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Introduction to Part Twelve: The Resource Nexus and its Relevance

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Introduction

The complexity of nature and its interactions with societies is nowadays often discussed under the narrative of the water–energy–food nexus.[1] This nexus approach refers to interlinkages among the use of natural resources, illustrated by water needed for both energy and food production. While research about interlinkages has a long tradition in sustainability research (Wichelns, 2017), the ‘nexus’ debate has emerged since 2011 in a couple of conferences and think tank papers. What can be considered new is the balanced approach across key sectors, rather than originating from one specific sector and reaching out to others, and a distinct attempt to grapple with urgent issues on the ground, such as access to resources and security. The nexus attracts attention because it provides a holistic and systemic view that enables fresh thinking on emblematic issues and could facilitate new solutions for research and actors on the ground.

With high popularity in a number of policy circles such as the OECD, UN and World Economic Forum, the term nexus might be seen at risk of becoming a buzzword used by a variety of stakeholders that all subscribe to quite different notions (Cairns & Krzywoszynska, 2016; Green et al., 2016). An editorial in the journal *Nature* suggests that this is exactly the case, if the popularity of the term is not supported by in-depth studies. Thus, the resource nexus needs a better conceptualization for both research and stakeholders. This section of the *Handbook* seeks to contribute to such clarification of the nexus concept.

Our introduction gives an overview on the debate and reviews the scope of the nexus. The subsequent chapters of this section have been carefully selected to shed light on important aspects. In doing so, we seek to demonstrate how the nexus concept underpins ongoing research on risk assessments and how it may facilitate efforts for transformations to sustainability, in particular implementing the UN Sustainable Development Goals (SDGs). The following propositions will be discussed in this introduction and throughout the section:

1. The nexus underpins environmental research. Having an understanding of resource-related interlinkages strengthens long-standing research efforts and allows the silo mentality of isolated planning for water, energy, food and other resources to be overcome.

2. The nexus contributes to security research. Analysing the conditions of access and use within fragile regions and geopolitical hotspots needs this resource dimension for risk assessments and developing integrated solutions. Potentially, nexus research moves from risk assessments towards tangible benefits for water security, food security, etc., thus also contributing towards delivering the SDGs.

3. The nexus contributes to new economic thinking. Building upon research on natural capital and ecosystem services, it supports analysis on supply chain risks and can grasp the business opportunities of a comprehensive resource efficiency and circular economy approach that explicitly accounts for such interlinkages across companies and from an international perspective.

These propositions shall structure the following subsections of our introduction. We will give an overview on the nexus debate and suggest a definition in the next subsection. We will then discuss the security angle before we address the economic dimension. While the other contributions to this section are mentioned several times throughout this introduction, the outlook will give a concise summary of their scope and conclude on the relevance of future nexus research.

The Resource Nexus: Overview and Key Issues

Overview and Systemic Relevance

The resource nexus comprises the numerous linkages among different natural resources on different scales. Research conceptualizes the nexus as a set of interactions, in particular in relation to important drivers for the use of resources (Andrews-Speed et al., 2012, 2014; Hoff, 2011).

Against the background of research, planning and management often being organized along single silos of water, energy etc., the aim of the resource nexus approach is to look at the connections in a more integrated manner. Such interlinkages are manifold and complex, as all resources need others as inputs for their production and along value chains for the delivery of goods and services for final consumers.

In general terms, resources serve as direct or functional inputs in the production process of another resource, or they can substitute the use of another resource. Indirect effects also have to be taken into account because claims for a resource can compete with other demands, as the case of land use for either food or bio-energy production may illustrate.

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Error! Reference source not found. in Figure 59.1 above shows the many ways in which the use of key resources interact. Some nexus issues may be more obvious than others, such as the connection between food and water (see e.g. Carole Dalin's contribution in this section, Chapter 60). Others have become more pressing recently, such as the water inputs needed for energy production when droughts occur.

The implication for decision-making is that all activities that are intended to manage a specific resource shall have knowledge about the estimated inputs needed from other resources in the future, and how those may compete with other demands. This is relevant for risk assessments, especially in water and energy planning, but also for land use planning and for strategic investments. Furthermore, it is systemic in addressing all relevant issues that can be related to the use of natural resources in societies and across many scales.

What Resources Should be Considered

The contemporary debate has a lack of clarity on what resources ought to be considered as part of the nexus. The most widely acknowledged scope covers *water – energy – food* (Bazilian et al., 2011; Hoff, 2011; Lawford et al., 2013; Slingerland et al., 201. Other studies focus on:

- The *water – energy* nexus (Ackerman & Fisher, 2013; Glassman, 2011, Howells & Rogner, 2014), inspired by the huge amount of energy needed for water pumping and by the impact a drought might have on electricity production;
- Water – energy – food – *land* (European Commission, 2012; PBL, 2014; Ringler et al., 2013; Sharmina et al., 2016) as main biotic resources originate from land use patterns;
- Water – energy – food and *mineral fertilizer* (Mo & Zhang, 2013; see also Minpeng Chen et al. in this section, Chapter 62), pointing at the potential depletion of such resources, their relevance for food security, and their complex supply chain with recovery opportunities from e.g. waste water;
- Water – energy – *minerals* (Giurco et al., 2014), illustrated by declining ore grades and the high intensity of using water and energy during extraction processes.

