On knowledge generation and use for sustainability

In order to address sustainability challenges, we posit that knowledge generation needs to move rapidly from a disciplinary linear 'tree' model to an interdisciplinary 'web' model. We show how such a shift is useful by looking at case studies in the context of water management.

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Sustainability relevant research is rapidly evolving with focus on the interactions among natural, social and engineering systems. It found impetus in the concept of sustainable development — formally introduced in 1987 by the World Commission on Environment and Development[1] — and has gone through continued refinement and strengthening thanks also to the efforts of the United Nations, most recently through the *2030 Agenda for Sustainable Development*[2]. The UN Sustainable Development Goals (SDGs) are the global community's response to the urgent sustainability challenges of our time. To achieve the SDGs, here we offer a perspective on how sustainability relevant knowledge could be generated to find solutions to complex problems, with examples from the water domain.

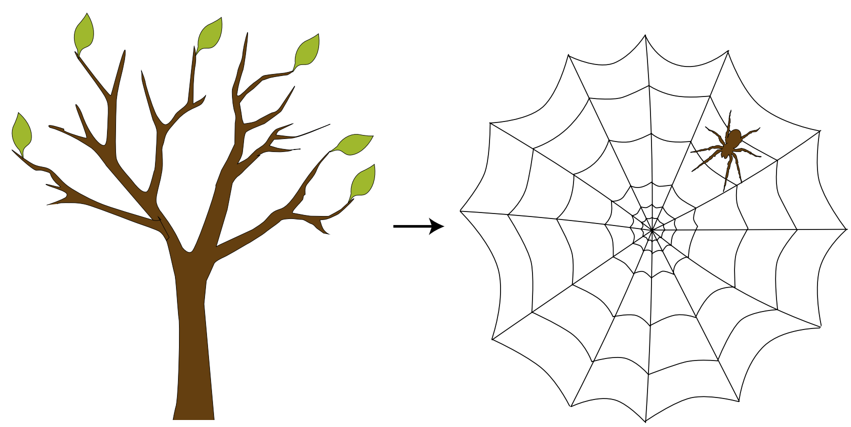

Fig. 1 | Paradigm shifts for sustainability relevant research from a tree-like to a web-like approach to knowledge generation.

A different knowledge generation model

The way knowledge is generated, integrated and disseminated co-evolved with advancements in science and technology. By the 17th century, the invention of the printing press had made books less expensive, facilitating the broader dissemination of knowledge and stimulating scientific advancement. Following the Industrial Revolution, scientific enterprise expanded through the proliferation of scientific publications, resulting in the categorization of scientific endeavours into sub-specialties, and sub-sub-sub specialties. The dominant metaphor illustrating this type of organizational strategy of science is a tree, in which disciplines are represented as limbs and sub-disciplines as branches, with the individual specialists as leaves at the end of their disciplinary twigs. The 'tree model' was first proposed in the Dewey Decimal Classification system in 1873 and was later adopted by libraries worldwide.

The Industrial Revolution improved the living conditions of many, but combined with other factors, industrial growth has resulted in several complex planetary challenges including water scarcity, climate change, pollution and biodiversity loss[3]. These challenges are complex and interconnected and as a result cannot be addressed by individual disciplines operating in silos[4]. We need to move away from disciplinary and linear approaches to knowledge generation, and embrace interdisciplinary approaches to conceptualizing questions, generating knowledge and developing solutions[5]. Thus, in our view the tree model, where researchers stay within their disciplines to establish a scholarly reputation, should be replaced with a 'web' model (Fig. 1), in which researchers weave knowledge between the disciplinary branches and build on the connections across disciplines to develop solutions.

Water as a case study

Managing water resources is at the heart of some of the most urgent challenges of the Anthropocene[6]. Water drives and maintains ecosystem functions, plays a critical role in socio-economic development and is essential to human survival. Problems surrounding water management often involve stakeholders with conflicting and competing values, as well as goals and survival needs that span multiple physical, political and jurisdictional boundaries[7].

