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The potential impact of Brexit on the energy, water and food nexus in the UK: A fuzzy cognitive mapping approach

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HIGHLIGHTS

- Coupled cognitive model captures the complexity of the UK Energy-Water-Food Nexus.
- GDP impacts on Energy Demand, whereas Water and Food depend on UK population size.
- Less integrated Brexit scenarios have threefold larger magnitude of predicted changes.
- Whilst dependant on choice of experts, the approach is attractive for Nexus mapping.

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ABSTRACT

Energy is one of the cornerstones essential for human life, along with other services such as water and food. Understanding how the different services in the energy-water-food (EWF) nexus interact and are perceived by different actors is key to achieving sustainability. In this paper, we derive a model of the EWF nexus using fuzzy cognitive mapping (FCM). Data were collected in a two-step approach from workshops with researchers and stakeholders involved in the three focal sectors. Four FCMs were developed; one for each of the EWF sectors, and one for the interactions that create the nexus between EWF. The FCM represents the combined views of the groups who participated in the workshops, the importance and limitations of which is discussed. To demonstrate its effectiveness, the aggregated FCM was applied to predict the impacts on the EWF nexus of four scenarios under which the United Kingdom would depart from the European Union (i.e. Brexit). The FCM indicated that energy-related concepts had the largest influence on the EWF nexus and that EWF demand will decrease most under a 'hard-Brexit' scenario. The demand for energy was shown to decline relatively less than other services and was strongly associated with gross domestic product (GDP), whereas UK population size had a stronger effect on water and food demand. Overall, we found a threefold change across all concepts in scenarios without freedom of movement, contribution to the EU budget, and increased policy devolution to the UK.

1. Introduction

"*Today the network of relationships linking the human race to itself and to the rest of the biosphere is so complex that all aspects affect all others to an extraordinary degree. Someone should be studying the whole system, however crudely that has to be done, because no gluing together of partial studies of a complex non-linear system can give a good idea of the behaviour of the whole.*" Nobel Prize winner Murray Gell-Mann made this statement at an International Society for the Systems Sciences (ISSS) seminar in 1997 [1]. Around the same time, the term 'nexus' started to be used to describe the interconnections between spheres of energy, water and food [2], but then fell out of favour until the second decade of the 21st century. Interest has grown rapidly since then (e.g. [3–5]), especially from the perspective of an environmental trilemma in managing the connections among these three sectors [6–8].

1.1. The energy, water and food nexus and its relevance to the UK

Energy and food production, as well as a secure supply of clean and available freshwater, are all vital to human survival. Yet, the energy,

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food, and domestic water sectors are intricately connected in ways that often lead to intense and undesirable competition for resources. For example, the consumption of water in the life-cycle of energy production can limit its availability for domestic uses such as drinking and sanitation [9]. Such competition amongst energy, water, and food may only be exacerbated by future climate change, economic development, and a growing human population [10]. van Vliet et al. [11] recently predicted that climate-driven changes in global water resources could reduce the usable capacity of most hydropower and thermoelectric power plants, which collectively generate 98% of the world's present-day energy. Furthermore, agriculture, already the largest user of freshwater in many countries, will also increasingly compete with the energy sector for available water, further threatening our potential to sustain human demands for energy, water, and food [12].

A better understanding of the interdependencies - or the nexus - amongst energy, water, and food can help align policies and governance across sectors and scales to deliver a sustainable future [10,13]. Explicit analyses of the energy-water-food (EWF) nexus, however, are rare. One approach is life cycle or material flow analysis [14–16], while another involves more integrated modelling of the dynamics of the energy, water, and food systems [3,17,18]. Here we describe an alternative and new approach aimed at developing a model of the linked 'nexus' domains of EWF and the environment using fuzzy cognitive mapping (FCM). Our aim was to capture the impact of policy changes on the connections between the component parts of the EWF nexus. We focused on parameterising this model in the United Kingdom (UK) and then tested it with different scenarios of governance change. These scenarios were centred on the possible consequences of the UK's departure from the European Union (EU), commonly known as Brexit. Policy, sourcing, and pricing of energy, water, and food in the UK are currently influenced by membership of the EU through access to free trade, subsidies, legislation, and membership of the internal energy market; all of which will see changes following the negotiations for a UK exit from the EU. These changes will, in turn, impact the demand for energy, water and food within the UK. To date, there has been very little analysis of the potential impact on the system as a whole, or into the connectivity of energy, food and water services.

