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ORIGINAL ARTICLE

Re-Assessing resource dependency and criticality. Linking future food and water stress with global resource supply vulnerabilities for foresight analysis

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Abstract While strategic studies on natural resources usually focus on the criticality of certain *single* materials, our paper starts from the inter-linkages between and among resources (called "the resource nexus"). It examines the impact any food and water stress may have on extraction activities in fragile states and regions. According to our approach, conflicts are likely to increase and may escalate in a number of countries, many of which are of relevance for the global supply of strategic materials. Future criticality for European and other industries, thus, is more likely to result from particular regions surpassing their adaptive capacities, and not mainly from limited availability or bottlenecks in the supply chain. The paper first develops a heuristic model of drivers for stress in resource-rich regions. Applying this approach, our paper then develops a global three-layered map along the dimensions of (i) future regional food and water stress, (ii) fragility of countries, and (iii) resource-rich countries with relevant reserves of strategic materials. As a result our paper tentatively identifies 15 countries at high risk and some 30 other countries being at relevant risk of causing resource supply disruptions. The conclusions underline the need to analyse those global inter-linkages and institutional mechanisms for strategic futures studies at a regional scale. As this may go beyond the capacities of actors on commodity markets, our paper also draws conclusions towards the establishment of an international data hub on the global resource nexus and for futures research. The paper points to some of the long-term implications of these issues.

Keywords Resource curse · Conflicts · Fragile states · Food stress · Water stress · Mapping

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Special issue on "Futures Research as instrument for policy development and strategic reasoning"

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Introduction

In the winter of 2011, a drought occurred in eastern China's wheat-growing region of Henan, Anhui and neighbouring provinces. Though the decreased wheat production still met China's internal demand, China supplied less wheat to global markets, which resulted in a price spike. This supply disruption and price increase particularly affected the biggest importer of Chinese wheat, Egypt, where bread prices tripled. Though the degree to which the high food prices were a contributing factor to the Arab Spring are difficult to disentangle from many other factors, futures research should put these events into a wider perspective. It reminds scholars to the challenges of what Nassim Taleb calls "black swans" [1], disruptive events that are either unpredictable or very hard for humans to isolate from among a complicated set of interrelated causes or mechanisms. Our questions for any Futures 2.0 agenda as outlined by Pang [2] are as follows:

1. If food and water stress are likely to accelerate in many parts of the world, what are the socio-economic repercussions in the respective region?
2. Could this lead into a downward spiral of events where those regions will be put at risk of socio-political breakdowns?
3. Might such a chain of events "out there" lead to interruptions of supply chains for energy fuels, materials, and preproducts that are essential for many key technologies "here"?

These questions are at the heart of our paper. It deals with such "wicked problems" in an explorative manner [3]. The aim of our paper is to start developing assessment tools for futures studies that look at regions and countries along the three dimensions of (i) future regional food and water stress, (ii) fragility of governance structures, and (iii) countries with relevant reserves of strategic materials. We use a number of different data tools to develop three layers for a mapping exercise, which then yields tentative results on what countries can be considered as being at high risks.

Before starting such a mapping exercise, however, our paper introduces the more recent debate about interconnections between different resources, what we refer to as the "resource nexus" [4–8]. The resource nexus is distinct from the prevailing discussion of critical materials done by the European Union's (EU) Raw Materials Initiative or the U.S. Department of Energy (DoE), both of whom identify priority materials of concern following more narrow criteria of availability and access.

Our approach resembles the long-lasting debate about resource conflicts and a resource *curse*, i.e. the institutional inability to transform natural endowments into economic development. However, our paper also contrasts with some recent outlooks about a potentially bright future of these states [9, 10]. The fine line between being optimistic and pessimistic for the future of these countries seems to lie in their adaptive capacities, i.e. their ability to become resilient to environmental stress and to manage potential socio-economic stress drivers. To make this more explicit and useful for futures research, our paper develops a heuristic model of such drivers and how they might overshoot the adaptive capacities of resource-rich societies.

Following this analytical section, this paper undertakes the mapping exercise as outlined above and identifies 15 countries that are most at risk for originating resource supply disruptions. Furthermore, it identifies 30 additional countries that, given more extreme circumstances, may also be at risk and impact global resource supplies.

It is important to note that this mapping exercise displays those countries that, given current conditions and trends, are likely to be at risk in the near future. Because political, economic, and resource extraction/production conditions are rapidly changing, the map only presents a snapshot of vulnerabilities as they stand now and represents an explorative foresight methodology that will need to be improved over time. It does not attempt to predict which countries will have resource supply disruptions.

The potential applications for futures studies such as these, however, are numerous. First, our approach adds to existing literature on both socio-economic country studies and regional analysis as well as engineering-driven approaches of analysing geology and industrial value chains. Second, it initiates long-term oriented strategic studies where more such interrelations need to be analysed.

Analysis

The resource nexus and impacts of food and water stress

The resource nexus is a conceptual model that illustrates the interconnections between and among different resources [Fig. 1 in 4]; in other words, it visually displays that one (or more) resource is used as an input to produce another resource [5]. For example, water and electricity (for pumping water) are necessary resources for producing food, in particular in South Asia where irrigation-based agriculture prevails.

