Chapter 2
The Water-Energy-Food Nexus: Enhancing Adaptive Capacity to Complex Global Challenges

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1 Introduction: Global Change, Grand Challenges

Multiple intersecting factors place pressure on planetary systems on which society and ecosystems depend. Climate change and variability, resource use patterns, globalization viewed in terms of economic enterprise and environmental change, poverty and inequitable access to social services, as well as the international development enterprise itself, have led to a rethinking of development that solely addresses economic growth. Fulfilling the essential human aspirations for quality of life, meaningful education, productive and rewarding work, harmonious relations, and sustainable natural resource use requires ingenuity, foresight and adaptability. Societal and environmental conditions are changing rapidly in ways that increase uncertainty for decision-making over a range of scales. The intimate links between social and ecological processes are strengthened (made more fundamental than perhaps previously believed) in the age of profound human manipulation of planetary processes characterized as the Anthropocene (Steffen et al. 2011). The shift in global thinking towards sustainable futures is underscored by the global community subscribing to the Sustainable Development Goals (SDGs), which in 2015 will supplant

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the more target-oriented Millennium Development Goals (MDGs) (Sachs 2012). We are confronted by a series of challenges to the resilience of the global social-ecological system. At the same time, we are developing and refining an expanding array of capabilities to understand and influence the complex dynamics of coupled systems. This places society at a crossroads: Follow the past decades' path of resource exploitation and social inequality, or usher in a new world order premised on planetary resilience (Rockström et al. 2009; National Research Council 1999).

A global transition of such sweeping importance has been extremely difficult to initiate for reasons of path dependence in political systems; economic models that permit accumulation at the expense of depletion; degradation and dispossession (largely outside the remit of regulation); and the precarious condition of ecosystems in a range of contexts globally that provide fewer and more riskier survival options for billions of the world's poor, thus allowing little flexibility to innovate and adapt. Yet the transition has begun, founded on a series of understandings that are rooted in holistic systems thinking, driven by new conceptions and lifestyle choices of a growing number of the world's youth fatigued by status quo arrangements, and crucially, aided by an emerging set of tools that permit citizens, community groups, organizations and policymakers to actuate adaptive responses to the drivers of global change. Among these tools are integrated approaches to resource use that emphasize longer-term social and ecological sustainability while offering operational means to internalize externalities, foresee and mitigate unintended consequences, and above all, strengthen resilience through outcome-oriented open learning and institutional change. This is a tall order, and while specific transition pathways that often emerge gradually must be seized rapidly, the conceptual development and tools application processes have benefitted from a decade or more of innovation and experimentation.

Enter the 'nexus' of multiple resources, linked in turn to management and policy frameworks, and embedded in broader political processes. The nexus conceptually links multiple resource-use practices and serves paradigmatically to understand interrelations among such practices that were previously considered in isolation. Here we will demonstrate that resource recovery is at the core of operationalizing the nexus. This is fundamentally different from efficiency and productivity, although nexus practices can be seen in terms of deriving increased output from limited resources.

1.1 The Nexus Approach: The Antecedents

It is instructive here to provide a historical review of the resource nexus. When, where and how did it emerge? Who supports and who opposes nexus frameworks and for what reasons? Indeed, how are multiple nexus[1] construed, interlinked or

[1] Etymologically and linguistically, nexus is both the singular and the plural form.

divergent? What implications do the past decades of conceptual development around the 'nexus approach' have for future resource use paradigms? How can the nexus be used to address global-change challenges?

Early references in the published literature to the term 'nexus' as cited in Google Scholar arise in philosophy to refer to overlapping experience and physical objects (Whitehead 1929), in the institutional literature to trace contractual relationships among multiple, tiered firms (Wigmore 1943), in cell biology to describe complex electro-chemical interlinkages required for organ and tissue function (Dewey and Barr 1962), in economics to characterize mutual dependencies of wages, prices and labour productivity (Bodkin 1962), and subsequently in numerous additional disciplines. With specific reference to interlinked natural resource use practices, nexus terminology appears to have begun in 1983 with the Food-Energy Nexus Programme of the United Nations University (UNU), which sought to better understand coupled food and energy challenges in developing countries paying particular attention to technical and policy solutions (Sachs and Silk 1990). Food and energy as crucial determinants of development (Batliwala 1982) were considered in their broader environmental context; thus, at least two international conferences were organized to develop and illustrate further the interlinkages among food (agriculture, nutrition), energy (biomass, post-harvest residues, animal traction, fuel, electricity) and ecosystems (land, forests, water). The first of these conferences on Food, Energy, and Ecosystems, was held in Brasilia, Brazil in 1984 (Alam 1988). The Second International Symposium on the Food-Energy Nexus and Ecosystems was held in New Delhi, India, February 12–14, 1986 (Parikh 1986). Modelling approaches to address the food-energy nexus were also developed and published for the UNU (Pimentel 1985).

In parallel fashion and approximately concurrently in the mid-1980s, but apparently dissociated from the UNU-initiated programmes in developing countries, there was emerging recognition in the Western United States of the implicit water-resource dimension of the nexus between energy (hydropower, thermoelectric generation) and agriculture (food production, groundwater pumping). Solomon (1987) identified land and water constraints to electrical power generation, while Durant and Holmes (1985) recognized that water management in the Western U.S. would increasingly have to account for energy and environmental needs for water, in addition to the prevailing agricultural-irrigation and urban-industrial demands. Although Ingram et al. (1984) did not undertake detailed analysis of resource coupling that we currently understand as the basic plane of the nexus, their analysis presented in *Water Resources Research,* intended to reach both technical and managerial audiences, was prescient of the institutional dimensions of water resource management in the Western U.S. Gleick (1994) provided an important overview of water and energy linkages.

Explicit reference to the 'water-energy nexus' so prevalent today appears to have begun in the mid-to-late 1990s and early 2000s. Thus, Sant and Dixit (1996) addressed energy supply for groundwater pumping as part of a Water-Energy Nexus project funded by International Energy Initiatives (in Bangalore, India), while Padmanaban and Sarkar (2001) and Malik (2002) identified the groundwater-electricity nexus analytical and policy approach, which was developed and consolidated in India by Shah et al. (2003, 2007a, b), who emphasized the need for knowledge transfer between the farming and electricity sectors, and by Kumar (2005). The electricity-for-water nexus was applied to Jordan by Scott et al. (2003) and extended to Mexico by Scott and Shah (2004) and Scott et al. (2004a, b) with particular attention to policy and legal dimensions that expanded the physical-resource conception of the nexus.

Simultaneously, but once again in relative isolation from groundwater-electricity linkages, the converse resource dependence of water demands for energy generation were emerging under the nexus banner in the Western U.S. (Lofman et al. 2002; Government Accountability Office 2009; Sovacool and Sovacool 2009 to cite a few), promoted by Sandia National Laboratory (Hightower and Pierce 2008), universities in water-scarce states (Scott and Pasqualetti 2010; Kenney and Wilkinson 2011), the Electric Power Research Institute (2002), Natural Resources Defense Council and Pacific Institute (Wolff et al. 2004), the Stockholm Environment Institute (Fisher and Ackerman 2011), and others (Griffiths-Sattenspiel and Wilson 2009; Carter 2010). Similar studies were also published in Europe (Bailey 2011; Floerke et al. 2011; Hardy et al. 2012) and for the Middle East (Siddiqi and Anadon 2011). Later studies cited here increasingly recognized bidirectional water-energy nexus links, accounting for the energy needed to produce energy as well as the energy requirements of water management.

