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Tracing the Water–Energy–Food Nexus: Description, Theory and Practice

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Abstract

The ‘nexus’ between water, energy and food (WEF) has gained increasing attention globally in research, business and policy spheres. We review the premise of recent initiatives framed around the nexus, examine the challenge of achieving the type of disciplinary boundary crossing promoted by the nexus agenda and consider how to operationalise what has to date been a largely paper exercise. The WEF nexus has been promoted through international meetings and calls for new research agendas. It is clear from the literature that many aims of nexus approaches pre-date the recent nexus agenda; these have encountered significant barriers to progress, including challenges to cross-disciplinary collaboration, complexity, political economy (often perceived to be under-represented in nexus research) and incompatibility of current institutional structures. Indeed, the ambitious aims of the nexus—the desire to capture multiple interdependencies across three major sectors, across disciplines and across scales—could become its downfall. However, greater recognition of interdependencies across state and non-state actors, more sophisticated modelling systems to assess and quantify WEF linkages and the sheer scale of WEF resource use globally, could create enough momentum to overcome historical barriers and establish nexus approaches as part of a wider repertoire of responses to global environmental change.

Introduction

It is increasingly clear that effective and sustainable solutions to the challenge of global environmental change, or more narrowly climate change, will require greater understanding and consideration of the linkages and inter-dependencies between sectors such as water, energy and food. Many of these issues were captured in Sir John Beddington’s (2009) notion of the ‘Perfect Storm’ in which increasing global population and resource demands are threatened by resource availability. Addressing these challenges demands new ways of thinking and flexible forms of governance (Allouche et al. 2014). In recent years, profiling water, energy and food as a nexus (the water–energy–food nexus, hereafter WEF) has been strongly promoted as a global research agenda and emerging development paradigm. At the core of nexus debates are natural resource scarcities and the recognition that water, energy, food and other resources are interlinked in a web of complex relations where resource use and availability are interdependent (Dupar and Oates 2012; Hoff 2011). As a result of these interdependencies, decision-makers in all sectors face the significant challenge of accounting for synergies, tensions and potential trade-offs between food, energy, water and environment at multiple spatial and temporal scales (Howells and Rogner 2014). Mounting global resource pressures, combined with climate change and other threats also open up opportunities for new ideas, approaches and collaborations. In this light, the ‘nexus’ has gained significant interest as a potentially effective approach for considering the interdependencies between WEF security and climate change at various scales. Put simply, a nexus is defined as one or more connections linking two or more things. The term is widely used

(e.g. the environment—development nexus, the population—migration nexus, etc.). Here, we focus on the recent high profile development of its use in the context of water, energy and food. In this review, we describe recent initiatives framed around the nexus and the range of actors involved, examine the challenge of achieving the type of disciplinary boundary crossing promoted by the nexus agenda and consider how to operationalise what has to date been primarily a framing of issues and call for action with limited practical action. Our aim is to provide a source of reference on recent developments in what remains an emerging agenda, and while the nexus is intellectually appealing, we recognise it faces significant conceptual and practical challenges.

The Water, Energy and Food Nexus

Water, energy and food are inextricably linked. Access to these resources and their effective management underpin development progress. The persistence of sectoral approaches to policy-making, however, has led to key resource constraints and policy responses being considered in isolation due to segmented planning and decision-making frameworks, with inadequate attention to the complex interactions that exist between sectors and resource systems (Pittock et al. 2013). This has often resulted in policies creating unintended consequences, such as increased WEF resource pressures, thereby exacerbating livelihood insecurities and undermining sustainable development (Bizikova et al. 2013). The close relationship between biofuels and food and water security encapsulates many of the WEF nexus issues. Biofuel production and supporting policies can lead to both positive and negative effects on food security (HLPE 2013) and water security (Gerbens-Leenes et al. 2012); the unintended effects of subsidised biofuels for transport may generate increased competition for land and water (ADB 2013). Linkages are also strong at the river basin scale where competing demands for water (upstream, downstream and between states in trans-boundary basins) can sharpen the trade-offs and opportunity costs of water use across agriculture (food production), electricity generation, of which many forms are water intensive (hydropower and cooling), and urban and environmental needs. Future climate change represents an additional set of stressors on the nexus. Climate plays an important role in determining medium-term water availability and potential agricultural production, and some components of energy production and demand. Changes in the climate will drive fluctuations in WEF elements with secondary effects across the whole nexus (IPCC 2014). Furthermore, the ways in which demand for energy services are met lies at the core of efforts to mitigate climate change (World Energy Council/University of Cambridge 2014).