The studies published by Chatham House (Lee et al., 2012) and the Transatlantic Academy (Andrews-Speed et al., 2012, 2014) share a wider recognition of resources as manifold inputs into economic processes in line with Figure 59.1 above; as has McKinsey Global Institute (Dobbs et al., 2012) with a focus on opportunities for some industrial sectors.

There are also a large number of regional case studies, e.g. on India (Rasul, 2014), South Asia (Mukherji, 2008; Rasul, 2014; see also Adnan Hezri and Michelle Kwa on Asia in this section of the *Handbook*, Chapter 61) and the MENA region (Siddiqi & Anadon, 2011), which assess those resource interlinkages that are most relevant in the region. Without being exhaustive here it can be said that the resource nexus concept is fairly often applied on the ground on different scales.

A Suggested Definition and Scope

We define the resource nexus as the set of context-specific critical interlinkages between two or more natural resources used as inputs into socio-economic systems. The aim of the resource nexus approach is to look at critical connections in a more integrated manner, in particular at minimum supply conditions, threshold values, synergies and tradeoffs. The nexus can be conceptualized as a set of critical interlinkages between the different natural resources, with human activities shaping the drivers, intensity and efficiency of resource use, and humans and the environment either benefiting or being impacted by the outcomes of resource use.

In line with Figure 59.1 above, research may adopt a scope that comprises all direct resource inputs into socio-economic processes on appropriate scales, especially taking into account the following resources:

- Water
- Energy (fossil fuels and other fuels such as nuclear)
- Food and biomass. Food is often referred to in nexus research; however, there is usually a series of processing steps between biomass production and consumable food (harvest, separation of edible fraction, milling, peeling, pressing, drying, cooking etc.), which depends on inputs of energy, water and other resources. One

could also acknowledge the many ways in which crops can be directly used as food, especially for livelihoods of the poor.

- Land, because it is an ultimately limiting factor of production and serves all environmental functions of support, regulation, provisioning and cultural services.

- Materials and minerals (with suggested subcategories for metals and critical materials, construction and industrial minerals and a possible separate account for mineral fertilizers), because:

    - Materials make up ~ 50% of resource use in most industrialized countries (measured in physical units according to Material Flow Analysis methodology);

    - The costs for the manufacturing industry are significant;

    - Base metals, critical materials and construction minerals are relevant for the SDGs related to water, energy and urbanization; mineral fertilizers are relevant for food production;

    - Materials have been assessed as being important intermediaries of environmental impacts (UNEP, 2010, p. 81).

Having a five-node nexus of water–energy–food–land–materials (see **Error! Reference source not found.**) leads to more complexity compared with the vast majority of previous studies that analyse a two-node or a three-node nexus, but we propose in line with Liu et al. (2015, p. 3) that it also captures greater reality, and thus it facilitates bringing in the social dimension. We consider this approach to be flexible and open (as the contributions to this section demonstrate): case studies may focus on a few core critical interlinkages, and may also analyse interlinkages within some of these dimensions, such as biomass and food.

The security dimensions of the nexus

A relevant element of the whole debate about the resource nexus is the acknowledgement of the security dimensions (e.g. Lee et al., 2012), along with a focus on how people are affected, how regions might run into serious conflicts and what threats and risks might affect other countries. It can be considered a relevant feature of the debate that (a) addresses the interrelations between science and the human dimensions beyond the traditional scope of environmental research and (b) may yield insights into potential future knock-on effects such as conflicts and disruptions of supply. The following graph can be seen as illustrative of how the security notion is being integrated with the nexus debate (it should be noted that the scope in this figure differs slightly from what we discuss, as land and materials are not explicitly referred to).

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Water, energy and food security are fundamental for human life and well-being. As regards to water, access to clean drinking water is a key UN Sustainable Development Goal (SDG 6) and considered a human right. The current provision is unsatisfactory for some 750 million people lacking such access, and for the 2.5 billion people without access to improved sanitation. The challenges of supplying 7 billion people with clean and safe water, with a further 1 billion expected by 2030, are likely to increase. Looking ahead, the growing middle class, ongoing urbanization and the risks of climate change are all adding to the pressure.

