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Opportunities for knowledge co-production across the energy-food-water nexus: Making interdisciplinary approaches work for better climate decision making



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ABSTRACT

The relationship between the energy-food-water nexus and the climate is non-linear, multi-sectoral and time sensitive, incorporating aspects of complexity and risk in climate related decision-making. Current methods of analysis were not built to represent such a complex system and are insufficiently equipped to capture and understand positive and negative externalities generated by the interactions among different stakeholders involved in the energy-food-water nexus. Potential amplification effects, time delays and path dependency of climate policies are also inadequately represented. This paper seeks to explore how knowledge co-production can help identify opportunities for building more effective, sustainable, inclusive and legitimate decision making processes on climate change. This would enable more resilient responses to climate risks impacting the nexus while increasing transparency, communication and trust among key actors. We do so by proposing the operationalization of an interdisciplinary approach of analysis applying the novel methodology developed in Howarth and Monasterolo (2016). Through a bottom-up, participative approach, we present results of five themed workshops organized in the UK (focusing on: shocks and hazards, infrastructure, local economy, governance and governments, finance and insurance) featuring 78 stakeholders from academia, government and industry. We present participant's perceptions of opportunities that can emerge from climate and weather shocks across the energy-food-water nexus. We explore opportunities offered by the development and deployment of a transdisciplinary approach of analysis within the nexus boundaries and we analyse their implications. Our analysis contributes to the current debate on how to shape global and local responses to climate change by reflecting on lessons learnt and best practice from cross-stakeholder and cross-sectorial engagement. In so doing, it helps inform a new generation of complex systems models to analyse climate change impact on the food-water-energy nexus

1. Introduction: exploring complexity in the nexus

Understanding the impacts of climate change on socio-economic development, international decision-making and financial markets stability is challenging. An important challenge for the academic community, practitioners and policy-makers is understanding how the cost of climate change impacts and climate policies affect socio-demographic and economic development – and how feedbacks in this complex system affect outcomes. There is increasing recognition by academics and policy makers that the relationship between human-environmental systems and the climate are interconnected (Jacobs and Mazzucato, 2016; Fagerberg et al., 2016). In this complex system where

cross-sector feedback loops, time delays at the macro-economic level (Hake et al., 2016; Stacey, 1992), and heterogeneous short-term thinking agents at the micro-economic level, influence non-linearity and policy uncertainty (Mercure et al., 2016; Rezai and Stigl, 2016). A key challenge is understanding the sources of uncertainties in our knowledge of these interactions, how they manifest themselves (e.g. parameters' values, model structure, behavioral responses, or knowledge of fundamental processes) and how they affect model scenarios. Such uncertainties are inherent in the dynamics of the complex networks that shape climate change and our responses. Uncertainty of climate impacts on sectors within the nexus such as food production and food security at different geographical levels (Burke et al., 2011;

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Asseng et al., 2013; Rosenzweig et al., 2014) and scales (Garcia and You, 2016) has recently been analysed in the literature (Gillingham et al., 2015; Weitzman, 2011; Nordhaus, 2011; Knutti and Sedláček, 2013). Yet how to tackle the sources of climate uncertainty may result in increased risk and may affect different sectors across the energy-food-water nexus and development dimensions (social, economic, environmental, political) remains unclear. Indeed, sector based and integrated assessment models which usually represent Computable General Equilibrium (CGE) economies, endowed with a carbon/GHGs cycle of different complexity, are mostly used for climate policy analysis but have well-known limitations for modeling the dynamics of a complex system. Recently, the limits of these models have been highlighted by an increasing number of scholars (Pindyck, 2013; Farmer et al., 2015; Ackerman et al., 2009; Stanton et al., 2009) and include: substantial model-to-model variability; difficulty in estimating growth parameters; difficulty in representing a range of behavioral responses within individual sectors to different kinds of climatic and/or economic stresses; underestimation of the negative externalities of carbon and, in turn, its social cost. The issue of time lag also requires further exploration, particularly between the impositions of a stress and how sectors, agents and markets respond, which potentially constitute a major source of uncertainty. Simple considerations of dynamics therefore suggest that time lags in complex dynamic systems have the potential to be destabilizing.

The climate policy and research agenda continues to explore the interdependencies that exist among multiple sectors (Zimmerman et al., 2016) particularly where competing demands require strategic and careful management (Sharmina et al., 2016). Assessments of the science of the impact of anthropogenic climate change on ecosystems and human societies (IPCC, 2014) demonstrate that these will be mixed and evolve in nature, affecting commodities and limited resources that are fundamental for current and future generations. However, it remains unclear how the introduction of climate policies (e.g. global carbon tax, or phasing out fossil fuel subsidies) could impact the multiple actors that span the food-energy-water nexus. Indeed, climate policy has been identified as a potential source of carbon stranded assets – i.e., assets that are at risk of losing much of their value as a result of un-burnable reserves (Caldecott and McDaniels, 2014; Leaton, 2012) for companies who own them and investors who own shares in such companies. Risk transmission from climate policies to the real economy, and to some extent to the financial sector, for example, is becoming an increasing area of focus in this regard (Battiston et al., 2016; Dietz et al., 2016; European Systemic Risk Board, 2016).