Water, energy and food security lie at the heart of the nexus (summarised in Table 1). According to Hoff (2011) nexus thinking is concerned with addressing externalities across multiple sectors, with a focus on system efficiency, rather than on the productivity of isolated sectors. Thus, the nexus encourages socio-ecological systems perspectives and system wide approaches to planning and decision-making (Davis 2014). Nexus framings thus have considerable overlap with resilience thinking as both draw on systems thinking for conceptualising the interlinkages across socio-ecological systems, although they are often applied separately (Stringer et al. 2014). Integrated management and governance across sectors, systems and scales have been strongly emphasised by nexus proponents (Allouche et al. 2014; Davis 2014). However, as Middleton and Allan (2014) caution, systems approaches have also been widely critiqued as inadequately theorised or under-politicised, particularly from historical and relational perspectives. Various incentives operate for government, business, civil society and other actors to adopt nexus approaches such as improving financial efficiency and effectiveness of development interventions by achieving multiple sustainable development goals and minimising the trade-offs and the risks of adverse cross-sectoral impacts (Bazilian et al. 2011; Beck and Walker 2013; Hoff 2011; Pittock et al. 2013).

Table 1. Water–energy–food nexus components (adapted from Bizikova et al. 2013, 5).

Food security elements	(i) Food availability—affected by production, distribution and exchange of food; (ii) access to food—including affordability, distribution, sufficient and safe and preference (e.g. culturally appropriate); (iii) utilisation: nutritional value, social and cultural value and food safety (iv) sustained/long-term food stability (e.g. Chen and Kates 1994; Ericksen 2008; Ericksen et al. 2009)
Water security elements	Three key elements: water access; water safety; and water affordability. 'The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.' (UN-Water Task Force on Water Security 2013, 1)
Energy security elements	(i) Continuity of energy supplies relative to demand, (ii) physical availability of supplies and (iii) supply adequate to fulfil demand at a given price (Department of Energy and Climate Change (DECC) 2009; International Energy Agency 2008; Winzer 2011)

Integrated resource management has a long history; WEF nexus framings gathered momentum in the late 2000s (Table 2) in response to the need to shift the conventional landscape of natural resource management beyond specific cases to broader-ranging and cross-sectoral approaches in natural resource decision-making (Bizikova et al. 2013; Hoff 2011). Debate continues about whether there is essentially anything new or innovative about the nexus that distinguishes it from preceding holistic framings such as integrated natural resource management (Pittock et al. 2013; Rees 2013). The nexus framing certainly bears similarities to and builds on principles from other holistic approaches to environmental decision-making, including integrated natural resource management, integrated water resources management (IWRM) and sustainable development (Allouche et al. 2014; Davis 2014; Rees 2013; Stringer et al. 2014). Some have argued that the nexus could be interpreted as a new lexicon for or sub-set of sustainable development (Middleton and Allen 2014). While recognising this, as well as the concern that a WEF nexus approach risks overlooking trade-offs or conflicts with other excluded sectors, Pittock et al. (2013) argue in their research on energy, water and climate policies in Australia that a nexus framing is potentially better at uncovering more appropriate approaches and methods for successful cross-sectoral integration through an emphasis on minimising conflicts and realising positive synergies through linking disparate knowledge, developing new technologies, encouraging broader markets and improving governance.

The IWRM approach takes water as its point of departure, whereas the nexus ideally looks at WEF holistically or as a system from the outset. This is a defining point of the nexus approach. However, in reality, owing to the original foci of those involved, path dependency in modelling and data availability, and other complexities, nexus thinking often begins from one perspective and then attempts to integrate others (Bazilian et al. 2011; Rees 2013). For example, the nexus diagram presented in Hoff (2011) situates available water resources at the centre of the nexus (Figure 1, see next section). Ideally, because the initial departure point is not necessarily from water, the nexus approach is potentially more appealing and relevant to energy, food and other perspectives than IWRM framings (Rees 2013).

Recent Initiatives on the WEF Nexus

The increasing prevalence of the WEF nexus has been most visible in the form of international conferences and workshops, emerging research agendas and reports in the 'grey' literature. The water security community made the early running in the nexus with rising energy costs adding

Table 2. Examples of recent landmark events, publications and networks on the water–energy–food nexus (March 2009–May 2014).

Nexus-related event/resource/network	Relevant website
Beddington, John (2009). 'Food, Energy, Water and the Climate: A Perfect Storm of Global Events?' Chief Scientific Adviser to HM Government. London: Government Office for Science World Economic Forum (WEF 2011) launched a landmark report <i>Water Security: The Water–Food–Energy Climate Nexus</i> Background Paper for the Bonn 2011 conference published: 'Understanding the Nexus', coordinated and led by the Stockholm Environment Institute (SEI) (Hoff 2011) Bonn 2011 Nexus Conference: The Water Energy and Food Security Nexus—Solutions for the Green Economy (November 2009)	http://www.friendsofimperial.org.uk/Media/Slides/A_Perfect_Storm_-_Sir_John_Beddington_-_12.11.2013.pdf http://islandpress.org/ip/books/book/islandpress/W/bo8065703.html http://www.water-energy-food.org/en/news/view_255/understanding-the-nexus.html http://www.bonn-perspectives.de/en/dialogue-events/bonn2011_nexus_conference.html
Planet Under Pressure International Conference (March, 2012)—'Interconnected risks and solutions for a planet under pressure' (Gaffney et al. 2012)	http://www.icsu.org/rio20/policy-briefs/interconnected-issues-brief
Future Earth launched in June 2012 at the UN Conference on Sustainable Development (Rio + 20)—importance of nexus thinking recognised from outset	http://www.futureearth.info/
Nexus 2014: Water, Food, Climate and Energy Conference was held at the Water Institute at the University of North Carolina (UNC) at Chapel Hill (5–8 March 2014)	http://nexusconference.web.unc.edu/
Academic and Practitioners network for the Water Energy Food and Climate Nexus launched at Nexus 2014 Conference	http://nexusconference.web.unc.edu/files/2014/03/concept-note-WEFC-network.pdf
Nexus Declaration delivered to the UN Secretary General on March 26 2014 (for input to formulation of Sustainable Development Goals (SDGs))	http://nexusconference.web.unc.edu/files/2014/04/Declaration_Final_4_21.pdf
Nexus Network launched in the UK—funded by Economic and Social Research Council (ESRC) 2014	http://www.thenexusnetwork.org.uk/
Sustainability in the Water–Energy–Food Nexus international Conference (2014)	http://wef-conference.gwsp.org/

