Part I

Understanding the resource nexus

Setting scenes

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The *Resource Nexus*

Preface and introduction to the Routledge Handbook

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Preface

Demand for natural resources has grown rapidly for decades, and is expected to continue growing. These trends lead to repercussions, risks, and threats for humans and ecosystems at different scales. The challenges of sustainable resource management and governance are on numerous agendas, ranging from the G7 and G20 summits to UNEP's International Resource Panel, World Economic Forum, SDG implementation, and a growing community of international scholars. Research highlights the importance of accounting for the interdependencies of resource use and sustainability goals such as eliminating hunger, mitigating climate change, and expanding energy access. There is a need to understand interdependencies and the feasibility of more integrated approaches.

Debate is often framed in terms of a "nexus" between water, energy, and food (sometimes including other resources).[1] The main aim of this handbook is to come to grips with what the nexus[2] is about, provide a reference textbook with an overview, and a survey on emerging and cutting-edge research, and application of the concept.

1 The Resource Nexus

This handbook is edited by five dedicated scholars, drawing on different schools of thought from different continents. Assembling a wide group of more than 50 authors across a host of disciplines and interdisciplinary fields, this volume rests on a thorough review of relevant literature and, in emerging with a distinct and original perspective, it conceptualizes the resource nexus as *a heuristic for understanding critical interlinkages between uses of different natural resources for systems of provision such as water, energy, and food*. The editors organized a symposium which took place in London in March 2015, debating various aspects of the resource nexus and refining the concept and defining the structure of the handbook. All chapters have been reviewed several times.

Many chapters seek to contribute to realization and implementation of the UN' Sustainable Development Goals (SDGs, see Chapter 32, as well as Chapters 4, 19, 22, 26, 27, 28, 29), which endeavor to achieve greater opportunities and a better life for the world population as a whole and for our globe's poorest citizens, in particular while reducing environmental pressures. These goals – especially SDG2 (food), SDG6 (water), SDG7 (energy), SDG12 (sustainable consumption and production), and SDG15 (sustainable use of terrestrial ecosystems) – have extensive and enumerable links to natural resource use, underlining the need for integrative approaches. If implemented in ways that overlook critical interlinkages, the SDGs may well risk a further acceleration of natural resource demand and degradation, ensuing numerous knock-on effects on individuals, communities, businesses and societies – and the ecosystems on which all depend.

Similarly, we perceive this nexus handbook to be connected to topics such as *resource efficiency*, *circular economy*, and many others – all grappling with solutions aimed at more sustainable use of natural resources at different levels (micro, meso, and macro).

This handbook enables readers to understand (Part I), measure (Part II), assess and model (Part III), compare political economies (Part IV), learn from applications (Part V), and upscale solutions (Part VI). The handbook's six parts and 32 chapters are carefully organized around these aims. As a whole, the handbook seeks to combine analytical rigor with attempts to be transformative – i.e. shaping transformations towards sustainability – in realms of research and knowledge-making, as well as practice and implementation.

Introduction

What is the nexus? An integrated approach

In the past, resource governance mostly focused on single resource categories such as water or energy along a supply chain that ran from primary natural resource, through processing, distribution, and final consumption and disposal. Some of these supply chains are global in scope, such as those for oil, while others are more commonly national or local, such as those for coal and water. Graedel and van der Voet (2010) emphasized the need for a more integrative approach, signaling the existing linkages between the different resources. The nexus concept has been formulated and has become widely used in analytical and practitioners communities at least since the Bonn Conference 2011 (Hoff, 2011) and work at the Transatlantic Academy in 2011–2012 (Andrews-Speed et al., 2012), in response to the predominant single-resource "silo" thinking, emphasizing critical interlinkages across resources, particularly synergies and trade-offs, in a more integrated manner.

1 The Resource Nexus

Authors in this handbook define the resource nexus as a set of context-specific critical interlinkages between two or more natural resources used as inputs into systems providing essential services to humans, such as water, energy, and food.[3] While a multitude of possible relationships, resources, and systems can be considered, we outline in this chapter a clearly defined five-node nexus for the systems of water, energy, food, land, and materials that seeks to provide consistency, focus, and adaptability to the respective scope and context of analysis and application. Advantages of this particular scope of a five-node nexus are detailed in the following section, with a focus on making robust choices across different contexts, linking with ecosystem services, and bringing in the dimensions of scale and the socio-economic metabolism.