1.2 Emergence of the Water-Energy-Food Nexus

Use of any two terms suggests specific subsectors or issues, while three inter-linkages are considerably more multivalent. For example, the water and energy linkage may suggest hydropower, power plant cooling or groundwater pumping. The water and food linkage usually evokes irrigation and perhaps rainwater harvesting. The energy and food linkage most commonly raises concerns about biofuels versus crops trade-offs. However, the three sectors considered jointly include and transcend these specific sectoral linkages. They imply integrated, almost comprehensive, natural resource systems.

However, formal published recognition of the three-way mutual interactions among water, energy and food; branded as the WEF Nexus that is of principal concern in this chapter did not appear until 2008 (Hellegers et al. 2008; Siegfried et al. 2008). Again, the WEF Nexus had a significant focus on India, in part because the Hellegers et al. piece emanated from a workshop held in 2006 in Hyderabad, India, which itself built on groundwater irrigation (electricity nexus work cited above). This was followed in short order by Lopez-Gunn (2009) placing the WEF Nexus in an adaptation context, Lazarus (2010), Hoff (2011) as further elaborated below, Scott (2011) with emphasis on climate change drivers, Wescoat and

Halvorson (2012), Bogardi et al. (2012), Granit et al. (2013), and Siddiqi and Wescoat (2013) to cite a few of the burgeoning set of publications on the WEF Nexus. In parallel fashion, and again approximately co-terminously with research developments in the mid-2000s, institutional support for the WEF Nexus gained significant momentum via the Bonn Freshwater Conference, the Bonn 2011 Nexus Conference, the Stockholm World Water Week, the United Nations Economic Commission for Europe, and the now well established Water, Energy, and Food Security Nexus Resource Platform Nexus.[2]

A series of broader international initiatives to develop a coherent and comprehensive analytical framework for WEF Nexus, particularly as related to sustainable development, have emerged. This includes 'The Nexus between Energy, Food, Land Use, and Water: Application of a Multi-Scale Integrated Approach',[3] which applies the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) to case studies such as sugarcane biofuel in Mauritius, groundwater irrigation in Punjab, India, and alternative electrical generation in South Africa. The metabolism approach of MuSIASEM represents a social-ecological system of understanding linked to resource use (Madrid et al. 2013).

The November 16–18, 2011 'Water, Energy and Food Security Nexus—Solutions for the Green Economy' Bonn 2011 conference, in particular, provided an institutional platform and continuity to WEF Nexus initiatives. Follow up to Bonn 2011 includes a series of regional dialogues, private-sector participation including a focus on infrastructure and investment, practical tools (analytical models, best practices, etc.), and knowledge-based assessments of the nexus. These contributed to the Rio 2012 United Nations Conference on Sustainable Development and a subsequent series of international meetings focusing on the nexus, including those held in Stockholm and Dresden. UNU-FLORES in Dresden was established to advance the nexus approach to integrated management of environmental resources: water, waste and soil (UNU-FLORES 2013). UNU-FLORES will extend and upscale the nexus concept through adopting an integrative framework by considering inter-related resources (water, soil, waste) and emphasizing fluxes of resources between phases and compartments (Lall 2013). Given the limitations of the conventional technology-transfer model, it is acknowledged that capacity development approaches that aim to facilitate technology adaptation offer a better chance of achieving integrated management of environmental resources. Continued institutional development for the nexus includes the 2014 World Water Week in Stockholm on the theme, 'Water and Energy—Making the Link,' and the UNU-FLORES 2015 Nexus Conference.

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[2] See http://www.water-energy-food.org/ for more information.

[3] UN Food and Agriculture Organisation—FAO with support from the Deutsche Gesellschaft für Internationale Zusammenarbeit—GIZ. See also http://nexus-assessment.info/ for more information.

1.3 Characterizing the WEF Nexus

The central role played by water and energy resource use and governance in assuring food sufficiency and security required, even forced, the systematic synthesis of siloed resource management regimes. Yet this is not synthesis for its own sake, a question of intellectual or conceptual elegance. The nexus approach requires that interrelating factors be brought together, those that previously had been considered separated, indeed even isolated. As we will demonstrate, the nexus is fundamentally about resource recovery, closing the loop and capturing true efficiency gains instead of simply displacing or masking increased resource use (Lankford 2013; Scott et al. 2014). Understanding and acting upon this core of the nexus is central to diminishing the human footprint on planetary boundaries. Thus, resource recovery is the fundamental biophysical expression of the nexus approach.

Figure 1 indicates the interlinkages of water, energy and food on three planes: biophysical resources, institutions and security. Linkages between any two of the

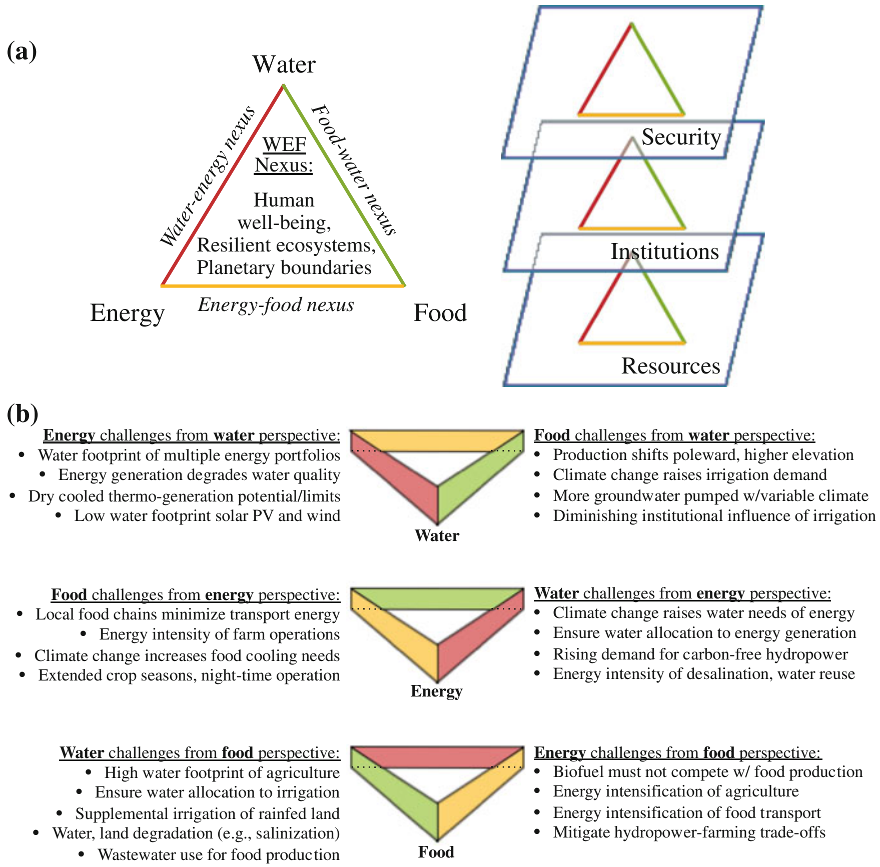

Fig. 1 **a** Water-energy-food nexus interlinkages at multiple levels. **b** Water-energy-food nexus tri-opticon challenge perspectives

nodes are expressed as the water-energy nexus, the food-water nexus, etc. The nexus is simultaneously about resource recovery through efficiency improvements and the recovery of saved resources in the process of efficiency conversions.

Below, we will demonstrate, via a series of thought exercises, how use of the other two resources is viewed from the position of each node of the nexus (see Fig. 1a, b). In other words, from a water resource perspective, how do food (production, distribution and security) and energy (generation, supply, dependence within the water sector) appear in terms of resource recovery and operational efficiency gains? In order to represent these challenges as seen from multiple nexus perspectives, in Fig. 1b we characterize processes and management distinctly from materials and resources.