momentum to the emergence of a variety of calls to develop a more integrated approach to what had previously been treated as separate problems (Rees 2013). In 2011, the World Economic Forum (WEF 2011) launched a landmark report *Water Security: The Water–Food–Energy Climate Nexus* alerting the world's political and business leaders to the need to examine the interrelations between these global challenges: 'Water security is the gossamer that links together the web of food, energy, climate, economic growth and human security challenges that the world economy faces over the next two decades' (WEF 2011, p. 1). The run up to the Rio + 20 Summit in 2012 marked the emergence of 'nexus thinking' as a clarion call for a new approach to, or framing of, interdependent water, energy and food problems (Davis 2014). The German Federal Government has been a prominent advocate of the nexus approach and were key sponsors and organisers of first the first major WEF nexus event, the *Bonn 2011 Nexus Conference: The Water Energy and Food Security Nexus—Solutions for the Green Economy* as a contribution to the *Rio + 20 Summit*. *Bonn 2011* was a significant catalyst for increased nexus attention from international organisations, the private sector and other major global players. As a primer for the Conference, Hoff (2011) produced a Background Paper titled '*Understanding the Nexus*', which became an influential statement on the benefits of a nexus framing and shaped

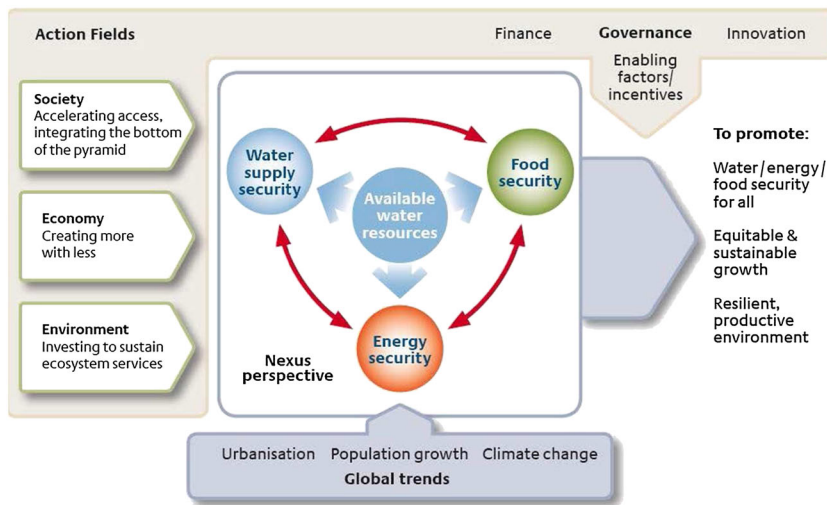


Fig. 1. Bonn 2011 Nexus Framework (Hoff 2011).

widely used interpretations and applications of the term. Figure 1 depicts Hoff's (2011) nexus framework that integrates global trends (drivers) with fields of action (e.g. finance) with available water resources at the centre. As noted earlier, it would be equally valid to have other central goals such as sustainability or equity. Indeed, given the challenges of evaluating the complexity across the WEF nexus, developing convincing visualisations of the nexus approach is a complicated task.

Hoff (2011) also located the nexus within the green economy and green growth debate. Building on *Bonn 2011*, a *Nexus 2014: Water, Food, Climate and Energy Conference* was held at the Water Institute at the University of North Carolina (UNC) at Chapel Hill at which an international 'Nexus Academic-Practitioner Network' was launched. The *Bonn* and *Nexus 2014* conferences also initiated a plan for annual meetings from thereafter, to be held at UNC Water Institute. Table 2 and Appendix 1 list some of the main nexus-related events, resources and networks between 2009 and mid-2014. More recent activities include the development of international nexus networks such as the UK Economic and Social Research Council funded 'Nexus Network' launched in June 2014. The 'Nexus Network' is a 'three-year initiative to foster debate, innovative research and practical collaborations across the linked "nexus" domains of food, energy, water and the environment' (<http://www.thenexusnetwork.org.uk/about/the-nexus/>), as well as a recent call for proposals for developing a new research centre 'Centre for Evaluating Complexity across the Energy–Environment–Food Nexus' led by the Economic and Social Research Council, the Natural Environment Research Council, the Department for Environment, Food and Rural Affairs, the Department of Energy and Climate Change, the Environment Agency and the Food Standards Agency ([http://www.esrc.ac.uk/funding-and-guidance/funding-opportunities/33584/centre-for-evaluating-complexity-across-the-energy-environment-food-nexuscentre-for-evaluating-complexity-across-the-energy-environment-food-nexus-\(18-march-2015\).aspx](http://www.esrc.ac.uk/funding-and-guidance/funding-opportunities/33584/centre-for-evaluating-complexity-across-the-energy-environment-food-nexuscentre-for-evaluating-complexity-across-the-energy-environment-food-nexus-(18-march-2015).aspx)).