Nexus resources are fundamental for societal development, however they are limited and are being depleted at a rate faster than ecosystems can cope with (WWF, 2014; Rezaei and Stagl, 2016). The concept of the nexus entails a holistic view of the world that surrounds society and interactions with a complex system of feedback loops, different sectors and natural resources (Hamiche et al., 2016; Fang and Chen, 2016). In this sense, it can be seen as the epicentre, or meeting point of a series of (often complex) components, which come together to represent something that is more than the sum of its parts. As a result, debates on the nexus often centre on: (i) what it is that is ‘connected’; (ii) the exact nature of those connections; and (iii) boundary issues, i.e. if everything is linked in some way, then when and where do we draw the line? In addition to consisting of a network of relationships between energy, water and food systems and the complexities that characterise them, the nexus requires an understanding of ‘soft’ factors which are difficult to measure but are nonetheless key in delivering and supporting decision-making (Howarth and Monasterolo, 2016). These factors include, but are not limited to human values and perceptions, natural and technical processes related to systems considered, and the role of time in the interactions among different sectors (past and future).

The interactions across the energy-food-water nexus raise questions about traditional sectorial-based and focused systems that evolve and relate to one another. In order to work effectively on nexus issues,

existing and new concepts that fundamentally exist within the nexus need to be explored. There have been attempts to disentangle the complexity of the food-water-energy nexus moving through case studies at the regional and local levels, to identify useful lessons. One such example is the case of Hindu Kush Himalayan ecosystem services in South Asia, which demonstrated that in order to sustain resilience of resources and food, water, and energy security in the region, cross-sectoral integration was needed, along with regional integration between upstream and downstream players, critical for ensuring food, water, and energy security (Rasul, 2014). Another example, is the context of sustainable consumption of food, water and energy, a practices approach would explore the social organisation of cooking, which, as an activity, consumes food, water and energy, and can complement more traditional approaches in sociology or psychology. Similarly exploring the full impacts of a complete food chain through life cycle thinking (Azapagic, 2015) could increase understanding of the diverse mechanisms that could be used to reduce the impact of this sector on exacerbating nexus shocks such as climate change (Jeswani et al., 2015).

There is growing recognition of the relevance of nexus thinking and approaches to increase understanding of its characteristics and intricate interactions that would enable decision makers to better address sustainability challenges. However whilst this term is growing in use to capture the importance of integration of approaches and stakeholders in solutions to sustainability and resource challenges, Cairns and Krzywoszynska (2016) urge caution about the risk of ‘turning nexus into a “matter of fact” where it remain a ‘matter of concern” (164). Yet, a comprehensive framework of analysis based on robust methods of analysis which fully captures the complex dimensions of the nexus and related decision making processes (Mowles, 2014), is missing. Specifically, more knowledge is needed on (i) how nexus stakeholders – from across academia, policy, business, finance and insurance sectors – perceive the impacts of climate change on their activities within the nexus, (ii) the direction and intensity of their network of relations within the nexus and (iii) the potential effect of other nexus actors on their climate decision making strategies. Indeed, this information is fundamental to inform the current debate on how to shape the broad context on international, national and local responses to climate change. Further analysis is needed to explore and understand how heterogeneous nexus actors will react to alternative climate mitigation and adaptation policies, either supporting or blocking their implementation according to their perceived gains and losses, and consequently the impact of their behaviour on the nexus.

Understanding the sources of shocks and potential impacts on and responses by the nexus require integrated and transdisciplinary systems thinking, adopting innovative approaches to the analysis of coupled human-environmental systems to develop effective solutions and decision making processes (Howarth and Monasterolo, 2016). An innovative approach to analyse the nexus is required involving a spectrum of qualitative and quantitative methodologies, traditionally used for sector-specific analyses in different research fields (e.g. natural sciences, social sciences, mathematics and physics), to be applied in innovative ways to complement and add value to each other’s results. By building on Howarth and Monasterolo (2016), we develop such an approach that acknowledges the limitations of siloed and single-sector approaches and draws on the rich expertise of stakeholders that work and interact in the nexus. Most importantly, such an approach will need to provide decision-makers with transparent and accessible results that enable them to gain a deeper understanding of the characteristics of the nexus and how, in the aftermath of a shock, these develop a higher degree of complexity, non-linearity and uncertainty.