A resource nexus view allows the complexities of environmental change and supply issues to be dealt with. An interesting angle is the intersection with drivers for demand, security of supply, governance and innovation. In the future, this is very likely to become more important. Recent evidence on the dangerous conjunction of high prices for food and water and social tensions could be witnessed during the Arab uprisings in 2011. Sternberg (2012) points to the drought that occurred in Northern China as a global trigger mechanism for higher food prices; the International Food Policy Research Institute (Breisinger et al., 2011) underlines additional domestic factors such as malnutrition, the phasing out of food support programmes and a high share of angry young men caring for their families. Indeed, other factors have been relevant too, and may have contributed even more.

Another striking observation can be seen in the *return of geopolitics* since the rise of China, Russia and others. Traditionally, one looks at political risks and threats stemming from potential conflicts between one of the superpowers and their neighbours or between powerful states. Resource risks emerge from an asymmetry between such powerful states using their command over resources as a control mechanism to enforce their political will upon weaker or dependent nations. In line with this, major suppliers such as Russia and Brazil look at their resources as strategic assets; major commodity platforms such as China and India impose all kind of policies to maintain their development interests all over the world. They all have established state-owned enterprises with tremendous power in international markets and do not adhere to principles of the Atlantic Charta (1944), i.e. a liberal order with open markets and open access, the rule of law and democracy.

As a case study, one might consider the conflicts arising in the South China Sea. There are territorial disputes involving both island and maritime claims among several sovereign states within the region, namely the People's Republic of China, Brunei, the Republic of China (Taiwan), Malaysia, the Philippines and Vietnam. Those disputes (see **Error! Reference source not found.**) are over fishery rights, the potential exploitation of strategic reserves of crude oil, natural gas and a number of minerals all located in the seabed, and indeed over important shipping lanes. China looks at the region as an area of core interest and as non-negotiable (i.e. on a par with Taiwan and Tibet), whereas other nations claim their rights within the 200-mile zone acknowledged by international law. Incidents between those nations since ~ 2011 can be characterized as gunboat diplomacy, recently involving the US Navy. A dispute settlement attempt at the International Court of Justice has been without success as China did not accept the verdict in 2016. Border disputes are aggravated by Chinese efforts to transform reefs into islands (partly used as a military base), claiming that those islands would extend Chinese territory. As historian Herfried Muenkler reminded observers, the Great War (WW I) emerged out of a similar constellation in Europe in 1914, and the situation should be taken seriously. The nexus point to make here is the access to a number of resources that all can be considered vital interests.

[TS: Insert Figure 59.3 about here]

For a long time, cases like this have been disputed as potential ‘resource wars’ (e.g. Michael Klare), i.e. interstate or national conflicts over access to and control over a natural resource such as oil. This debate continues and is controversial on the issue of whether or not resources are a strong causal factor for such conflicts. Research applies advanced methods to prove the relative contribution of key factors to such conflicts and, by and large, arrives at mixed results. Establishing analytical coherence and having a representative and comprehensive sample selection is a research frontier (see e.g. Halvard Buhaug). A lesson learned can be seen in the historic record of how many contentious disputes have been resolved, although the case of the China Sea also shows how easily pre-existing conflicts can turn relatively minor disputes into matters of intense nationalism.

The important point from a nexus perspective is that those resource interlinkages enhance existing conflict constellations, as actors and their interests potentially multiply. Additional repercussions arise around transboundary issues, as the perspectives on using e.g. water not only differs between upstream and downstream actors but also between user groups such as agriculture, energy, industry.

The changing climate is likely to enhance geographical disparities and increase international tensions. The World Bank (2012) report on the likelihood of a plus 4º C world warns that such a change would significantly exacerbate existing water scarcity in many regions, particularly northern and eastern Africa, the Middle East and South Asia. In such a world, food security could be substantially undermined. Compounding these risks is the adverse effect of projected sea-level rise on agriculture in important low-lying delta areas, such as in Bangladesh, Egypt, Vietnam and parts of the African coast. As countries have started to fortify borders to keep mass migration out, a number of security repercussions related to the resource nexus can be expected.

Another security dimension arises with regard to internal conditions of weak states, often called failing states or fragile states. In line with water, energy and food security this can be called a *human security dimension* rather than interstate or international security. Previous research has often looked at it in the realm of the 'resource curse', the inability of resource-rich states to turn their natural endowments into well-being. So-called conflict minerals are a nexus case in point. They can be characterized as those minerals whose control, exploitation, trade, taxation, or protection contribute to, or benefit from the context of, armed conflict. The actors directly involved in these activities can be warlords, rebel groups, a country's regular national army, or renegade members of the army. The armed actors use the profits derived from conflict minerals to finance their purposes (e.g. purchasing weapons, ammunition and supplies) and in some instances to enrich them. In such cases, conflict minerals are a main driver for perpetuating armed conflicts. Conflict minerals thus may not cause a conflict, but they are a factor in how a conflict evolves and how long it lasts. International customers and consumers are indirectly involved through using those minerals in a number of products (e.g. ICT).