The nexus is becoming increasingly prominent on policymakers' agendas, notably in relation to the post-2015 development agenda (Weitz et al. 2014). The Sustainable Development Goals (SDGs) currently being debated by the United Nations are at the centre of this agenda. The SDGs will be the successor to the Millennium Development Goals whose target period ends in 2015. Research institutes such as the German Development Institute/Deutsches Institut für

Entwicklungs politik and the Stockholm Environment Institute have proposed a nexus approach to support cross-sectoral integration for the SDGs (Brandi et al. 2013; Weitz et al. 2014). The Colombian Government has shown support for a nexus approach to the SDGs to foster dialogue on broad development issues rather than sectoral challenges, thereby enabling interactions to emerge as central foci (Weitz et al. 2014).

The private sector has also been engaging with nexus events and a number of nexus-related public–private partnerships are emerging (Reynolds and Cranston 2014; SABMiller/WWF 2014; Zahner 2014). Partnering with the private sector has been promoted as important to further improve returns on nexus-based investments (SABMiller/WWF 2014). The last decade has seen growing interest in water security from the private sector, which has been framed as a new paradigm of corporate water stewardship (Hepworth and Orr 2013), and features strong recognition of inter-connections between resources. For example, SABMiller highlighted through a valuation study of malting barley in Rajasthan the need to find better approaches to handling trade-offs between water, energy and food and the company is now attempting to make business decisions through a resource nexus lens (Wales 2014). The major oil and gas companies have long talked of the ‘Resource Trilemma’, and Shell (2013) includes the ‘Stress Nexus’ in its most recent scenarios. Significant concerns have been raised about water use and business risks in recent debates over fracking (Reig et al. 2014). For example, Shell faced strong opposition to their plans to seek shale gas in the semi-desert Karoo region of South Africa based on concerns over water availability (Reig et al. 2014). Beyond production and supply chain concerns, the retail, banking and finance industries all have interests in issues relevant to nexus thinking. In addition to global corporations and national champions, small and medium enterprises (SMEs) and local businesses are becoming increasingly active in the nexus space, often in partnership with public sector actors (see the Nexus Resource Platform—<http://www.water-energy-food.org/>). An example of SME-level nexus solutions in the agrifood sector is the Indonesian soybean processing sector, which has adopted nexus-orientated energy efficiency and biogas technologies (Zahner 2014). Perceived co-benefits relate to reductions in firewood consumption, greenhouse gas emissions and smoke and illnesses in the workplace, as well as improved treatment of wastewater (Zahner 2014).

The private sector is paying increasing attention to nexus thinking and resource management for supporting the supply of critical resources such as water for breweries and other beverage producers and thereby supporting their own economic and other interests (Reynolds and Cranston 2014; Wales 2014). Some argue there is potential for wider socio-ecological system benefits from meaningful business engagement through the cumulative effects of more efficient resource use, investments in natural capital, and so on. (Reynolds and Cranston 2014). Yet, the risk remains that businesses will just use the nexus to re-label and/or legitimise business-as-usual agendas, without addressing underlying issues of sustainability beyond their immediate needs. It is thus important that research interrogates business motivations and incentives for championing the nexus.

In summary, there has been wide ranging support for nexus approaches across academia, business and policy communities. However, nexus research faces significant theoretical tensions in developing effective analytical frameworks that transcend disciplinary boundaries; a concern that has been somewhat overlooked to date (Stirling 2014). The following section explores these critical issues in further detail.

The Nexus and Disciplinary Boundary Crossing

The notion of the Anthropocene suggests that the scale of human impact is such that ‘humans and our societies have become a global geophysical force’ (Steffen et al. 2007, 614) and that research approaches fit for the Anthropocene require ‘the rethinking and reshuffling of

disciplines, in order to craft an academe suitable for the gigantic task ahead' (Palsson et al. 2013, 3). The natural sciences have led recent calls for a more integrated approach to environmental change research and decision-making. This is reflected in the development of 'Earth Systems Science' to integrate primarily science disciplines to understand the planetary ecosystem. According to the International Council for Sciences, Earth System Science 'is the study of the Earth System, with the emphasis on observing, understanding and predicting global environmental challenges, involving interactions between land, atmosphere, water, ice, biosphere, societies, technologies and economies'. This definition includes areas that are the traditional purview of the social sciences, but there is scope for a more proactive approach to social science that sees human activity at the core of environmental challenges and change. In the recent authoritative *World Social Science Report 2013*, Moser et al. (2013, 48, author emphasis) call for 'a new kind of social science, one that is *bold* enough to reframe and reinterpret global environmental change as a fundamentally social process; *better* at infusing social science insights into real-world problem solving; *bigger* in terms of having more social scientists to work on addressing head on the challenges of the Anthropocene era; and, *different* in the sense of reflecting upon and changing its own ways of thinking and doing science'. Fulfilling these demands on the social sciences, together with facilitating greater collaboration and integration between the natural and social sciences, will be important for advancing environmental change research, policy and action.

