STEPPING UP

What will it take to accelerate a step-change
in sustainability for water, energy and food?

UP
STEPPING

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EXECUTIVE SUMMARY

Joined-up research can reveal positive, but also negative impacts of future policy decisions.
Collecting and examining data, engaging stakeholders and mapping out scenarios across the nexus of water, energy and food can highlight the unintended negative consequences of possible future policies as well as the perceived benefits and these must be accounted for within the decision-making process.

Blurred boundaries between sectors signal a need for more integrated planning and management to tackle environmental challenges.
There needs to be wider acceptance that boundaries between energy, water and food systems are increasingly blurred, both physically and politically. Analysis across these boundaries allows for greater understanding of how innovations may or may not work. Adaptive forms of governance can also help, as can a multi-stage decision-making process.

Responses to global environmental challenges must consider a range of contexts.
Policymakers and organisations must ensure that social, geographical and governance considerations are factored into decision-making to ensure the successful uptake and sustainable development of innovations designed to respond to environmental challenges.

"One size fits all" solutions are unlikely to achieve sustained success.
Designing context-specific solutions to environmental problems flexible enough to adapt as conditions and circumstances change may be complex and challenging for policymakers, but it offers a more sustainable pathway than the "one size fits all" approach often adopted today.

Stakeholder engagement is critical when seeking solutions to social and environmental challenges.
Giving a range of stakeholders opportunities to reflect, challenge and contribute throughout a decision-making process is key to creating a framework that encompasses a wider context, delivers realistic insights and avoids the common prioritisation of financial concerns that can stifle innovation.

Good decision-making requires reflexivity to manage complexity and uncertainty.
An awareness of the extent to which policy- and decision-making within one area of the water-energy-food nexus can impact other areas can help to mitigate and manage unintended consequences of those decisions. To support a step-change in sustainability, governance must find space for continuous and transdisciplinary reflection.

Relationships between producers, consumers and the environment matter.
For an innovation to be up-scaled, there is a need to reconfigure systems of production, provision and consumption to create space for new emergent systems. This raises questions over risk, justice, equality, prosperity and societal wellbeing that researchers and decision makers must engage with.

To be sustainable, change must be made across multiple domains.
In order to maximise the potential benefits of innovation in the areas of water, food and energy, focus must be on changing socio-tech-environmental conditions in multiple domains.

INTRODUCTION

Current systems of water, energy and food provision are unsustainable and the decisions made in each sector, though often arising independently, have implications for sustainability in each of the others. Faced with challenges that include changing climates and increasingly urgent greenhouse gas mitigation targets, rising resource scarcity and growing societal inequalities, there is need for a step-change that puts the UK on a pathway towards sustainable Water-Energy-Food (WEF) management.

Stepping Up aims to understand the processes, implications and challenges of scaling up nexus-innovations to achieve transformational change at different scales. We use a mixed method approach, consisting of quantitative and qualitative modelling techniques. Recognising the critical importance of a transdisciplinary approach, we are engaging with stakeholders throughout the project to develop insights into the drivers, motivations, enablers, and constraints of up-scaling nexus-innovation in the UK.

What do we mean by?

WEF nexus
The 'water-energy-food (WEF) nexus describes the interactions between the water, energy and food systems. Although each are governed in silos, none are truly independent.

Nexus-innovation
Technologies or practices that have potential to reduce negative impacts of water-energy-food provisioning on other systems, in addressing major challenges such as climate change. Innovations comprise new technologies, processes and practices, varying in maturity, from occupying niche spaces, to becoming mainstream.

Scaling up
Scaling up takes various forms, including expansion (an increase in size); replication (an increase in number); extension (new applications or on larger scales); and transfer (lessons learned applied in different contexts). Positive scaling up of niche-innovations represents an increase in the benefits of nexus-innovations, without simultaneously increasing the negative consequences.

THE HERE AND NOW

Innovations already active

We focus on three innovations: anaerobic digestion; insects for food and feed; and the redistribution of surplus food. While none are entirely new, they exist as alternatives to established systems of production and consumption, within a range of contexts and scales. They are also not purely technological innovations, although each includes some aspect of novel technological application or development. As such, they represent potential seeds of transformation and possible opportunities to adapt to the pressures of societal challenges, with benefits that span the WEF nexus.

From household, community and small businesses, to local authorities and large corporations, each deployment of an innovation demonstrates the new business models and practices involved in implementation and thereby informs our understanding of the conditions that would support its uptake and traction.

However, the present and possible impacts of these innovations in the context of the WEF nexus are not well understood. Focusing on these innovations allows **Stepping Up** to grapple with complex questions such as:

Can innovations be purposefully scaled up, either to function on a larger scale or to proliferate in their current form, so as to provide greater benefits across the WEF nexus?