Conflict minerals such as coltan, a mineral mined in Africa and used e.g. in mobile phones, may cover a significant share of some 20% of the world markets, perhaps even more (Bleischwitz et al., 2012). But the issue goes much further. Nexus research can shed light on how the livelihood of actors on the ground is being affected (Biggs et al., 2015) and how poverty and lack of access to food and water often drives people into small-scale artisanal mining, which in turn affects ecosystem services and land use. The following figure illustrates further resource interlinkages and the scales that are involved. In the end, relevant industries are affected as relevant production sites might be located in fragile areas and supply chain security is at stake. Add the need of those materials for low-carbon technologies and the scope for nexus research should become obvious.

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In order to enhance *supply chain security* and avoid *reputational losses*, a certification of value chains, such as the one proposed by OECD's due diligence guidelines, will certainly increase transparency and help to establish accountability (Gupta & Mason, 2014). However, certifying single materials will be challenging since global value chains are organized along products and are difficult to monitor (Bleischwitz, 2014). The cumulated risks and threats can be described from a nexus perspective as follows: first, the environmental and social repercussions on the ground may deteriorate, if certification is not accompanied by dedicated support programmes; secondly, illicit or criminal actors will be able to switch to more profitable activities, clearly with environmental and social security implications; third, non-compliant weak links along the value chain (such as refinery processes in China) may find ways to by-pass rules and supply parallel markets without any such certification.

In fact, many commodity suppliers beyond those of conflict minerals can be considered fragile; in particular, new suppliers are at risk of suffering from the *'resource curse'*, the institutional inability to transform natural endowments into prosperity for the poor. The price rally of the 2000s may have offered opportunities to escape the various traps of underdevelopment. Fragile states would nevertheless need to build up capacities to comply with international social or environmental standards, or develop comparable rules. As a constraint, their institutions are often 'extractive' (i.e. not inclusive; see Acemoglu & Robinson, 2012) and yet too weak.

With stress multipliers such as climate change, volatile commodity prices and pressure from population growth – factors that are very difficult to be influenced by those states – risks of violent conflicts increase, and many of these countries may actually fail. This is especially likely in those countries that are in a post-war or civil war period, such as Afghanistan, Iraq, Libya, Syria and others.

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The combination of these factors could translate into cumulative risks of what we call a *redux of the resource curse* (Bleischwitz et al., 2013): triggered by the emergence of a food and/or water crisis – whatever the causes may be – local and national governance mechanisms are vulnerable and may not be able to cope with such a shock. If people start rioting for access to water and food and if the existing institutional resilience is low, fragile states and regions will be put at risk of further instability, where the above-mentioned mechanisms might escalate. Any such escalation will certainly affect all three security dimensions, inter-state and international, the human security, and supply chain security for essential materials. Needless to say, it will deter the implementation of the SDGs – unless nexus research can turn risk assessments into governance opportunities of better collaborations. By pointing at critical interlinkages related to actors, nexus research should be able to do exactly this.

The economic dimension of the resource nexus

Another relevant feature of the nexus concept complementing environmental research and being able to reach out to stakeholders addresses the economic dimension. It stems from dynamics of human production processes that are all underpinned by inputs of resources. Our introduction considers two main entry points for economic analysis:

- Prices and the relevance of the price mechanism
- Natural capital and the material basis of the economy

Prices and the Relevance of the Price Mechanism

With the exception of non-municipal water, livelihood-based and barter-type of exchanges, all resource inputs into economic activities have a market price, which is determined via supply and demand on markets and their regulatory settings. In that regard, the resource nexus approach can become operationalized with monitoring physical exchanges and existing market prices in a first instance, which should yield insights about demand trends and relative scarcities. For purposes of scoping risks one may not necessarily need to add shadow prices that reflect negative externalities or other non-market costs.

As the demand is expected to increase for all resources on a worldwide level it is essential to monitor and analyse commodity prices. Future research activities should be based on such analysis and should aim at filling the gap that exists between the areas of food and energy where a number of relatively sophisticated price monitoring mechanisms exist (e.g. from the Food and Agriculture Organization (FAO) and International Energy Agency (IEA)) compared with land and materials where such capacity is lacking.

Between 2005 and 2011 commodity prices roughly doubled, essentially erasing the long-term price decline that had occurred in the 1980s and 1990s. Since 2011 most commodity prices have declined, especially for energy commodities. While the additional energy supply coming from both unconventional fuels and renewable energies should be regarded as a trend and a potential 'game changer', any such additional major supply has not occurred for metals and agricultural commodities. At the Mining 2014 conference in Brisbane, Australia, most analysts forecast an upturn of prices even as key commodity prices continued to slide. Drivers for upward demand trends are urbanization, housing and infrastructure, mobility, and food consumption, which will all require minerals and related value chains.