Historically the 'tree model' has been useful for understanding and solving specific and localized problems. For example, when London was confronted by a deadly cholera epidemic in the 19th century, John Snow traced the disease back to a single contaminated well. The corresponding solution was centralized water treatment and distribution, which led to the creation of a new discipline called sanitary engineering (later, called environmental engineering). Yet, this engineered solution would now be insufficient to address current environmental issues, because such issues transcend localities and political boundaries and involve multiple nonlinear interactions between human agency and environmental processes[8]. Successful water management should consider the interconnections between human and natural systems[8], and the kind of knowledge

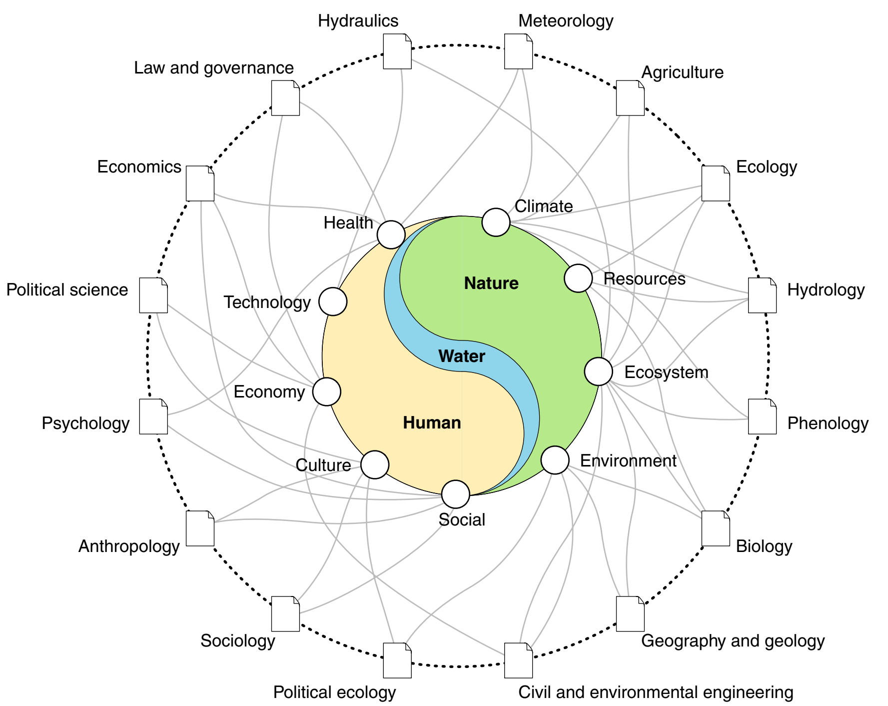

Fig. 2 | Schematic illustration of a web-based approach for research on water sustainability.

we need in order to manage water resources sustainably straddles multiple disciplines such as hydrology, ecology, public health, sociology, psychology, meteorology and so on. In our view, a web model of knowledge generation would best suit current needs in water management (Fig. 2). Cooperation is essential in order to address many issues, such as water scarcity adaptation, water allocation policy and upstream and downstream impacts of water pollution.

China's restoration project for the Heihe River Basin (HRB) presents an example of how a web model works in practice. The HRB is China's second largest inland river basin located in the arid and semi-arid northwest, and is an important source of the terminal Juyan Lake, a water body critical for supporting the oasis in surrounding areas. The lake became dry in 1992, and degradation of the lake not only led to a decrease in oasis coverage, but also made the lake bank a potential source of dust pollution for regions thousands of kilometres away, for example, the city of Beijing. Early investigation of the HRB problems followed the tree model; prior to the 1990s, disciplinary research dominated the study of the hydrological processes, agricultural water use and so on. But such research did not help reverse the trend of ecological degradation; the degradation of the lake made researchers and policymakers realize that the knowledge produced from this model was insufficient. Interdisciplinary investigation emerged in early 1990s, and an interdisciplinary collaborative research team from several different institutions was formed in 1995 to investigate the driving forces for the drying-up of the Juyan Lake. Experts in hydrology and social development collaborated with ecosystem health experts to shed light on the phenomenon[9]. The amalgamation of efforts was invaluable to understanding that the route of the downstream lake degradation problem was mostly the increased water consumption in middle streams where agriculture had expanded[10]. This new interdisciplinary knowledge led to a transdisciplinary effort with researchers and central and local governments working together to co-design research to identify ways to use water resources more sustainably across the entire river basin.

One outcome of the 1995 collaboration effort was the proposal of a water allocation scheme, which the central government accepted in 2000. As a result, a water diversion intervention asking for a minimum water release from the middle to lower stream was implemented, which played an important role in improving the ecological environment in the coming years. In 2010, the National Natural Science Foundation of China launched a 200 million Chinese Yuan research programme on integrated research on the eco-hydrological processes of the Heihe River Basin to explore the interrelationships among water, ecosystems and the economy[11,12]. Researchers from dozens of institutes have been involved in the programme with backgrounds ranging from hydrology, ecology, environmental science and climate sciences to economics and law.