And if so, what are the conditions on which scaling up depends, the processes that might enable this to happen, and the resistance that might be faced?

Anaerobic digestion	Anaerobic digestion (AD) provides a route to dispose of food waste and agricultural residues that produces by-products with implications across the WEF nexus. For example, both biogas, as a substitute for fossil fuel-derived energy, and digestate, an organic fertiliser that can replace manufactured fertiliser, can soften the environmental impact of farming. More info.
Insects for food and feed	Insects offer an alternative protein source for animal feed and human food. As animal feed, insects could reduce the impact of meat and dairy production on land, water and the climate. As a meat substitute, insects could offer comparable nutritional value yet release fewer greenhouse gas emissions, requiring less land and water. More info.
Redistribution of surplus food	It is beneficial that as far as possible, food that is produced for people is eaten and that surplus food is prevented from entering waste streams. As well as offering societal benefits in conditions of austerity, redistribution of surplus food helps offset the impact of food production and manufacture and ensures that the water and energy embedded in food produce is used as intended. More info.

What do we mean by?

Niche
A protected space within which nascent innovations become established. While their scale may vary, niches are distinctive as they operate according to a different set of rules to the incumbent system, therein enabling innovations to emerge and mature.

Case study
A real world example in which an innovation has been deployed that might enhance our understanding of the processes and implications of scaling up.

Transformation
A departure from current modes of thought and action presenting a fundamental challenge to the existing state of socio-environmental systems. Note that transformation describes the extent rather than the direction of change; it does not guarantee a move towards sustainable systems.

The approach

In **Stepping Up**, we conducted interviews with people involved in case studies representing each innovation to explore the systems around them as well as external or internal pressures that either help or hinder their development and growth. The case studies were chosen to represent a range of scales and, where possible, a range of project maturity and success. This was a deliberate decision to better understand why certain approaches have worked and some have not, and where different pressures act constructively or destructively. Case studies were found through engagement with representative bodies, networking at industrial events, and via referral. Each interview was recorded and transcribed, allowing analysis by a multi-disciplinary team. Key findings were shared with project partners.

The results

Stepping Up encompasses a range of novel methods and approaches[3]. It is one of the first to explore the concept of the nexus from a trandisciplinary perspective, acknowledging the need to involve stakeholders in the design and conduct of the research so that the research reflects their needs, values and interests. Its innovation-centric focus is novel in comparison to many other nexus studies that focus on policy coherence. Several specific insights from the project were identified following investigations of existing WEF innovations, each relevant to current issues within environmental policymaking:

1. **Scaling up can amplify negative impacts too.**
As examples of niche innovations, the case studies explored within **Stepping Up** are characterised by attributes that, on the face of it, merit scaling up, or making mainstream. However, on closer inspection it is evident that scaling up innovations implies scaling up aspects that are negative, as well as positive. For example, while the social redistribution of food may be useful, scaling up this redistribution implies: a) maintaining inefficiencies in terms of the oversupply of food at retail outlets; and b) increased demand for free food by the most vulnerable. So while focusing on innovations is useful, focusing only on the merits and not the costs (in their broadest sense) of such innovations is a mistake. **Stepping Up** highlights the importance of reflecting on the why, rather than just the how, of innovation.

2. **From whole-system to cross-system analysis.**
Whole-system approaches are increasingly acknowledged to be central to tackling large, complex challenges. **Stepping Up** has furthered our understanding of how system outcomes can be affected by decisions made outside of system boundaries, highlighting the importance of cross-system analyses. For example, policies and practices associated with the collection and management of food waste can affect decision-making on how the energy generation infrastructure can best manage such material, i.e. anaerobic digestion or 'Energy from Waste'. This, in turn, has implications for environmental, social and economic consequences in the mid- to long-term.

3. **Outcomes at the nexus are shaped by politics.**
Politics shapes the mechanism to achieve intended outcomes of government departments. It also shapes the unintended outcomes of policy, both positive and negative, within and across policy domains. **Stepping Up** unpicked this in the context of domestic policy differences across the UK. For example, waste policy in Wales and Scotland has differed markedly from England since devolution. Wales and Scotland both offer separate domestic food waste collection and both favour the use of AD. In the absence of political consensus in England, approaches to food waste collection and management varies across and even within counties, with implications for food and energy systems alike.

4. **Scale and context matters.**
For any innovation, the context – social, governmental and geographical – in which it evolves is critical to its development. We unpick the challenges for innovations across a range of scales to identify how support might be offered to help each scale flourish. For example, AD can meet a variety of needs depending on its specific application[4]. In agriculture, it can be used in nutrient recycling, odour control and integrated land management for energy and food. In the UK, however, these benefits have not been as heavily incentivised as AD's contribution to energy generation.