2. Methods

The methodology for knowledge co-production and development applied in this paper consists of a further development of the

transdisciplinary approach developed by the authors for the analysis of climate shocks on the food-water-energy nexus (Howarth and Monasterolo, 2016). The methodology has been refined in order to focus on the key objective of the analysis: to identify opportunities to respond to nexus challenges by innovatively assessing complexity of societal responses to nexus shocks, in order to better inform business and policy responses through bottom up solutions across the food-water-energy nexus. The co-production methodology adopted a tailored snowball approach with the following steps:

- An initial evidence review was carried out on climate change, energy-food-water nexus, climate change shocks, sources of resilience, and policy responses to these shocks to the nexus;
- A preliminary focus group was held with members of an Advisory Group (of the UK Nexus Shocks Network) to lay foundations of the research, refine the workshop methodology, identify key themes to explore and assess suitable participants (Howarth et al., 2016). Participants were selected among experts from academia, policy makers and practitioners, and industry according to their knowledge, expertise and experience of decision-making on climate change and nexus related issues;
- Implementation of a programme of five half-day themed workshops in London (UK), involving 78 stakeholders based in the UK. Each workshop adopted a semi-structured approach and focused on a specific issue: (i) Predicting shocks and hazards, (ii) Transmission and mitigation of nexus risks through infrastructure, (iii) Local economy responses to shocks, (iv) Insurance and finance for resilience, and (v) Governance, governments and shocks. Each theme was agreed in collaboration with workshop co-hosts (Met Office, Chatham house, Atkins, Lloyds of London, Climate UK) to maximize relevance to end users. In each workshop, participants were asked to elaborate on characteristics of risks linked to the nexus challenges; perceived challenges represented by basing climate responses on sector-based knowledge and models; issues at stake for building resilience to nexus shocks at sector and societal levels; understanding of the role of governance on policy implementation; best practices, lessons learned and evidence-based solutions for successful introduction of measures along the food-water-energy nexus;
- Qualitative analysis of workshop results leading to the identification of main opportunities to build resilience to climate shocks on the food-water-energy nexus;
- Organization of a final symposium with key stakeholders to present and discuss results;
- Dissemination of results through publications, policy briefs and engagement activities.

The overall aim of this paper is to present and critically discuss additional findings from the five-themed workshops (see Step 3 above) building on findings from Howarth and Monasterolo (2016) and to explore how knowledge co-production can help identify opportunities for building more effective, sustainable, inclusive and legitimate decision making processes around climate change. We do so by (i) exploring the concept of co-production, (ii) assessing key stakeholder's perceptions of opportunities that emerge from climate and weather shocks to the energy-food water nexus and (iii) discuss implications for climate decision making.

2.1. Co-production approach

Innovative transdisciplinary approaches are being increasingly used to address important societal challenges (Bammer, 2013) and facilitate and navigate the interrelationships and tradeoffs between energy, food and water within the nexus in parallel to the varying and often conflicting needs of actors involved (Zhang and Vesselinov, 2016; Polk, 2015). Co-production is one such approach enabling an inclusive, self-reflective approach whilst embracing challenges the process faces and

acknowledging the opportunities this provides. Co-production is not a new concept, and has existed in a wide range of fields such as political ecology, public policy, community engagement to name a few. It has gained prominence more recently due to a focus on end users (Voorberg et al., 2014), incorporating actors beyond academia (Polk, 2015), relevance to rapidly evolving policy landscapes, resource and capacity constraints and increased need to demonstrate value for money. By facilitating a collaborative approach, acknowledging the need for a 'more democratic and reflexive research agenda' (Kumazawa et al., 2016), it involves active involvement of multiple stakeholders in the design of research aims, its scientific process and the delivery and testing of research findings. It's characteristics of inclusion, collaboration, integration, usability and reflexivity (Polk, 2015) make in an important process for democratising politics (Jasanoff, 2010) with the incorporate of a larger set of diverse voices bringing different but ultimately complementary perspectives to an issue, in so doing, this facilitates the co-creation of a solution and the process by which to reach that solution (Turney, 2014).

The term co-production is used widely to refer to approaches that recognise the evolving nature of challenges the research community faces in remaining relevant to real world solutions and filling known evidence gaps. Whilst results obtained from adopting co-production approaches do not always result in alignment with sector-based groups (Polk, 2014), co-production frameworks have been applied to societal issues such as climate change (Howarth et al., 2017), urban development (Omondi et al., 2014), multi-level governance and planning (Watson, 2013), policy evaluation (Fagan-Watson et al., 2017) and ecosystem services (Palomo et al., 2016). The Royal Geographical Society held its 2014 annual conference with the theme 'co-production of geographies' chosen to encapsulate the new encounters 'commercialisation, open innovation, participatory social science, engaged arts and public engagement [which are] disrupting conception of where knowledge resides, how problems are framed and who should be mobilised to influence research' (Larner, 2014: 1). Not only did this theme assess the impact this process can have in investigating geography-related challenges but also enabled participants to self-reflect on their role in co-production, collaboration of learning and limits of adopting such a process (Mahony, 2014).

