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The Water-Energy-Food Nexus

The term nexus describes the key interactions between parts of a system or systems. This POSTnote summarises current understanding of the interactions between water, energy and food production and examines how nexus approaches can be used to inform policy decisions.

Overview

- A nexus assessment seeks to describe the interactions of water, food, energy, environmental and social systems to identify the interdependencies and trade-offs between these systems.
- Failure to take account of interactions and trade-offs creates vulnerabilities to shocks, such as extreme weather events, which can have cascading impacts across systems.
- There are no set methods for undertaking nexus assessments, but key aspects involve understanding the interactions between systems and people.
- Awareness of interactions and trade-offs is necessary, but addressing them also requires an understanding of the social, political and environmental context.

What is the Water-Energy-Food Nexus?

Water, energy and food (WEF) systems interact with each other and the environment. For instance, food crops require energy for fertilisers, water for irrigation, and rely on environmental processes for cycling of nutrients and pollinating crops. Agricultural practices have also led to declines in pollinators and an excess of nutrients in the environment (POSTnotes 442, 477, 478). The term nexus has been used to describe these interactions since the 1980s.[1] It has become prominent in discussions of international resource policies[2] and is the focus of UK research programmes.

Exact definitions of the water, energy and food nexus differ (Box 1), but all seek to describe interactions across and between relevant systems. These interactions are either: [3]

- Interdependencies (where systems depend on another). For example, fossil fuel electricity generation may require water abstraction (Box 2), and energy is required to extract, treat and distribute drinking water.
- Constraints (such as trade-offs between systems). For example, increasing the amount of water abstracted for irrigating food crops will reduce availability for other uses, such as drinking water or energy generation.
- Synergies (shared benefits for systems). For example, increasing water and energy efficiency and reducing food waste can all reduce pressure on WEF systems.

There are many such interactions between WEF systems. However, to date, governance of WEF sectors remains separate with limited attention given to the interactions that exist between them.[4] For instance, the 2013 UK Energy Act does not refer to either food or land-use and only mentions water in a narrow legal context, whereas the UK Water Act 2014 makes no mention of either energy or land use.[5]

Water, Energy and Food Security

Decisions made relating to water, energy and food resources are often politically contested. [6,7] They have tended to prioritise short-term benefits over the long-term security of systems.[8] However, global projections of increasing population size, urbanisation and changes in consumption patterns suggest increasing future demands on WEF systems (POSTnote 516).[9] In 2009, the then UK Chief Scientific Adviser set out concerns about a 'perfect storm', stating that *'we have got to deal with increased demand for energy, increased demand for food, increased demand for water, and we've got to do that while mitigating and adapting to climate change. And we have but 21 years to do it'*.[10] Water, food and energy security can never be fully achieved, however they are defined, because of the instability and unpredictability of WEF systems.[11] Despite this, understanding the interactions between WEF systems can help decision makers balance trade-offs made between them, in response to increasing demand. This in turn could increase security in these sectors.[5]

Box 1. Nexus Definitions
The Economic and Social Research Council (ESRC) defines the nexus as a way of thinking about the interdependencies, tensions and trade-offs between food, water and energy security, in the wider context of environmental change with a focus on the impact on social systems.[12] By contrast, the Engineering and Physical Sciences Research Council (EPSRC) defines the nexus as the link between water, energy and food resources where any disruption of one resource will disrupt the other two.[13] The extent of the systems covered for nexus research also often differs depending on the question being considered. In addition, the range of political, economic and environmental challenges that influence water, energy and food resources at different geographical scales and time scales may mean there are no clear limits to the systems covered. Finally, the context within which nexus interactions are being considered, such as a river catchment, can inform what systems might be most useful to cover. However, the ambiguous nature of the nexus has been criticised as limiting how useful the approach is for policy.[14]

Nexus Assessments

Most nexus assessments have been carried out at the community or local scale. Their complexity increases with geographical scale, timescale and number of systems considered. Assessments can help identify trade-offs between the WEF systems and how to mitigate their effects. They can also identify where systems are interdependent, or if shared benefits can be achieved across systems.[15] For example, the UN Sustainable Development Goals' set a number of water, energy and food targets. The Stockholm Environment Institute has studied how the different targets interact, to identify trade-offs, interdependencies and synergies between the targets.[16] There are more than 100 different academic methods that can be used for appraising nexus interactions.[12,17] Which approaches are most applicable depends on the study's purpose, the available data and stakeholder context. However, two approaches are considered particularly important: modelling of systems; and stakeholder participation.[18]