Nexus thinking embraces both the social and natural sciences and the arts and humanities stand to make an important contribution around traditional knowledge, environmental valuation and other key nexus aspects. This is particularly important if nexus approaches are to be effective in generating real-world solutions that involve the policy-making, business, scientific and engineering communities. However, knowledge integration across ecological/natural and social sciences is challenging because these fields apply very different concepts and languages (within and across disciplines) and may focus on contrasting types of interactions (Stirling 2014). Such differences can prevent shared and/or comprehensive understandings of the range of factors influencing social–ecological systems (Mattor et al. 2013). Considerable epistemological and ontological tensions will need to be negotiated to avoid the risk of theoretical incoherence or contradiction.

Calls for a nexus research agenda also seek engagement with real-world problems and practitioners. As such, multi or transdisciplinary research, which relates science and policy in tackling diverse issues such as environmental change, is important for advancing nexus approaches (Harris and Lyon 2014). Nevertheless, incomplete information about the natural and social systems under investigation, together with the plurality of interpretations of such information, may be difficult to overcome (Mattor et al. 2013).

Disciplinary 'boundary crossing' has long been encouraged in academic and policy circles (pre-dating the escalation of nexus thinking), especially within the Geography discipline where there is a constant concern about crossing the boundary between physical and human geography, but has proven difficult to achieve (Francis and Lyon 2014; Mooney et al. 2013; Moser et al. 2013). The effectiveness of an integrated analytical nexus framework depends on a comprehensive understanding and translation of indicators, framings and concepts used from different research traditions. We propose that what Sil and Katzenstein (2010) call 'analytical eclecticism' is a potentially effective lens to guide nexus research in traversing disciplinary boundaries. They define analytical eclecticism as 'an intellectual stance that supports efforts to complement, engage and selectively utilise theoretical constructs embedded in contending research traditions to build complex arguments that bear on substantive problems of interest to both scholars and practitioners' (Sil and Katzenstein 2010, 411). The approach encourages greater dialogue across research traditions through considering and utilising, rather than replacing or displacing, critical research efforts by adherents of specific traditions and theoretical framings. As Sil and Katzenstein (2010, 414) explain, analytical eclecticism's distinctiveness lies

in ‘its effort to specify how elements of different causal factors might coexist as part of a more complex argument that bears on problems of interest to both scholars and practitioners’. Analytical eclecticism is characterised by the following: (i) a pragmatic ethos that targets the world of policy and practice; (ii) interest in wide-scope problems (in contrast to narrowly defined theoretical dilemmas) that ‘incorporate more of the complexity and messiness of particular real-world situations’, and (iii) the aim of providing complex causal stories that account for multiple causal mechanisms predominantly explored in isolation within particular research traditions (Sil and Katzenstein 2010, 412). Notwithstanding the potential of transdisciplinary approaches and analytical eclecticism, some still argue that more research and critical theoretical engagement is required to advance the nexus (Harris and Lyon 2014). Insights can be shared from experiences during the past two decades of interactions between the natural and social science in global change research programs such as the gradual integration of social science contributions within the Natural Science Global Change Programs as they have evolved and the Millennium Ecosystem Assessment which successfully brought together natural and social science communities to deepen understanding of social and ecological systems (Mooney et al. 2013). Of particular relevance for the nexus is the observation that many areas of social science have tended to adopt local scale approaches, focusing on detailed case studies with fewer generalised regional level studies (Mooney et al. 2013). Such divergences in scale of interest and conceptual development require attention in nexus research (Francis and Lyon 2014; Mattor et al. 2013). Building on the above conceptual discussion on the implications for nexus approaches of the need to cut across multiple academic disciplines, the following section considers some of the fundamental challenges to operationalising the nexus.

Implementing Nexus Approaches

Our reading of the nexus literature suggests that it is long on ambition and rhetoric but lacks nuanced and detailed research-based evidence on how to implement nexus research and deliver real world solutions at multiple scales and in different contexts (Rees 2013). There is very little literature that focuses on all three sectors of the nexus from a social science theoretical or applied angle. Moreover, as noted earlier, there are some asymmetries in nexus starting points; the water security community has tended to lead many nexus initiatives; however, greater integration of the energy sector into the nexus has occurred (Bazilian et al. 2011; Williams et al. 2014)