Co-production helps to interpret complex phenomena whilst linking local, multi-sector knowledge to national and global social change movements, with a variety of components allowing for the incorporation of knowledge from across scales (Corburn, 2007) making it an innovative and fitting approach to consider complex nexus related issues. As an inclusive process, with the mutual construction of 'good science', it is not solely determined by the scientific community but by interactions with external audiences thus enabling 'less explicitly acknowledged common cultural and epistemic commitments [to] unite political bodies, scientific researchers and the hybrid area between them' (Shackley and Wynne, 1995: 228). This concept has evolved beyond the science-policy interface and the inclusion of end users and other audiences. Durose et al. (2011) state the importance of including non-experts in deliberative processes on issues of relevance to different communities by empowering them in the process through an experiential process (Collins and Evans, 2002), including arguments that may have been overseen by experts and ultimately enabling these communities to contribute to improving outcomes and implementing solutions (Ostrom, 1996). Involvement of practitioners in co-production processes thereby forces them to go beyond their role as providers and (passive) recipients of knowledge to those who play an active role in commissioning, overseeing and assessing evidence which can lead to higher levels of engaged and utilised work and better alignment with end user needs (Martin, 2010). Considerations are nonetheless needed for potential politicisation of the process and failure to adequately consider the context within which coproduction takes place and is applied.

It is with this in mind that this paper explores how knowledge co-

production can help identify opportunities for building more effective, sustainable, inclusive and legitimate decision making processes around climate change. Co-production provides a space to facilitate knowledge exchange and sharing of insights from a range of perspectives and expertise whilst acknowledging that all those who contribute to the process have something to contribute (i.e. that no one and everyone is an expert in something). Section 2.2. describes the method adopted for data collection and analysis through a co-production lens to bring together stakeholders from a range of sectors who have direct theoretical or applied knowledge and experience of decision making in response to climate and weather related shocks and insights into the implications for decision making across the energy-food-water environment nexus. The literature referred to in this paper is by no means exhaustive, and it is beyond the scope of this paper to provide an in-depth critical assessment (see Polk, 2015 for an overview of this) however it is with this literature in mind that we have explored decision making in response to climate and weather shocks. In so doing an assessment of key stakeholder's perceptions of opportunities that emerge from climate and weather shocks to the energy-food water nexus are presented and implications for climate decision making are discussed.

2.2. Data collection and analysis

The results reported in this paper complement findings presented and discussed in Howarth and Monasterolo (2016) which called for “a transdisciplinary approach of assessment and analysis requires active engagement of stakeholders from different sectors in all the phases of knowledge development to acquire a clearer picture of their needs and expertise in the decision making process” (p59). The method adopted to collect data and inform the discussions here builds on the co-production process outlined above and adopts the same method described in Howarth and Monasterolo (2016), recapped briefly here. Five half day workshops were held in London, UK between September and October 2015 with $n = 78$ individuals excluding 7 who did not show up (Table 1) stratified into three pre-defined categories: (i) academic, (ii) practitioner (directly involved in implementation of climate-related solutions or decision making processes on the ground) and (iii) policy communities (involved in formulating policies and decisions on climate change and nexus related issues). Participants were approached based on their knowledge, expertise and experience of decision-making on climate change and nexus related issues, for example decision-making processes directly related to or with implications for energy, food and/or water interactions. These were identified using an assessment of the literature and of UK institutions and individuals in positions that fit one of the aforementioned categories. Organisations represented by participants included universities, UK local and national government departments, city-based climate initiatives, NGOs, businesses, finance organisations, consultancies and climate media/communications agencies. Consequently the sample is inherently biased towards individuals and organisations who have direct or indirect knowledge and experience of working on decision making processes in response to climate and weather related shocks. Each workshop was conducted under the Chatham House rule and covered one the following themes as

defined in the preliminary workshop: (i) Predicting shocks and hazards (PSH), (ii) Transmission and mitigation of nexus risks through infrastructure (I), (iii) Local economy responses to shocks (LE), (iv) Insurance and finance for resilience (FI), and (v) Governance, governments and shocks (GG).

The findings reported here are based on the workshop discussions which explored the following themes: (i) decision making processes and responses to nexus shocks, (ii) opportunities that emerge to improve communication and collaboration, and (iii) the role of modeling tools in these decision making processes. Each workshop adopted a semi-structured approach, with a structure piloted and refined beforehand. Workshops lasted half a day each with discussions recorded in written format with consent from all participants. Thematic analysis was conducted to explore key themes that emerged from the data and a report of discussions was shared with participants as part of the internal review and quality assurance process.

3. Findings

Exploration of workshop discussions identified five themes, which provide insights into opportunities that may emerge from nexus shocks. Whilst these are a descriptive analysis of workshop discussions, and are limited to a UK context, these still provide a fascinating take to improve understanding on approaches through which responses to nexus shocks and tools for better informing these responses may be shaped. These five themes are outlined in Table 2, and discussed in the sections below and can be summarised as: exacerbation and mitigation of shocks, strategic thinking, communication and collaboration, anticipating social responses, process. The following codes are used to identify the source of discussion: PSH: Predicting shocks and hazards; I: Infrastructure; LE: Local economy; FI: Finance and insurance; GG: Governance and governments.

