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Adaptation of interconnected infrastructures to climate change: A socio-technical systems perspective

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ABSTRACT

Climate change is likely to affect how society will function in this century. Because climate change effects may be severe, a next step is to study not only the effects on natural systems, but also the effects on built infrastructure systems and, in response to anticipated effects, the adaptation of those systems. Studies that discuss interconnected infrastructures, society's backbones, in light of climate change are emerging. We apply a socio-technical systems perspective in order to gain insight into the effects of climate change on our infrastructure systems and possible adaption strategies for the coming decades. We use this perspective to collect and describe the literature on adaptation of infrastructures to climate change. We find that the analysed papers predominantly focus on specific geographic areas and that various types of impacts on and interdependencies of built socio-technical systems are recognized, not only for energy and transport, but also for water infrastructures. A missing step is the modelling of adaptation measures. Recent literature enables an exploration of strategies for adaptation, which should be expected in the coming years.

1. Introduction

Climate change is likely to affect the way in which society will function in this century (IPCC, 2007). Scientific consensus is in favour of accepting climate change and the seriousness of its potential impacts (Doran and Kendall, 2009; IPCC, 2007). There is a vast body of literature on climate change itself and the effects on our natural environment. Recent literature shows that serious impacts may be expected on our infrastructures as well (e.g. Decicco and Mark, 1998; Hor et al., 2005; Van Vliet et al., 2012), systems that form the backbones of society and are fundamental for many of our daily activities (Chappin, 2011). There is an increasing awareness of the interdependencies of infrastructures (e.g. Wilbanks and Fernandez, 2003), such as the effects of the water infrastructure on health (e.g. Costello et al., 2009). Nevertheless, climate change effects on interconnected energy, transport, and built infrastructures remain less studied in the scientific literature (Hunt and Watkiss, 2011; Bollinger et al., 2013).[1] Throughout the current literature, the nature of the expected consequences stresses the need for adaptation. Consequently, mitigation (reducing our impact on the climate) may prove insufficient to safeguard the proper functioning our infrastructures in the coming decades. When severe consequences of climate change occur, adaptation (anticipating and responding to the impacts of climate change) may be crucial. Awareness of how to adapt infrastructures against the consequences of climate change is essential for considering what to do now in order to assure provision for energy and transport services in the decades to come. This paper's objective is to analyse and provide an overview of scientific studies of interconnected (energy and transport) infrastructures in this area.

We frame infrastructures as complex socio-technical systems (de Bruijn and Herder, 2009; Van der Lei et al., 2010; Chappin, 2011), which are large-scale systems with a huge number of elements and their connections. As illustrated in Fig. 1, this includes the technical infrastructure systems and networks such as roadways and electricity grids. Goods or services flow through these systems and networks and thus, the technical infrastructure provides the basis for many daily activities. Socio-technical systems thinking suggests that in order to shape this infrastructure, the "social elements and the corresponding relations must also be considered as belonging to the system" (Ottens et al., 2006, pp. 133). The social infrastructure includes the humans, organizations and governments that make decisions and form our economy as well as our institutions and policies. Purposive actors in the system

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[1] Interdependencies suggest the influence that infrastructures have on each other, i.e. the effects across infrastructures and the dependencies that follow. Various interdependencies are often acknowledged and described. In this paper we focus on the underlying but less studied connections between the infrastructures, which we label as interconnectedness.