Although the long-term future price expectations face major uncertainties and the resources boom of the 2000s may have faded, a commodity crunch may return, if those drivers continue and if neither major new discoveries come on stream (caused by low investments following low prices), nor resource productivity activities deliver large scale. Two trends are of special interest for any socio-economic nexus research:

- More fragmented commodity prices, i.e. prices for oil and gas may stay lower than prices for metals and agricultural commodities. Water prices are fragmented anyway as they are determined at a local or regional level;

- With the majority of economic growth expected to come from outside OECD countries, commodity prices will increasingly be determined there, i.e. partly outside the Western liberal order.

The World Economic Forum expects ensuing global risks such as protectionist measures, resource nationalism and geopolitical tensions. The resource nexus can be seen as an additional driver underlying those global risks that impacts especially the regional and national level. It is likely that these risk factors will lead to abrupt supply disruptions for commodities in the near-term and long-term future.

Accordingly, price volatility is likely to remain high. Price volatility is additionally triggered by uncertainties about future demand and short innovation cycles in key markets downstream that often do not match with long-term planning of investments in the supply of energy, water and minerals.

The relevance of the price mechanism for analysing the role of natural resources and materials in economies is underlined by data from the EU suggesting that the share of material costs in overall production costs for manufacturing companies is in the order of 40%, i.e. higher than the share of labour costs.[2] The significant share of material costs is a relevant parameter for modelling approaches that yield net economic benefits while raw material consumption is being reduced (CE / BioIS, 2014). The currently used data are based on surveys and capture not only the costs of energy and materials but also those of natural resources, products or semi-finished products as well as the added value e.g. processed natural resources from upstream activities. Some studies thus suggest removing as many costs as possible related to the supply chain and focusing on the pure costs of using natural resources in economies (Wilting & Hanemaaijer, 2014); tentative results following such an approach, however, also arrive at shares of up to 60% of those basic raw material costs for industries such as food, chemicals and base metals and related exports, while the share in total final demand is lower.

The approaches used to calculate the share of resource costs in overall production costs are certainly a useful starting point for modelling purposes. More research is needed to arrive at an accurate representation of total resource costs – and proper values! – in economies; this is especially relevant for land accounting. The important point to stress is the relevance of such life-cycle material costs for the competitiveness of industrial sectors and whole economies, extending the scope of analysis beyond the few sectors supplying raw materials. A nexus modelling approach thus should help to establish knowledge on how a number of resource-dependent industries perform over time, how international commodity trade (and virtual trade with water etc. hidden in early stages of the value chain) can be incorporated and how the performance may change once nexus-related shocks occur. Future modelling approaches should link single resources in the most comprehensive manner and capture prices as well as physical units of resource use.

The historic evidence of the two oil price shocks occurring in the 1970s suggests that security issues and the political economy of natural resources matter for supply and for commodity prices. The more contemporary evidence are e.g. the export restrictions in the markets for rare earth elements or for some agricultural commodities during seasonal shortages. The nexus concept should be able to help identify potential future supply shocks that may occur, if water stress and food stress hit vulnerable regions that are home to significant extraction or manufacturing processes and could be put at risk. Accordingly, modelling approaches should capture the nexus interlinkages between resources and socio-economic systems, perhaps starting with key interlinkages, and integrate shocks and other non-linearities as well as different scales as comprehensively as possible.

Expressing the relevance of the price mechanism nexus for critical interlinkages research might actually focus on changes on the ground with relevance for the people over the next few years. Applied nexus research could thus support resource governance in key countries and regions as well as along supply chains.

Resource Economics, Natural Capital and the Material Basis of the Economy

The well-established principles of shifting the resource base from using non-renewable resources onto renewable resources are intuitively appealing, yet they have to be critically re-examined. Environmental research reveals very limited capacities of eco-systems to provide additional renewable resources on a large scale. The seven principles developed by Bringezu and Bleischwitz (2009, p. 8) instead focus on increasing resource efficiency and assume that non-renewable resources will continue to have a share in providing materials (albeit possibly a smaller one compared with today); they are as follows:

1. Secure adequate supply and efficient use of materials, energy and land resources as reliable biophysical basis for creation of wealth and well-being in societies and for future generations.
2. Maintain life-supporting functions and services of ecosystems.
3. Provide for the basic institutions of societies and their co-existence with nature.
4. Minimize risks for security and economic turmoil due to dependence on resources.
5. Contribute to a globally fair distribution of resource use and an adequate burden sharing.
6. Minimize problem shifting between environmental media, types of resources, economic sectors, regions and generations.
7. Drive resource productivity (total material productivity) at a rate higher than GDP growth.

We may now compare the resource nexus with the natural capital concept. Natural capital has been 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' (UK Natural Capital Committee, 2014, p. 8), a definition evidently much broader than our definition of the resource nexus that focuses on the direct use of resources as inputs into economies. Many nexus papers, however, also analyse direct pressure on ecosystem services[3] and provide case study evidence, or make reference to established methodologies such as material flow analysis and other environmental accounting tools. The ability to analyse relevant environmental pressures through the resource nexus is furthermore supported by carbon accounting and the wider debate about ‘planetary boundaries’ (Rockström et al., 2009; Steffen et al., 2015) where the resources of nitrogen, phosphorus and freshwater are featured, and the carbon indicator can be traced back to the use of energy and other resources.