5. **Geographical context matters.**
Stepping Up explored how a change in type and hence location of protein provision can significantly change resource consumption patterns. For example, rearing insects for protein creates a shift between water and energy consumption compared to other animal proteins. As energy consumption in terms of heating needed is related to the species of insect and rearing location, a change in protein source will shift the consumption burden between domains (e.g. water compared with energy) and this will vary with geographical location.

6. **Reflexivity is needed to manage unintended consequences.**
Innovation of any kind is likely to result in some unforeseen negative consequences. If these consequences are not recognised and addressed, this introduces risk to large-scale deployment. **Stepping Up** demonstrates that innovation is sometimes guided by institutions with little capacity to consider, understand or respond to the emergence of unintended outcomes.

Changing protein patterns has implications for water, energy and land use. While increasing the use of insects as food or feed can reduce demand for water and land in one location, it may simply be transferred to another. It may also increase demand for energy, depending on the climate in which the insects are reared.

For example, energy incentives have played a significant role in the development of AD in the UK. In some circumstances, however, energy incentives direct AD development in ways that may not offer the greatest cross-sectoral benefits. Reflexivity allows the suitability of current values, assumptions and methods to be questioned. Given that interventions of some government departments affect the objectives of another, this reflexivity must be cross-departmental. Nexus research helps to instil an understanding of how system interdependency can threaten policy goals and impede systems resilience and how these might be managed. More here[1].

7. **Embedding stakeholder engagement is already working.**
The project was conducted in collaboration with stakeholders. ADBA, the anaerobic digestion industry body, invited **Stepping Up** to run a workshop at their annual Research and Innovation conference around understanding the future of AD, which resulted in an invitation from BBSRC's ADNet network to run a workshop with early career researchers in the sector. Work with industrial insect farms has brought new learning to the sector, supporting a move to more sustainable business practices. The project has also engaged with WRAP's Courtauld Commitment 2025.

LOOKING AHEAD

Sustainable innovations for the future

The future is fundamentally uncertain. There are limits to what we know and how the information that we have can be used to understand future condiitions. What the future looks like depends on decisions that are yet to be made, and what is desirable in the future is subjective and changeable. These uncertainties are even more apparent when studying nexus systems, given the variety of sectors involved and the range of scales within which action occurs[1].

Scenario planning is a proven method for understanding uncertainty. Scenarios enable different futures to be visualised and their consequences understood. They provide a talking point to allow learning across different resource management sectors and between stakeholders operating at different scales[3].

Scenarios provide a means to enable decisions to be made despite conditions of uncertainty. The capability of Agent-Based Models (ABMs) to simulate the interaction between agents complements the use of qualitative scenarios, helping to quantify the evolution of specific innovation and their subsequent impacts on the WEF nexus, by characterising the different priorities of the agents involved in driving innovation[2].

Table 1:
Summary of each Stepping Up scenario

SHARE AND CONNECT

Decentralised digital society with high levels of connection between producers, consumers and awareness of the environment.

CREATE AND COPE

A society troubled by climate change, but with vibrant innovation in service systems catering for most needs.

BIG AND SMART

A highly centralised society where big infrastructure supplies basic needs, regulated for transparency and efficiency.

What do we mean by?

Scenarios
Plausible, internally consistent visions of the future that provide a reference point to explore the implications for societal change.

Backcasting
Allows pathways towards a given future scenario to be examined, working backwards to identify policies and actions that will realise the changes implied, achieve their benefits, or mitigate their consequences.

Agent-Based Model (ABM)
A mathematical simulation of how interactions between agents (e.g. individuals & instititions) and their surroundings shape whole systems.

Complexity
A system is complex when the interactions between its components, and the interaction between the system and its environment, are such that the system as a whole cannot be fully understood simply by an analysis of its components. In complex systems, we apply a holistic approach to our analysis and account for the uncertainties and ambiguities arising as a result of system operations.

The approach

There are few published scenarios that describe changes across the WEF nexus, but throughout the literature on water, energy and food there are excellent transdisciplinary scenarios, where researchers and practitioners have worked together to understand the uncertainties that face these three individual resource domains[6].

To develop the **Stepping Up** scenarios, researchers drew on this body of knowledge to identify common narratives of the changes that can occur. This exercise produced three qualitative scenarios **(Table 1)** depicting possible changes in technology, society and climate and their implications for the WEF nexus in the UK.

The scenarios provided the basis for an expert workshop, offering rich descriptions to catalyse discussion on how nexus-innovations adapt; the implications of future change for innovation performance; and the prospects for supporting their effective innovation in different scenarios. In addition, two ABMs **(Table 2)** were developed to simulate innovation up-scaling and to quantify consequent environmental, social and economic impacts under these scenarios.