In addition to the recent debates about a more narrow nexus between water, food and energy [7], there is also concern

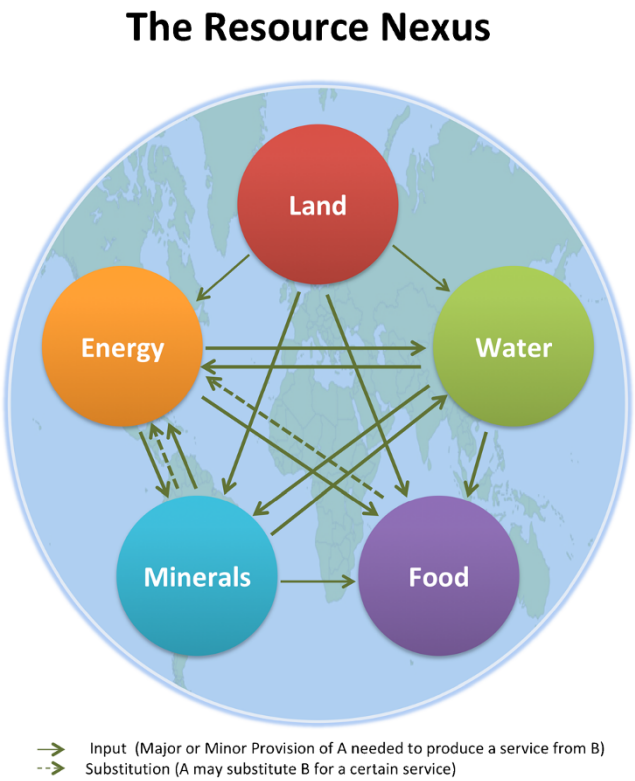

Fig. 1 The global resource nexus. *Source*: The Global Resource Nexus [4]

- Over the nexus with minerals such as phosphorus being non-substitutable for world food production [11], or the vast array of resources needed for urbanization and
- Over the nexus with critical minerals such as rare earth, gallium and lithium being essential to the clean technologies that are needed to combat climate change [12, 13].

In a more general way, dams illustrate the importance of considering the resource nexus beyond food, water and energy in a more comprehensive manner. Usually built to produce electricity, they require immense quantities of construction materials and metals, they intervene into hydrological systems and management regimes, and they impact—often negatively—downstream agriculture. Moreover, many of the dam projects in upstream states increase political tensions with downstream states such as in Vietnam, India, Iraq, Egypt and elsewhere [14].

The resource nexus has become more pressing in recent years because volatile commodity prices transmit turbulences from local to global markets faster than ever before [8, 15]. 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 [16] points to the drought that occurred in Northern China as a global trigger mechanism for higher food prices. Johnstone and Mazo [17] discuss possible impacts of climate change as stress multipliers. The International Food Policy Research Institute [18] underlines additional domestic factors such as malnutrition, the phasing out of food support programs and a high share of angry young men caring for their families. In a historical perspective [19] the impact of food prices on the great revolutions in France (1789), Russia (1917), and other civil wars helps to explain the security dilemmas of the population and the contingent political outcomes.[1]

However, the relationship between local water and food shortages and socio-economic struggle and political unrest is a complicated one. Our paper does not attempt to add fundamental new insights to this debate. We will examine the debate linked to the scope of our paper and derive potential drivers of a conflict spiral that have been observed in a number of case studies.

Resources and conflicts: a short survey

It is now common knowledge that both scarcity and abundance of natural resources can be underlying factors in conflicts [20–26]. Common pool resources (CPRs) especially, such as water and land, can foster cooperation if affected groups manage property rights, limit free access and establish mechanisms of trust and enforcement, but also lead to conflict in fragile states [27]. The legal and regulatory contexts around property rights vary widely across jurisdictions (at the local, national, regional, and global levels) just as the adaptive capacities and resilience also varies widely [28]. A key is to understand the local patterns and their ability to cope with shocks that are often generated elsewhere such as water shortages and food price increases.

Conflict and security literature has focused on what drives people to become involved in armed conflicts. "Neo-Malthusian" approaches link demographic changes, especially population growth, with resource scarcity, environmental problems, and increased propensity for violent conflict (e.g. Homer-Dixon). One may thus derive drivers such as a young population and malnutrition as preconditions for conflicts. A second school of thought, represented by the work of Paul Collier, has been influential because it challenged previously held assumptions that resource scarcity was the primary driver of conflict; in fact, abundance is strongly related to the presence of violent conflict. Abundance creates incentives and opportunities for looting of resources and making profits of transporting minerals from remote land-locked areas to ports. Large-n studies of conflict have identified a correlation between the proximity to mines, for example, and the level of violence. These first two types of research usually intermingle in terms of causation, and are topped with a third strand of research focused on grievances over ethnic, class, or racial identity as a cause of conflict [see 20, 29, 30]. From our perspective, however, usually these studies focus on a limited number of commodities rather than at the strategic interconnections of the resource nexus. The conclusions drawn by Humphreys [20], countries dependent on agricultural commodities are at political risk independent of their other endowments, and by Carmignani and Avom [31] on negative social developments resulting from commodity exports is seen as valid for our heuristic model on drivers (A heuristic model on drivers of a new vulnerability section). In addition, one may also derive tendencies of secessionism and incentives for organized crime to become involved in issuing property rights as being driven from new discoveries and profits.