For the purposes of this introduction we may propose that environmental pressures related to energy, materials, land, water and biomass/food can well be treated with the resource nexus. However, it is certainly fair to also conclude that the wider indirect environmental impacts and changes in the state of the environment are likely to remain outside the scope of the resource nexus unless there is substantial progress in interlinking different types of models (Liu et al., 2015).

Having expressed the likely limits of the resource nexus concerning environmental changes, which are an essential part of the research agenda on natural capital, the nexus concept could be expected to complement weaknesses in prevailing attempts to conceptualize natural capital research, which focuses on understanding ecosystem services and valuing nature. A critical appraisal of the Natural Capital Accounting (NCA) framework seen from a nexus perspective could, in our view, start from the following issues:

- To what extent does NCA accurately reflect minerals and other raw material resources?
- Does NCA lead to an understanding of how such raw material resources are used throughout value chains and in societies?
- Does NCA increase the knowledge about resource interlinkages as well as why and how resources could potentially be used in a more sustainable manner?

As the explanatory power of the natural capital framework also seems to have some limits, this introduction concludes that the resource nexus offers a perspective close to natural inputs in production processes and relevant for decision-makers about using resources actors that is likely to enhance understanding of the material basis of economies.

Related to the latter, the nexus can put the evidence provided by the geological surveys (British Geological Survey, US Geological Survey and others) into a sustainability perspective. While geologic assessments do not find much evidence of absolute physical scarcities in the supply of resources for a time span of some decades, the resource nexus underlines other constraints (Bleischwitz et al., 2011) that can be translated into restrictions for future decision-making and international guidelines for planetary mineral consumption (Nickless, 2016):

- Applying findings on limited absorptive capacities of ecosystems to the output side of resource-intensive production processes along with nexus constraints

- At the input side of extractive industries (due to increasing energy- and water-intensity of extraction) with relevant implications for the supply of resources

    - A minimum amount of water needed for cooling a power station, or generating electricity from hydropower, or for irrigation in agriculture in order to safeguard food security

    - A minimum of energy needed to run key industrial activities or to keep a water distribution system running

    - A minimum of biomass and land to feed a certain number of people based on current agricultural patterns (likely conflicting with aims to increase bio-energy or biomass production for other purposes)

    - A minimum of materials needed to produce one unit of a certain product based on current technology.

An interesting development discussion is related to decoupling resource use from GDP and the *saturation effect* in societies, i.e. a stage in development when a capital stock (housing, infrastructure, manufacturing industry etc.) will have been built up and countries will be able to increase GDP without further major increase in resource use (Bleischwitz et al., 2017). The development of scenarios about resource futures should take such saturation effect into account.

As most minerals and metals can furthermore potentially be subject to advanced recycling processes, societies may be able to provide more and more materials from secondary sources and, accordingly, establish a circular economy based on a low material input and throughput (EMF, 2014). At the same time, the innovation-oriented perspective of enhancing resource productivity is enriched by insights into resource interlinkages, e.g. on how water savings translate into energy savings etc. Industrial symbiosis is a well-tested concept for business collaborations that seeks to fertilize by-products and synergies using outputs of one production process as input into another, as discussed further by Teresa Domenech Aparisi in Chapter 63.

Nexus perspectives on the SDGs

It will be interesting to bring a nexus perspective into the implementation of the SDGs launched in 2015. A nexus approach suggests that the SDGs are likely to have major implications for future resource markets. However, those implications are mixed:

On the one hand, many of the new SDGs will lead to an increase in demand for a number of materials:

> Goal 2: 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' – implies increasing demand for land, mineral fertilizers, water, biomass and food.
>
> Goal 6: 'Ensure access to water and sanitation for all' – implies investments in water supply and a water distribution infrastructure, i.e. increasing demand for materials.
>
> Goal 7: 'Ensure access to affordable, reliable, sustainable and modern energy for all' – is likely to imply increasing demand for bio-energy and renewable energy,

plus more traditional energy sources, which again implies more demand for land, biomass, water and materials.

Goal 9: ‘Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation’ – will require more construction materials, metals and other materials.

Adding the promotion of economic growth, as well as efforts to eradicate hunger and enhance health, the signals for future demand for resources stemming from the SDGs are clearly upwards. At least for key metals (aluminium, iron ore, copper and nickel, which altogether make up more than 80% of world production of metals), for construction minerals, for biomass and food, for water and for arable land, the SDGs are very likely to lead to new and additional demand compared with business as usual forecasts (for food and land use issues, see Obersteiner et al., 2016). The situation for energy fuels is less straightforward as climate policy will probably lead to restrictions on using fossil fuels, if political efforts succeed, although major suppliers may not join any future international agreement and have announced plans to expand production; if prices for fossil fuels stay low, efforts to curb demand will be difficult to achieve.