One team led the development of an ABM to examine the potential implementation of AD in Lincolnshire initially and then nationwide, using scenarios to focus on 35 years of different decision-making priorities and then scaling up for the whole of the United Kingdom.

Another team led the development of an ABM to represent the spread of water harvesting technologies in domestic properties in the River Lark catchment.

The AD ABM explored a non-mainstream energy-generation technology that has potential benefits for land, water quality and food production. The water harvesting ABM, meanwhile, explored water management options in a water-stressed, climate-vulnerable catchment in which high-energy and high-cost water treatment plants for low quality water (seawater or wastewater) are considered for development by mid-century.

ABMs are built from the bottom-up to improve our understanding of dynamic and complex systems in spite of multiple sources of uncertainty by employing Monte Carlo simulations.

Table 2:
Summary explanation for the two ABMs.

Anaerobic Digestion
The environmental, social and economic impacts of future AD implementation are quantified for the UK. The model enables comparison of the different innovation profiles of AD under the *Share & Connect* and *Big & Smart* scenarios against a baseline, by simulating: assumed changes to feedstock volume; the associated financial costs and emissions of feedstock transport; operational and capital costs of plants; and local enthusiasm for AD in 2050.

Water harvesting technologies
Demand for water and investments in new water harvesting technologies were modelled for seventy thousand households in the Lark catchment for each scenario. The model simulates the effect of people's experiences of water shortage; their affinity for new technologies; the influence of neighbouring households' technology uptake; how technologies fit with people's experience of technologies; expectations of water service systems; and capital requirements.

The evolving behaviour of the 'agents' (or decision makers) adapts and changes over time and can reveal the behaviour of innovation in a system. This is particularly useful when input parameter values are unavailable, allowing estimates based on the knowledge and understanding of stakeholders.

Developing a successful ABM requires careful validation so results are not products of imprecise or inappropriate parameterisation. The best-informed parameterisation has the highest chance of producing a successful ABM. Workshops informed the parameterisation of the scenarios, helping us to develop a robust representation of future society.

The results

1. Stakeholders readily connect innovation to societal developments.

The scenarios examined implications of changing circumstances for up-scaling nexus-innovations. Workshop participants considered who would be involved in our nexus-innovations in 2050, at what scale and what challenges they might respond to. Most interesting is how readily stakeholders connect changes that take place in nexus-innovations to changes in society, governance and everyday routines. For example, in considering futures of food waste and surplus, participants described how food procurement and preparation differed in each scenario, and the different mealtime routines and systems of food provision that influence how nexus-innovations evolved and performed. These rich interpretive discussions interrogated broader suites of change that must occur to support sustainability transitions, offering insights as to why conventional modelling techniques may be overly optimistic about the impacts of technological solutions[1].

2. Social, geographical and governance developments influence innovation diffusion.

Examining case studies of innovation through a WEF nexus lens captures the multidimensionality and uncertainty of the real world. The analysis draws attention to the significance of social, geographical and governance factors that influence innovation uptake and thus diffusion, showing that these must be taken into consideration in a meaningful way when designing responses to global environmental challenges, such as climate change. This illustrates why forecast and modelled projections sometimes endorse solutions that, when given greater scrutiny, have benefits that are less rapidly achieved or less profound than anticipated.

3. Widespread uptake of water harvesting could postpone developing energy-intensive alternatives.

Though agent-based approaches to assessing water resources are common, the inclusion of parameters to consider changing patterns of household water use, and the adoption and diffusion of influential technologies within the water harvesting model are much less so. Incorporating these parameters within a model that also considers the impact of climate change on water demand and water resources offers an innovative contribution attracting interest from within the water sector. Preliminary results suggest that while water harvesting technologies are not overall as cost-effective as large-scale water source development, their widespread uptake could postpone the development of energy-intensive technologies with high capital costs **(see Table 3)**.

4. Community coherence influences innovation adoption.

Scenarios with high levels of community coherence (i.e. where there are high levels of interaction and collective action) provide the most promising reductions in demand for water, followed by those where action to reduce household demand is emphasised. Results suggest that a future with higher levels of social cohesion and pervasive community-level water harvesting could delay the requirement for new water processing plants for desalination and reuse.

5. The rainwater harvesting ABM offers valuable insights for the water industry.

Water resource managers in the UK and internationally will benefit from improved understanding of the dynamics of domestic water demand. This is critical to making more informed predictions such as when and whether new water infrastructure should be developed and how future droughts will affect demand for water. The potential benefits of such findings are valuable to both water companies (who benefit from more informed water management plans and lower infrastructural costs) and their customers (who may benefit from lower water bills as a result). This could prevent damage to the environment from unnecessary development and energy use.

