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Use of fuzzy cognitive maps to study urban resilience and transformation

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ABSTRACT

Transformative change for urban sustainability and resilience calls for the use of new governance approaches that take into account the complexity of urban systems and associated stakeholder knowledge and perceptions. This raises the need to explore the cognitive dimension in the management of urban resilience and transformation. The article presents a Fuzzy Cognitive Mapping approach to develop plausible policy scenarios that support the decarbonisation of the urban energy system of the city of Bilbao, Basque Country. Scenario results indicate that a combination of local institutional and social action may be most conducive for stimulating effective and sustainable transformation of Bilbao's urban energy system. We address the properties of the resulting cognitive network, with a focus on the role of the energy system's connectivity which is found to present conflicting potential for resilience and transformation.

1. Introduction

With the pursuit of sustainability and resilience in the context of a rapidly changing world, managing the process of transformation is becoming an urgent need. This is especially evident in the case of urban systems. Currently, cities account for approximately 70% of global CO_2 emissions and 70% of primary energy demand (IEA, 2008). Further, it is expected that the influence of urban structures and their management on global energy demand will not diminish in the foreseeable future (Madlener and Sunak, 2011), thus remaining critical in a context of global climate change and increased resource scarcity.

There are two main perspectives by which sustainability, resilience and transformation are collectively approached in current literature: a social–ecological perspective and a socio-technical one. The social–ecological perspective, associated with resilience management research, often describes resilience as the ability to adapt to shocks and reorganise without suffering significant changes in structure and identity (Walker et al., 2004). However, it is possible for social–ecological systems to exist in resilient but undesirable states (Walker et al., 2006). Therefore, identifying the most appropriate and desirable management options for sustainability and resilience in these systems requires a process where different management approaches can be tested while emphasising learning, monitoring and continuous knowledge acquisition (Berkes et al., 2003; Folke et al., 2002). These processes are key for creating opportunities for transformation, i.e. system's deliberate and desirable change. Within this social–ecological perspective, the capacity of a system to undertake a process of transformation requires two things. First, that those within the system recognise themselves as being locked in an

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undesirable (unsustainable) state and second, the recognition that there is a need to reconfigure the system by means of new components and processes (Walker et al., 2004). So, from a social–ecological perspective, a core responsibility of resilience management is to facilitate the deliberate alteration of the fundamental properties of a system thereby undertaking a process of transformation in order to better cope with emergent conditions (Nelson et al., 2007). The complementary socio-technical perspective is associated with transition management research. This perspective is rooted in innovation and technology studies (Rotmans et al., 2000) and views transitions to sustainability as a long-term process of societal change entailing interactions between technology, policy, economics and culture (Geels, 2011).

Both the social–ecological and socio-technical perspectives attempt to understand complex systems through emphasising the importance of continuous processes of learning and adjusting (Van der Brugge and Van Raak, 2007) and by highlighting the need to support innovative means of knowledge acquisition (see e.g. Beratan, 2007; Nevens et al., 2013). Therefore, emerging from these perspectives, both resilience and transition management research recognise the importance of participatory processes to motivate and engage stakeholders in the process of change. Within these bodies of research, stakeholders' knowledge and experience is seen as a necessary prerequisite for any system's transformation in order to foster understanding and to develop a shared vision for alternative pathways (see e.g. Holling, 2001; Loorbach and Rotmans, 2010). This points directly to the need for recognising the importance of the cognitive dimension, mediated by values and cultural contexts, in analysing drivers of change towards resilience and transformation management,[1] especially in complex and uncertain decision-making environments.

Human cognitive processes are mechanisms of memory, attention and vision that allow acquiring knowledge and understanding through reasoning and judgement (Adams and Aizawa, 2010a; Lewandowsky et al., 2007). Cognitive processes are context specific and deeply influence decision-making processes (Adams and Aizawa, 2010b; Sieck et al., 2007). Cognition affects leadership, policy making and governance culture, three aspects that are crucial in the management of any process of change, including adaptation and transformation (Adger et al., 2012). Increasing visibility of actors' knowledge helps deepen understandings of how systems are structured and how they work, which is essential for making better policy decisions that avoid undesired social or environmental impacts. Multiple approaches exist for capturing how actors' cognitions affect decision making, including discourse analysis (e.g. Q methodology and Delphi techniques), multi-criteria evaluation (e.g. social or participatory MCA) and mental models (e.g. agent-based or fuzzy modelling). Among them, Fuzzy Cognitive Mapping (FCM) is an interesting tool with numerous comparative advantages including the ability to simplify a complex decision environment while integrating actors' different perspectives and ideas using a semi-quantitative approach. Although not uniquely associated with FCM, an important advantage of this method is its ability to support the development of policy scenarios. In this paper we apply a participatory FCM approach in the context of urban low carbon energy transition planning. We draw from previous work on fuzzy cognitive modelling applied to the resilience management of social–ecological systems (Kok, 2009) and on the potential of fuzzy thinking for addressing complex urban problems (Habib and Shokoohi, 2009) especially those related to climate change and the environment (e.g. Reckien, 2014).

As mentioned, a focus on urban systems requires understanding resilience and transition dynamics from a social–ecological perspective (Ernstson et al., 2010), as these are inherently coupled with complex environmental systems across scales. In addition, a socio-technical perspective is also necessary as there are multiple interactions among industry, technology, markets, policies, culture and civil society in any urban energy system. To date, resilience management has been viewed as a promising application of FCM (Kok, 2009) due to its potential for modelling the non-linear dynamics of social–ecological systems emphasised in resilience approaches (see e.g. Folke, 2006), however, the use of FCM for urban decision-making has not yet been sufficiently explored.

To the best of our knowledge, this paper represents the first time a participatory FCM approach has been used as a way to explore urban resilience and transformation. For this purpose, we provide an interpretation of network indices that allows for their utilisation in resilience and transformation management. A case study of Bilbao's energy system allows us to show how FCM can help to identify and connect actors' perceptions of mechanisms underpinning sustainable urban energy transformation processes. We also present an innovative approach to use FCM for the development and comparison of alternative action pathways towards achieving low carbon futures in urban areas.

An overview of the use of FCM for environmental management is provided in the next section. In Section 3, we discuss how the FCM approach can be utilised to study the resilience and transformability of urban energy systems based on a scenario analysis. This is followed by the introduction of the Bilbao case study and a description of the application of FCM there (Section 4). Results are presented and discussed in Section 5, with special attention focused on policy scenarios. The paper concludes by reflecting on the potential applicability of FCM for resilience and transformation management towards urban sustainability.

2. FCM for environmental and urban management

Cognitive maps are originally attributed to Tolman (1948), and were introduced in the context of human systems by Axelrod (1976) to illustrate parts of a system associated with a certain decision. Cognitive maps can represent an individual

[1] We use the concept of 'transition management' as generally used in innovation studies and 'transformation management' as a more general notion that refers to the process of managing change from both a socio-technical and a social–ecological systems perspective.

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