim. "It's similar with complex systems."

First off, a complex system consists of many elements that interact so strongly that they tend to organize themselves in one way or another. This "emergent behavior" makes the group more than the sum of its parts. A car may be complicated, but it is not a complex system, as each of its parts interacts with a few others in a predictable way. That can be traffic from a complex system, as drivers' jockeying for position can lead to surprises such as a "phantom" traffic jam that arises for no obvious reason.

Complex systems also tend to be unpredictable. A tiny change among the pieces may lead to a big swing in the behavior of the whole

NEW

Ourselves and Our Interactions: The Ultimate Physics Problem?

In the field of complex socioeconomic systems, physicists and others analyze people almost as if they were interchangeable electrons. Can that approach decipher society and what ails it?

ZÜRICH, SWITZERLAND—Janine Helyst sounds frustrated. "When I look to the textbooks on emotion, there are no numbers, there are no equations," laments the theoretical physicist from the Warsaw University of Technology. Helyst hopes to supply what the books are lacking, however. He aims to develop the tools to analyze emotions quantitatively. Then he intends to use them to literally read your feelings.

With €3.6 million of support from the European Commission, Helyst and eight colleagues aim to develop a computer program that can analyze dialogue from Internet chat rooms and tell when people are growing excited, angry, and so on. Flagggingly words isn't enough, he says, because people use language differently. Some, for example, curse regardless of their mood. Ultimately, Helyst hopes to decipher group emotion, such as the euphoria that pervades a stadium full of sports fans when the home team wins. "There are tons of models of opinion formation," he says, "but there are no models of emotion."

Helyst is one of a small but growing number of physicists who are turning from atoms and electrons to study social phenomena such as terrorism, the growth of cities, and the popularity of Internet videos. Joining with social scientists, they treat groups of people as "complex socioeconomic systems" of many interacting individuals and analyze them using conceptual tools borrowed from physics, mathematics, and computer science. Last month, 130 researchers of various stripes gathered here to discuss such work.

Pongys into "sociophysics" began in the early 1970s. Physicists proposed, for example, that individuals interact to form public opinion much as neighboring atoms make a crystal magnetic by aligning their magnetic fields; researchers analyzed the social phenomenon by adapting the Ising model used to describe such magnetic interactions. In the 1990s, many physicists turned to economics in the controversial hubfield of econophysics (see sidebar, p. 406). Now, the movement seems to be gathering momentum, at an international Workshop on Coping with Crises in Complex Socio-Economic Systems, 8–12 June 2009.

Online
science.mag.org
Podcast interview with author Adrian Cho.

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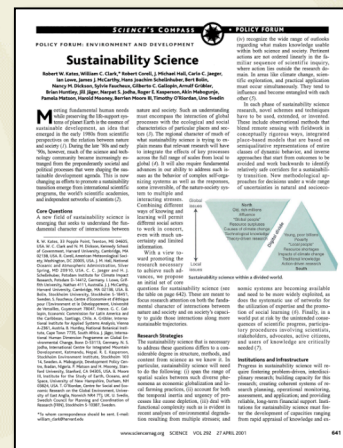
Kates et al., 2001, Science, 292, 641-642