Pros and cons about the resource curse—what's new

The related debate about a potential resource curse has been alive since the early 1990s with Paul Auty's seminal paper [32, see also 33]. The fact that particular oil-exporting countries had poor economic performances compared to some of the top-performing emerging economies, such as South Korea, led to two main explanations:

- Macro-economic deficits of overvaluing a currency in foreign exchange rates based on the booming resource extraction sectors while neglecting other sectors as well as failures to establish a robust fiscal system and to

[1] See also ongoing research at the New England Complex Systems Institute at: http://necsi.edu/research/social/foodprices/updatejuly2012/

diversify the economy beyond resource extraction ("Dutch Disease"); and

- Political-institutional deficits of negotiating contracts, corruption and organizing resource rents for purposes of social development and infrastructures. This strand of explanations offers more variables for cross-country comparisons and hence appears more complex than macroeconomic issues. The more recent literature seems to focus on this aspect.

It is important to acknowledge that the commodity price hikes since the year 2000 in combination with better policies have benefited some countries such as Botswana, Chile, and Kazakhstan. The lessons learned there have been widely discussed [34–37], and in recent surveys, van der Ploeg [15], Heinrichs [38] and Di John [39] question the evidence of any resource curse.

Accordingly, the more recent discussion among academics and practitioners seems to adopt a slightly more optimistic view for overcoming the resource curse [9, 10]. Based on the lessons learned, online tools for better policies are now available. The "Natural Resource Charter,"[2] with its 12 principles on how to turn the natural endowments into extraction and development, is such a tool available for resource-rich developing countries. In addition, a model mining development agreement[3] has been formulated by the Mining Law Committee of the International Bar Association. In May 2013, Revenue Watch Institute produced the Resource Governance Index[4], measuring the quality of governance in the oil, gas, and mining sector of 58 countries, particularly in Africa and Asia. The African Mining Countries have developed their own vision and an action plan.[5] These tools, though, overlook the harsh reality of structural deficits and unfavourable conditions as well as the obstacle of adapting and applying the tools at the local level. However, they offer the ingredients from which countries can start or improve and, in particular, the move towards greater transparency and less corruption is notable.

In our view, the challenges of the resource nexus are not yet built into these future policy tools and not yet reflected properly by research. Climate change and other environmental impacts will have to be fully incorporated into regional planning processes, and can be considered game changers for socio-economic perspectives [40]. The possible cumulative changes of very large numbers of people over the course of years, and potentially disruptive impacts on existing institutions are poorly assessed yet. A more critical view of the aforementioned tools suggests two main weaknesses. Firstly, the international economic order with volatile commodity prices and existing distortions such as illicit trade has been left out. Secondly, destructive tendencies of organized crime, secessionism, fundamentalism and terrorism may have been underestimated. This leads to the conclusion that the socio-economic interconnections between environmental change and the resource curse should receive wider attention in Futures 2.0 research and politics.

A heuristic model on drivers of a new vulnerability

A combination of factors at the interface of regional environmental change and socio-economic dynamics demands new models on the adaptive capacities of societies [41–46]. While we fully acknowledge the enormous challenges of turning slowly reacting adaptive capacities into anticipating and pro-active ones, our attempt here is more moderate: to derive relevant drivers from the debates above and develop a heuristic model that describes these new vulnerabilities as challenges for adaptive capacities in the long-run Fig. 2).

In general terms, we observe two new main challenges. First, global drivers can overshadow local drivers in the management of common pool resources such as river basins management and agriculture. Second, increasing connectivity allows local turbulences to spread rapidly, with unintended side-effects on other resources and regions. Thus, fragile countries and regions are likely to become vulnerable, but other regions including the industrialized countries will have to cope with the indirect impacts too. Adaptive capacities will have to be developed for the directly affected regions and others more indirectly affected.

The following Fig. 2 distinguishes three more general stress multipliers: climate change and weather extremes, volatile commodity prices, and population growth from the following drivers at the local and regional level:

- Malnutrition: following the observations about the pressing local and national urgency of any food and water crisis, one may consider malnutrition as an entry point for socio-economic and political impacts.
- Migration: beyond general issues, this is a key social issue arising during and after the time when a mine is constructed. Humphreys [20] calls it one of the grievance mechanisms. Rudra and Jensen [47] and Bearce and Laks Hutnick [48] provide new insights on the nexus between migration and natural resources.
- Fundamentalism and Terrorism: some regions may adopt anti-Western attitudes, in particular, if their national government appears to cooperate with them. Natural resources could provide a way to finance rebellions that have been started for other reasons and may extend the duration of civil wars; [see, e.g., 49, 50].