2 Resource Use and Policy Integration

Integration of resource-use practices and comparative views across distinct disciplinary domains had gained traction before the mid-2000s advent of the WEF Nexus. Early thinking on irrigation management linked to integrated pest management (IPM) arose out of serious environmental and agronomic challenges presented by the Green Revolution in the 1960s and 1970s. But these were local, and occasionally regional, management problems even though globalization trends during that period raised evidence of their recurring nature. Systems thinking, integrated approaches and interdisciplinarity were making headway. Irrigation, for example, was in vogue as a socio-technical domain of study and practice. Natural resources in a watershed context were increasingly linked to food production, while water and food access was recognized to be strongly mediated by social and institutional dynamics, especially via diverse forms of collective action around common-pool resources (Kurian and Dietz 2012). This became a development imperative, a moral and ethical challenge. In line with the quality of life view that we espoused in the introductory paragraphs, above, there is heightening awareness of the ethical and moral dimensions of water, energy and food (López-Gunn et al. 2012).

Parallel trends in thinking were emerging for energy resources, in which end-users' behaviours and choices strongly influenced energy sufficiency and unleashed the development potential of economic opportunity and quality of life at local, regional, national and indeed global scales. Energy self-provisioning in many developing country settings was transitioning over to utility-based or cooperative forms of energy supply. The links of the energy sector with food production and supply were recognized and consolidated programmatically (e.g. via UNU initiatives cited above). But it was the same Green Revolution set of challenges necessitating coordination between irrigation and pest management that ultimately raised the need for water-energy-food linkages, which a generation later is expressed as the WEF Nexus. Thus, India with chronic water, energy and food insecurity undergirded by poverty and development challenges, was centre stage for emergence of the nexus concept. India also became, and in some respects remains, the hub of WEF experimentation due to innovation and polycentric governance (with an active and informed civil society constellation of NGOs and social movements, often in collaboration, occasionally in conflict with formal state institutions that themselves were not impervious to change and new ways of thinking).

Water for food production has required significant investments in infrastructure (dams, canals, conveyance systems) that, with the advent of pumping technology, has been developed to the detriment of landscapes re-plumbed as a result. Food production was not necessarily the ultimate imperative; it was also the settlement of lands as in the western United States, the domination of territory and subjugation of local populations as in British famine relief initiatives in colonial India. Much of this goes back to the Wittfogel hydraulic society hypothesis whereupon the ability to control water allowed for the control of food supply, population, settlements, society and the environment (for reviews, see Wescoat 2000; and Wescoat and Halvorson 2000).

Indeed in some cases, water requirements for energy production compete with water requirements for food production. Recently in the United States, the diversions of freshwater for electrical power plant cooling exceeded the diversions of fresh water for irrigation. Is energy the ‘wild card’ driving the WEF Nexus? Energy resource extraction has rising environmental and social costs, with commercial interests driving voracious resource extraction and depletion. The private sector feigns ‘ungovernability’; the allure of mobile and often fugitive foreign direct investment can lead to a blind eye on national and regional regulation of energy development. With its transportability and commodification, energy exhibits a fundamental contradistinction to water as an ‘uncooperative commodity’ (Bakker 2003); the capturability, resource-use exclusion and commodification dimensions of energy make it fundamentally different than water, which is increasingly subject to ethical claims of water as human right and water as public good.

2.1 Dynamics of the Water-Energy-Food Nexus

Over the course of a decade and a half working with the nexus in South Asia, the Americas and Europe, it has become evident to us that the term ‘nexus’ can have negative implications, as in various nexus manifestations involving crime (Mears 2001), corruption (Phy 2010), etc. In the Roman Republic, ‘nexus’ was a bond slave serving a ‘nexum’ debt bondage contract.[4] This belies the benign complexity that is intended by our use of the term and instead casts doubt by simplifying the nexus as subterfuge.

Furthermore, by placing the nexus in the resource security context, which we have done (Scott et al. 2013; Wescoat and Halvorson 2012) along with numerous

[4] See http://en.wikipedia.org/wiki/Nexum for more information.

others (Bogardi et al. 2012), one is exposed to the military and intelligence situation-room conception of strategic resources to be protected through military force, espionage and the exercise of state power. This 'guns, gates, and guards' view is indeed the origin of the concept of security. International and transboundary initiatives for water management, for example, increasingly must avoid 'security', which nation states view in sovereignty terms, in relation to the United Nations Security Council (Varady and Scott 2013). Here, our intent is not to engage directly in debates over the securitization of resources (Zeitoun et al. 2013; Fischhendler and Katz 2012; Mollinga et al. 2012), but instead to relate the nexus to the more benign human and ecosystem dependence dimensions of resource security (e.g. Scott et al. 2013 for water security). Critical to enhancing water security is an improved understanding of complex socio-ecological systems, causes of declining resilience in such systems and the role that adaptive management can play in mitigating the effects of such trends.

Complex socio-ecological systems are evident at different levels: from a policy/legal perspective, complexity is evident in 'rules in use' that affect decisions relating to allocation of resources, coordination of financial and human resources and equity effects on human populations. Examples of allocation rules include formulas or criteria for allocation of water among different water uses like industry, agriculture and water supply. Coordination rules could include rules that guide allocation of central funds by regional departments/ministries or criteria for monitoring water quality standards for river systems. Examples of equity rules could include daily allocation norms for water supply between rural and urban areas or criteria for allocation of central grants for wealthy and resource poor regions/communities or households. Organizational rules are evident in formal rules in operation within public sector and extent of discretion that is allowed by administrative culture that characterizes the work of line departments and ministries.

Complex socio-ecological systems that successfully deal with 'shocks' in the policy, environmental or socio-economic realm are usually characterized by resilience. Some have argued forcefully that resilience is a measure of: (a) the amount of change the system can undergo and still retain the same control on functions and structure, (b) the degree to which the system is capable of self-organization and (c) the ability to build and increase the capacity for learning and adaptation (Resilience Alliance 2001). Resilience is an important property of a system because the loss of resilience moves a system closer to a threshold, threatening to flip it from one equilibrium state to another (Berkes 2002). Highly resilient systems can absorb stresses without undergoing a flip; they are capable of self-organization based on relationships of trust and have the ability to respond to unpredictable 'events' through approaches that place a premium on learning by doing and trial and error (Kurian and Dietz 2013).

The concept of resilience is based on the assumption that cyclical change is an essential characteristic of all social and ecological systems. For example, resource crises such as a forest fire are important for renewal of ecosystems in as much as demographic growth and educational opportunities can serve to renew communities. But such processes of renewal and change are seldom linear and predictable leading to uncertainty. Systems theory emphasizes that uncertainty can be addressed in part by understanding inter-dependence and inter-connectedness of social and bio-physical systems. Robust feedback loops between policy/programme interventions, structural changes within communities of resource users and bio-physical processes are key in regulating the effects of uncertainty (Berkes 2002; Scoones 1999). Systems that respond effectively to uncertainty are usually supported by flows of information on biophysical and institutional processes. Information flows are verifiable, disaggregated and more amenable to decision-making processes (Kurian and Turral 2010).

The notion of adaptive management can resonate with decision-makers in developed economies who are confronted with challenges of a loss of capacity to exploit a system's potential for novelty (examples include rigidly interconnected water and energy infrastructure), declining redundancy of critical components (e.g. sole-source dependence on groundwater for irrigation in water-scarce regions), and the risks of cascading failure arising from heightened connectivity (e.g. energy-dependence of urban water supply systems). On the other hand the concept of adaptive management in the context of developing and/or emerging economies can relate to building capacity for dispersed problem solving. The first generation debate on political decentralization furthered the idea of dispersed problem solving by emphasizing autonomy. The second-generation debate on fiscal decentralization should emphasize issues of political accountability (Kurian and McCarney 2010). The goal of adaptive management should not be limited to the highest biological or economic yield but on furthering our understanding of how accurately socio-ecological systems can predict 'uncertainty' by using feedback from management and institutional outcomes to shape policy and programme interventions at appropriate scales, thus contributing to enhanced autonomy and accountability in decision-making processes and structures (Kurian and Dietz 2013).