The analyses reported here address the following research questions:

- What do experts and stakeholders from different disciplinary backgrounds perceive to be the influences on and relationships among food, water and energy demand in the UK?
- Based on the "cognitive system model" of these experts, how does the demand for food, water and energy change as the UK leaves the EU?
- To what extent are changes in food, water and energy demand governed by the nature of the future relationship between the UK and the EU?

Our approach was first to capture information from different stakeholders in workshops that ran during November and December 2015 and use these to model the EWF nexus in the UK. FCM [19–21] is widely used for developing an understanding of how components of a system interact in situations where complex interdependencies and feedbacks are thought to exist, but where quantitative and empirically-tested information about these interactions is currently unavailable or difficult to obtain, especially in a short timeframe. Broadly, FCM aims to encapsulate the qualitative knowledge of expert participants to construct a simple systems dynamics model of a specific issue [20]. The resulting output can be used for projection or scenario testing purposes, and to facilitate further discussion and interaction within or with a stakeholder group [20]. We then used expert opinion to demonstrate how scenarios (e.g. [22,23]), in our case centred on Brexit, can be constructed and used within FCM to map policy impacts across the different EWF dimensions.

1.2. Exploring changes in the energy-water-food nexus through Brexit

Brexit provides a particularly useful case study for demonstrating the potential of FCM to model changes in the EWF nexus. The UK has been a member of the EU, and its predecessor (the European Economic Community), since 1973. However, the membership has always generated a degree of discomfort within sections of the UK. In January 2013, against the backdrop of a political party split on EU membership, and the rise of a single issue party, the UK Independence Party (UKIP), then Prime Minister David Cameron pledged that if the Conservative Party were to win the 2015 General Election the government would call a Referendum with one simple question, "should the UK remain a member of the European Union (EU)?". The referendum took place on 23rd June 2016. The UK electorate voted to leave the EU by a margin of 51.9% to 48.1% with a turnout of 72.2%. The result surprised many politicians and policy makers. The majority of major political parties had supported the campaign to remain in the EU, leaving great uncertainty about the potential outcomes of Brexit.

Any major political change at a national level can have serious implications on the broad range of energy, water, and food sectors. The UK energy system is connected to the EU in several ways that will be impacted by Brexit - from physical links through infrastructure (e.g. electricity and gas interconnectors), economic (favourable trade relations), managerial (companies such as EDF Energy working across borders), regulatory (shared legislation through Brussels and Strasburg, jurisdiction of the European Court of Justice) and population (workers from Europe, British citizens living in other EU states). Water policy, pricing and regulation in the UK is also controlled by the EU Water Framework Directive, while farm subsidies and environmental cross-compliance are predominantly driven by the EU Common Agricultural Policy. For energy, there has been an open European market since 2002. While Brexit will impact each of these sectors directly, the interactions among these sectors generate impacts that are not able to be foreseen if only a single system is considered.

2. Methods

2.1. Fuzzy cognitive mapping

Fuzzy cognitive mapping (FCM) is a simple approach used to extract mental models from people who possess various forms of knowledge about the causal interactions of a specific system. FCMs are a development of the cognitive maps used to elicit the causal structure of decision-making processes and social systems [24]. In a cognitive map, a number of characteristic features of the system (concepts) are identified and the causal connections (interactions) between these concepts are mapped using binary directional interactions in a signed digraph. Kosko [19] developed FCM primarily to address criticisms of the binary representation and the lack of dynamical analysis of system interactions in cognitive maps that are needed to predict changes in system components [25]. Kosko [26] later defined FCMs as 'fuzzy signed digraphs with feedback' where the interactions between components are weighted. FCMs have been used to map complex systems in diverse fields such as ecology, engineering, and medicine [27]. As well as being a useful approach to facilitate discussions between stakeholders, the semi-quantitative analysis of system dynamics provides an opportunity to conduct analyses of future scenarios.

2.1.1. Terminology

FCMs are a form of graph and as such a wide range of terminology applied in graph theory is often used when applying them. For the purposes of this study, we will refer to concepts (sometimes also termed nodes, vertices, components, or factors) which are connected by interactions (also termed edges, arcs or links). Concepts represent characteristic features of the system and are connected by a network of interactions. As signed digraphs, interactions in FCMs have a direction