[2] See: www.naturalresourcecharter.org
[3] See: www.mmdaproject.org
[4] See: http://www.revenuewatch.org/rgi
[5] See: www.africaminingvision.org; see also the Africa Progress Report 2013.

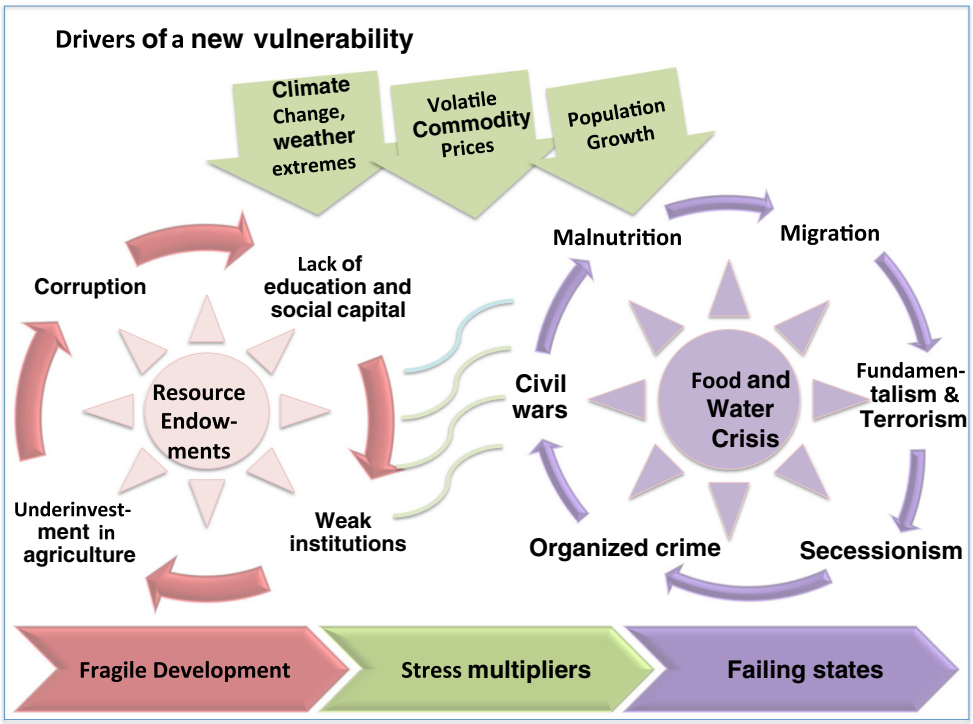

Fig. 2 Drivers of a new vulnerability. *Source*: own compilation, adopted from *The Global Resource Nexus* [4]

- Secessionism: this is estimated to be the biggest source of violent conflicts according to the conflict barometer according to the conflict barometer done by Heidelberg Institute for International Conflict Research [51]) and is especially relevant for those extraction activities and reserves that are located in well-defined areas of a country with socio-cultural heterogeneity. Sudan may be the most illustrative case study.
- Organized crime: an issue that starts at a lower level with vengeance-seeking group grievance but could increasingly involve extraction and trade with conflict-minerals (but also other natural resources), drugs, and other illicit activates [see 20, 52, 53]. The cases of Mexico's drug trade and Western Africa may be most illustrative.
- Civil wars and severe violations of human rights in general: this is especially prominent in those regions that have long-lasting civil wars such as Iraq, Afghanistan, Sudan, Aceh/Indonesia where natural resource production is hampered [54] and chances for peace are undermined [55].

The combination of these factors could translate into what we call a redux of the resource curse: 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 may then lead to interruptions of supply chains for essential materials and have international repercussions.

Many resource-producing countries and regions can be considered fragile. In particular new resource suppliers in Africa and Asia that started extracting on a large scale basis during the boom of the years 2000–2008 and in the aftermath of the financial crisis have to struggle with basic governance challenges, including:

- Negotiating fair agreements with extractive industries;
- Managing the switch from the employment-intensive construction period of a mine to the more capital-intensive extraction period, which usually comes with huge lay-offs;
- Establishing a transportation infrastructure that meets the needs of broader development purposes and environmental standards, in particular if the country is land-locked;
- Balancing the needs of the affected local communities with other regions and the general public (quite often the population in the capital);
- Establishing a robust fiscal regime with permission grants, royalties, and rents; and
- Dealing with environmental issues that partly arise through mining processes but usually have other causes.

In general, such fragile states can hardly be assumed to comply with international norms for labour safety or environmental protection. Moreover, their institutions are often weak and have low resilience to stress. According to Paul Collier [56] a domestic institutional capacity comparable to Portugal

in the 1980s is necessary to embark on a path for inclusive and sustainable growth. Stress multipliers such as climate change, volatile commodity prices and pressure from population growth – factors that are not easily managed by weak states—further limit capacity-building in fragile states, increasing the risk of violent conflicts. Some of these states may even fail.

Such drivers of a new vulnerability may not only occur within those states that are currently considered fragile but also within authoritarian regimes (e.g. in Asia or Latin America, or the Russian type of democracy), where resource revenues help to maintain political structures. The lessons learned from countries such as Egypt and Libya might be that such countries may be more fragile than observers believe, with inappropriate "extractive institutions" [57] and the mechanisms explained above leading into conflicts and a new resource curse. Exploring this and putting it into any mapping is, however, beyond the scope of this paper.