Cho, A., 2009, Science, 325, 406-408

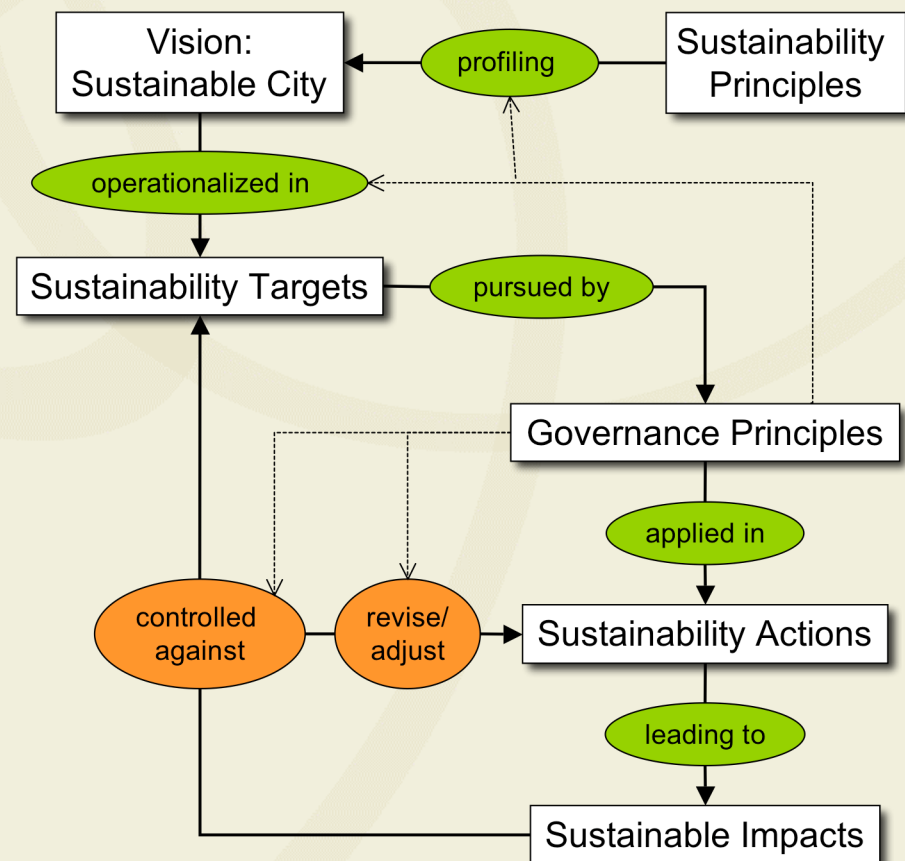
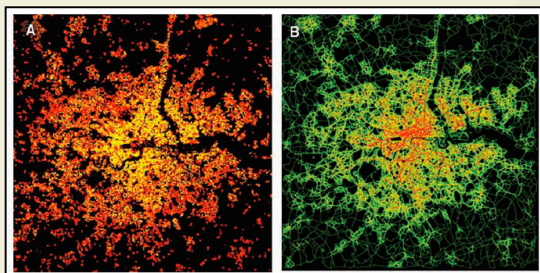
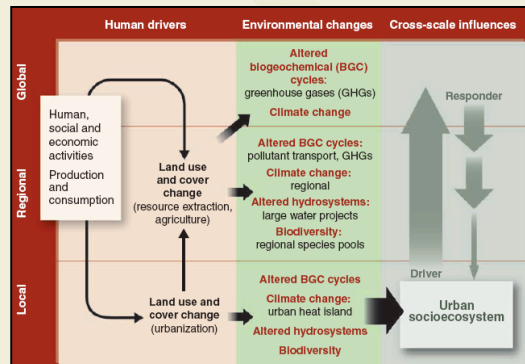
A Transformative Agenda

“Pertinent actions are not ordered linearly in the familiar sequence of scientific inquiry, where action lies outside the research domain. In areas like climate change, scientific exploration, and practical application must occur simultaneously. They tend to influence and become entangled with each other”.

“Participatory procedures involving scientists, stakeholders, advocates, active citizens, and users of knowledge are critically needed”.



Sustainability Research & Problem-Solving



Moving Agent Network Analysis “Downstream”

From: “ How are agent networks constituted and structured?”

To: “What are critical constellations in agent networks and how should agent networks be formed to support sustainability?”

Studies

- Study on Agent Networks of Nanotechnology
 1. Study on National Strategy for Sustainable Development
 2. Study on Water Governance

Reference Points

Elinor Ostrom's work on failures, successes, and design principles for collective action on common resources

Brian Wynne's work on public involvement (co-construction) of technology

Not a Problem ... Yet!

Nanotechnology

- Emerging technology
- Risk indications
- Public debate
- ‘Collingridge dilemma’



COMMENTARY

Scientists worry about some risks more than the public

DIETRAM A. SCHEUFELE^{1*}, ELIZABETH A. CORLEY², SHARON DUNWOODY³, TSUNG-JEN SHIH⁴, ELIOTT HILLBACK² AND DAVID H. GUSTON⁴

¹ is in the Department of Life Sciences Communication, University of Wisconsin-Madison, 440 Henry Mall, Madison, Wisconsin 53706, USA; ² is the School of Public Affairs, Arizona State University, 411 North Central Avenue, Phoenix, Arizona 85004, USA; ³ is the School of Journalism & Mass Communication, University of Wisconsin-Madison, 621 University Avenue, Madison, Wisconsin 53706, USA; ⁴ is the Department of Political Science, Arizona State University, PO Box 874421, Tempe, Arizona 85287, USA.
*e-mail: scheufele@wisc.edu

A comparison between two recent national surveys among nanoscientists and the general public in the US shows that, in general, nanoscientists are more optimistic than the public about the potential benefits of nanotechnology. However, for some issues related to the environmental and long-term health impacts of nanotechnology, nanoscientists were significantly more concerned than the public.