2.2 Governance Challenges for the WEF Nexus

Environmental governance in developing and emerging economies suffers from fragmented approaches to planning and policy implementation. Fragmented approaches arise from competition among urban and rural local governments for central fiscal transfers, overlapping jurisdictional boundaries and inadequate management coordination among line departments and ministries. In many instances fragmentary approaches are supported by a poor evidence base on the relationship between infrastructure construction and environmental outcomes. For example, absence of disaggregate, reliable and more frequent information at appropriate scales makes it difficult to predict the environmental outcomes of constructing dams, tube wells or storm drains in terms of sediment capture, aquifer recharge and wastewater reuse respectively. Institutional fragmentation is also supported by weak feedback loops between legal and policy formulation, spatial and temporal variation in biophysical environment and socio-economic change within communities of environmental resource users. As a result decision-makers cannot design programme and project interventions with precision and may be unable to respond effectively to feedback from consumers on changes in service delivery parameters (affordability, reliability or quality) or to the effects of increased variability in frequency, intensity and duration of environmental shocks (droughts or floods).

2.3 *Expanding the Conventional WEF Nexus: An Institutional Perspective*

In the context of developing and emerging economies, an institutional perspective on the WEF Nexus would encompass three broad questions: (a) Intersectionality: what are the critical mass factors at the intersection of material fluxes, public financing and changes in institutional and biophysical environments that can define the scope and relevance of the nexus approach to environmental management? (b) Interactionality: how can feedback loops be structured to capture both vertical and horizontal linkages among (i) legal and policy reform, (ii) structural changes in economy and society and (iii) variability in the biophysical environment? (c) Hybridity: what role can trans-disciplinary approaches play in building capacity through support for innovative planning instruments and monitoring and assessment methods, advances in pedagogic and didactic techniques, formative and summative assessments and accreditation and certification of blended learning curricula that support the achievement of nexus competency.

There are at least three ways to examine institutional dimensions of the WEF Nexus. One important method starts with institutional 'levels' of analysis (sometimes mislabelled as 'scales'), beginning at the smallest household level and increasing to the community, municipal, substate regional, state, interstate, macroregional, national, binational and multinational levels. As each level often has a different legislation, organizations and guiding rules for resource management in the water, energy and food sectors, it is valuable for analytical as well as descriptive purposes to identify the relevant levels and examine how they interact within and across sectors.

If the first perspective analyses institutional structures, a second perspective can focus on institutional functions. The roles of public institutions for resource management, for example, span the range of state functions (e.g. Clark and Dear 1984). These include fostering social consensus, enabling increased economic production, promoting social integration through education and ritual activities, and administrating laws and regulations justly. Insofar as these public institutions promote economic production, they converge with some of the functions of private institutions; while insofar as they promote social consensus and integration, they converge with some of the functions of non-governmental institutions. Ostrom (1990) elaborates and instrumentalizes these structural and functional relationships of resource management institutions in her 'institutional design principles' for common property resource management.

Ostrom's research also points toward the rich human breadth and depth of resource management institutions in the water-energy-food nexus; which invites consideration of a third perspective on institutions in relation to human wants and needs. These are often articulated in sectoral assessments of emergent resource problems and solutions, for which existing institutions are generally inadequate. Examples include the Millennium Development Goals, Kyoto Protocol, Hyogo Convention on disaster risk reduction, etc. These often address the lower half of the pyramid of the oft-cited hierarchy of human physiological and safety needs (Maslow 1943). However, it is worth considering that many of these problems originate from, and are sometimes addressed by, the purportedly higher needs of esteem and self-actualization. While simple hierarchies and dynamics of nexus institutions appear logical, they are in practice more heterogeneous and complex over space, time and cultural context.

3 Trade-off Between Efficiency and Effectiveness: Illustrative Cases

3.1 Water for Energy: Carbon and Nuclear Legacies and the Transition to Renewables

The breathtakingly rapid post-World War II expansion of the world economy would not have been possible without the development and harnessing of fossil fuels (including coal, petroleum and natural gas, as well as non-renewable nuclear fuels, which impose many of the same environmental and social 'legacy' impacts as carbon-based fuels). The widespread quality-of-life benefits of conventional energy development have come at staggeringly high costs to the environment, especially climate change driven by carbon emissions. Additionally, social transformation and ecological devastation have been spatially displaced from consumption. For example, cheap fuel at filling stations worldwide but chiefly in high-demand developed countries like the U.S. has wrought war and irreversible pollution in the Niger Delta. This is far more than 'collateral damage'. Furthermore, the impacts of current consumption are temporally deferred, including the intergenerational effects of atmospheric carbon and social-environmental devastation, as cited in the two examples above, but also the technological, financial and political difficulties inherent in reversing decades of lock-in to fossil-fuel energy dependence. But reverse we must, and the transition is underway, in countries like Germany where solar and other renewables account for a growing share of energy portfolios and where, for the first time, there is a serious and sustained national dialogue on alternative energy futures. For example, what are the energy supply, technology development and financial models to support the transition? What are the respective roles of civil society and the state? The path is not without hazards; in the U.S., for example, natural gas development through non-conventional (but now increasingly conventional) fracking has reasserted the grip of petroleum giants and lowered gas costs to such an extent that, in just a few years, nascent initiatives to transition to renewables have been undone or set back.

The water and food dimensions of renewable energy futures will require improved technology, management and policy in order to diminish the energy intensity and dependence of the water and agricultural sectors. Localized forms of production, low-impact agricultural practices, surface- and gravity-irrigation including through rainwater harvesting, all offer important potentials.

3.2 The Large Dams Debate: Irrigation, Hydropower and Environment

Large dams constitute one of the largest, and most contested, movements of twentieth century water management (World Commission on Dams 2000). Some issues date to antiquity, physical and cultural traces of which still survive at the Marib Dam originally built in eighth century BCE, and failed for the last time in sixth century CE. The Qur'an (34:15–16) refers to the failure of this dam as a 'sign' for those to see what happens to the arrogant, sinful and unfaithful.

Debates in the mid-twentieth century were different, though they sometimes involved hubris. On the one hand, were those who felt dams should serve a single primary purpose, such as flood control storage, to avoid trade-offs among competing aims that could jeopardize public safety (White 1957). There were advocates for numerous small structures and watershed management versus advocates for a smaller number of massive dams and levees in a river channel engineering framework (Leopold and Maddock 1954).

A major shift in the mid- twentieth century saw the move from single objective-single means to multiple objective-multiple means water management (White 1957). Multipurpose storage was deemed a major component of integrated river basin development. After a massive wave of both patterns of development, their environmental and social impacts, and consequent overestimating of net economic benefits became increasingly evident (www.IRC.nl website 2013). Opposition to large dams grew internationally, albeit with passionate resistance from countries like Brazil, India and China. To address these controversies a World Commission on Dams was established that commissioned scores of reports and yielded a summary report that established best practices for future dams. Although on one level it was a remarkable achievement in international negotiation, it was criticized by dam building countries and organizations for its constraints on implementation.