The mapping

Methodology of mapping countries

To map countries worldwide where the resource nexus could affect governance and resource supplies, the following three exercises were carried out:

1. Mapping possible future agricultural and water stress to determine where there is a likelihood of a food and water crisis break-out;
2. Mapping today's fragile states and regional political instabilities; and
3. Mapping the future reserves of fuels and minerals, particularly those of critical importance for future supply.

The resulting "Global Resource Supply Vulnerabilities" map (Fig. 3) is, therefore, actually a composite of three underlying maps.

- Step I: Mapping Agricultural and Water Stress

  The first layer uses information from the Food and Agriculture Organization of the United Nations (FAO) to identify the agricultural systems at risk from future environmental impacts such as extreme weather events and climate change, natural conditions, and disasters [58]. These risks include floods/sea-level rises, water scarcity, pollution, loss of biodiversity, deforestation, desertification/droughts, loss/low soil fertility, erosion, and land scarcity. States facing environmental risk may not be able to achieve sustainable levels of food and water resources. Such risks as water and land scarcity may also compromise the extraction and production of minerals and energy resources. With new assessments coming up (such as the forthcoming Intergovernmental Panel on Climate Change reports) more detailed analyses can be undertaken.
- Step II: Mapping Political Instability

  The second layer measures each state's political instability. Using information from the Fund for Peace's Failed States Index, states are grouped into five categories: failing, fragile, troubled, moderate, and stable [59]. The Fund for Peace ranks states based on the following conditions: mounting demographic pressures, massive movement of refugees or internally displaced persons, vengeance-seeking group grievances, chronic and sustained human flight, uneven economic development, poverty or sharp/severe economic decline, legitimacy of the state, progressive deterioration of public services, violations of human rights and rule of law, security apparatus, rise of factionalized elites, and intervention of external actors. While we acknowledge the limitations of the categories and data sources used by the Fund for Peace, for the purposes of this map political instability is used as a proxy for understanding a state's ability to effectively manage the extraction, production, consumption, and export of its food, water, energy, and mineral resources. Note that the mechanisms above are close to these indicators, though our scope is closer on the resource nexus.
- Step III: Mapping Reserves of Minerals for Future Supply

  Naturally, a map displaying nexus points of resource supply risks must also consider where the world's natural resources are located. This layer provides information about each state's reserves of key natural resources. These include fossil fuels (oil, coal, natural gas), base metals (iron ore, bauxite and alumina, copper), and critical elements (rare earth elements, cobalt, lithium, manganese, nickel, indium, gallium, tellurium). The fuels and minerals considered are critical to many aspects of developed and developing economies. Oil is essential to transportation, base metals to construction, and so on. The other elements are considered critical for their importance for future technologies (especially green ones) according to both the U.S. Department of Energy (DoE) and the European Union (EU). Reserve estimates were obtained from the United States Geological Survey's *Mineral Commodity Summaries* [60].

  Once the information for each layer was compiled, they were overlapped to see where all three factors meet. That means, for example, that even though Canada and Australia have significant resource reserves, they are neither politically unstable nor at significant risk for environmental stress to warrant inclusion of at-risk states.

  After identifying the approximately 45 countries that showed resource supply vulnerabilities, the last step was to identify the most at-risk states. For each state, we scored the severity of political instability, the severity of