Systems thinking is key. In general terms, natural resources serve as direct or functional inputs for socio-economic systems of provision, either for the production of another input, for general production and consumption purposes, or for the built environment. Figure 1.1 illustrates the *main resource interlinkages* between five essential resources and how these provide a basis for societies and sustainable development. Looking at those interlinkages, some may be more obvious to many readers than others, such as the bi-directional connections between energy and water. Others become more critical during periods of rapid increase in the use when sticking to typical silo approaches without assessing the availability of core inputs from other resources, such as the materials needed for energy production.

Figure 1.1 also introduces three *layers* in order to illustrate the value chains from nature to consumers for each resource. The first layer gives categories for the primary production of the respective natural resource; the second layer adds the socio-economic supply systems based on such resources. The third layer adds the dimension of recycling and re-use and inputs from secondary resources – essential for enhanced resource use efficiencies, a circular economy, and a more sustainable use of resources in general. Critical interlinkages may occur between corresponding or different layers, as illustrated by energy needs for pumping water through distribution systems to end-users. We will discuss our proposed categories below.

<Insert Figure 1.1 ABOUT HERE>

Figure 1.1 The resource nexus

Source: Author compilation (developed by Catalina Spataru with Raimund Bleischwitz)

The figure illustrates main interlinkages in a generic manner based on the many existing studies. Certainly more such interlinkages exist, and the figure looks at them from the perspective of resource inputs being transformed and providing essential services for humans. Nexus research should be quite explicit about those layers, their scales, and how critical interlinkages can be identified. As this figure is applied throughout the entire handbook, we seek to demonstrate the usefulness of a nexus approach. Systems thinking, however, suggests research and practitioners should start from a broader nexus understanding but may well focus on certain critical interlinkages across selected layers. Accordingly, the handbook also entails chapters on cases related to water–energy–food in China (23), metals and energy (24), unconventional fuels and the nexus (25), and energy and water in California (31).

The importance of natural resources for development was repeatedly identified at Earth Summits in 1992, 2002, and 2012, and in SDGs such as (renewable) energy (SDG7), (sustainable) food production (SDG2), and sustainable management of water (SDG6). As such, Figure 1.1 also illustrates some of the links between natural resources and relevant SDGs.

The nexus approach stresses the need to generate relevant information about critical interlinkages that enable decision-makers to plan for robust governance and management across resources and spatial scales – consistent with planning frameworks such as national development plans, sustainable development strategies, or energy or agricultural transitions. Planners ‘on the ground’ are probably a key target group of a nexus approach. While many previous nexus studies are limited to one particular scale, e.g. the national or regional levels, analyzing interlinkages helps to connect across scales, from small, local places to international trade and global cycles (Hoff, 2017, see also Chapter 3 and Chapter 28 on urban governance). In the future we expect more findings connecting to global scales such as the planetary boundaries approach (Steffen et al., 2015) which emphasizes interlinkages between different large-scale environmental processes. Likewise, the nexus approach should enable more consistency as critical interlinkages become part of mission-oriented strategies such as resource efficiency or a circular economy (Ellen MacArthur Foundation and McKinsey, 2014).

Building on diverse strands of expertise, a nexus approach generates improved knowledge of cross-resource needs and impacts for decision-making and management. As Wichelns (2017) points out, such multifunctional management approaches have a long tradition of being embedded in UN principles and legal frameworks, especially in forestry management and the Dublin principles on water management. Yet, integrated approaches are still an exception rather than the rule. If practitioners or scholars in one sector attempt to reach out to others, feedback from other sectors or policy implementation remains weak in integrated concepts such as integrated water resource management (IWRM). The nexus approach acknowledges that integration adds complexity and hence is difficult to implement, and that addressing all interlinkages is impossible. Yet it rests on the assumptions that (i) identification and assessment of critical interlinkages is essential, and (ii) managing and governing such interlinkages is a key to achieve the SDGs, clearly superior to managing single resources in silos. The nexus framework enables actors to identify risks of overuse, to exploit synergies (ancillary benefits, co-benefits, more sustainable investments, cost reduction in joint policy implementation, etc.), and to manage trade-offs and contradictions.