Ten years later, a major set of essays reflected upon the legacy of the WCD report (Water Alternatives 2011). The World Bank and other multilateral lenders moved away from multipurpose storage projects. Some nations proceeded on their own. China completed the Three Gorges Dam, India, the Narmada Dam and irrigation scheme, Turkey, the GAP project, and so on. However, as regional energy demand escalated, aggravating regional power outages, a 'race to the top' was renewed in the Himalayan, Andean and Southeast Asian regions. In this wave of projects, estimated hydropower benefits outweighed irrigation, leading to debates once again about run of river versus multipurpose storage projects (Siddiqi and Wescoat 2013). The International Hydropower Association is currently developing a streamlined assessment project.

3.3 The Groundwater Irrigation Power Nexus

One of the reasons for continuing emphasis on surface water storage projects arguably stemmed from the almost worldwide failure in modern times to manage groundwater resources. From antiquity, shallow groundwater lifts were likely the most pervasive means of domestic water and local food supply. This was certainly the case in semi-arid plains environments prior to large-scale colonial canal irrigation. Canal irrigation employed gravity flow and in some cases generated hydropower for milling and transportation. A monumental example of successful gravity-fed groundwater development involved qanats (aka qarez, foggara, aflaj) emanating from Persia and found from the Americas to China.[5] They involved intensive control of piedmont groundwater aquifers, tapped by drilling 'mother wells', avoiding well interference, managing time-based water shares, as well as maintaining subterranean channels over the course of centuries.

Groundwater pumping technologies changed these early patterns of groundwater dramatically from the 1950s onwards with the development of increasingly deep pumping technologies. Cities drew upon water supplies with more consistent temperature and water quality conditions. But it was groundwater pumping for irrigation with tubewell and centre pivot irrigation systems that vastly increased irrigated areas including those with variable terrain (Green 1981).

Groundwater appealed to farmers for their more precise individual control over the timing and quantities of irrigation supply. Naturally, some farmers could afford individual pump sets while others could not, which gave the former additional markets, generally monopolistic, over their less prosperous and more dependent neighbours. Other farmers joined together to co-purchase movable pump sets, while still others set themselves up in the business of pump rental services.

As groundwater pumping expanded, so too did food production, but at a cost and in unsustainable patterns. Well interference was an early concern. In places where it was obvious which well dewatered its neighbour, it became a source of litigation, remedy and progressive development of groundwater law. In other areas, groundwater drilling cut through saline aquifers that leaked into fresh ones, diminishing crop yields. In other areas groundwater injection contaminated supplies for domestic and irrigation use.

[5] For more information see http://en.wikipedia.org/wiki/Qanat.

More problematic at a regional scale were water level declines ascribable to all wells rather than some, and for which the initial remedy was deeper drilling or boring. This triggered the energy dimension of the water-energy-food nexus, as it became apparent that depletion may ultimately take land out of production more due to increased pumping costs than to absolute scarcity. Some governments, notably states such as Punjab in western India addressed this by subsidizing or providing free electricity for irrigated farms, which only accelerated depletion, and which few politicians have had the courage to reverse. The adjacent Punjab province in Pakistan provides a valuable comparison, as it does not receive as large an electricity subsidy or have as reliable an electric power supply, it has relied on diesel pumping (Siddiqi and Wescoat 2013). This has reduced water level declines and helped sustain groundwater management. The 'third Punjab' in central California faces similar problems, particularly so in the grips of severe drought in 2014, the consequences of which include dramatic areas of land subsidence, which necessitate drainage and pumping and thus further increased energy costs.

These groundwater market failures are symptomatic of broader water-energy-food nexus failures. Whereas surface water rights and uses were relatively easy to define, visually monitor and publically administer, groundwater development is highly dispersed, located on individual lands, difficult to measure, and seemingly impossible to administer. There is rarely a market in groundwater supplies, only in their costs, and even these markets are often distorted or absent. This situation is described in South Asia as 'anarchic' (Shah 2008), which may apply in many other if not most regions of the world.

3.4 Wastewater Reuse for Peri-Urban Agriculture

Approximately 20 million hectares worldwide is estimated to be under agriculture that relies on wastewater reuse (Rijsberman 2004). It has been argued that policy support for encouraging wastewater reuse for agriculture after adequate treatment would increase water use efficiency in agriculture. Some have even argued that when wastewater is managed better, significant economic benefits can be derived in developing countries through reuse for productive purposes like agriculture, kitchen gardens and poultry rearing (Kurian et al. 2013). Further, by encouraging freshwater swaps, wastewater reuse in agriculture could also potentially enhance source sustainability of water supplies, especially to urban centres. A study in India also found that effective wastewater reuse in agriculture had the potential to mine organic nitrogen, potassium and phosphorus and thereby reduce the country's reliance on expensive imports of fertilizers. But one specific knowledge gap that prevents the realization of efficiency and productivity gains relates to a lack of consistent and agreed upon water quality standards for different crop and production systems. This knowledge gap constrains the development of standardized policy guidelines that could facilitate wastewater reuse.

3.5 Waste Remediation, Resource Recovery, Water Reuse

The term ‘waste’ and its underlying conceptual understanding represent the ultimate example of resource-impact externalization. This results as much from disciplinary and operational specialization as it does from practices on the ground, where indeed reuse and recovery of urban wastewater in this particular case are common despite official bans on the practice. We have described the transition from waste ‘disposal’ to ‘resource recovery’ in past work (Scott et al. 2004a, b; Drechsel et al. 2010); however, here we offer a targeted WEF Nexus view on water reuse and recycling. The most common use of treated or untreated effluent is agriculture in its broadest sense, taken to include irrigation of livestock fodder (for reasons of perennial flow, nutrients and human health-risk aversion), as well as landscaping irrigation (in many developed country contexts). Treatment and redistribution of reclaimed water is highly energy intensive; for example, in Tucson, Arizona, planners and the public are transitioning toward aquifer storage and recovery (itself not without energy costs) due to financial, infrastructural and public-acceptance challenges of dual water-supply and ‘purple-pipe’ reclaimed water networks.

In the developing country context, agriculture and food production are central to water reuse schemes, and will remain so in the future due to water, nutrient and urban proximity imperatives. An excellent example is Bolivia, where UNU-FLORES and the University of Arizona are keen to engage with local researchers and stakeholders to systematically develop the technical guidelines and institutional norms for safe and productive schemes for water reuse in agriculture.

3.6 Renewable Energy: The Water-Land Nexus

Wastewater reuse has tremendous scope to advance the nexus through fostering opportunities for multiple uses of water. But although a huge potential exists for wastewater reuse in agriculture, its effectiveness as an adaptation pathway may depend on critical aspects of local farming practices, market conditions, crop varieties and implementation of cost-effective treatment measures that facilitate wastewater reuse. For example a case study in India revealed that cultivating with wastewater may be less financially viable as compared to cultivating with well water. Further, when health risks for humans and livestock and returns on crops were considered, a number of interesting perspectives emerged (Kurian et al. 2013). First, because of better nutrient value of wastewater, farmers do not apply fertilizer. Further, due to assured availability of wastewater, farmers can grow two crops. On the other hand, farmers spend more on pesticides due to high incidence of pests (whitefly and jassid) under well irrigation. Wastewater reuse for agriculture is sensitive to soil and crop type; in our study area only paddy could be grown using domestic wastewater. Crops grown using wastewater sell for less in local markets compared to crops grown using well water. The study also found that better wastewater management had the potential to increase returns of wastewater agriculture by up to six times because of double cropping and lower expenses incurred on fertilizers. Depending on the location of individual plots, farmers also potentially stood to benefit from higher crop yields because of lower risk of flood damage and pest attack.