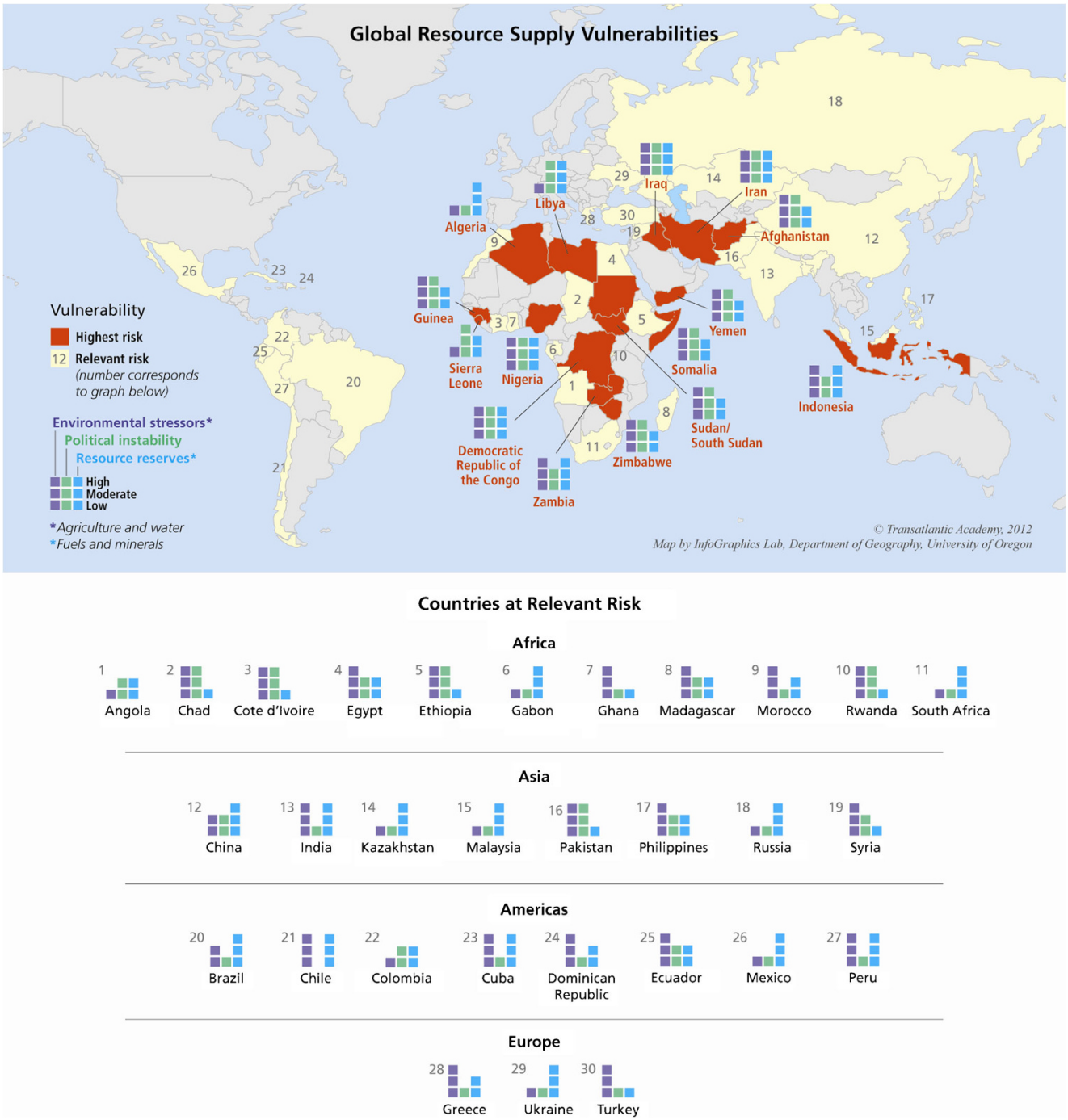

Fig. 3 The global resource supply vulnerability map. *Source*: own compilation (Not all countries were considered for inclusion on the map for reasons of obvious political stability, known lack of resource reserves, or minimal threat of environmental stress)

environmental stressors, and the amount of commodity reserves on a scale of 0–3 (3 being the highest). The scores for the three categories were added for a total score between 0 and 9. Zambia, for example, received a score of 8, while Mexico received a 5. Those states with the highest scores were grouped into the high-risk states and the remaining countries were grouped as those at relevant risk. The rankings appear on the map next to each state or in the table below it.

The global resource supply vulnerabilities map

The following map displays the countries at risk of not being able to supply essential resources to global markets in the near

future. States are divided into two categories: high-risk and relevant-risk. This map originated as part of a report of the Transatlantic Academy [4] on the global resource nexus and the intersection of markets, international politics, and human security.

The highest risk countries (see Table 1) include Afghanistan, Algeria, Democratic Republic of the Congo (DRC), Guinea, Indonesia, Iran, Iraq, Libya, Nigeria, Sierra Leone, Somalia, Sudan/South Sudan, Yemen, Zambia, and Zimbabwe. These countries share a high degree of political instability and environmental stress, and they also hold enormous fuel and/or mineral reserves.

Thirty additional countries are identified as "relevant risks," meaning they risk causing disruptions to global resource supplies but, if they do, not to the same degree as the high-risk states. These states are much more geographically diverse and their conditions vary widely. Consider the examples of Chile and Angola. Chile has a stable democratic government with large amounts of natural resources, especially copper. However, its long coast and diverse terrain as well as water shortages in the mining areas make it susceptible to the type of environmental stress that could restrict supplying the resources to global markets. On the other hand, Angola faces less environmental stress, but the political instability there threatens to disrupt resource supply nonetheless. Overall, the risk from these countries is relevant to interested stakeholders, but not of the highest degree. One should also consider that such risk factors could occur at a regional scale within large countries such as Brazil, Mexico, India, Russia, China, and others.

To highlight the importance of the countries at highest risk, they are included on the map in red along with markers of the severity of environmental stress and political instability and the level of resource reserves. The countries at relevant risk are shown in yellow, and their data information is included in the table below the map.