On the other hand, the SDGs also endorse the sustainable production and consumption agenda, and call for global increases in resource efficiency as well as for aims to achieve sustainable and resource-efficient infrastructures by 2030 (Goal 9) and sustainable management and efficient use of all resources by 2030 (Goal 12). Moreover, they aim to ‘improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation (…)’ (Goal 8).

The balance between such expected demand increases and other goals, however, is not entirely clear, in particular as key terms (such as sustainable management and efficient use of all resources) are insufficiently defined and will leave space for quite different implementation pathways. Nexus research will thus have a key role to play in clarifying trade-offs and identifying synergies. It will also be required to develop principles for a sustainable management of resources and to understand future dynamics on resource markets and within societies.

Outlook

Emerging from sustainability research, the nexus approach can be seen as a relatively new and promising attempt to bridge the gaps between environmental research and the human dimension. The definition and the scope provided in this introduction suggest a high relevance for a number of established research areas such as environment and development, international relations and modelling. It is also an opportunity for trans-disciplinary research as actors on the ground have driven the application of the nexus from the very beginning and stakeholders would need to be included in any research design. The 'added value' of a nexus approach comes from the dedicated aim to overcome a silo approach in managing water, energy, food and other resources, as well as from the focus on critical interlinkages. In short, it is about minimizing risks and enhancing opportunities. While being part of research it is also a compelling narrative for stakeholders and actors on the ground. Such relevance becomes even more obvious when the new SDGs are to be implemented by the year 2030.

Research, however, needs to strengthen the conceptual understanding and clarify those critical interlinkages. Subsequent chapters of this section of the *Handbook* address:

- Water and the interlinkages with energy food security and land; discussing water related risks, in Chapter 60 Carole Dalin also develops propositions about a more sustainable water management. She discusses the heritage of the Integrated Water Resource Management approach and the value a nexus perspective may be able to add. Crossing the regional scale she also analyses virtual water trade on a global scale and develops conclusions on how a nexus approach can help decision-makers and sustainability research.

- Fertilizers are a relevant interlinkage across minerals, food, and biomass. In Chapter 62 the authors, Minpeng Chen, Yunfan Wan and Li Yue discuss the relevance of fertilizers for food production and analyse the interlinkage with energy markets and water consumption. They also look at the environmental impacts of fertilizers. Applying a nexus perspective, they conclude on fertilizer management within multiple resource management.

- Industrial symbiosis can be seen as a bottom-up concept applied by business actors and related networks since the 1990s; in line with our nexus concept it also stresses the relevance of materials. In Chapter 63 Teresa Domenech Aparisi analyses the concept in relation to the nexus and lessons learned from a number of international case studies. She looks in particular at opportunities, if such a concept can be enhanced, and she draws conclusions for a future alliance of research on industrial symbiosis and the nexus.

- Asia and the role of institutions is at the core of the contribution made by Adnan A. Hezri and Michelle Kwa in Chapter 61. Asia is becoming a hub for a number of megatrends in relation to the resource nexus, and it is clearly relevant for both the security dimension and international economics. The contribution looks at expected drivers of demand for all resources considered in our nexus section.

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Notes

[TS: Insert End notes here]

References

Acemoglu, D. & Robinson, J, 2012. Why Nations Fail: The Origins of Power, Prosperity, and Poverty. MIT Press.

Ackerman, F. & Fisher, J., 2013. Is there a water–energy nexus in electricity generation? Long-term scenarios for the western United States. Energy Policy, 59(0): 235–241.

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

Andrews-Speed, P., Bleischwitz, R., Boersma, T., Johnson, C., Kemp, G., VanDeveer, S.D. (2014). Want, Waste or War? The Global Resource Nexus and the Struggle for Land, Energy, Food, Water and Minerals, Routledge (Abingdon-on-Thames).

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

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

Bleischwitz, R., Nechifor, V., Huang B., Geng, Y, 2017. Extrapolation or saturation – Revisiting growth patterns, development stages and decoupling. Accepted for publication in: *Global Environmental Change* (14 Nov 2017).

Bleischwitz, R. (2014). Transparency in the extractive industries: Time to ask for more, in: *Global Environmental Politics*, 14(4), http://.dx.doi:10.1162/GLEP_e_00254

Bleischwitz, R., Johnson, C.M., Dozler, M. (2013): Re-assessing resource dependency and criticality. Linking future food and water stress with global resource supply vulnerabilities for foresight analysis, in: *European Journal for Futures Research*, Special issue on Futures research as instrument for policy development and strategic reasoning, http://dx.doi.org/10.1007/s40309-013-0034-1

Bleischwitz, R., Dittrich, M., Pierdicca, C. (2012). Coltan from Central Africa, international trade and implications for any certification. Resources Policy, 37(1): 19–29, doi:10.1016/j.resourpol.2011.12.008.