3.7 Biofuels and Food Trade-offs or Complementarities

Although increasingly evoked as a new problem, trade-offs between biofuel and food production are once again an issue with ancient origins. Consider the situation of villages that deforest watershed hillslopes for fuel, at the expense of agricultural land productivity downslope. Likewise, water-food trade-offs include land cover change through hillslope grazing that aggravates watershed sedimentation, erosion and flooding. A third trade-off occurs in the decision of how much fodder versus food crops to supply, at both farm and larger agro-ecological scales. Fodder is a food and fuel for animal nutrition. Animal draft power (energy) has declined in most regions, as has reliance on animal dung for fuel versus manure. Fodder for dairy production (the 'white revolution') is increasing, and is more demanding than simple grazing.

Perhaps the greatest source of current concern, however, has arisen from the late twentieth century shift in water and cropping to supply biofuels production, mainly through maize for ethanol production (Berndes 2002). National Research Council (2007) cited water quality problems (increased nitrogen runoff), as well as consumptive use of water for biofuels rather than food and fodder production. It also cited the economic inefficiencies of biofuels production subsidies, and the potential social impacts of higher food prices. The vision of decreased water demands, non-food crops for cellulosic ethanol production, such as switchgrass, have not proven commercially viable on a large scale to date (National Research Council 2011). These concerns, and tensions among the water, energy and food sectors are yielding a new politics in which multinational food and beverage corporations are coming out in opposition to using any water for biofuel production. Some of the same companies, sometimes accused of human rights violations when they impinge on common property water resources or push for privatization and market pricing of water supplies, are advocating for a human right to water for basic domestic needs, realizing that it does not impinge upon gross industrial water demand.[6] This position does not extend to a human right to water for basic food needs, however, as that would constitute a significant volume of consumptive water use.

[6] See World Economic Forum 2011, Water Security: The water-energy-food-climate nexus.

3.8 Small-Scale, Appropriate Tech Approaches

Parastatal agencies such as irrigation and forest departments in developing countries have historically played an important role in creating physical assets (such as dams and trees) and arranging for their maintenance (Brookfield and Blaikie 1987). However, over the years there has been a realization that the public sector has failed to ensure cost-effective management due to rent seeking behaviour by public officials and resulting conflicts with local communities (Peluso 1992). Such trends have impaired mechanisms to monitor access to common pool resources such as forests and exacerbated problems of soil erosion. In recent years, public choice theory has successfully argued that community-based organizations can provide low-cost arenas for management of forest and soil resources (North 1995; Ostrom 1990). Scholars have pointed out that factors such as trust, density of social ties, shared norms and minimal recognition by governments of the rights of citizens to organize may significantly lower transaction costs of monitoring access to soil and forest resources. But studies on co-provision involving partnerships between government agencies and community need not always deliver predicted outcomes on account of simplistic assumptions guided by notions of linearity between human-environment interaction (Kurian and Dietz 2013). For one, low accountability involving infrastructure construction may prevent the establishment of a basis for community cooperation for management of environmental resources. Second, successful community cooperation need not always lead to predicted environmental outcomes on account of the influence of confounding variables such as slope and soil type. Third, for successful environmental outcomes at the level of watershed to be replicated at the basin scale would require robust feedback loops that support both vertical and horizontal institutional linkages that can respond to vagaries of both socio-economic heterogeneity and also bio-physical change and variability.

The cases presented briefly above demonstrated that three-way linkages among water, energy and food are exceedingly complex. Specific interactions among two resources or sectors (for instance, energy and water) raise important challenges for biophysical resilience and institutional dynamics not simply for these resources but additionally for the third (food). Consideration of these case examples in historical perspective also indicates that there exists accumulated knowledge and management experience. In the concluding remarks, we outline opportunities to seize the WEF Nexus to improve human quality of life, enhance ecosystem resilience and respect planetary boundaries.

4 Conclusion: Harnessing the WEF Nexus for Global Change Adaptation

Based on our review of the conceptual development of three-way linkages among water, energy and food that are now firmly established as a nexus of resources and institutions, we turn to the WEF Nexus as a management and policy tool that offers real potential to address global change and indeed modify development trajectories and outcomes. This is especially salient in the lead up to the 2015 transition to Sustainable Development Goals.

The water-food nexus, in other words, irrigation and virtual water, have been recognized for some time. The food-energy nexus, similarly with the intensification and mechanization of agriculture plus requirements for transport of food, is also plainly apparent from the dual perspectives of resource use and management. In this chapter, we treated the evolution of the concept of the water-energy nexus, both as water for energy and energy for water. There is growing awareness of the need for policy measures to address the institutional dimensions of the water-energy nexus.

Taken together, the three resources form the WEF Nexus, which we have shown carries multivalent implications for human society and ecosystem resilience. Notwithstanding the heightened complexity, new insights on the WEF Nexus point to the three-way coupling of resources and multi-level institutional linkages that have profound implications for human well-being, societal welfare, ecosystem resilience and ultimately the sustainability of life on the planet as we know it. The WEF Nexus, in other words, is a pivotal concept for scientific research and a policy tool that allows for operationalization of links between sets of two resources (water-food, food-energy, water-energy) building up to a triple nexus or triad approach to adaptive management.

If we consider resource use efficiency in Lankford's (2013) terms where conservation of resources leads to real savings that must then be subject to common-property management in the 'para-commons', we are presented with a unique set of opportunities to internalize saved resources to offset depletion, mitigate third-party or off-site damages, or for future use. The internalization of resources that previously had been externalized is the essential nexus challenge. There is no longer any scope to externalize impacts; the planetary system is ultimately bounded and we must allow for resource use and waste recovery to be practiced in such a way that does not perpetuate with the conceptual fallacy of externalization.

Finally the WEF Nexus is particularly evident in countries such as India that exhibit both emerging economy status and particularly acute constraints on resources. While the nexus has emerged in contexts such as agriculture in South Asia, it will increasingly play out in broader scales in this region. This poses particular opportunities for innovation and experimentation. The principal challenges that remain, having demonstrated a series of resource linkages, are to upscale innovative management concerns from local levels to address the policy and institutional dimensions that we have indicated form the under-pinning societal and ecosystem resilience practices leading to a virtuous cycle of sustainable and equitable development.

References

Alam, A. (1988). Energy requirements of food production and utilization in the rural sector. In Food-energy nexus and ecosystem: Proceedings of the Second International Symposium on Food-Energy Nexus and Ecosystem, held in New Delhi, India, during February 12–14, 1986 (vol. 131, p. 270). Missouri, USA: South Asia Books.

Bailey, R. (2011). Using an adapted Delphi methodology for defining low carbon futures. Bristol: Institute for Sustainability, Health and Environment, University of the West of England.

Bakker, K. J. (2003). *An uncooperative commodity: Privatizing water in England and Wales*. Oxford: Oxford University Press.

Batliwala, S. (1982). Rural energy scarcity and nutrition: A new perspective. *Economic and Political Weekly, 17*(9), 329–333.

Berkes, F. (2002). Cross-scale institutional linkages: Perspectives from bottom up. In T. Dietz, N. Dolsak, E. Ostrom, & P. Stem (Eds.), *The drama of the commons*. Washington, DC: National Research Council.

Berndes, G. (2002). Bioenergy and water—the implications of large-scale bioenergy production for water use and supply. *Global Environmental Change, 12*, 253–271.

Bodkin, R.G. (1962). The wage-price productivity nexus. New Haven, CT: Cowles Foundation for Research in Economics, Yale University. (No. 147).

Bogardi, J. J., Dudgeon, D., Lawford, R., Flinkerbusch, E., Meyn, A., Pahl-Wostl, C., et al. (2012). Water security for a planet under pressure: Interconnected challenges of a changing world call for sustainable solutions. *Current Opinion in Environmental Sustainability, 4*(1), 35–43.