6. There is no perfect model for AD upscaling.

The AD ABM demonstrates the varied strengths and weaknesses of different levels of centralisation for AD development. When modelled, *Share & Connect* could result in bigger reductions in carbon dioxide emissions than *Big & Smart*, but is more costly. This is due to assumptions made about reduced travel distances associated with collecting inputs and distributing outputs from the AD process in the *Share and Connect* scenario, which ensures the emissions associated with AD are reduced. However, the centralised development of AD plants in *Big & Smart* has lower costs than *Share & Connect*. In addition, the more effective collection and separation of food waste in the *Big & Smart* scenario, compared to *Share & Connect* results in more energy (biogas) production and higher water consumption for AD operation (unless sufficient liquid wastes are found to substitute water use). Assuming digestate is used to replace artificial fertiliser; *Big & Smart* also offers greater benefits for agriculture as it produces more digestate than *Share & Connect*.

	2030	2040	2050
Minimal rainwater harvesting	14	20	24
Share and Connect	4	8	11

7. Emergent behaviours demonstrated.

The AD ABMs provide tools to evaluate different decision alternatives or future scenarios relative to each other. Using the AD AMB as an example, new viable areas from where to derive resources – collection areas – emerged in the model and some collection areas expire over time as a result of the collective behaviour of source (agents creating food waste), collector (agents collecting food waste) and plant feasibility (AD operator) agents. The emerging behaviour of the whole system is revealed in the spatial distribution of the plants and collection areas, distribution of the plant capacities and saturation of AD in the whole area (county or nation). The AD ABM demonstrates the self-organisation and emergence of sub-systems and reveals the emergence behaviour of the whole system.

8. Data collection is a significant challenge.

A large amount of high quality and relevant data is needed to set appropriate ABM rules and assign precise values for the model input parameters. Attaining the required data at the required granularity to develop the ABM was challenging. Some data was unavailable, some inaccessible by the team, and some of the available data was collected for other purposes and not viable to feed into the model. Getting the trade-off right between time dedicated to data acquisition and good representation within a model is critical to the success of future studies.

9. Interactions, benefits and consequences beyond those modelled may also be important.

AD implementation may improve the market by creating more jobs, but the ABM did not account for these potential benefits. The ABM did not predict costs avoided, government incentives or financial returns produced from AD implementation. This is mainly due to the lack of reliable data since some financial parameters (e.g. incentives) are politically driven and likely to change over the next few decades.

Context is crucial and must be taken into consideration in a meaningful way when designing responses to global environmental challenges to avoid designed solutions failing to deliver the intended benefits in the longer term.

10. Confronting complexity opens up new pathways for change.

While the precise recommendations that emerge from nexus research can be challenging to interpret, transdisciplinary research projects offer findings that enhance discussions regarding cross-sectoral resource management. Confronting complexity of future change provides data and discussion on the ways in which changes, particularly societal and behavioural changes, may depart from existing trends, and what this could mean for the future of innovation. This is a quality lacking in many scenario analyses, particularly those deriving from scenarios that assume technological change occurs within a world that looks otherwise similar to that of today. While interpreting the qualitative data derived from the workshops into numeric values for the ABM input parameters was challenging, there is significant demand for these more complex research outputs to enable more informed modelling and robust planning.

AN ENVIRONMENT TO THRIVE:
Allowing innovation to flourish

Decision-making that impacts on how innovation can flourish happens concurrently, at multiple scales and with organisations overlapping in terms of their sphere of influence. Good 'solutions' must go beyond embracing scientific or environmental constraints, to consider a wide range of interlinked parts of the system – from infrastructure to regulatory constraints that cut across sectors. They need to be fit for purpose, take in the full 'solution space' and not lead to negative unintended consequences.

We know that decision-makers take a multitude of factors into account, including conflicting stakeholder priorities, when aiming to deliver 'good' solutions. However, judging what is more or less important is extremely challenging. Rational decision-making requires more than a set of indicators, with a need to mitigate impacts of preconceptions and biases.

Here, we embrace complexity and encourage sharing of different perspectives to facilitate discussions around WEF innovations by designing a structured process to engage decision-makers around issues such as scale, locality and diffusivity, while conveying benefits to the environment. The challenge with WEF innovations in particular, is that they bring together cutting-edge knowledge around several different disciplines. This means that tailored decision support is needed – there isn't a "one size fits all".

Agent-based modelling (ABM) is combined with Multi Criteria Assessment (MCA), to form a Decision Support Toolkit (DST) to enable the sharing of different perspectives to support decision-making. MCA simplifies information limits biases and improves objectivity. The DST provides scope for conversations around, for example, how new energy technologies interlink with the water and food systems. As part of the DST, video game prototypes are repurposed to raise awareness of the WEF nexus complexity.