Thus, a nexus approach seeks a more efficient resource management that addresses multiple targets in a more integrated manner. This is why the solution-oriented concepts of *resource efficiency* and a *circular economy* are closely linked with the nexus; Part VI of this handbook is devoted to such solutions. Note that such integrated approaches could also be applied when one resource (e.g. a forest) is governed for multiple and often conflicting goals, such as protecting biodiversity and water resources, community livelihoods, and timber production.

The scope of the nexus

Little agreement exists in the literature as to what natural resources are included in the nexus. The most widely acknowledged nexus approach covers *water–energy–food* (WEF, 2011; Bazilian et al., 2011; Lawford et al., 2013; Green et al., 2016). Other studies and some chapters of this handbook focus on:

- The *water–energy* nexus (Ackerman and Fisher, 2013; Howells and Rogner, 2014; Talati et al., 2016; see also Chapters 23, 25, and 31) inspired by the huge amounts of energy needed for water pumping or desalination and vice versa: the large amount of water needed in the energy sector, as illustrated by the impact a drought might have on electricity production;

- *Water–energy–land* (European Commission, 2012; Ringler et al., 2015; Senger and Spataru, 2015; Sharmina et al., 2016; Obersteiner et al., 2016; see also Chapters 16, 22 and 26) all pointing to the manifold ecosystem services provided by land and the intersections with water, biomass, biodiversity, and energy;
- *Water–energy–mineral fertilizer* (Mo and Zhang, 2013, see also Chapter 26) highlights the potential depletion of non-renewable natural resources (minerals), their relevance for food security, their complex supply chains with recycling and recovery opportunities from e.g. wastewater or agricultural residues, and the potential environmental risks from accumulation of these minerals via eutrophication;
- *Water–energy–minerals* (Giurco et al., 2014; Kleijn et al., 2011: see also Chapters 18, 19, 21, 24) as illustrated by the increasing intensity of water and energy use in mineral extraction processes with declining ore grades. The reverse interlinkage is an increasing demand for minerals including metals for energy infrastructures, renewable energy such as photovoltaics or wind power, batteries, and unconventional fuels.

More policy-oriented studies published by Chatham House (Lee et al., 2012) and authors at the Transatlantic Academy (Andrews-Speed et al., 2012, 2014) share a wider recognition of natural resources as manifold inputs into socio-economic processes and metabolism in line with Figure 1.1. A similar approach is taken in the analysis by the McKinsey Global Institute (Dobbs et al., 2011), which focuses on opportunities of a 'resource revolution' for steel and related industrial sectors.

In order to provide a meaningful scope, this handbook proposes a five-node nexus to address:

1 The Resource Nexus

- Water
- Energy
- Food
- Land
- Materials

While food – like water and energy – has been an essential category of the nexus debate from the very beginning, one may discuss consistency by pointing at the need to produce food rather than seeing it as a primary resource. Yet, our approach of including food points at its relevance as a system of provision (SDG2) with inputs needed from all other resources, manifold critical interlinkages, and resource-intensive value chains at all layers. Indeed, a life cycle approach is essential for systems thinking and for all categories of the nexus.

Inclusion of land in a resource nexus approach is necessary because of its many critical environmental functions, and as a prerequisite to relevant provisioning services and development. Figure 1.1 illustrates land as an input into all other categories, and its critical interlinkages with water.

This nexus handbook further includes materials in the resource nexus for at least four reasons. First, non-energy abiotic resources are essential for housing and shelter and account for about 50% of natural resource use in most industrialized countries measured in physical units according to material flow analysis (see Bringezu and Bleischwitz, 2009; Wiedmann et al., 2013). Second, base metals, critical minerals, and construction minerals have significant implications for energy production, storage, and distribution (SDG7); water provision and re-use

(SDG6); and urbanization (SDGs9+11). Mineral fertilizers are also critical inputs for food production (SDG2). Third, costs associated with purchasing and processing materials in manufacturing industries are significant and have been estimated in the order of 40% of gross production costs throughout the 2000s (Wilting and Hanemaaijer, 2014). Lastly, base metals and nutrients cause particularly significant environmental impacts, including land and water resource degradation and GHG emissions (Hertwich et al., 2010). Nevertheless, intensifying agriculture with optimal fertilizer inputs can also prevent or slow the expansion of the agricultural frontier. Within materials one may have subcategories for metals and critical minerals, construction, and industrial minerals and mineral fertilizers. Like for 'food', our use of the term 'materials'[4] refers to a life cycle approach of the nexus rather than primary resources alone and is in line with the industrial ecology approach (see also Chapter 10).