In previous controversies surrounding emerging technologies, such as nuclear energy and food biotechnology, scientists, in most cases, perceived lower risks associated with these new technologies than the general public or the journalists covering these stories. These findings seem to hold in both the US and Europe^{1,2}, and most recently, an exploratory comparison of a quota sample of 375 lay people and a convenience sample of 46 experts in Switzerland suggested that the same pattern is beginning to emerge for nanotechnology as well³.

However, two large-scale systematic data collections in the US now show that the dynamics surrounding risk perceptions of nanotechnology among members of the general public and nanoscientists shape up to be much more complex than for previous issues. In particular, historical patterns of the difference between the perceptions of scientists and the general public of risks may be reversed for nanotechnology.

We collected survey data from both lay individuals and nanotechnology scientists. Both surveys used questions with identical wording, providing a unique opportunity for systematic comparisons across two large-scale, national data sets. The first data source

was a general population telephone survey of 1,015 US adults; the second data source was a mail survey of 363 nanotechnology scientists and engineers. The fieldwork was conducted from May to July 2007 for the public opinion survey, and from May to June 2007 for the scientist survey (see Methods).

Not surprisingly, scientists were generally more optimistic about the benefits and less concerned about the risks of nanotechnology than the general public. For example, scientists were more optimistic about the potential for nanotechnology to lead to breakthroughs in medicine, environmental cleanup or national defence (Fig. 1a). Members of the general public, in contrast, were more concerned about potential drawbacks of nanotechnology than scientists, including the potential loss of privacy or adverse economic impacts (Fig. 1b).

However, scientists expressed more concern than the general public about two areas of potential risks: more pollution and new health problems as a result of nanotechnology. This makes nanotechnology unusual among emerging technologies in that scientists working directly with the technology express stronger concerns about specific potential risk areas than the general public does.

These differences in risk perceptions between scientists and the general public for nanotechnology can be explained to some degree by how the issue has evolved, both in scientific circles and in the public debate. In particular, the fact that scientists are more concerned about new health problems and potential pollution than the general public should not be too surprising for at least two reasons.

First, there has been an ongoing debate in science and policy circles about a lack of systematic nano-related risk research in both academia and business⁴. Although many of these discussions were initially driven by specific toxicological concerns, similar concerns are now being voiced more broadly. In 2006, for instance, the Royal Society and the Royal Academy of Engineering in the UK recommended an expansion and standardization of research on the environmental, health and safety (EHS) impacts of nanomaterials⁵. Similarly, concerns about these have been the subject of public hearings in the US, organized by the Food and Drug Administration and, most recently the Environmental Protection Agency⁶.

Second, and somewhat related, interest groups in the US have pushed for specific regulations and safety procedures for new nano-enabled products. For

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Scheufele et al., 2007, *Nature Nanotechnology*, 2, 732-734

Research Design

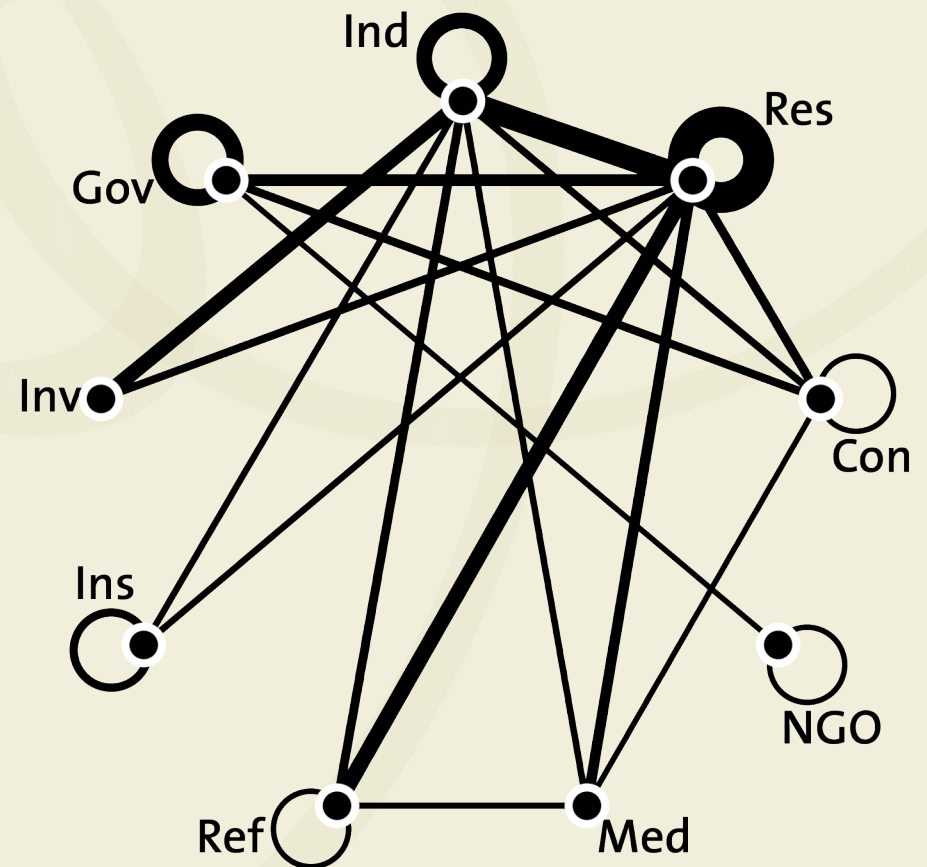
Table 5
Number of agents and key agents of nanotechnology in Switzerland (interviewees $n = 47$, multiple entries allowed)