The shift towards an interdisciplinary, solution-oriented approach has played an important role in restoring the degraded ecosystems in the Heihe River Basin, expanding the surface area of the Juyan Lake[11] and increasing ground water levels in downstream areas. The research and management practice in the HRB has fostered sustainability in other arid and semi-arid river basins in China[11], for example, the implementation of a pilot project by the Chinese Academy of Sciences for the integrated assessment of mountains, water, forests, farmland and lakes in Qilian Mountain region, including the Shule River Basin and the Shiyang River Basin in northwest China.

Recent research on the Arkavathy river in southern India offers another example of how a complex web of knowledge is required to understand both the nature of water crises and the possible ways to address water shortages. The Arkavathy river originates in Nandi Hills to the north of Bangalore, a city of over 12 million people, and flows via a series of cascading lakes into the Thippagondanahalli reservoir. Constructed in 1935, the reservoir was once the major source of water to Bangalore. Today, it can no longer supply water to the city; inflows into the reservoir have gradually declined to trickles. Early fieldwork and discussions with local farmers and government agencies suggested that there was no consensus on the causes of historical drying[13].

Earth scientists identified mainly biophysical factors, such as the predominance of eucalyptus plantations and stream fragmentation, as being responsible for both surface and groundwater declines[13]. In response to these proximate factors, governmental policies initially focused on technological fixes, which were not helpful since they merely moved water around without resolving the issue of water mismanagement. Further research by social scientists helped reveal the underlying drivers of water mismanagement, namely farmers moving away from rain-fed agriculture and converting their land to eucalyptus plantations, which required the drilling of deep bore wells for irrigation[14]. Social scientists also showed how urbanization explained the growing demand for water-intensive, high-value commercial crops, and additionally reduced the labour availability for traditional-style agriculture[14]. The research outputs from Earth and social scientists together yielded practical water management recommendations. Because all available water is currently being utilized, it is a zero-sum game; supply side options alone would not work, and communities within the watershed would have to operate within resource constraints, through water budgeting principles. Such principles were adopted at national level by India's National Water Mission. In fact, by 2018, eleven states had already stepped up to create regional water budgets. Such a management plan could potentially include climate change scenarios to prepare for India's adaptation to fluctuating weather patterns. And it all originated from interdisciplinary research collaboration.

Pathways to the web model and beyond

The examples from China and India show how moving from a tree to a web model of knowledge generation is critical to resolve sustainability relevant problems by improving the design of research processes and ultimately leading to policy decisions fit for purpose. These examples also show challenges that researchers face during the generation of knowledge, first and foremost the challenge of formulating holistic questions, which requires an interdisciplinary, or web, approach. Yet, our academic structures generally do not foster the type of interactions required by the web model. It takes several rounds of discussions to change the mind set ingrained by thinking of issues using the tree model, but fortuitously, in both the case studies analysed, institutional structures and the urgency of the problem brought researchers together and encouraged the formation of webs.

The second challenge is that of moving from understanding a problem holistically to proposing and implementing solutions. Many academics are loath to cross from an objective pursuit of truth to a more normative view of the world requiring, among other things, transdisciplinary efforts. In both our examples, the urgency of the problem and perhaps constant personal exposure to water crisis led experts to think beyond pure knowledge generation.

The third challenge is that of bringing about a large-scale change. In the cases discussed, large-scale change was the result of a transdisciplinary approach, with researchers working together with policymakers and practitioners to identify solutions. In our view, the web model creates interactions not only among academic communities but also among scientists, society and policymakers. Scalability was a clear goal in both examples from the start; close attention to policymaking processes, engagement with local stakeholders and communication of results via media made it possible.

Finally, there is the challenge of restructuring institutions to foster collaboration across disciplines and stakeholders[5]. In 2018, Shenzhen, Taiyuan and Guilin were China's first cities to pilot the implementation of the SDGs through financing, launching research projects and involving stakeholders at all levels. The Ashoka Trust for Research in Ecology and the Environment, the institution responsible for the cited Indian project, has structured programmes around topics, instead of disciplines, and interdisciplinary work and translation to policy and practice are actively encouraged and rewarded[15].

We have illustrated the potential of the web model for generating sustainability relevant knowledge and solutions. The model provides a framework for bringing together not only different disciplines but also various stakeholders and enablers from government and society. Across the globe, academia is seizing new opportunities for interdisciplinary research to address the complex problems that lie at the interface of society and the environment, and we argue for the need to scale up the web approach, which will only be possible by the rapid restructuring of academic institutions, as argued by colleagues before us[5]. ❐

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