Having those five categories is consistent but not necessarily exclusive. Biomass, for instance, should be considered relevant and has manifold interlinkages with land, food, energy, water, and materials. Those interlinkages across layers could be specifically addressed for biomass at the interface of ecosystems assessments and market analysis. Our Chapters 21 (related to land), 26 (feeding Africa), and 30 (green chemistry) seek to address this debate. As expressed above, the five-node nexus is adaptable to specific contexts and should help to focus on the respective most relevant resource interlinkages across layers. Research also explores the interlinkages with biosphere integrity and climate change, the two core planetary boundaries (Dodds and Bartram, 2016; see also Chapters 2 and 4).

Thus, while we propose such five-node nexus we also suggest to utilize it in a flexible manner. Having such nodes may add complexity compared to most previous studies that analyze a two-node or a three-node nexus. Like Liu et al. (2015) we however argue that it better captures the realities and complexities of human-environment systems and related environment-development goals as specified in the SDGs, and it should make research more relevant.

The nexus and the wider picture of environment, resource scarcities, and human securities

The rapid increase in global resource use along with an increase of the human influence on their global environment since the Industrial Revolution led some researchers to refer to the current era as the '*anthropocene*' (Steffen et al., 2015b): the era where humans are a geological force. While the exact implications of this situation and classification remain under debate, some of the ensuing implications and risks are apparent: global resource use has reached such a magnitude that it causes scarcities and degradation of natural resources at different scales, and on the capacity of ecosystems and the earth systems to regenerate, to provide the required services, and to absorb the resulting by-products and waste products such as CO_2 in a life-sustaining manner for humanity. In particular biosphere integrity and the world oceans are areas of concern from an environmental perspective. Climate change acts as a threat multiplier in this context.

Nexus research is about understanding, assessing, and predicting dynamic interlinkages across the spectrum of natural resources and the value chains by which essential services can be derived out of these resources. Focusing on inputs it also acknowledges wider environmental functions of water and land as supporting, regulating, and stabilizing the provision of inputs for other resources, such as biomass for food production. This links to research on the environment as natural capital[5] (see also Chapter 2). The resource nexus thus complements broader environmental sustainability research in regard to quantifying and assessing critical interlinkages in regard to natural resource management and governance. It provides a basis through which to reduce negative externalities of mono-sectoral approaches and increase system-wide resource efficiency, while looking at the bottom of a green economy in a consistent manner.

Another novel element of our proposed nexus scope is attention paid to inter-related *scarcities* and constraints on using different natural resources. While earlier discussions have often been on 'limits to growth' and limited availabilities of single resources, the geological surveys (USGS, BGS, and others) usually confirm the availability of a sufficient reserve base for mineral resource supplies in coming decades. Among the new constraints that nexus research can address are the following:

- Improve integrated knowledge of input-side resource constraints, e.g. due to decreasing ore grades and increasing energy and water intensity of extraction of minerals, or increasing water or land intensity of some renewable energies. Such evidence shall inform extractive industries and help to develop guidelines for planetary resource consumption, as suggested by Nickless (2016) and discussed in Chapters 18, 19 and 29.
- Constraints on global biomass production which are likely to compromise food security and the achievement of biofuel and bio-economy strategies, all requiring an integrated approach to manage the biosphere, land, water, and other natural resources.
- Apply research findings on inter-related constraints at the output side ('limited absorptive capacities of ecosystems and environment') to analyze and assess inter-related environmental impacts of resource use (e.g. due to potentially higher energy demand and CO_2 emissions of land- and water-smart agriculture).