Bleischwitz, R., Welfens, P., Zhang, Z.X. (Eds) (2011). International Economics of Resource Efficiency. Eco-Innovation Policies for a Green Economy, Springer.

Bringezu, S. & Bleischwitz, R. (2009). Sustainable Resource Management. Trends, Visions and Policies for Europe and the World, Greenleaf.

Cairns, R. & Krzywoszynska, A. (2016). Anatomy of a buzzword: The emergence of 'the water-energy-food nexus' in UK natural resource debates. Environmental Science & Policy, October 2016, doi: 10.1016/j.envsci.2016.07.007

CE BioIS (2014). Study on modelling of the economic and environmental impacts of raw material consumption. European Commission Technical report 2014-2478, Brussels.

Dobbs, R., Oppenheim, J., Thompson, F., Brinkman. M., Zornes, M. (2011). Resource revolution: Meeting the world's energy, materials, food and water needs. McKinsey Global Institute, http://www.mckinsey.com.

Ellen MacArthur Foundation (EMF) (2014). Towards the circular economy. Accelerating the scale-up across global supply chains. Cowes, Isle of Wight.

European Commission (2012). Confronting scarcity: Managing water, energy and land for inclusive and sustainable growth. The 2011/2012 European Report on Development. Accessible at: http://ec.europa.eu/europeaid/index_en.htm.

Giurco, D. et al. (2014). Responsible mineral and energy futures: Views at the nexus. Journal of Cleaner Production, 84: 322–338. Available at: http://www.sciencedirect.com/science/article/pii/S0959652614006805.

Green, J. et al. (2016). Research priorities for managing the impacts and dependencies of business upon food, energy, water and the environment, Sustainability Science 12 （2）： 319-331.

Gupta, A. & Mason, M. (2014). Transparency in Global Environmental Governance. Critical Perspectives, MIT Press.

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

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

Lawford, R. et al. (2013). Basin perspectives on the water–energy–food security nexus. Aquatic and Marine Systems, 5(6): 607–616.

Lee, B., Preston, F., Kooroshy, J., Bailey, R., Lahn, G. (2012). Resources Futures. A Chatham House Report. London: Chatham House.

Liu, J. et al. (2015). Systems integration for global sustainability. Science, 347(6225), doi: 10.1126/science.1258832.

Mo, W. & Zhang, Q. (2013). Energy–nutrients–water nexus: Integrated resource recovery in municipal wastewater treatment plants. Journal of Environmental Management, 127(0): 255–267.

Mukherji, A. (2007). The energy-irrigation nexus and its impact on groundwater markets in eastern Indo-Gangetic basin: Evidence from West Bengal, India. Energy Policy, 35(12): 6413–6430.

Nickless, E. (2016). Resourcing Future Generations, European Geologist 42: 46–50.

Obersteiner, M. et al. (2016). Assessing the land resource–food price nexus of the Sustainable Development Goals. Science Advances, 2016;2:e1501499.

Rasul, G. (2014). Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. Environmental Science & Policy, 39(0): 35–48.

Ringler, C., Bhaduri, A., Lawford, R. (2013). The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency? Aquatic and Marine Systems, 5(6): 617–624.

Rockström, J. et al. (2009). A safe operating space for humanity. Nature, 461: 472–475.

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

Siddiqi, A. & Anadon, L.D. (2011). The water–energy nexus in Middle East and North Africa. At the crossroads: Pathways of renewable and nuclear energy policy in North Africa. Energy Policy, 39(8): 4529–4540.

Steffen, W. et al. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347: 6233.

UK Natural Capital Committee (2014). The State of Natural Capital: Restoring our Natural Assets. Second report to the Economic Affairs Committee. Retrieved from http://www.naturalcapitalinitiative.org.uk/wp-content/uploads/2014/06/1f06ffa9eaf0af134d7022af36fe17cf.pdf

UNEP (2010): Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. Hertwich, E., van der Voet, E., Suh, S., Tukker, A., Huijbregts M., Kazmierczyk, P., Lenzen, M., McNeely, J., Moriguchi, Y.

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.

Wilting, H.C. & Hanemaaijer, A. (2014). Share of raw material costs in total production costs, PBL publication number 1506, The Hague, PBL Netherlands Environmental Assessment Agency.

[1] See also the work of the UK nexus network at: http://www.thenexusnetwork.org; the Future Earth Knowledge Action Network on the nexus at: http://futureearth.org/future-earth-water-energy-food-nexus; or one of the origins: http://www.water-energy-food.org

[2] Data based on surveys conducted for Eurobarometer (2011) and German Statistical Agency.

[3] See e.g. Andrews-Speed et al., 2014; CE/BioIS, 2014; Hoff, 2011; PBL, 2014; Slingerland et al., 2011.