Table 1 Countries at high risk and their relevance

Country	Relevance
Afghanistan	Major resource endowments (e.g. lithium) estimated to be near US $1 trillion; long-lasting war and civil war; large drug producer
Algeria	Major producer of natural gas
Democratic Republic of the Congo	Major endowments of copper, diamonds, and critical minerals; long-lasting civil war in eastern portions of the state
Guinea	Major endowments in bauxite (aluminium) and iron ore
Indonesia	Major producer of forest products and agricultural goods (e.g. bio-fuels) as well as fuels (natural gas), nickel, copper and aluminium ores; vulnerable to sea level rise and climate change; secessionist conflicts; strategic position at the Strait of Malacca
Iran	Major producer of natural gas and oil; regional de-stabilizer
Iraq	Major producer of natural gas and oil; long-lasting war and civil war
Libya	Major producer of gas and oil; recent civil war
Nigeria	Major producer of oil, including major off-shore oil reserves; recent political changes towards democracy
Sierra Leone	Major reserves of bauxite (aluminium)
Somalia[a]	Holds strategic position near the Strait of Hormuz
Sudan, South Sudan[b]	Major producer of oil; currently in armed conflict about disputed areas, including oil fields; plans to erect dams for agricultural use along parts of the Nile River that may put downstream countries at risk of water shortages
Yemen	Severe water shortages; home of terrorists; strategic position at the Strait of Hormuz
Zambia	Major producer of copper, major endowments in coal and cobalt
Zimbabwe	Major reserves in coal and lithium; relevant producer of platinum

Source: authors' compilation

[a] Note on Somalia and Somaliland: In this paper Somaliland is considered to be a legal part of Somalia, since Somaliland does not have internationally recognized independence. Furthermore, the data for political stability, agricultural stressors, and resource reserves does not consider the two entities separately. Therefore, on the map, the designation between Somalia and Somaliland is shown with a dotted line, but the data and evaluation does not distinguish between the two.

[b] Note on Sudan and South Sudan: The data for this paper comes from before South Sudan's separation from Sudan proper in July 2011. Therefore, for the purposes of this paper, assessments of Sudan and South Sudan's political stability, agricultural stressors, and resource reserves were considered as a unified Sudan. When new data for the two separate countries becomes available, new risk assessments should be made in which case both countries may not necessarily be at high risk.

Discussion of the results and relevance

The results of our mapping process are striking. In total, the likelihood of interruptions of international supply chains is quite significant. On top of that, we made two more observations:

- Sub-state or cross-boundary regions could experience supply disruptions in large states that may not otherwise be regarded as fragile (e.g. Aceh/Indonesia, Northern Caucasus/Russia, Northern Mexico); and
- Risks of regional international resource-related conflicts in areas such as the Chinese Seas [see 4] should also be figured in.

At a lower risk level, stress caused by the resource nexus also leads to cross-boundary tensions, irrational supply strategies and international distortions. Hence, the risks for international markets could become quite severe.

Data uncertainties

Without question, the political, environmental, and resource supply future remains uncertain. This report acknowledges the many scientific and behavioural uncertainties inherent in looking to future possibilities in resource supplies. Despite those uncertainties, by using the most recent data on the different dimensions of the resource nexus from multiple sources together we have taken a first step in producing a more comprehensive look into the interplay among factors influencing a state's ability to supply resources to global markets. Furthermore, our hope is that our analysis and mapping exercise will result in further research that produces data specifically related to the resource nexus and its impact on the resource curse.

Uncertainties in food/water stress

Data on possible future food and water stress were taken from the FAO based on recent estimations of the Intergovernmental Panel on Climate Change (IPCC), and other sources. Besides the obvious scientific uncertainties there is also the uncertainty about future demands for water and food as well as future diets. Much here will depend on how Asia will manage its irrigation-based agriculture, whether China might change into becoming a large-scale food importer, and what diet patterns the emerging middle class across the globe will develop.

Uncertainties in political stability

Many organizations and groups assess the fragility of states using different criteria, but often with similar methodologies and findings.[6] The Fund for Peace provides one of the most comprehensive measurements of political stability through data on 12 primary social, political, and economic indicators for 177 countries. Data on political stability is though, by its nature, only a snapshot of current trends and does not provide a good basis for predicting political stability in the near-, middle-, or long-term. A measure of political stability for Egypt in 2008, for example, would not have predicted the Arab Spring of 2010. Our analysis, however, is concerned most with countries experiencing chronic or severe political instability, which can be seen in fragile state indices over time. Using the available data, then, we can identify those states with the greatest instability with some confidence.

Uncertainties on reserve estimates

Reserve estimates usually carry a number of uncertainties. In the most basic terms, exploration is a risky and cyclical business, with asymmetric information between some consultants and companies on the one hand and the public on the other. Africa, especially, is a continent where, due to political turbulences, not much exploration has been done until very recently. The African Mining Vision (AMV), which African leaders adopted in 2009, recognizes the crucial need to strengthen efforts towards exploration. Thus, an optimistic perspective would assume more reserves to be discovered. On the other hand, material and geological science tends to be cautious and not assume large discoveries in the near future. Offshore reserves are another source of uncertainties. Recent oil discoveries tend to speak in favour of optimists, but costs of production (including environmental and safety costs), regulatory uncertainties, and risks of inter-state conflicts over access and production-sharing agreements should also not be underestimated.