Our handbook Parts II on metrics, III on modelling, and IV on applications are especially useful to study these nexus topics. Clearly, more research on relationships between natural resource use and inputs, socio-economic processes and metabolism and environmental degradation will be needed. Figure 1.1, with its five-node nexus, may help to orient such work. The figure highlights the potential of nexus research to grasp how water systems, energy systems, and other systems actually use natural resources via multiple and complex pathways and relationships. For example, UNEP's International Resource Panel proposes data and modelling approaches to quantify critical interlinkages between different resources, addressing questions such as: how will demand growth in one resource impact its use efficiency and demand for and use efficiency of other resources? Which (co-)constraints are likely to become more serious over time and how can a nexus approach help to mitigate these? How do the different footprints (water, land, carbon, etc.), as driven by consumption patterns and international commodity trade, affect each other? How can they be reduced jointly? How can a nexus approach help to avoid the transgression of planetary boundaries? Our handbook Part III on modelling touches those issues in more depth, see in particular Chapter 16 on a modelling perspective.

In addition, concern about the intersections of resources, environment, and *security* – in terms of both traditional national and inter-state security and a much broader human security agenda and livelihoods (see here Adger et al., 2014; Biggs et al., 2015) – resulted in a rapid proliferation of scholarly research and reports from think tanks, research institutes, national governments, and international organizations (see also Chapter 4). For example, related research and policymaking efforts have been seen within the UN system (including within both UNEP the Security Council), NATO, the G7, the World Bank, a host of national foreign policy and security think tanks and institutes, the US Department of Defense, Central Intelligence Agency, Department of State, and National Intelligence Council – to name only a few. A growing set of case studies, assessment and modelling exercises, and pilot programs have been produced, engendering a need for more systematic assessment of what is known and how this might be better integrated in the resource nexus framework. Certainly numerous national, international, and human security threats in and among wealthier countries and across the global south are identifiable.

Security-related research has long focused on resources such as water, energy, and minerals access and distribution. But here again, one sees mostly single-resource framings. Interest now turns towards the need to more systematically assess multi-resource linkages to security-related aspects, including those of climate change – its ecological and social impacts, as well as the resource implications and pre-conditions of mitigation and adaptation policies. The governance challenges at the intersection of the resource nexus, climate change, and traditional and human security are legion, occurring at and across multiple scales, including provision of resources needed to survive and thrive, and identifiable risks of local, national, and transnational violence. While research has begun to focus on the ways such connections raise the risks of conflict, violence, and loss of human security and health, these challenges also connect to research on criminality, peacebuilding, and post-conflict reconstruction and a host of vexing justice and equity-related concerns embedded within natural resources, climate change mitigation and adaptation, and Sustainable Development Goals and governance. Traditional and human security concerns are thus central to SDG implementation, and many aspects of climate change and resource nexus governance. We consider it a strategic importance of nexus research to address those issues and, therefore, be able to connect to important areas of policies and decision-making. Special contributions to this security angle can be studied especially in Chapter

4, as well as in Chapter 3 on different scales, Chapter 9 on criticality, Chapter 17 on a non-equilibrium perspective, Chapter 20 on international trade, and Chapter 32 on the UN.

What should a nexus perspective help to accomplish?

Nexus terminology is increasingly popular, and possibly at risk of becoming a ‘buzzword’ as a recent editorial in *Nature* suggests (Nature, 2016; Cairns and Krzywoszynska, 2016). Acknowledging this debate, the authors of this handbook clearly see a value in a nexus approach that is well defined, conceptualized, and applied. Nexus research should be able to improve understanding of resource interdependency by complementing and adding value to existing strands of research – rather than replacing them; relevant contributions can be expected in particular to these areas:

- Closing gaps between environmental sustainability research by adding analysis of resource degradation, exploitation, and use across scales and value-chain systems;
- Industrial ecology research on material flows, stocks, and footprints tracked through economies, by analysing interlinkages across resources and adding socio-economic dimensions;
- Ambitions towards integration coming from one sector (such as integrated water resource management, integrated land-use planning, integrated resource planning as known from energy), by looking more specifically at interactions and feedbacks with other resources, critical thresholds, and use patterns;

- Economic and social science research on commodities, conflicts, and security issues, by adding analysis on natural resource inputs and critical thresholds of resource use;
- Informing resource-related governance and decision-making by public, private, and civil society sector actors.