Modelling of Systems

The use of models is highly developed within WEF sectors, but linking up models across sectors is less common. One example of linking up models of is the Australian National Outlook 2015, this integrated nine evidence-based physical and economic models to analyse water-energy-food interactions, rural land use, material flows and climate change. The framework was used to assess whether ecological pressures could be reversed while still improving living standards and allowing for a growing population up to 2050. It used more than 20 scenarios to examine the different factors influencing possible future outcomes.[28]

Box 2. Water Abstraction for Thermal Power Generation
The electricity sector accounts for 90% of water abstraction in the UK, for use in hydroelectricity and thermal power plants. Thermal power stations, which contributed 87% (294 TWh) of the UK's electricity generation in 2014,[19] require water mainly for cooling but also for boiler feed-water and flue gas desulphurisation [20] Over the past decade, thermal power stations in Europe have experienced difficulty because of droughts that have reduced freshwater availability.[20] In 2010, only 23% of the UK's energy was generated from power plants cooled from freshwater sources,[21] with most cooling water abstracted from tidal or coastal water.[22] Some future energy options, such as carbon capture and sequestration and extraction of shale gas could increase demand for water.[20,21] This demand may have to be met by using coastal waters or non-traditional sources, such as treated wastewater, particularly as climate change is likely to reduce freshwater availability.[23] The policy implications of the water-energy interdependencies have been more widely considered in the US.[24,25,26]

Box 3. Agent-based Modelling
Agent based models simulate the behaviour and interactions of agents (individuals or organisations) with one another and the consequent effects on their decisions. For example, the CASCADE research project on smart grids reduced the agents down to two types: prosumers, (energy customers with the ability to generate and store their own electricity at various scales); and, aggregators, who sell energy bundled together from a range of prosumers.[27]

The EPSRC funded Stepping-Up project is a large multidisciplinary project focussed on how to deliver a decarbonised energy system that has minimal impacts on water and food systems. It uses agent based models and case studies to assess how low carbon innovations may affect the WEF nexus. There will be approximately six agent types, representing organisations such as energy producers. The behaviour of the agents determines the model's outcome and this can lead to unexpected results. Sufficient understanding is therefore required of what agents can and can't do and where there are loopholes that allow behaviour contrary to the system rules. Once this is understood, then agent based models can be linked to other types of model, such as physical models of specific river catchments. Early work suggests that the nexus interactions between systems frequently manifest in competing demands for land uses.[5]

However, such integrated modelling is subject to a number of limitations that may restrict its usefulness for informing policy.[29] For example, modelling of interdependencies between land management and water quantity/quality is specific to the river catchment the model is based on. This limits wider use in policy. However, more generic modelling at a regional or national scale will not have level of detail necessary to inform policy. It is also difficult for models to capture the complexity of environmental interactions arising from both natural and human factors.[30] A complementary approach is to use agent-based models (Box 3) to understand how systems interact, but such models are not intended to be predictive. In order to be useful, model outputs have to be robust and produced in a form that meets the needs of stakeholder groups.[5]

Participatory Approaches

The UN has suggested that stakeholder participation is a fundamental aspect of nexus assessment. The UN also suggest a range of other factors are important, such as inclusion of different types of knowledge and scientific analysis.[31] Engaging stakeholders on nexus issues may improve policy co-ordination and could also help identify beneficial technological choices.[32] Stakeholder dialogue can be informed using models that present information in a tangible format or by considering a range of scenarios to understand their implications. Scenarios can be developed with stakeholders and be informed by outputs from modelling or help inform modelling approaches.

Informing Decisions

Governance of WEF sectors remains separate, with the interactions between sectors receiving only limited attention.[33] These tensions at multiple scales, from the global to the local. Decision makers in both the public and

Box 4. Bioenergy Policies and the WEF Nexus
Bioenergy refers to renewable natural material (biomass) that is used to produce electricity, heat and liquid fuels. It has been suggested that bioenergy policies have implications for food prices and global trade, as production of bioenergy crops could reduce land and water availability. The DECC 2011 Carbon Plan included scenarios where demand for biomass for bioenergy affected about 4.5 million ha of land currently under production (agriculture and forestry) or converted from natural habitats, both in the UK and abroad. The plan suggested that there could be a number of negative effects if relevant criteria were not applied to assess the suitability of biomass feedstocks.[34] These included carbon emissions from land use change, loss of habitats of conservation value, reductions in air quality, impacts on water resources and a reduction in the area available for food crops (POSTnote 410).