Brookfield, H., & Blaikie, P. (1987). *Land degradation and society*. London: Methuen.

Carter, N. T. (2010). *Energy's water demand: Trends, vulnerabilities, and management*. Washington, DC: Congressional Research Service.

Clark, G., & Dear, M. (1984). *State apparatus: Structures and language of legitimacy*. London: Allen & Unwin.

Dasgupta, S., Deichmann, U., Meisner, C., & Wheeler, D. (2005). Where is the poverty-environment nexus? Evidence from Cambodia, Lao PDR and Vietnam. *World Development, 33*(4), 617–638.

Dewey, M. M., & Barr, L. (1962). Intercellular connection between smooth muscle cells: the nexus. *Science, 137*(3531), 670–672.

Drechsel, P., Scott, C. A., Raschid, L., Redwood, M., & Bahri, A. (Eds.). (2010). *Wastewater irrigation and health: Assessing and mitigating risks in low-income countries*. London: Earthscan.

Durant, R.F. & Holmes, M.D. (1985). Thou shalt not covet thy neighbor's water: The Rio Grande Basin regulatory experience. *Public Administration Review*, pp. 821–831.

Electric Power Research Institute (EPRI) (2002). *U.S. Water consumption for power production; and U.S. electricity consumption for water supply & treatment*. Palo Alto, CA: EPRI.

Fischhendler, I. & Katz, D. (2012). The use of "security" jargon in sustainable development discourse: Evidence from UN commission on sustainable development. International Environmental Agreements: Politics, Law and Economics, pp. 1–22.

Fisher, J., & Ackerman, F. (2011). *The water-energy nexus in the western states: Projections to 2100*. Somerville: Stockholm Environment Institute.

Floerke, M., Teichert, E., & Baerlund, I. (2011). Future changes of freshwater needs in European power plants. *Management of Environmental Quality, 22*(1), 89–104.

Gleick, P. H. (1994). Water and energy. In R. H. Socolow, D. Anderson, & J. Harte (Eds.), *Annual review of energy and the environment, 19* (pp. 267–299). Palo Alto, CA: Annual Reviews Inc.

Government Accountability Office (GAO) (2009). *Energy-water nexus improvements to federal water use data would increase understanding of trends in power plant water use*. Washington, DC: GAO-10-23.

Granit, J., Fogde, M., Holger Hoff, S.E.I. & Joyce, J. (2013). Unpacking the water-energy-food nexus: Tools for assessment and cooperation along a continuum. Cooperation for a Water Wise World, p. 45.

Green, D. (1981). *Land of the underground rain: Irrigation on the Texas high plains, 1910–1970*. Austin: University of Texas Press.

Griffiths-Sattenspiel, B., & Wilson, W. (2009). *The carbon footprint of water*. Portland, OR: River Network.

Gunn, E.L. (2009). Spain, water and climate change in COP 15 and beyond: Aligning mitigation and adaptation through innovation. Documentos de Trabajo Real Instituto Elcano de Estudios Internacionales y Estratégicos, Working Paper 65/2009.

Hardy, L., Garrido, A., & Juana, L. (2012). Evaluation of Spain's water-energy nexus. *Water Resources Development, 28*(1), 151–170.

Hellegers, P., Zilberman, D., Steduto, P., & McCornick, P. (2008). Interactions between water, energy, food and environment: Evolving perspectives and policy issues. *Water Policy, 10*, 1–10.

Hightower, M., & Pierce, S. A. (2008). The energy challenge. *Nature, 452*(20), 285–286.

Hoff, H. (2011). Understanding the nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm.

Ingram, H. M., Mann, D. E., Weatherford, G. D., & Cortner, H. J. (1984). Guidelines for improved institutional analysis in water resources planning. *Water Resources Research, 20*(3), 323–334.

Kenney, D., & Wilkinson, R. (Eds.). (2011). *The water-energy nexus in the American West*. Cheltenham, UK: Edward Elgar.

Kumar, D. M. (2005). Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from western India. *Energy Policy, 33*, 39–51.

Kurian, M. (2010). Making sense of human-environment interaction-policy guidance under conditions of imperfect data. In M. Kurian & P. Carney (Eds.), *Peri-urban water and sanitation services—Policy, planning and method*. Dordrecht: Springer.

Kurian, M., & Dietz, T. (2013). Leadership on the commons: Wealth distribution, co-provision and service delivery. *The Journal of Development Studies, 49*, 1532. doi:10.1080/00220388.2013.822068.

Kurian, M., Reddy, V., Dietz, T., & Brdjanovic, D. (2013). Wastewater reuse in peri-urban agriculture—A viable option for adaptive water management? *Sustainability Science, 8*(1), 47–59.

Kurian, M., & Turral, H. (2010). Information's role in adaptive groundwater management. In M. Kurian & P. Carney (Eds.), *Peri-urban water and sanitation services- Policy, planning and method*. Dordrecht: Springer.

Lall, R. (2013). The nexus of soil, water and waste. Lecture Series –No. 1. UNU-FLORES, Dresden.

Lankford, B. (2013). *Resource efficiency complexity and the commons: The paracommons and paradoxes of natural resource losses, wastes and wastages*. Oxford and New York: Routledge.

Lazarus, J. (2010). Water/energy/food nexus: Sustaining agricultural production. *Water Resources Impact, 12*(3), 12–15.

Leopold, L. & Maddock, T. (1954). *The flood control controversy*. New York: Ronald Press.

Levidow, L. & Papaioannou, T. (2012). State imaginaries of the public good: Shaping UK innovation priorities for bioenergy. *Environmental Science & Policy*.

Lofman, D., Petersen, M., & Bower, A. (2002). Water, energy and environment nexus: The California experience. *International Journal of Water Resources Development, 18*(1), 73–85.

López-Gunn, E., De Stefano, L., & Llamas, M. R. (2012). The role of ethics in water and food security: Balancing utilitarian and intangible values14. *Water Policy, 14*(1), 89–105.

Madrid, C., Cabello, V., & Giampietro, M. (2013). Water-use sustainability in socioecological systems: A multiscale integrated approach. *BioScience, 63*(1), 14–24.

Malik, R. P. S. (2002). Water-energy nexus in resource-poor economies: the Indian experience. *International Journal of Water Resources Development, 18*(1), 47–58.