Clearly, nexus research comes with an inter- and transdisciplinary agenda (Stirling, 2015). The years ahead will require such approaches if states, local communities, societies, and transnational actors are to deliver on the goals and promises made in the SDGs and the Paris Agreement on climate change, for example, as well as for long-term visions of low-carbon, circular economies around a globe in which the worst manifestations of poverty and human deprivation are alleviated.

Organizing the nexus handbook

Part I: Understanding

Part I sets the scene by providing a conceptual overview (Chapter 1), clarifying the relationship of the nexus to environmental sustainability research (Chapter 2), outlining the importance of scale (Chapter 3), and emphasizing the inescapable relevance of climate change and security concerns (Chapter 4).

Part II: Analysing the resource nexus

Part II responds to the need for quantification, especially on metrics accounting for resource interlinkages. This part introduces a number of existing methods from the field of industrial ecology. These methods each describe, in some manner, stocks and flows of materials and energy through society. As such, they link different resources from a functional point of view being useful for analysing the interdependencies across resources in fulfilling society's needs for energy, food, shelter, infrastructures, and products. The following methods are included in Part II:

- Life Cycle Analysis (LCA), capturing the environmental impacts especially of products (Chapter 5);
- Material Flow Analysis (MFA), tracking the material use along value chains and across countries (Chapter 6);
- The various footprints on water, carbon, and materials that have been developed (Chapter 7);
- Input–output analysis as a worldwide data tool and method needed for other tools (Chapter 8);
- Criticality assessments and underlying methodologies as introduced within a number of countries responding to demand for critical materials (such as rare earth elements) (Chapter 9);
- A concluding chapter on such tools with a nexus perspective (Chapter 10).

Part III: Modelling the resource nexus

Part III introduces key modelling tools cutting across different approaches. Modelling is a valuable tool for assessing system implications and dynamics for existing interlinkages and for future strategies, as well as building knowledge about these interdependencies. Accordingly, chapters in this part focus on modelling sustainability transformations with both environmental and social impacts (Chapter 11), challenges of integrating different scales (Chapter 12), the long-term dynamics of K-Waves (Chapter 13), foresight and scenarios (Chapter 14), and macro-economic modelling (Chapter 15). In addition to collecting contributions on existing modelling approaches with relevance for the nexus, Part III concludes with a chapter (Chapter 16) on future nexus modelling, proposing a next generation modelling approach of integrated methods to analyse trade-offs and interlinkages of the five-node resource nexus dynamics.

Part IV: The international political economy of the resource nexus

Beyond better metrics and modelling approaches, comparative research on governance will be needed to better connect nexus analysis to worlds of business transactions, public and civil society practice, and cautioning against mono-sectoral optimization efforts inherent in scenario and modelling processes. This part of the handbook intends to complement and strengthen other research on the anthropocene, on ‘planetary boundaries’, and on ‘earth systems governance’. Accordingly, chapters address mining, commodity trade, and rare earth elements, the latter being a case for critical materials needed for transitions to low-carbon economies. The chapters also attend political economy in the global South, with chapters on equity in the real world of uncertainties, on land governance, and the risks of new resource curses.

Part V: Applying the resource nexus: regional and global scales

A significant number of regional nexus studies have been conducted. They assess the resource interlinkages most relevant in respective regions. Such case studies demonstrate the ways regional contexts often determine the selection of relevant resources and critical interlinkages. In addition, many published papers contribute to understanding resource interlinkages without explicitly using the term ‘nexus’. As in Part I, the scale dimension is essential for the nexus. While we propose a five-node nexus, we also encourage research addressing more focused approaches as appropriate. This part of the handbook allows readers to zoom in, with chapters on China, on the energy demand for metals needed for future low-carbon economies, and the nexus dimension of new energy fuels. Another chapter sheds light on the nexus dimension to hunger in Africa and opportunities for improving food security. Finally, this part also addresses oceans – covering large portions of our planet and relevant for all nexus dimensions.

Part VI: Governing the nexus: emerging responses

While the previous parts intend to analyse nexus challenges and seek to enable actors to apply metrics and modelling as well as to compare cases, this part addresses a few illustrative, emerging response strategies. The array of such strategies has grown as many actors on the ground, in business and among policymakers, deal with nexus risks and seek to turn them into opportunities. One thing is already clear: Overcoming silo-type of thinking and planning is easier said than done. This part of the handbook addresses cities and the UN as the two angles of the political spectrum beyond states. It also offers chapters on eco-innovation and decoupling, on green chemistry as a key enabler for the supply of sustainable resources, and on improved infrastructure planning, illustrated by the state of California. The illustrative chapters in this section seek to inspire future research and future practice, as analysts and policymakers alike grapple with the complexities, challenges, and opportunities presented by the resource nexus.