However, nexus analysis suggests the relationship between food security and biofuel policies are complex and context-specific, and generalised messages about impacts deduced from global scale analysis may be misleading.[35] When resources such as land and water are managed efficiently, bioenergy projects in developing countries can reduce the vulnerabilities that lead to food insecurity, through increasing energy security, diversifying incomes and improving local infrastructure.[35,36] For example, in Brazil sugarcane production has been confined to zones that are not valuable for biodiversity and food production, choosing areas within the zones with the most suitable weather and soil. This strategy has minimised effects on water and food security, while maintaining an industry that supports 4.5 million jobs.[35,37,38] However, if bioenergy projects are to enhance food security, the local causes of food insecurity (for example inefficient food production systems) have to be understood.[35]

the private sectors could benefit from understanding the implications of nexus interactions for policy decisions.[39] Having the tools to describe these interactions is a starting point, but managing them requires an understanding of the social, political and environmental context. For example, it has been suggested that the demand for bioenergy has affected food security,[40] but a recent nexus assessment suggested bioenergy can enhance food security in the appropriate context (Box 4).

Addressing Risks and Vulnerabilities
A failure to take account of interactions between WEF systems into account can create vulnerabilities to nexus 'shocks': these are low probability, high impact events with systemic cascading effects across the WEF sectors.[32] Understanding interdependencies – how an event in one system affects others – can identify risks and allow 'graceful failure' to be designed in (ensuring the failure of a system does not impact other systems catastrophically). For example, WEF systems are dependent on physical infrastructure, such as transport and IT systems. After Hurricane Sandy in 2012, fuel and food supplies were rapidly exhausted in New York because consolidation of supply chains meant that over half of these resources were routed through one location, with key routes disrupted by flooding and high winds.[41] However, only a few studies have begun to provide practical insights into the complexity of nexus interactions and risks.[17] Public perceptions of nexus risks may also differ from those of expert assessments. Unforeseen societal responses can complicate management of shocks.[12]

Box 5. Clarifying Resilience
Resilience has been adopted as an objective in a number of policy frameworks, such as the Environment (Wales) Act 2016, Section 6 of which places a biodiversity and resilience of ecosystems duty on public authorities. Resilience is often interpreted by policymakers as a system's ability to withstand disturbance and is viewed as a desirable quality.[42,43] However, if poorly defined, it may undermine both the value of resilience as a concept and its practical application.[42,44] Resilience can be applied to specific to parts of a system for certain shocks or used more generally to refer to the overall capacity of systems to adapt to change.[45] In ecological systems, resilience was initially defined as the amount of disturbance that a system can withstand before it shifts into an alternative stable state (POSTnote 370).[46] However, there is now a range of resilience concepts including:

- engineered resilience - the ability of a system to withstand disturbance or shocks
- resistance - the amount of disturbance a system can absorb before changing into an alternate state
- stability - the ability of the system to return to the initial state
- adaptive capacity - the ability of a system to adapt to pressures.

Recent interpretations of resilience also include the ability of systems to recover to a better state than before a shock.[47] The complexity and ambiguity of the term may hinder its effective application in policy.[44] For example, for human systems increasing the capacity of recovery processes from nexus shocks may not address root causes of vulnerabilities to shocks, such as poverty.[48] In ecological systems, degraded ecosystems are often resistant to improvement, but this kind of 'resilience' is not a desirable quality.[42,49]

'Shocks' from Climate Change
Vulnerabilities to nexus shocks may be exacerbated further by chronic stressors such as climate change. Research has suggested the effects of climate change may have already contributed to volatility in food and energy prices and increased risks of political instability.[50] This may in turn have increased the risks of high social and economic costs of shocks, such as 'breadbasket failures', large impacts on key commodity crops (maize, soybean, wheat and rice). As global production is concentrated in particular regions, extreme weather events, particularly drought, can cause shocks. For example, in 2007/8, a small weather-related wheat production shock in Australia, coupled with historically low stock-to-use levels, led to rapid global food price inflation.[51] A similar price spike occurred in 2010/11, partly influenced by weather in Eastern Europe and Russia.[52] The UK food supply chain is vulnerable to shocks in countries that are already water stressed.[53] Data from previous drought related production shocks, suggests an extreme drought event (one with a 1 in 200 chance of occurring in any given year) could result in the global loss of almost 10% calorie production.[54]

Resilience
Research suggests 'resilience' to shocks could be increased through better understanding of WEF interactions.[32] The term resilience has a number of meanings (Box 5), but in the context of nexus interactions, the ability of systems to withstand and recover from the impacts of shocks is critical (Box 6). However, increasing such abilities in one system can reduce those of others if trade-offs are not considered.[5]

Integrated Policy Approaches
In itself, identifying nexus interdependencies may not be enough to drive more integrated policy approaches. Greater