Computer game worlds share many properties with complex systems. They have many agents (stakeholders) interacting in space and time, include agent- and system-scale responses to events, but also offer 3D representations of large datasets depicting a system or 'world'. When developing useful indicators, we ask whether they influence policy development (instrumental), or provide a common knowledge base or shared understanding of complex issues (conceptual).

Our three scenarios can then provide insights into the importance of each indicator in future. Indicators must be measurable, but in addition to those such as CO_2 emissions, others include social factors to focus attention away from financial measures and place more emphasis on social and environmental factors.

The approach

We developed a three-stage support process that can be applied to explorative decisions by assisting with understanding the challenges and opportunities for up-scaling niche innovations in the WEF nexus space. This process specifically uses AD innovation within Lincolnshire as context and involves (1) a systems model of the innovation and its context; (2) a set of criteria to be applied to each decision-making process, and (3) a visual tool created to structure the ABM output for a future decision. This process links the Agent Based Modelling for Lincolnshire with a Multi Criteria Decision Analysis (MCDA tool to assess alternative patterns of action within a given sustainability initiative (innovation) context. The focus is AD, for which effective spatial patterns (number and size of facilities) and diffusion rates (linked to policy initiatives) were sought. Effectiveness is assessed via a set of indicators measuring impact and benefits of WEF nexus function. TOPSIS (a MCDA technique) is used to rank alternative solution within a scenario, based on decision criteria weightings.

What do we mean by?

Decision-making framework
An approach to determine sustainable operating conditions around an innovation. This includes: a model of the system in question (e.g. ABM for AD); a set of indicators to assess sustainability; a method to elicit stakeholder preferences (e.g. multi-criteria assessment).

Multi-criteria assessment (MCA)
An approach to determine different stakeholder preferences, reduce biases and present resulting information in a structured and objective way to facilitate informed decision-making.

Serious game
A way to 'play' that goes beyond entertainment, that can help identify choices and the consequences of those choices in a game setting.

Interactive catalogue of indicators
A suite of indicators developed for this project to articulate sustainability that can be applied across different innovations to define and manage complex human-environmental systems.
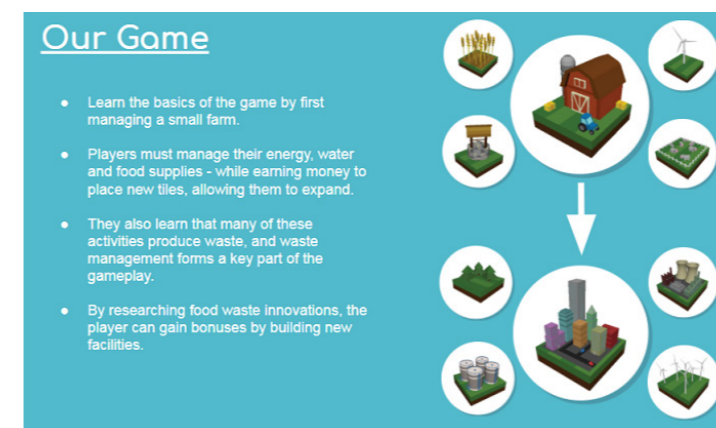
Figure 1:
Serious game prototype development. Examples of different Game Concepts with the theme of exploring the concept of the Water Energy Food Nexus.

Figure 2:
Example User Story for Local Authority Waste Manager

The results

1. WEF stakeholder diversity requires tools designed to be user-specific.

With three main elements to our decision support toolkit, we found that some tools were a closer fit for some stakeholders than others. For example, policy makers, local authority decision makers, regulatory groups, academics and industrial stakeholders, found the decision-making framework (ABM + MCA) and interactive catalogue of indicators most relevant. While entrepreneurs, schools/educational organisations, community groups and farmers found the serious game the most engaging and informative.

2. Trade-off identification requires a three-stage framework.

Given the uncertainty around 'solutions' to WEF problems, a three-stage decision-making framework is needed. First, a systems model that includes specific contextual factors; second, a set of criteria for each decision-making process; and third, a visual tool to interpret outputs.

3. Context matters.

As discussed in previous sections, the context to a particular problem – social, geographical and governmental – makes a big difference to the decision being made.

Scenarios can be used to compare trade-offs. Prioritising CO_2 reduction can lead to other social or economic impacts, and tools such as Agent Based modelling can be used to analyse these complexities. However, with any complex modelling, understanding the assumptions embedded in the model is critical.

This is why the multi-stage framework is essential if good decisions are made that avoid negative unintended consequences, and maximise positive benefits.