Agent category	Number of agents		Key agents
	Mentioned	Mentioned ≥ 4 times	
Industry	54	7 →	Bühler AG, Ciba Specialty Chemicals, F. Hoffmann-La Roche, IBM, Ilford, Nanosurf, Novartis
Consultants	15	3 →	The Innovation Society, Foundation Risiko-Dialog, Centre for Technology Assessment TA-SWISS
Insurers	6	1 →	*
Investors	6	0	
Public research institutes	27	10 →	Swiss Center for Electronics and Microtechnology (CSEM), Swiss Federal Laboratories for Materials Testing and Research (EMPA), Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Federal Institute of Technology (ETH Zurich), Paul Scherrer Institute (PSI), Universities of Basel, Bern, Zurich, Geneva, Neuchâtel.
Government regulatory agencies	24	3 →	Federal Office for the Environment (BAFU), Federal Office of Public Health (BAG), State Secretariat for Economic Affairs (SECO)
Government research funding agencies	6	3 →	Commission for Technology and Innovation (KTI), Swiss Academy of Engineering Sciences (SATW), Swiss National Science Foundation (SNSF)
Non-Government Organizations (NGOs)	7	2 →	Greenpeace, WWF Switzerland
Media	26	2 →	Neue Zürcher Zeitung (NZZ), Tages-Anzeiger
Others	1	0	
Total	172	31	

*Because of the small sample in this agent category (see Section 4.1.2), we do not name this key agent due to the de-personalization code.

Agent Network Relations

	<i>Ind</i> (<i>N</i> =10)	<i>Con</i> (<i>N</i> =8)	<i>Ins</i> (<i>N</i> =2)	<i>Inv</i> (<i>N</i> =2)	<i>Res</i> (<i>N</i> =8)	<i>Gov</i> (<i>N</i> =4)	<i>Ref</i> (<i>N</i> =4)	<i>NGO</i> (<i>N</i> =4)	<i>Med</i> (<i>N</i> =5)
<i>Ind</i> (<i>N</i> =10)	2.8								
<i>Con</i> (<i>N</i> =8)	1.3	1.0							
<i>Ins</i> (<i>N</i> =2)	1.2	!	1.5						
<i>Inv</i> (<i>N</i> =2)	2.7	!	!	!					
<i>Res</i> (<i>N</i> =8)	4.2	1.6	1.2	1.5	5.4				
<i>Gov</i> (<i>N</i> =4)	!	1.5	!	!	2.1	3.0			
<i>Ref</i> (<i>N</i> =4)	1.6	!	!	!	2.8	!	1.0		
<i>NGO</i> (<i>N</i> =4)	!	!	!	!	!	1.0	!	1.0	
<i>Med</i> (<i>N</i> =5)	1.2	1.0	!	!	1.9	!	1.1	!	!