Notes

References

Ackerman, F., and Fisher, J. (2013). Is there a water–energy nexus in electricity generation? Long-term scenarios for the western United States. *Energy Policy*, 59, 235–241.

Adger, W. N., Pulhin, J. M., Barnett, J., Dabelko, G. D., Hovelsrud, G. K., Levy, M., Oswald Spring, U., and Vogel, C. H. (2014). Human security. In *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*, Cambridge, United Kingdom and New York, pp. 755–791.

Andrews-Speed, P., Bleischwitz, R., Boersma, T., Johnson, C., Kemp, G., and VanDeveer, S. (2012). *The global resource nexus: The struggles for land, energy, food, water, and minerals*. Washington, DC: Transatlantic Academy.

Andrews-Speed, P., Bleischwitz, R., Boersma, T., Johnson, C., Kemp, G., and VanDeveer, S. (2015). *Want, waste or war? The global resource nexus and the struggle for land, energy, food, water and minerals*. London: Routledge/Earthscan.

Bazilian, M., Rogner, H., Howells, M., et al. (2011). Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy*, 39(12), 7896–7906.

Biggs, E. M., Bruce, E., Boruff, B., et al. (2015). Sustainable development and the water–energy–food nexus: A perspective on livelihoods. *Environmental Science & Policy*, 54, 389–397.

Bleischwitz, R., Welfens, P., and Zhang, Z. X. (Eds.). (2011). *International economics of resource efficiency: Eco-innovation policies for a green economy*. Springer Publisher.

Bringezu, S., and Bleischwitz, R. (Eds.). (2009). *Sustainable resource management: Global trends, visions and policies*. Sheffield: Greenleaf Publishing.

Cairns, R., and Krzywoszynska, A. (2016). Anatomy of a buzzword: The emergence of 'the water-energy-food nexus' in UK natural resource debates. *Environmental Science & Policy*, 64, 164–170.

Dobbs, R., Oppenheim, J., Thompson, F., Brinkman, M., and Zornes, M. (2011). *Resource Revolution: Meeting the world's energy, materials, food, and water needs*. New York: McKinsey Global Institute.

Dodds, F., and Bartram, J. (Eds.). (2016). *The water, food, energy and climate nexus: Challenges and an agenda for action*. London and New York: Earthscan/Routledge.

Ellen MacArthur Foundation and McKinsey & Co. (2014). *Towards the circular economy: Accelerating the scale-up across global supply chains*. Geneva: World Economic Forum.

European Commission. (2012). *Confronting scarcity: Managing water, energy and land for inclusive and sustainable growth*. Brussels: European Union. https://ec.europa.eu/europeaid/sites/devco/files/erd-consca-report-20110101_en_0.pdf.

Giurco, D., McLellan, B., Franks, D. M. T., et al. (2014). Responsible mineral and energy futures: Views at the nexus. *Journal of Cleaner Production*, 84, 322–338.

Graedel, T. E., and Voet, E. v. d. (2010). *Linkages of sustainability*. Cambridge, MA: MIT Press.

Green, J. M. H., Cranston, G. R., Sutherland, W. J., et al. (2016). Research priorities for managing the impacts and dependencies of business upon food, energy, water and the environment. *Sustainability Science*, 1–13.

Hertwich, E., Voet, E. v. d., Suh, S., and Tukker, A. (2010). *Assessing the environmental impacts of consumption and production: Priority products and materials*. Nairobi: UNEP.

Hoff, H. (2011). *Understanding the Nexus*. Background paper for Bonn 2011 conference: The water, energy and food security nexus, Stockholm Environment Institute.

Hoff, H. (2017). *Integrated SDG implementation – how a vertical (cross-scale and cross-regional) nexus approach can complement horizontal (cross-sectoral) integration*. Background paper for the Dresden Nexus Conference 2017.