4. Prioritising financial aspects can stifle innovation.

While many stakeholders indicated that financial aspects are a deciding factor in driving many decisions, it was also clear that in certain situations, they could also stifle the innovation process. Discussion of innovation within a workshop process, where other aspects are given more air time, can lead to enhanced knowledge, and recognition of influential issues that conventional processes may overlook.

CONCLUSIONS AND FUTURE DIRECTION

A joined-up approach is challenging, but essential

Nexus research is not only very challenging to conduct, but raises questions where 'solutions' are perceived to already exist. It can highlight potential unintended negative consequences of future policy decisions, enabling insights that currently only come to light through hindsight, once any damage – environmental or social – may be irreversible. Despite the difficulty of research at the WEF nexus, with barriers including multi-scale data collection and access, stakeholder identification and engagement, communication and pathways to dissemination, this type of analysis is essential in our increasingly interconnected world.

By incorporating new transdisciplinary methods that are both helpful and disruptive, creative dialogue emerges that can support decision-making under high levels of uncertainty. Researchers may find their results more difficult to analyse and effectively communicate compared with more traditional, disciplinary or sector-specific analysis, with many issues that come to light being unavoidably political. Nevertheless, research in the space is vital if we are to develop meaningful, whole-system responses to current global environmental and societal challenges. This section highlights the principal outcomes from our research, and makes recommendations for its further development.

Context is vital

Policy responses to global environmental challenges must consider social, geographical and governance contexts to ensure new innovation diffuses in a productive way. The scale and diversity of a particularly innovation – such as the size and shape of a particular anaerobic digestion plant – influences both the success and fit of this 'solution' within any specific context.

Overlooking context-specific challenges can lead to "one size fits all" solutions that are unlikely to succeed. While it may be more costly in the short-term, designing context specific solutions to environmental problems that can be moulded and shaped as contexts change is a more sustainable approach than those typically adopted today. Contextual nexus analysis requires user-specific decision support tools, underpinned by transferable methods, able to deliver the most relevant solutions to a particular problem.

The decision support method used in **Stepping Up** explores trade-offs between water, energy and food challenges by first considering the context of the problem, now and in the future, building an appropriate systems model and then complementing the process with visualisation tools.

The systems model (in our case the Agent-Based Model) needs to go beyond what is offered by conventional modelling tools and incorporate critical stakeholder reflection on how future changes in society might practically influence people's lives, and the possible implications of this for innovation diffusion. This provides a framework to consider a wider context, delivers more plausible insights than conventional approaches and avoids the prioritisation of financial aspects that can stifle innovation.

A key element of the decision support method was the innovative use of participatory scenario analysis. By recognising that the future is fundamentally uncertain, our approach enabled a rich, multi-dimensional understanding of the implications of social, technological and climatic change for nexus-innovations. This helped us to explore the interconnections and tensions arising and unravel the challenges and opportunities that different futures present. **Failing to consider the future context in which an innovation is set, is to fail to develop solutions that will benefit future society.**

Accepting blurred boundaries

Boundaries between energy, water and food systems are increasingly blurred, both physically and politically. Good decision-making requires reflexivity to accommodate this new complexity. Analysis beyond domain boundaries provides a way to better understand how innovations may or may not work.

Tools such as scenario planning can help researchers and stakeholders alike to identify potential negative unintended consequences for wider society and sectors impacted by decisions targeting a single domain (e.g. energy). Complementing quantitiative assessments with participatory methods highlights that stakeholders can immediately connect technical innovation to a wide range of social, political and institutional factors in ways that conventional models are unable to. **This highlights the real value of stakeholder engagement for good decision-making in a complex world.**

Scaling up is not always good!

When an innovation is scaled up for good reason, there will be negative unintended consequences that need to be mitigated and social, economic and environmental costs accounted for. Transdisciplinary approaches are vital to tease out these issues, with data and process transparency as well as trust between stakeholders important aspects of the mitigation process. Despite challenges, confronting complexity can enable more informed modelling and robust planning.

With the increasing blurring of system boundaries, system thinking is required – or needs to at least be acknowledged. Adaptive forms of governance can also assist in this regard, as can a multi-stage decision-making process such as the one designed in **Stepping Up**. Attention to public opinion must also be given, and not be assumed to be static. Opinions change and can be shaped to the extent that what works in one place may not work in another. **Ownership and organisation (political, legal and financial) will also play a key role in the scaling up process.**

Innovation requires change across systems

In the UK, the Government is supportive of innovation, but because it treats it as a by-product of competition, there will be too many unwanted trade-offs between sectors, and not enough acknowledgment of the co-benefits of cross-sectoral approaches.