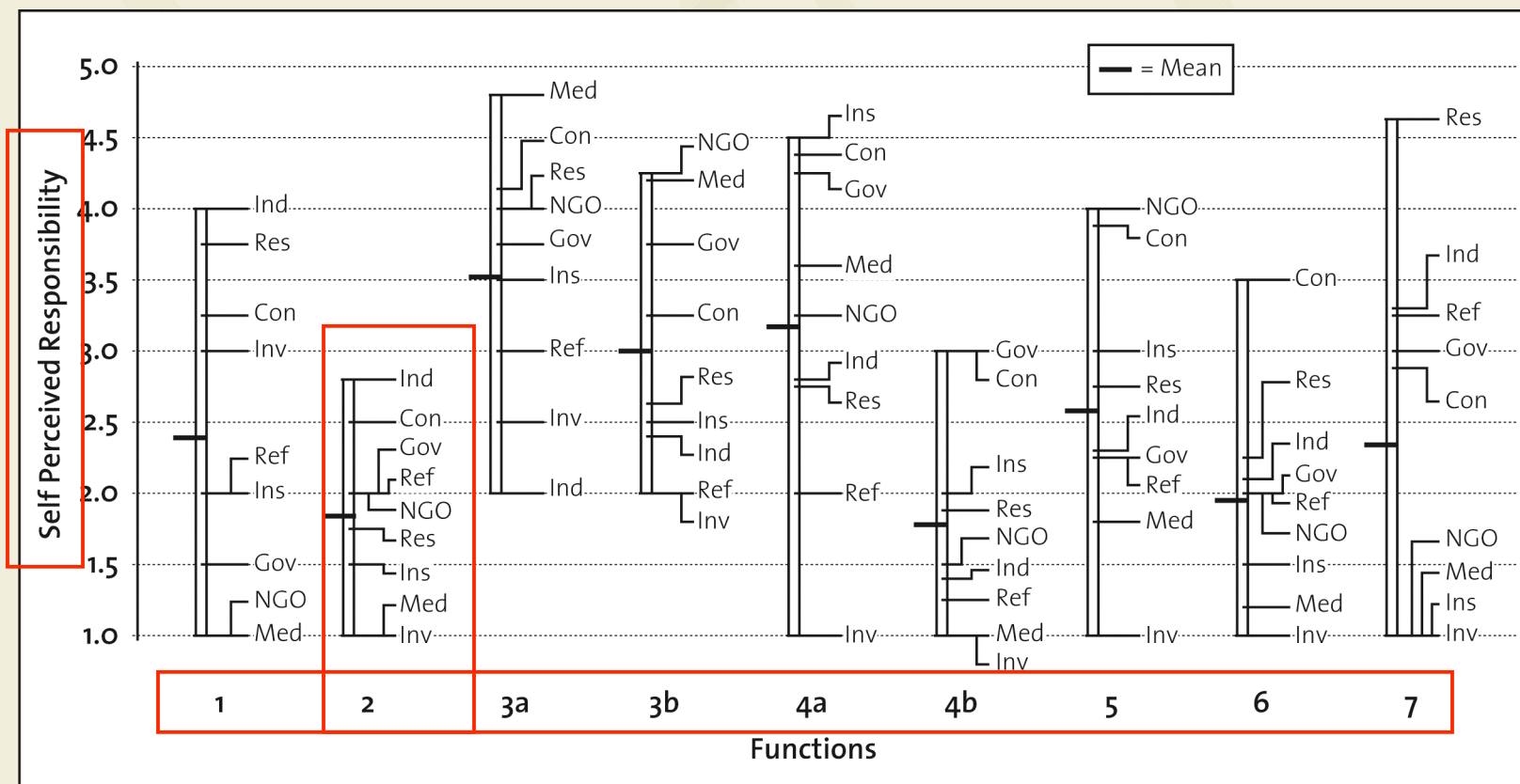


Agent Roles

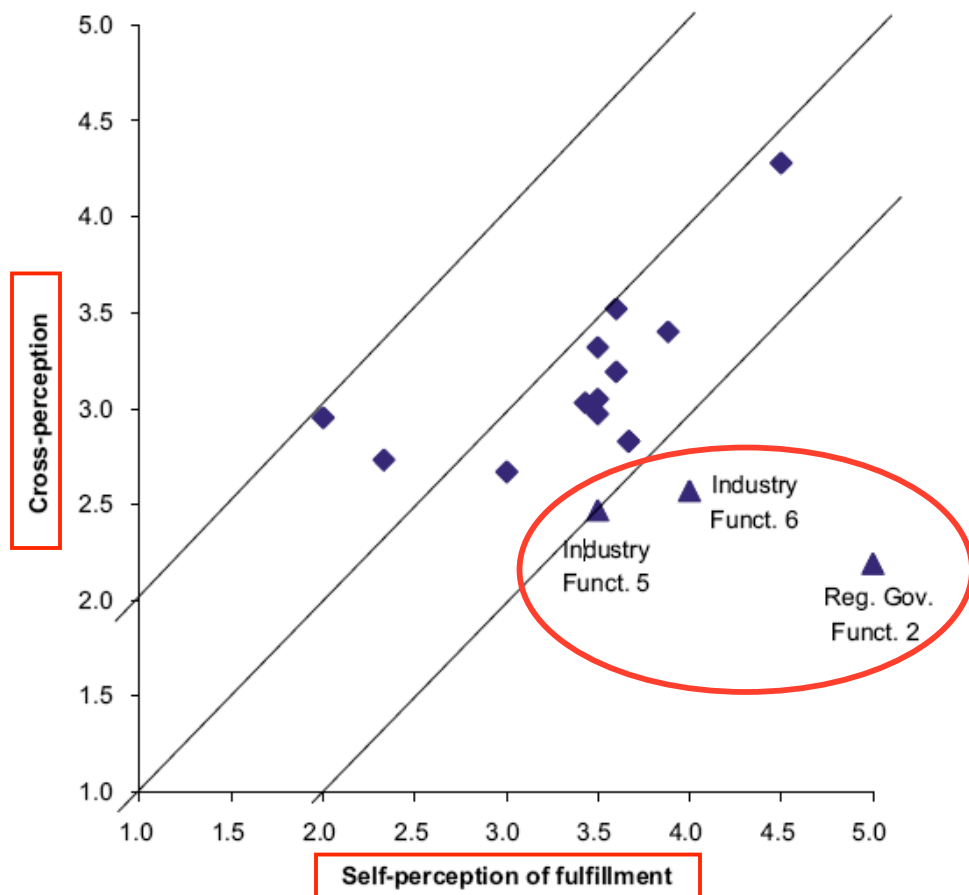
Table 2
Set of agents' functions/roles in sustainable technology governance

Field of sustainable governance (Fig. 1)	Function/role
1 Economic	To generate profits from applying available knowledge and realizing market potential of the emerging technology
2 Economic-social	To monitor potential hazards at workplaces
3a Social/institutional	To inform the public about research results, opportunities and risks of the emerging technology
3b Social/institutional	To ensure that opinions and concerns of the public are seriously taken into account
4a Social-environmental	To assess risks of the emerging technology for humans and the environment
4b Social-environmental	To regulate the emerging technology concerning human health (norms, instructions, thresholds)
5 Environmental	To ensure that environmental aspects are seriously taken into account in R&D, production, consumption, and regulation
6 Environmental-economic	To promote the sustainable usage of resources along the life-cycle of the emerging technology and its applications
7 Environmental-economic-social	To publicly fund, or conduct publicly funded research on integrated sustainability issues of the emerging technology

Agent Responsibilities



Cross-Perceptions



Function	Agent	Self	Entries	Cross	n