3.1. Exacerbating and mitigating shocks

Context is an important component to consider in decision-making processes particularly when these are further complicated by their unpredictable, interdisciplinary nature and bring together at times conflicting interests of stakeholders. We explored the role of factors that act to exacerbate (i.e. to make worst) or mitigate (i.e. to reduce the impact of) shocks, their nature and the impacts that they have. Participants discussed as a group the factors that, in their view and based on their experiences, exacerbate and mitigate detrimental impacts of nexus shocks.

A variety of issues emerged, some of which are discussed in Howarth and Monasterolo (2016), and we present new data here on *exacerbating factors*, which focused on timing, collaboration, evidence, culture, responsibility and responses, technology, and technology. *Timing* in decision-making processes and particularly the lack of accuracy in predicting a shock and its characteristics of relevance to stakeholders involved, can result in a misalignment in the communication of potential risks in an effective and timely manner to those on the ground. Similarly the growing recognition of cross-stakeholder

Table 1
Workshop participants (from Howarth and Monasterolo, 2016).

		Participant type			Total	No show
		Academic	Practitioner	Policy		
Workshop	Predicting shocks & hazards (PSH)	7	4	4	15	2
	Infrastructure (I)	6	6	3	15	1
	Local economy (LE)	1	7	3	11	0
	Finance & insurance (FI)	4	14	2	20	1
	Governance & governments (GG)	7	5	5	17	3
	Total	25	36	17	78	7

Table 2
Perceived opportunities to increase resilience to nexus shocks.

Contextual factors that help mitigate nexus shocks and include the (i) importance of clarifying what we consider as a cost, differentiating between computable, perceived and opportunity costs, and between costs that could be afforded (financial) or not (human lives) in case of shocks; (ii) emergence of a strong internal leadership; (iii) increasing collaboration across stakeholders and sectors as well as transparency and information sharing; (iv) improving communication of evidence and impacts of shocks targeting the language to the specific audience.

Strategic thinking that builds on the understanding of the big picture of nexus shocks' complexity and consists of (i) having a context-specific plan B to react quickly to nexus shocks prioritizing interventions based on lessons learned from previous experiences; (ii) clear division of roles to allow clear identification of interlocutors and match policy response to shocks; (iii) decentralization of decision-making and shared responsibility to increase stakeholders' engagement and ownership of responses to shocks.

Collaboration and communication characterized by the importance of establishing knowledge-transfer partnerships to design and implement a robust and efficient response to shocks by better understanding the longer term risks associated with nexus shocks, and building nexus narratives and framing responses with a focus on opportunities and business solutions. Moreover, the creation of a common stakeholders' language and narrative around nexus shocks is important to coordinate responses.

Anticipating social responses, by blending insights from the multiple sectors involved in the response to nexus shocks thus complementing knowledge and providing a framework which considers the big picture, to better deal with the complexity of nexus shocks. In this regard, it is fundamental to increase the accountability of the decision making process combining evidence and data from decision makers and narrowing the gap between short-term policy objectives and long-term frameworks of measures to manage nexus shocks.

Processes to shape the right governance structure to respond to nexus shocks with the following desirable characteristics (i) resilience and efficiency to enable flexible planning and procedures, (ii) complementary and flexible mechanisms and institutions able to operate swiftly when needed, and (iii) innovation to decentralise decision making to better manage tailored, case-by-case solutions to cope with nexus shocks.

The relevance of **proper timescales in decision making** emerged as a transversal opportunity in all the five themes.

involvement in the design and implementation of solutions in response to these shocks can lead to *competing demands* where continuous efforts to optimise a system and increase efficiency are made which can potentially increase the likelihood of shocks cascading through the nexus and increasing infrastructure vulnerability and reduced systems resilience. Whilst significant advances have been made in developing and perfecting *technology* to better predict and respond to nexus shocks, the rapid pace of society's dependency on technology and ICT tools creates conflicting and at times unknown vulnerabilities in the system. Decision making in response to nexus shocks requires cross-stakeholder and interdisciplinary *collaboration* Howarth and Monasterolo (2016) yet this collaboration often is a result of agglomerated siloed-working. This in itself can exacerbate the impacts of shocks, particularly at local levels or in the context of complex policy solutions where a lack of strategic coordinated cross-departmental *responses* (which can lead to conflicting outcomes) as local businesses and local authorities fail to adequately see how their role fits in the bigger picture and how their actions can have an impact on other sectors/actors. Attributing *responsibility* and owning leadership in responses can be challenging particularly when a shock will exhibit impacts and characteristics which aren't static and span more than one sector, stakeholder or policy issue. Failed or misinterpreted projections of nexus impacts or responses needed can negatively affect *credibility* (i.e. if limited time and resources spent when a shock occurs or abundant resources spent when no shock manifests) leading to overly precautionary approaches or over-reliance on insurance and others to take the lead. An underlying exacerbator of shocks was felt by the majority of participants as relating to the *evidence* produced and used (and the social factors that influence this), which informs subsequent decision making on shocks and hence addressing issues of evidence produced to inform decision making could create greater opportunities for cross-sector collaboration.