Policymaking would do well to consider a suite of objectives to support innovation and provide a framework for it to emerge from the bottom-up. Our findings demonstrate that achieving the potential benefits from innovation is conditional on change to socio-tech-environmental conditions in multiple domains and across systems.

As with other innovations, WEF nexus innovations can be prone to lock-in once they are no longer delivering improved sustainability.
To avoid problems persisting, governance must build in a process of transdisciplinary continuous reflection to facilitate flexibility in order to deliver more sustainable outcomes.

RECOMMENDATIONS FOR FUTURE RESEARCH

As illustrated in Conclusions and Future Direction, **Stepping Up** demonstrates that in-depth exploration of nexus issues and using a nexus approach, has considerable value. Several avenues have been identified for future research:

Taking forward agent-based modelling of WEF nexus problems.
There is considerable scope for an enhanced simulation of groundwater abstraction where we investigate the role of non-domestic users of water and include more novel water-saving interventions. It would add value to investigate the impact of a shifting social response to innovation over time. This will complement the AD ABM study where a fixed social response to new technology is assumed.

Developing and using the new decision support framework.
Merging elements of the decision support tool together would enable us to design, develop and apply a 'serious game' to aid context specific decision-making and resource management, based on real data. This research would be underpinned by technical innovation e.g. how best to merge game technologies and high resolution spatial data. An expansion of the analysis to other innovations would provide a broader suite of useful indicators that, by working with stakeholders to refine, could lead to an actionable framework better able to deal with the unknown and unexpected.

Applying the transdisciplinary methods in different contexts.
The methods used here are transferrable across innovations, and could be deployed within the context of a contemporary societal challenge, such as the current political drive to end the use of single-use plastics. Removing single-use plastics from supply chains is likely to necessitate changes to policy and regulatory regimes, as well as requiring significant behavioural change and innovation, all of which can result in unintended negative impacts across multiple domains. Similarly, the WEF nexus approach could also as support the drive to improve resilience to climate change at the same time as decarbonising the energy system.

By placing our stakeholder engagement processes and decision support framework into local authority contexts in different UK regions, this research could directly support the challenge of making low-carbon choices when faced with an uncertain future climate.

PROJECT PUBLICATIONS TO DATE

1. Larkin, A., Hoolohan, C., and McLachlan, C., Embracing context and complexity in the water-energy-food nexus, Global Environmental Change, in review.

2. Larkin, A., Hoolohan, C., Soutar, I., McLachlan, C., Pregnolato, M,, McLeod, K. and Suckling, J., Messy but meaningful – how to make interdisciplinary water-energy-food-environment research more influential, Policy@Manchester blog.

3. Hoolohan, C., Larkin, A., McLachlan, C., et al., 2018, Engaging stakeholders to address water-energy-food (WEF) nexus challenges, Sustain Sci, https://doi.org/10.1007/s11625-018-0552-7

4. Hoolohan, C., Soutar, I., Suckling, J., Druckman, A., Larkin, A., & McLachlan, C. Stepping-Up innovations in the water-energy-food nexus: a case study of anaerobic digestion in the UK, 2018, The Geog. Journal, https://doi.org/10.1111/geoj.12259

5. Haltas, I., Suckling, J., Soutar, I., Druckman, A., and Varga, Anaerobic digestion: a prime solution for water, energy and food nexus challenges, Energy Procedia, 123, https://doi.org/10.1016/j.egypro.2017.07.280

6. Hoolohan, C. McLachlan, C. Larkin, A , 'Aha' moments in the water-energy-food nexus: A new morphological scenario methods to accelerate sustainable transformation, Technological Forecasting and Social Change, in review.

7. Suckling, J., Moore, C.D., Driscoll, D. and Druckman, A., Life Cycle Assessment of Crickets: a UK Case Study, International Journal of Life Cycle Assessment, in review.

8. M Abdel-Aal, I Haltas and L Varga. Modelling the Diffusion and Operation of Anaerobic Digesters in Great Britain under Future Scenarios within the Scope of Water-Energy-Food Nexus. Journal of Cleaner Production (to be submitted).

9. Falconer, R.E. , Haltas, I., Varga, L., Forbes, P. J. Abdel-Aal, M., Panayotov, N.   Anaerobic Digestion as a Water-Energy-Food Nexus Innovation: Hybridizing Agent Based Modelling with Interactive Multi Criteria Analysis. Journal Cleaner Production. Under Review.

10. Hoolohan et al. (2018) Change Points: A toolkit for designing interventions that unlock unsustainable practices. The University of Manchester, Manchester, UK. http://changepoints.net

http://steppingupnexus.org.uk　　　　www.tyndall.manchester.ac.uk　　　　www.tyndall.ac.uk