The World Economic Forum (2011) contends that any approach that focuses narrowly on one part of the WEF nexus without paying attention to its interconnections risks major unintended consequences. Yet, resource insecurities and the drivers thereof in each sector are highly complex and steeped in considerable uncertainty (Beisheim 2013). Bizikova et al. (2013) argue that the WEF nexus requires research attention to improve our knowledge of three core areas: the nature of the linkages or relationships between the three or more resource elements, often through modelling approaches (e.g. input–output analyses); considerations of WEF changes and changes in other sectors such as infrastructure, health and urban planning, especially in the context of climate change and urbanisation pressures; and thirdly, the implications for policy and actions for addressing the three interconnected insecurities. There have been various recent attempts by academic institutions, private entities and international organisations to develop guiding frameworks for nexus implementation and policy, several of which were developed in preparation for Rio +20 in June 2012 (e.g. Allouche et al. 2014; Bizikova et al. 2013; Hoff 2011; ICIMOD 2012; World Economic Forum 2011). Proposed nexus frameworks typically focus on security, and more recently resilience as key elements, and attempt to enable trade-off assessments and identify policy entry points to facilitate impact and support long-term planning horizons (Beck and Walker 2013; SABMiller/WWF 2014; Stringer et al. 2014).

However, operationalisation has proven difficult, especially across all three or more sectors: ‘while such integrated approaches are being explored conceptually, there is much less emerging to implement or operationalise such integrated approaches that optimize the three critical securities in a coherent or balanced manner’ (Bizikova et al. 2013, 20). Only a few studies have begun to evaluate and provide useful practical insights into the numerous and complex interactions among water, energy, food, land and so forth (e.g. Allouche et al. 2014; Bazilian et al. 2011; Beck and Walker 2013; Bierbaum and Matson 2013; Bizikova et al. 2013). Bazilian et al. (2011: 7903) conclude that treating the three areas WEF nexus holistically ‘would lead to a more optimal allocation of resources, improved economic efficiency, lower environmental and health impacts and better economic development conditions, in short, overall optimisation of welfare’. However, they caution that the tools, expertise and institutional capacity are not yet sufficient for supporting the nexus dialogue and modelling tools that can support integrated decision-making require further development and application (Bazilian et al. 2011).

Studying three-way and higher resource interactions while accounting for the implications of climate change and other pressures requires in-depth understandings of resource relationships and interconnections across multiple scales (Hussey and Pittock 2012; Peronne and Hornberger 2014). If this is not achieved there can be significant risks of overlooking conflicts and trade-offs with omitted sectors. Yet, interactions among water, energy and food and economic systems are highly complex and there are major uncertainties about socio-environmental and economic futures (Peronne and Hornberger 2014). There are also significant data and modelling constraints to analysing three or more elements as an interrelated system (Bazilian et al. 2011). As a result, even when policies are designed to focus on multiple areas, nexus analyses often encompass only two resources and two-way interactions such as energy for water or water for energy. Bazilian et al. (2011, 7897) also note that very few people are expert in more than one let alone all three areas of the nexus. Moreover, the governance of each sector is highly complex and often dependent on the perspective of the policymaker and the wider political economy of resource management and decision-making.

Long-term sustainable development can only be achieved through careful assessment of the interlinkages between sectors and working within resource constraints, over time and between sectors and locations (Weitz et al. 2014). Significantly, decisions and actions relating to natural resource use often occur within politically charged and contested contexts. The nexus approach faces the obstacles encountered by previous integrative approaches, which have often failed to deliver in practice, frequently because political economy (e.g. the role of power and vested interests) in resource allocation, linkages to markets and equitable approaches for negotiating inter-temporal trade-offs have been inadequately addressed (Allouche et al. 2014; Peronne and Hornberger 2014; Rees 2013). Access to and utilisation of water, energy and food are closely linked with structural issues such as political processes, poverty and entitlements; the prevailing development and political-economic environment will therefore strongly influence both the way in which nexus approaches are implemented and their outcomes (Allouche et al. 2014; Dupar and Oates 2012; Pittock et al. 2013; Rees 2013). However, political economic considerations are largely under-represented in nexus research with analyses often completely neglecting political contexts or overlooking underlying existing unsustainable activities. As Allouche et al. (2014, 23) explain, ‘if the nexus is to be a useful framework for exploring alternative pathways rather than a narrative that legitimises existing dominant pathways, the political economy of the nexus must be more explicitly addressed’, they also emphasise a focus on ‘bottom up ways of knowing the relationship between water, food and energy’. Identifying winners and losers in WEF nexus decision-making and giving explicit attention to justice and equity concerns are central for nexus agendas to be socially progressive (Dupar and Oates 2012; Stringer et al. 2014).

Analytical starting points are also critical for operationalising the nexus. Top–down or ‘bottom–up ways of knowing’ represent important epistemological differences with consequences for understanding and outcomes. Studies on the WEF nexus often adopt a broad-scale top–down approach without considering the nexus’ central importance at household or village levels, especially in rural contexts. As Allouche et al. (2014: 23) explain, ‘food, water and energy have never been conceptually separated in the way that experts have sought to understand them. Indeed, it may be that the WEF nexus is the (re)discovery by experts working in silos of what practicing farmers and fishers already knew’. Thus, while there is a long history of nexus practice and governance at local scales it has not necessarily been labelled as such. This highlights the need for understanding local governance forms when it comes to operationalising the nexus.