Howells, M., and Rogner, H-H. (2014). Water-energy nexus: Assessing integrated systems. *Nature Climate Change*, 4(4), 246–247.

Kleijn, R., Van der Voet, E., Kramer, G. J., Van Oers, L., and Van der Giesen, C. (2011). Metal requirements of low-carbon power generation. *Energy*, 36(9), 5640–5648.

Lawford, R., Bogardi, J., Marx, S., et al. (2013). Basin perspectives on the water – energy – food security nexus. *Current Opinion in Environmental Sustainability*, 5(6), 607–616.

Le Blanc, D. (2015). Towards integration at last? The sustainable development goals as a network of targets. *Sustainable Development*, 23(3), 176–187.

Lee, B., Preston, F., Kooroshy, J., Bailey, R., and Lahn, G. (2012). *Resources futures*. London: Chatham House.

Liu, J., Mooney, H., Hull, V., et al. (2015). Systems integration for global sustainability. *Science*, 347(6225).

Mo, W., and Zhang, Q. (2013). Energy–nutrients–water nexus: Integrated resource recovery in municipal wastewater treatment plants. *Journal of Environmental Management*, 127, 255–267.

Nature. (2016). Editorial: Scientific buzzwords obscure meaning: 'Nexus' is enjoying new-found popularity. But what does it actually mean? *Nature*, 538(7624).

Nickless, E. (2016). Resourcing future generations: A global effort to meet the world's future needs head-on. *European Geologist European Geologist*, 42, 46–50.

Obersteiner, M., Walsh, B., Frank, S., et al. (2016). Assessing the land resource – food price nexus of the sustainable development goals. *Science Advances*, 2(9).

Ringler, C., Bhaduri, A., and Lawford, R. (2013). The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency? *Current Opinion in Environmental Sustainability*, 5(6), 617–624.

Senger, M., and Spataru, C. (2015). *Water-energy-land nexus- modelling long-term scenarios for Brazil*, Published in Modelling Symposium (EMS), 2015 IEEE European, IEEE. doi:10.1109/EMS.2015.47

Sharmina, M., Hoolohana, C., Bows-Larkina, A., et al. (2016). A nexus perspective on competing land demands: Wider lessons from a UK policy case study. *Environmental Science & Policy*, 59, 74–84.

Steffen, W., Richardson, K., Rockstroem, J., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223).

Steffen, W., Broadgate, W., Deutsch, L., et al. (2015b). The trajectory of the anthropocene: The great acceleration. *The Anthropocene Review*, 2(1), 81–98.

Stirling, A. (2015). *Developing 'Nexus Capabilities': Towards transdisciplinary methodologies*. Brighton: University of Sussex.

Talati, S., Zhai, H., Page Kyle, G., et al. (2016). Consumptive water use from electricity generation in the Southwest under alternative climate, technology, and policy futures. *Environmental Science & Technology*, 50(22), 12095–12104.

UNEP. (2015). *Policy coherence of the sustainable development goals: A natural resource perspective*. Paris: International Resource Panel.

Wichelns, D. (2017). The water-energy-food nexus: Is the increasing attention warranted, from either a research or policy perspective? *Environmental Science & Policy*, 69, 113–123.

Wiedmann, T. O., Schandl, H., Lenzen, T., et al. (2013). The material footprint of nations. *Proceedings of the National Academy of Sciences*. doi:10.1073/pnas.1220362110.

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[1] See e.g. http://futureearth.org/future-earth-water-energy-food-nexus ; www.thenexusnetwork.org; www.water-energy-food.org, www.youtube.com/watch?v=T-eATjiXTOQ.

[2] "Nexus" is the Latin word for interlinkages.

[3] One may note this definition resembles the term 'systems of provision' originating from research on consumption and work done by Ben Fine and Ellen Leopold in the early nineties of last century; while this strand of research puts consumption in relation to processes of production, distribution, and retail, and into a historical and socio-cultural context, our definition of the nexus focuses on the natural resource base of such systems,

the value chains from nature to consumers across such systems, and the interlinkages across them.

4 The term ‘materials’ refers here to non-energetic raw materials; note some glossaries define materials rather broad including energy and other resources, which we consider in other categories of the nexus approach.

5 Natural capital can be defined as “the elements of nature that directly and indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions”, a broad definition with roots in environmental research.