Comparative institutional analysis and challenges across scale and time

The challenges to govern natural resources in a sustainable manner while acknowledging their inter-linkages and intergenerational fairness are enormous. Since administrations and institutions are usually centred along one specific resource (think about ministries for agriculture and water treaties), establishing cross-divisional capacities will have to climb up on the governance agenda. Long-term planning that is usually discounted against short-term benefits both in politics and in businesses should be strengthened. In addition, governments need to build resilient institutions (i.e., institutions that are able to cope with price shocks and extreme weather events). Recalling disasters such as the nuclear accident in Fukushima, Japan (2011); the Deep Water Horizon oil spill, Gulf of Mexico (2010); Hurricane Katrina, Southern United States (2005); and the heat wave in central Europe (2003) it appears that even in well-developed countries mechanisms for such

[6] Most measures of fragile or failing states are rooted in and build upon the United Nation's Millennium Development Goals, which are the eight areas of international development that all UN members committed to achieving by 2015. They include eradicating extreme poverty and hunger; achieving universal primary education; promoting gender equality and empowering women; reducing child mortality rates; improving maternal health; combating HIV/AIDS, malaria, and other diseases; ensuring environmental sustainability; and developing a global partnership for development. Thus, most indices of fragile states measure a state's ability to achieve these goals because they reflect the relative strength and control a state has over formal and informal institutions, security, and society. The World Bank, for example, defines "fragile situations" using two criteria: a Country Policy and Institutional Assessment (CPIA) score and the presence of UN and/or regional peace-keeping/building missions. The second criterion though, in particular, places more emphasis on violent conflict as a measure of a state's fragility. Many other organizations, such as the Organization for Economic Cooperation and Development, identify and work with fragile states, without generating their own lists of which states are considered "fragile." The Overseas Development Institute, a British think tank, for example, provides analysis and policy guidance on aid, delivery of human services, human security, poverty, and crisis response in dealing with fragile states but does not distinguish which countries are considered fragile. The Global Peace Index as well as the Food Security Index also provide useful data and analysis.

institutional resilience are lacking or ineffective. Coping with food and water crises in developing countries along with other stress factors, therefore, will need new and additional research; futures research will have to assess the near-term and long-term risks along the inter-linkages as outlined in this paper *and* it will have to develop tools for enhancing the adaptive capacities of industries and societies. In doing so it will likely follow polycentric approaches that look at cross-regional capacities from a bottom-up perspective [61] rather than a global system governance perspective. This is a challenge across scale and time:

- Transparency and accountability, usually seen as clear-cut correlations, will have to accept indirect dynamics where demand from end-users far away triggers unwanted effects in remote areas. Thus, the polluter-pays-principle from environmental policy and international law needs to be converted into a more general and binding responsibility for materials along their value chains and within regional environmental boundaries. Actors to be involved comprise regional and national authorities with assessment capacities, key industries, and concerned stakeholders.
- The cumulative causation of decisions and their impacts go beyond the traditional risk criteria of availability of resources and access. It would be far too simple to conclude from geological surveys that *if* the availability is for more than one generation and *if* the access can be safeguarded by a legal order future generations wouldn't have to suffer. The precautionary principle needs to be translated into principles for sustainable resource management at the level of countries that help to maintain the most relevant resource functions over time.

Conclusions

In the future, the global resource nexus will likely put all countries under stress. This paper underlines a risk that is just emerging: a spiral of resource-driven conflicts that may be triggered through regional food and water crises and escalate into socio-economic breakdowns with subsequent interruptions of supply chains for materials. The foresight exercise of our mapping process has revealed the result that, based on current evidence, 15 countries can be considered at high risk, while additional 30 countries will also face serious challenges. Thus, this is a major challenge for futures research to assess those dynamics and their impacts.

Future analysis should certainly address the critical uncertainties that have been highlighted, including data needs, and undertake sensitivity analyses to validate findings. Our map is a preliminary exercise and we hope that this work will inspire more thorough research into the intersection of agricultural and water stress, political stability, and resource management. These uncertainties, nevertheless, should not hinder relevant actors to draw conclusions and to re-assess risks.

With regard to the futures research on adaptive capacities, our paper adds insights to a multi-level approach. While the local and regional level is important for managing resources and resilience, the country-based institutions are essential as back-up mechanisms that could either mitigate or escalate a serious crisis. With regard to the international level, our analysis contingency planning, suggests analysing a strengthening of regional trans-boundary cooperation and of international relations along material flows and supply chains. In other words, issues such as virtual water flows from trade, the energy-intensity of food commodities, and the 'ecological rucksacks' of materials [62] will become more relevant if their institutional dimension is incorporated.

Yet, prevailing criticality assessments (e.g., in the US and the EU) end with a few priority materials of concern. Our approach suggests that at least two new assessment criteria should be added to those of geology and supply chain concentrations: firstly, environmental risks and its impacts stemming from the global resource nexus and, secondly, socio-economic risks at the level of supplying countries. It is here where futures research should play a strong role: the development of an international data hub on those issues with foresight tools, comparative analysis on choice architects within and across administrations who facilitate foresight processes, and nudges such as interactive maps that help decision-makers to reduce complexity. In the long run, a global model on resource flows at the intersection of environmental change and socio-economic development would be needed, that helps resource-rich countries to manage their endowments while Europe and the rest of the OECD/G20 would invest in adaptive capacities worldwide.

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