Box 6. The Nexus Shocks Network
The ESRC funded Nexus Network project brought together 80 academic, industry, policy and NGO stakeholders to consider the impact of weather and climate related shocks across the WEF nexus. It identified key concerns, opportunities and barriers to inform decision making about nexus shocks. The barriers identified included the lack of an integrated overview across the WEF sectors and a lack of ownership for the responsibility to respond to and prepare for future nexus shocks. Opportunities for addressing these constraints included moving to proactive decision-making that attempts to anticipate shocks, co-ordinating policy programmes for resilience building through participatory decision making and having the flexibility to implement innovative approaches.[32]

integration between WEF sectors has been advocated for decades through frameworks such as integrated water resources management (POSTnote 373) and sustainable development (POSTnote 408), but have fallen short of expectations.[55] Nexus approaches to policy integration may fail because of the politically contested nature of WEF decision making.[56] Commentators suggest nexus problems require 'bottom up' approaches to drive socially equitable outcomes.[12,6,4,57] This would involve many different individuals, companies and organisations working collaboratively in differing contexts (Box 1).[58]

Partnership approaches already exist within some WEF sectors in the UK, such as catchment management partnerships in the water sector.[59] However, trade-offs between the competing and conflicting priorities of stakeholders still need to be managed. Existing governance approaches are unlikely to be able to address the complexity involved,[4,60] and lack sufficiently diverse participation mechanisms.[39] The new Centre for the Evaluation of Complexity Across the Nexus (CECAN) is researching the nexus effects of policy decisions for a range of areas as they are being implemented (rather than before or after).[61]

Role of the Private Sector
The private sector often has the most direct influence over decisions affecting the provision of water, energy and food. Businesses have an interest in ensuring that their operations can be sustained cost-effectively.[62] However, this becomes more challenging if shocks occur, if resources become scarcer or if regulation to halt environmental degradation becomes a significant cost burden.[63] Some multinational corporations take account of water security to protect their supply chains (POSTnote 385), and some, such as SABMiller and Coca-Cola, have published results. There is increasing recognition of the interconnection between resources.[4] For example, a SABMiller evaluation of malting barley in Rajasthan highlighted a need to find better approaches to handling trade-offs between water, energy and food.[64]

The finance and insurance industries also have an interest in ensuring risks associated with investment in WEF resources and infrastructure are adequately understood (Box 7). However, rather than quantifying the probability of every risk arising from nexus interactions, it may be more effective for businesses to enhance their ability to withstand or recover from shocks.[65] This could be encouraged by

Box 7. Understanding Risks to Supply Chains
UN analysis has suggested that the financial loss associated with natural disasters (such as wildfires, droughts, earthquakes and tsunamis) equated to about $1 trillion in the first decade of this century, although such estimates only partially reflect total losses.[66] The UN '1 in 100 Initiative' initiative is promoting a 1-in-100 year financial "stress test", similar to that developed in recent decades by the insurance sector to assess its own ability to underwrite risks.[67] The test evaluates the maximum probable annual financial loss that a company, city, or region could expect once in a hundred years to ensure these risks are managed in a more informed and effective way. For companies, this includes risks to supply chains, such as reliance of food production on commodities supplied by drought prone regions.

Once a company is aware of liabilities, scenario planning could be used to determine what mitigation measures would be effective for reducing supply chain risk exposure. Even if a component only costs $3, manufacturing processes may be halted by its scarcity and the network effects can be substantial. For example, the Fukushima tsunami affected the production of automotive parts used in UK car production. The 2011 flooding in central Thailand along the Mekong and Chao Phraya river basins caused a shortage of hard disk drives well into 2012.[66] However, many companies find it difficult to get data on extensive global supply chains, which may not be possible beyond certain geographic scales as localised risks may not be well characterised in developing countries.

investors taking account of a business's resilience strategy when they make an investment decision.[39] For example, by recognising the value of protecting property from risks such as extreme weather, flooding and storm surges.[68] Companies may also have difficulty in obtaining affordable contingent business interruption insurance if insufficient data are available to understand supply chain risks (Box 7). An ESRC funded project has consulted businesses and academics to identify the research questions for managing the impacts and dependencies of business upon food, energy, water and the environment (Box 8).[62]

Box 8. Understanding the Nexus Dependencies of Business
The ESRC Nexus Network funded Nexus2020 project consulted a range of business and academic stakeholders on what were the major research questions for research and business that needed to be addressed to support understanding of the WEF nexus in the private sector.[62] The process generated over 700 questions that were distilled down into 40 main questions categorised into four main themes:
- Questions about tools for decision-making (including understanding the spatial and temporal challenges involved)
- Questions on the commercial case around risk, investments and profitability (including identifying risks and showing links between management of nexus interactions and supply chain security)
- Questions about levers for behaviour change
- Questions about governance and collaboration.

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