Maslow, A.H. (1943). A theory of human motivation. *Psychological Review*, *50*(4), 370–96. Retrieved January 18, 2014, from http://psychclassics.yorku.ca/Maslow/motivation.htm.
Mears, D. P. (2001). The immigration-crime nexus: Toward an analytic framework for assessing and guiding theory, research, and policy. *Sociological Perspectives, 44*(1), 1–19.
Mollinga, P., Hammond, L., Lindley, A., Mehta, L., Allouche, J. & Nicol, A. (2012). Not another nexus? critical thinking on the 'new security convergence' in energy, food, climate and water, October 26, 2012. Centre for Water and Development, University of London, Institute for Development Studies, and the STEPS Centre at the University of Sussex.
National Research Council (NRC). (2007). *Water implications of biofuels production in the United States*. Washington, DC: National Academies Press.
National Research Council (NRC) (2011). *Renewable fuel standard: Potential economic and environmental effects of U.S. biofuel policy summary*. Washington, DC: National Academies Press.
National Research Council (NRC). Policy Division Board on Sustainable Development (1999). *Our common journey: A transition toward sustainability*. Washington, DC: National Academies Press.
North, D. (1995). The new institutional economics and third world development. In J. Harris, J. Hunter, & C. Lewis (Eds.), *The new institutional economics and third world development*. London and New York: Routledge.
Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge: Cambridge University Press.
Padmanaban, S. & Sarkar, A. (2001). Electricity demand side management (DSM) in India: A strategic and policy perspective. Office of Energy, Environmental, and Enterprise; U.S. Agency for International Development—India. Retrieved January 18, 2014, from http://www.usaid.gov/in/whatsnew/articles/dsm.htm.
Parikh, J. K. (1986). From farm gate to food plate: Energy in post-harvest food systems in south Asia. *Energy Policy, 14*(4), 363–372.
Peluso, N. (1992). *Rich people, poor forests: Resource control and resistance in Java*. Los Angeles: University of California Press.
Phy, S. (2010). Foreign aid-corruption nexus in Cambodia: Its consequences on the propensity of civil war. Verlag: GRIN.
Pimentel, D. (1985). Energy and agriculture: Their interacting futures. In M. Lévy & J. L. Robinson (Eds.), *Policy implications of global models*. New York: Harwood Academic Publishers for the United Nations University.
Rockström, J., et al. (2009). A safe operating space for humanity. *Nature, 461*, 472–475.
Sachs, J. D. (2012). From millennium development goals to sustainable development goals. *Lancet, 379*, 2206–2211.
Sachs, I. & Silk, D. (1990). Food and energy: Strategies for sustainable development. vi, 83 p, ISBN: 92-808-0757-9.
Sant, G. & Dixit, S. (1996). Beneficiaries of IPS subsidy and impact of tariff hike. *Economic and Political Weekly*, pp. 3315–3321.
Scott, C.A. (2011). The water-energy-climate nexus: Resources and policy outlook for aquifers in Mexico. *Water Resources Research 47*, W00L04, 1–18.
Scott, C. A., El-Naser, H., Hagan, R. E., & Hijazi, A. (2003). Facing water scarcity in Jordan: Reuse, demand reduction, energy and transboundary approaches to assure future water supplies. *Water International, 28*(2), 209–216.
Scott, C. A., Faruqui, N. I., & Raschid-Sally, L. (Eds.). (2004a). *Wastewater use in irrigated agriculture: Confronting the livelihood and environmental realities*. Wallingford: CAB International.
Scott, C. A., Meza, F. J., Varady, R. G., Tiessen, H., McEvoy, J., & Garfin, G. M. (2013). Water security and adaptive management in the arid Americas. *Annals of the Association of American Geographers, 103*(2), 280–289.

Scott, C. A., & Pasqualetti, M. J. (2010). Energy and water resources scarcity: Critical infrastructure for growth and economic development in Arizona and Sonora. *Natural Resources Journal, 50*(3), 645–682.

Scott, C. A., & Shah, T. (2004). Groundwater overdraft reduction through agricultural energy policy: insights from India and Mexico. *International Journal of Water Resources Development, 20*(2), 149–164.

Scott, C. A., Shah, T., Buechler, S. J., & Silva-Ochoa, P. (2004b). La fijación de precios y el suministro de energía para el manejo de la demanda de agua subterránea: enseñanzas de la agricultura mexicana. In M. Lévy & J. L. Robinson (Eds.), *Hacia una Gestión Integral del Agua en México: Retos y Alternativas*. Mexico City: Porrua Editores.

Scott, C.A., Vicuña, S., Blanco-Gutiérrez, I., Meza, F. & Varela-Ortega, C. (2014). Irrigation efficiency and water-policy implications for river-basin resilience. *Hydrology and Earth System Sciences, 18*, 1339–1348.

Shah, T. (2008). *Taming the anarchy: Groundwater governance in South Asia*. London: Routledge.

Shah, T., Scott, C. A., Berkoff, J., Kishore, A., & Sharma, A. (2007a). Energy-irrigation nexus in South Asia: Pricing versus rationing as practical tool for efficient resource allocation. In F. Molle & J. Berkoff (Eds.), *Irrigation water pricing: The gap between theory and practice*. Wallingford: CAB International.

Shah, T., Scott, C.A., Kishore, A. & Sharma, A. (2003). Energy-irrigation nexus in South Asia: Improving groundwater conservation and power sector viability. IWMI Research Report No. 70. International Water Management Institute, Colombo, Sri Lanka. doi:10.3910/2009.088.

Shah, T., Scott, C. A., Kishore, A., & Sharma, A. (2007b). Energy-irrigation nexus in South Asia: Improving groundwater conservation and power sector viability. In M. Giordano & K. G. Villholth (Eds.), *The agricultural groundwater revolution: Opportunities and threats to development*. Wallingford: CAB International.

Siddiqi, A., & Anadon, L. D. (2011). The water energy nexus in Middle East and North Africa. *Energy Policy, 39*, 4529. doi:10.1016/j.enpol.2011.04.023.

Siddiqi, A., & Wescoat, J. L, Jr. (2013). Energy use in large-scale irrigated agriculture in the Punjab province of Pakistan. *Water International, 38*(5), 571–586.

Siegfried, T. U., Fishman, R., Modi, V., & Lall, U. (2008). An entitlement approach to address the water-energy-food nexus in rural India. AGU Fall. *Meeting Abstracts, 1*, 0846.

Solomon, B. D. (1987). Paradoxes of western energy development: How can we maintain the land and the people if we develop? In C. M. McKell, D. G. Browne, E. C. Cruze, W. R. Freudenburg, R. L. Perrine, & F. Roach (Eds.), *AAAS Selected Symposium*. Boulder, CO: Westview Press.

Sovacool, B. K., & Sovacool, K. E. (2009). Identifying future electricity-water tradeoffs in the United States. *Energy Policy, 37*, 2763–2773.

Steffen, W., Grinevald, J., Crutzen, P., & McNeill, J. (2011). The anthropocene: Conceptual and historical perspectives. *Philosophical Transactions Royal Society series A, 369*, 842–867.

UNU-FLORES. (2013). Academic work plan, Draft, Dresden, September.

Varady, R. G., & Scott, C. A. (2013). How should we understand "water security"? Guest View. *Arizona Water Resources, 21*, 1–5.

Wescoat Jr. J.L. (2000). Wittfogel east and west: Changing perspectives on water development in South Asia and the US, 1670-2000. In A.B. Murphy & D.L. Johnson (Eds.), *Cultural Encounters with the Environment: Enduring and Evolving Geographic Themes* (pp. 109–32). Rowman & Littlefield.

Wescoat Jr. J. L. & Halvorson, J. (2000). *Ex post evaluation of dams and related water projects: Patterns, problems and promise.* South Africa: Report to the World Commission on Dams.

Wescoat, J. L, Jr, & Halvorson, J. (2012). Emerging regional perspectives on water research and management: An introductory comment. *Eurasian Geography and Economics, 53*(1), 87–94.

White, G. F. (1957). A perspective on river basin management. *Law and Contemporary Problems, 22*, 157–187.

Whitehead, A. N. (1929). *Process and reality*. New York: Macmillan.

Wigmore, J. H. (1943). The scope of the contract-concept. *Columbia Law Review, 43*(5), 569–574.

Wolff, G., Cohen, R., & Nelson, B. (2004). *Energy down the drain: The hidden costs of California's water supply*. Oakland, CA: Natural Resources Defense Council and Pacific Institute.

World Commission on Dams. (2000). *Dams and development: A new framework for decision-making*. London and Sterling, VA: Earthscan.

World Economic Forum. (2011). Water security: The water-energy-food-climate nexus. Washington, DC: Island Press.

Zeitoun, M., Goulden, M. & Tickner, D. (2013). Current and future challenges facing transboundary river basin management. Wiley Interdisciplinary Reviews: Climate Change.

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