There is broad recognition that the interdependencies of sectors and resource systems have been inadequately acted upon. Pittock et al. (2013, 4) attribute these shortfalls to ‘the inability of governments to adequately manage the complexity and uncertainty associated with environmental issues, differing values and contested methods, the challenges of working across scales and lack of clarity of rights and responsibilities’. These governance and institutional issues are fundamental to the operationalisation of nexus ideas; however, current formal and informal institutional mechanisms may be inadequate for supporting the nexus in practice. As Howells and Rogner (2014) explain, the transition towards more integrated governance is not insignificant; it requires new skills sets, tools, funding and incentives. Key barriers to nexus based cross-sectoral integration relate to historically entrenched vertically structured (siloed) government departments, sector-based structures of agencies that complicate coordination, limited spatial and functional extent of jurisdictions, restrictive funding mechanisms, as well as legislative and regulatory barriers (Allouche et al. 2014; Bizikova et al. 2013; Peronne and Hornberger 2014; Pittock et al. 2013; Rees 2013; Scott et al. 2011). Regulatory landscapes for water, energy, food and other resources are crucial to understanding the potentials and barriers to nexus-based policies and actions in different contexts. A major concern for government engagement with the nexus is that responsibilities for different elements of the nexus are situated within different government bodies and at different scales of decision-making (as evident in the recent debate over regulating shale gas in the UK) (Are We Fit to Frack? 2014). Adding further complexity is the fact that water, energy and food, economic and other systems operate at different and overlapping spatial scales (e.g. river basin organisations rarely coincide with other administrative boundaries) thereby raising concerns about the possibility for synchronisation within existing regulatory and administrative systems. As mentioned above, scalar considerations are central to the nexus because water, energy or food interventions are not necessarily suitable or effective at all scales. For example, at finer scales, they are likely to be locally contingent because of the need to ensure local suitability and acceptance. Nexus governance may be effective in both centralised and decentralised ways as different arrangements and mechanisms may be required for different scales. New institutional arrangements and administrative reforms may be necessary for advancing the nexus agenda (Allouche et al. 2014; Pittock et al. 2013). However, as the history of integrated resource management and other interconnected approaches have shown, established institutional and administrative arrangements can be highly resistant to change, with reform usually being a slow and imperfect process. Experiences from IWRM and climate change adaptation in developing countries demonstrate how complex externally driven agendas can fail to take hold and even have a demotivating effect on staff tasked to deliver poorly specified objectives without effective capacity support (Biswas 2004; Conway and Mustelin 2014). It will thus be important to identify priority WEF linkages and to consider the most effective entry points for dealing with them.

The lack of clarity about what a ‘successful’ nexus approach looks like in practice and how this can be achieved, monitored and evaluated creates significant challenges for planners,

policymakers and other stakeholders tasked with developing nexus-orientated strategies within the confines of existing institutional silos and sectoral-based funding structures. Major conflicts persist between water, energy and food with stakeholders often competing for resources (Peronne and Hornberger 2014). Yet, while there is agreement that more effective frameworks need to be put in place for policymakers and other stakeholders to collaborate and develop cross-sectoral plans and actions, the political will, new planning tools and funds for capacity building are not always readily available (Hussey and Pittock, 2012; Pittock et al. 2013). Additionally, given the strong emphasis on integration, extensive and well-functioning intra-governmental and inter-governmental consultative mechanisms are important for nexus approaches. However, ministries and institutions continue to be designed predominantly to work in silos, and sectoral forces are very strong. Pittock et al. (2013) argue that the necessary nexus paradigm shifts can be driven by real or perceived need, financial incentives provided by governments or by markets and other catalysts. In reality, it is likely to be a combination of these and other drivers.

Concluding Remarks

We have traced the recent trajectory of nexus thinking and initiatives framed around the nexus, highlighting two important dimensions of this new agenda: the need to address conceptual tensions in disciplinary boundary crossing and how to move from theory to practice in operationalising nexus goals. Proponents of the nexus approach emphasise its potential for ‘joined-up thinking’, recognising connections and coordinating policy and decision-making to minimise negative externalities and unforeseen consequences in tackling interconnected local to global challenges.

Whether nexus framings persist and generate real change in our approaches to complex WEF problems or whether they fall prey to some combination of corporate greenwash, state over-enthusiasm for control and academic faddishness, only time will tell. From our review, it is clear that many aspects of nexus approaches pre-date the recent nexus agenda and that these have encountered significant barriers to progress, including challenges to cross-disciplinary collaboration, complexity, politics and incompatibility of current institutional structures. Indeed, the highly ambitious aims of the nexus could become its downfall; the desire to capture multiple interdependencies across three major sectors, across disciplines and across scales is beset with complexities, which could slow progress in understanding and obscure policy messages. What is different for nexus ambitions now, however, is the sheer scale of WEF resource use globally and the associated pressures emerging through inter-dependencies. This results from the cumulative effects of rapid economic growth, globalisation and consumption during the last two decades; stress points are more apparent and so necessity may become the driver for a nexus agenda to gain traction. These issues are manifest in, for example, the fracking revolution, significant food price spikes in the late 2000s and attention to cross-cutting agendas in the negotiation of the SDGs. There also appears to be greater recognition of interdependencies across state and non-state actors, including the private sector. Furthermore, we now have available more sophisticated modelling systems to assess and quantify WEF linkages coupled with the potential to communicate the knowledge more effectively through diverse formats and media. These differences, if supported by stronger processes of co-production between researchers and nexus stakeholders, could generate sufficient momentum to overcome the barriers and establish nexus framings as part of the wider repertoire of responses to global environmental change.