In the consideration of factors than can help *mitigate* the damaging impact of nexus shocks, participants discussed issues ranging from clarification of costs, leadership, communication and collaboration, clarity on timescales and identifying opportunities. Whilst nexus shocks are likely to have a range of impacts leading to a multitude of *costs*, making clear distinction between what is defined and perceived as cost and what is valued for non-financial reasons can help frame decision making where financial costs may be incurred but non-financial costs (such as loss of life) may be avoided. As discussed above and in Howarth and Monasterolo (2016), the interdependencies of shocks and infrastructure affected can also create opportunities to build resilience in targeted areas hence providing increased evidence to better *identify opportunities* to build resilience and effective sustainable decision making to nexus shocks. The unpredictable and uncertain nature of nexus shocks can lead to strong internal leadership pushing organisations towards sustainability and resilience at their core and thus facilitating engagement with other sectors and stakeholders to better respond to these shocks. Increasing *communication* of evidence and impacts to specific audiences can raise resilience awareness, strengthen *collaboration* across stakeholders and build partnerships across sectors to share claims data and increase transparency. Deep and broad consideration of the impacts of shocks enable a refinement of the importance of considering *timescales* in decision making processes with an opportunity to move away from short-termism and considerations for asset life: with a drive towards long term thinking enabling a better consideration of the operational lifetime of these assets.

3.2. Strategic thinking

Adopting a precautionary approach by establishing contingency plans to be context-specific and better align with the impacts and consequences of shock, would allow better foresight on what could potentially occur under a nexus shock (e.g. communications systems going down as a result a shock). These would be based on both evidence and lessons learnt from previous experiences of shocks and subsequent impacts to a system, combined with evidence produced (e.g. modeling outputs) that provides a map of possible outcomes to anticipate (PSH). In so doing, the bigger picture (or system) is considered and the risks themselves are managed as opposed to mitigated (PSH) where learning is captured and used to inform decision making under future shock scenarios as well as fed into modeling tools to better build the data set on which they are based. This enables prioritization of necessary/important infrastructure to protect directly linked to the nature of the nexus shocks and social impacts (I) and having a better understanding of potential costs and benefits of shocks with suggestions for a GDP-equivalent measure of resilience (GG). Greater resilience therefore ensues where both physical and social pathways are considered, with assessments made on the vulnerability, knock-on and feedback effects, through which shocks cascade within a system (I).

The consideration of roles and leadership then emerges with active role assignment where clarity is needed, for example insurance and finance sector calling on governments to give regulators a mandate to act (FI), within the broader context of a system of shared responsibilities, decentralization of decision-making (LE). This is where it is felt co-production can be useful as a mechanism for decision-making by incorporating both evidence and judgment based decisions (GG) enabling shared ownership of responsibility and of components of the process, this is particularly felt at the local level and the use of bottom-up approaches by involving local communities at early planning stages (LE). The bigger picture needs to be clarified early on (within the confines of what is possible under a nexus shock scenario which is uncertain, unpredictable and chaotic), enabling governments to be more visionary with a robust understanding of complexity within the nexus shock system and the risks involved in increasing resilience (GG).

3.3. Collaboration and communication

Collaboration and communication are vital to design and implement robust and efficient responses to nexus shocks. Participants emphasized the need to investigate and understand barriers to communication, to *create a common language* (GG), capture lessons learnt, establish how stakeholders can join efforts (I) and how the natural and social sciences could work together to address these issues (PSH). By *developing a joint vision* with all stakeholders involved (I), it was suggested this could be carried out through the creation of communication hubs or centres to provide support for collaboration between academic/business/policy (PSH), efforts can be better coordinated. There is a need for explicit effort to focus on less understood risks (PSH) to develop a greater sense of urgency by being pro-active, precautionary and preventative rather than reactive (I). A possible way proposed for doing this was by *improving means of utilising new media*, whilst being conscious of potential miscommunication this can lead to, in order to reduce time lag and facilitate rapid messaging of long-term vision (GG) within a broad context of decision-making as well as short term responses to ‘live’ nexus shocks.

Communication activities need a *strategic approach* with consideration for the audience and stakeholders engaged, for example sifting through the vast amounts of evidence available and providing decision makers with pertinent information and being selective about the choice of options available (PSH). In doing so the most appropriate and effective way to expedite research processes and evidence produced can be identified and aligned with the needs of decision makers on the ground (I). It was suggested that conducting a *mapping exercise of commonalities and differences* across stakeholder groups while simultaneously increasing understanding of role and remit of authorities on the ground can further facilitate collaborative processes (PSH). This is where *co-producing evidence and processes* was felt an appropriate mechanism to convene broader stakeholders (FI) and consider and take into account cultural differences to enable outputs to reflect different audience priorities (LE).