1	Ind	3.9	>50%	3.4	35
2	Gov	5.0	25%	2.2	36
3a	Res	3.4	>50%	3.0	38
3a	NGO	2.3	>50%	2.7	37
3a	Med	3.6	>50%	3.5	42
3b	Gov	3.7	>50%	2.8	29
3b	NGO	3.7	>50%	2.8	23
3b	Med	3.6	>50%	3.2	26
4a	Gov	3.5	>50%	3.0	29
4a	Ins	3.5	>50%	3.3	22
4b	Gov	3.0	50%	2.7	27
5	NGO	2.0	>50%	3.0	19
5	Ind	3.5	20%	2.4	17
6	Ind	4.0	20%	2.6	28
7	Res	4.5	>50%	4.3	39

Critical Constellations

1. Key agents missing
2. Lack of connectivity
3. Important functions not assigned (roles)
4. Divergences in assigned roles
5. Insufficient fulfillment of roles
6. Divergences in perceived fulfillment

Publications

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The Next Step – Water Governance in Phoenix



Indoors 78

- toilet** flushes gal/flush
- clothes washing** loads gal/load
- showers** min gal/min
- baths** gal
- faucet** min gal/min
- leaks** drips/sec
- other domestic** gal/day
- dish washing** loads gal/load

[Reset to current demand](#)

Outdoors 146

Density of urban expansion

Non-desert landscaping

Pools

[Reset to current demand](#)

Conclusions

1. Agent Network can contribute to the *transformative* agenda of sustainability science.
2. The *normative* component of this research is based on transparent criteria (societal discourse, expert opinions, meta-studies).
3. How far “moving downstream”? Constructing and *creating* networks!