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Appendix 1: Key events relating to the water-energy-food nexus (November 2011– May 2014)

Event title	Location and Date
Bonn 2011 Nexus Conference	Bonn, November 2011
Mekong Forum on Water, Food and Energy (Annually from 2011)	Hanoi, Vietnam, November 2011; 2012; 2013)
The Energy Water Food Stress Nexus - Nexus Discussion organised by the Royal Geographical Society and IBG	London, December 2012
International Conference on Regional Energy Governance and the Nexus Perspective: Challenges in the Asia Pacific Region	Kuala Lumpur, December 2012
Meeting - Young Professionals Perspectives on the Water and Energy Nexus	Koblenz, Germany, November 2012
Mekong-2-Rio International Conference on Transboundary River Basin Management	Phuket, Thailand, May 2012
Water–Energy–Food Security: New challenges and new solutions for water management Conference	Winnipeg, February 2012
6th World Water Forum (water, energy and food included as key conference priorities)	Marseille, March 2012
Planet Under Pressure Conference – water-energy-food nexus featured as a key theme in several side events	London, March 2012
Water, Energy, Environment and Food Nexus: Solutions and adaptation under changing climate Conference	Lahore, April 2012
South African Water, Energy and Food Forum: “Managing the mega-nexus”	Sandton, South Africa, April 2012
Colloquium: Not Another Nexus? Critical Thinking On The “New Security Convergence” in Energy, Food, Climate and Water	London, October 2012
‘Resource Efficient City’ - Session at the ICLEI – 2012 World Congress (nexus of food, water and energy challenges in urban areas was a key focus of the session)	Rio de Janeiro, June 2012
Powering Progress Together: Forum on Energy, Water and Food Forum	Rotterdam, May 2012
Corporate Sustainability in Africa 2012: “Living in the water, food and energy nexus” Conference	Johannesburg, May 2012
Workshop on “Integrated Resource Management in Asian Cities”: The Energy, Water and Food-Security Nexus	Bangkok, May 2012
Webinar: Biofuel Production – Dissecting the Water-Energy-Land Nexus	Online, May 2012
Water Food Energy Nexus—Blue aquaculture as an integrative part to minimize use of resources for animal and plant production- Workshop at 3. Water Research Horizon Conference	Berlin, July 2012
Managing Water, Energy, & Food in an Uncertain World Conference (Universities Council on Water Resources UCOWR)	Sante Fe, July 2012
India Water Week - 2013 theme focused on water-energy-food nexus: “Water, Energy and Food Security: Call for Solutions”	New Delhi, April 2012
Symposium on Connecting The Dots: “The Food, Energy, Water and Climate Nexus”	Stanford University, April 2012
World Water Week (2012 theme: water and food security)	Stockholm, August 2012
Initiative for Global Environmental Leadership (IGEL), Sixth Annual Conference Workshop – Nexus of Energy, Food and Water	Pennsylvania, March 2013
The Nexus Dialogue on Water Infrastructure Solutions regional “Anchor” workshops – held between 2013 and 2014 culminating in the Symposium on Water, Energy and Food Nexus (to be held in Beijing, China in November 2014)	Nairobi, Kenya (May 2013), Bogotá, Colombia (September, 2013), Bangkok, Thailand (March 2014), Istanbul, Turkey (July 2014)
Conference - “From Nebulous to Nexus: Operationalising the Water, Energy & Food Security Response”	South Africa, July 2013
Seventh Biennial Conference of the European Society for Environmental History (ESEH), “Circulating Natures: Water-Food-Energy”	Munich, Germany, August 2013 Berlin, November 2013

(Continues)

Appendix 1. (Continued)

Event title	Location and Date
Policy Forum - Berlin2013: "Realizing the Water, Energy and Food Security Nexus"	Viña del Mar, Chile, November 2013
First Conference of Natural Resources and Development : "Food, water and energy security: integrated science for sustainability"	London, 1 April, 2014
Intelligence Squared: Water, Food, Energy, Climate – Smart Solutions for 2050	Food and Agricultural Organisation (FAO) Rome, Italy March, 2014
Earth Observations and the Water-Energy-Food Nexus Workshop	Croatia, March 2014
Workshop on Water-Food-Energy-Ecosystems Nexus Assessment in the Sava River Basin	Bonn, May 2014
Sustainability in the Water-Energy-Food Nexus international conference	Chapel Hill, USA, March 2014
Nexus 2014: Water, Food, Climate and Energy Conference	Mexico City, Mexico, May 2014
IWA Water, Energy and Climate Conference	Abu Dhabi, May 2014
11th IWA Leading Edge Conference on Water and Wastewater Technologies	