An *iterative process* is encouraged with engagement between decision makers and relevant stakeholders ensured throughout the process, to *rehearse possible ‘what if’ scenarios* in order to help build responses and resilience in the system (LE) and build a rapport with all involved (PSH). It was suggested that increased collaboration occur between academics and experts (LE), and insurers and policymakers (FI) in decision making and building resilience to *improve credibility of decision making processes* and further share lessons learnt and celebrate success (LE). Performing cost-benefit analysis, which would also include costs and benefits of inaction, would enhance this iterative process and at times may highlight times when the more cost-efficient approach may enable nexus shocks to occur and manage the impacts (LE). Further reflection on what is meant by resilience and which assets need protecting, to establish better common understanding, identify parallel interests, this was felt to be a potential role for research into technology and behaviour solutions to overcome and prevent negative responses (LE). Through an iterative process, a better alignment of timescales can occur, to enable research delivery and outputs to better align with policy timescales and hence be of more relevance to policy making (I).

Managing evidence dissemination and coordinating scientists, policy makers and practitioners is needed to forge strong links of those involved in implementing solutions on the ground (PSH) which calls for a better understanding of how to use multiple strands of evidence at multiple scales and translate the into judgment-based decisions (GG). *Developing a clear compact* to manage resilience between different stakeholders (FI) and develop a confident message would enable stakeholders to contribute to this by incorporating messages on their day-to-day activities (I) and speak with a salient and unified voice to decision makers (FI). Building a *cohesive and well-framed narrative* on nexus shocks, their impacts and roles of those involved can contribute to a proactive collaborative approach (I). Within this, is the need to

establish knowledge transfer partnerships (LE) to identify challenges and propose new solutions (FI) and conduct visioning exercises to better understand the longer term risks associated with nexus shocks and build narratives for plausible futures (I). Framing responses with a focus on opportunities and business solutions to address impacts of nexus shocks would help overcome communication issues and better engage a broader group of stakeholders (FI).

3.4. Anticipating societal responses

Anticipating social responses, by blending insights from the social sciences and humanities with political science, engineering, scientists and so forth, can better take into account individuals, their decision making processes and motivations for these (PSH). The acknowledgement that the social sciences can offer insights where natural sciences can’t provides a *stronger basis for understanding* the drivers for different groups in society and tools available to them (GG). Workshop participants coined the phrase ‘negotiating a social contract with infrastructure’ to build a stronger picture and deeper understanding of how society currently interacts and depends on infrastructure (I) and how this is affected by nexus shocks. This relationship needs to evolve to assess the cumulative impacts of small societal changes and better respond to nexus shocks that limit a society’s ability to cope and progress under these scenarios and where infrastructure can be designed to better support this.

Decision-making processes need to be credible and logical and be seen to take into account both capacity to respond and evidence of social responses (PSH) that can overcome challenges within a real shock scenario (such as people refusing to leave their homes when evacuation is needed). This can be further achieved by understanding psychosocial responses to warnings and risk (LE), increasing democratic participation, communication of lessons learnt (GG) and building a shared economy of skills and knowledge across scales and sectors (LE). Combining evidence and data from decision makers, such as judgment on risk tolerance, and from scientists, such as pure data (LE), can better enable strong leadership within organisations that combine short and long-term thinking (GG). The social dimension of a shock (e.g social responses) needs deeper consideration where a process is designed, where a shock is ‘humanised’ and given an identity (e.g. naming storms before they make landfall) can increase public and stakeholder engagement and the effective design and implementation of responses (PSH). This provides space for the combination of short and long-term thinking to build better cultural understanding and acceptance of responses needed in a shock scenario (GG).

3.5. Process

The process by which decisions are made that affect the system in which a shock occurs is complex and evolves based on the system, its components, the nature and characteristics of a shock. Therefore ensuring the ‘right’ people are at the decision-making table with a *clear message and messenger* is vital (PSH) this however requires *humble stakeholders* who can accept when they are central to the process or need to take more of a back seat (GG) at different stages (or altogether). In doing so, a process of *internal learning and understanding of skills and culture* of other stakeholders involved would enable some (i.e. scientific advisors) to better understand the challenges faced by others (i.e. decision makers) (PSH). When considering the impacts of nexus shocks to infrastructure, a resilience league table for companies could be developed (I) where value is placed on an asset prior to a shock occurring (LE). Understanding and engaging with the broader international context can increase access to investment and finance tools (FI) whilst having a good understanding of the availability and value of local resources (LE) provides access to a rich array of tools and evidence base to be utilised and transferred in accordance with the needs of the nexus shock response.

Resilience and efficiency have a bigger role to play in these processes of decision-making to enable flexible planning and procedures (LE), complementary and flexible mechanisms and institutions to be in place with the ability to operate swiftly when needed (GG). However this must acknowledge that most risks are dealt with on a case-by-case basis with a range of diverse products and services available for finance, requiring a tailored approach (FI). This means opportunities for *innovation* to decentralise decision making (LE) may exist (GG) where individual actors and stakeholders have a mandate to advise on a specific issue relevant to the nexus shock (PSH). In addition, and complementary to the need to anticipate social responses (Section 3.4), encouraging personal investments from consumers, whether financial or other, into solutions would increase engagement, ownership and longevity in the nature of these solutions once implemented

4. Conclusion

This paper explored opportunities that exist to better inform decision making in the context of nexus shocks. The concept of the nexus represents a novel step in this direction as it captures the complexity of the interactions between water-food-energy resources and the climate and human activities [Howarth and Monasterolo \(2016\)](#). The nexus as an academic construct will naturally expand as our understanding of the world's dynamic increase, but it is unlikely that we will ever be able to draw its boundaries fully. Adopting a co-production approach, as outlined in this paper, enables a richer picture to be painted on the landscape of decision making processes in response to nexus shocks, the interactions between stakeholders from across energy, food, water sectors, challenges and opportunities that emerge and ultimately how trusted, transparent and evidence-based strategies can be designed for more effective responses to these shocks.

This paper builds on and complements the findings outlined in [Howarth and Monasterolo \(2016\)](#) and explores the application of a novel, transdisciplinary approach to knowledge co-production around the nexus. By consulting with and co-producing the research approach and aims discussed in this paper, by engaging with stakeholders from academia, insurance, infrastructure, finance and policy making in the UK, we have presented findings which fully represent the needs and challenges faced by these stakeholders. This approach challenges traditional academic approaches which have until now focused on descriptive and observatory approaches to capture this expertise. By embedding ourselves with these stakeholders throughout this process, this paper captures ground-breaking data providing the basis for constructive dialogue on responses to nexus shocks. The application of the transdisciplinary approach presented in this paper has identified key opportunities for building resilience to climate shocks along the food-water-energy nexus, as identified by workshops' participants (see [Table 2](#)). These opportunities include: understanding contextual factors that help mitigate nexus shocks, strategic thinking based on the understanding of the big picture of the complexity of nexus shocks, increased communication and collaboration, the ability to anticipate social responses, development of processes which represent opportunities to shape governance structures to response to nexus shocks. The role of timescales in decision making emerges as an underpinning theme as an enabling factor to unlock and build on the opportunities identified.

The introduction of targeted and timely decision making processes to build resilience to shocks to the water-food-energy nexus requires a deep understanding of (i) how nexus' stakeholders perceive climate risk if shocks on their core business, and (ii) the opportunities they foresee to take action. We have explored these dimensions in this paper providing a platform from which more work can be conducted. From these findings we encourage further cross-stakeholder collaboration to fully capture the current, and evolving landscape of decision making in this space and to develop reflective, robust and resilient approaches that can better capture the realities of these processes when applied in 'live' shock scenarios.

Participants were brought together from across sectors and communities to facilitate constructive dialogue on possible challenges and solutions to the impacts of climate and weather related shocks to the nexus. Through this co-production process a deeper understanding of the roles, values and needs of different stakeholders be better understood enabling more productive collaboration. These workshops have shown that by enabling actors to interact and clarify their reciprocal positions in shock-related decision making (i.e. promoting transparency among key nexus actors around the main issues at stake for building resilience to climate change shocks) this can increase trust and thus commitment to invest in decision making. We have introduced a complementary narrative, demonstrating that a stable climate decision making framework, could represent opportunities in both the medium and long terms for society. This could be considered reversal of the stranded assets narrative, for example. In so doing, we reverse the siloed and linear narrative on climate decision making opening a window of opportunity for further design, development and implementation of measures through a bottom-up approach that allows nexus stakeholders to have their voice in the policy discussion, increasing nexus actors' commitment and thus contributing to policy effectiveness.

In conclusion, the lessons that emerged from this research can be summarised in three ways:

- The introduction of targeted and timely decision making processes to build resilience to shocks to the water-food-energy nexus requires a deep understanding of (i) how nexus' stakeholders perceive climate risk of shocks to their core business, and (ii) the opportunities they foresee to take action.
- In order to design successful responses to nexus shocks based on the design and implementation of a transdisciplinary approach, knowledge co-production needs to move away from a prevailing sector-based, self-referencing approach towards a diversification of skills for both decision-makers and modelers.
- The benefits of transdisciplinary processes are recognized by nexus stakeholders themselves: transparency, accessibility, engagement with non-academic audiences and main nexus stakeholders, understanding the role of incentives to inform the introduction of climate resilient policies along the nexus.

The results of our analysis could not have been obtained without the integration of multiple types of knowledge, skills and expertise across sectors that is invaluable to a transdisciplinary approach for knowledge creation. We have explored these dimensions in this paper providing a platform from which more work can be conducted. From these findings we encourage further cross-stakeholder collaboration to fully capture the current, and evolving landscape of decision making in this space and to develop reflective, robust and resilient approaches that can better capture the realities of these processes when applied in 'live' shock scenarios.

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