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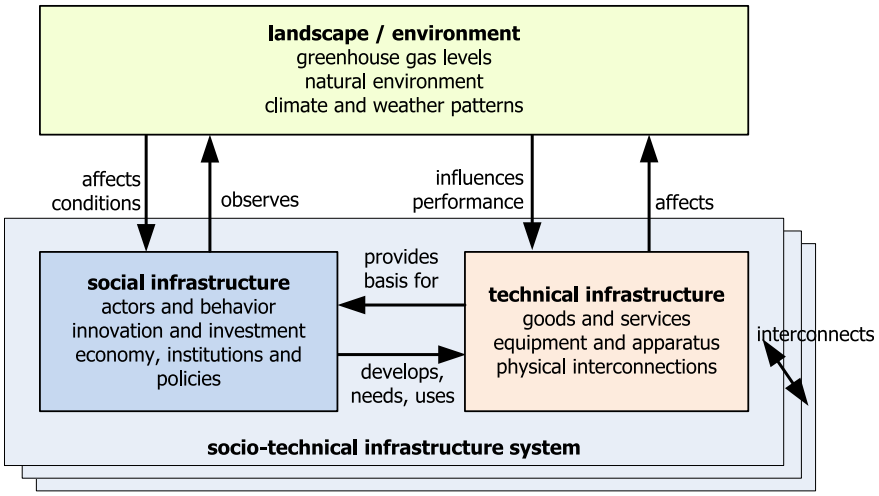

Fig. 1. Socio-technical system's perspective on climate-affected infrastructures. Adaptation implies changing (elements of) the socio-technical infrastructure system.

develop, need and use the technical artefacts, in order to function. The effort to adapt follows the observation of (expected) patterns in the so-called 'landscape' or environment, which includes the natural environment. This environment, including evolving greenhouse gas levels, climate and weather patterns, affects and is affected by the performance of the socio-technical infrastructure system.

In order to understand better how to govern our infrastructures, we have to accept that "change in social elements and technological elements cannot be fully separated" (Chappin, 2011: p. 3). Applying this perspective to the interdependencies of infrastructures implies study of the myriad of interconnections: i.e. 1) those between technical elements, 2) those between the social elements and 3) those between the social and technical elements, all within and across infrastructures. This is also needed in order to study *adaptation* of these systems, which suggests making purposeful changes to one or more of the various elements of the interconnected socio-technical infrastructure systems currently in place. In this paper, we use the socio-technical systems perspective as a basis for a literature review on climate change adaptation, focussing on energy and transport infrastructures.

In Section 2 we describe the review approach. The results of the literature review are presented in Section 3. In Section 4, we discuss the findings and draw conclusions.

2. Approach

We conducted a literature search in the scientific database Scopus[2]. We limited the scope of our search to articles pertaining to climate change or global warming. Furthermore, because we are mainly interested in interconnected infrastructures we searched for a single combination of two specific infrastructures, i.e. energy and transport infrastructures. The results, however, include findings across various infrastructures.

We expected to find a reasonable number of papers when we added *adaptation* as a required search term, but that search lead remarkably to only 4 results (i.e. Jollands et al., 2007; Younger et al., 2008; Prowse et al., 2009; Hunt et al., 2011). This does not necessarily imply, and our results confirm, that this is all the literature on adaptation of energy and transport infrastructures. In order to do a meaningful analysis, we broadened the analysis to the 258 papers that were obtained by also allowing for the term *impact.*

In order to focus our results, we narrowed the selection down by an analysis of the relevance of the papers on the basis of their title. Papers are excluded if the title (or the abstract) strongly indicates a focus on individual technical elements. We ended up with 54 papers for which the full text of 48 papers could be retrieved.[3]

We analysed the sample of papers from a socio-technical systems perspective on infrastructures (see Fig. 1). We assessed which papers include an analysis of interconnected infrastructures and report on which *systems* are covered and whether the research focus is on the technical, the social and/or the landscape aspect of the systems perspective.

In order to make our analysis more thorough, we characterize the various studies in terms of time frame (long term, >10 years, medium term 1–10 years and short-term <1 year); the core methodology (quantitative or qualitative); whether the analysis is about adaptation (or about mitigation instead); and which climate change aspects are covered.

3. Results

In this section we describe the results with respect to mitigation and adaptation and interconnected infrastructure systems. The complete list of results can be found in Table 5 (see Appendix).

3.1. Mitigation and adaptation

The papers can be categorized into five groups: climate change impact, mitigation measures, conceptualizing adaptation, enabling adaptation, and design or selection of adaptation strategies (See Table 1).

3.1.1. Climate change impact

The largest group of the retrieved papers do not discuss adaptation, but focus instead on the impacts of climate change or extreme weather patterns, a consequence of including *impact* as search term. A considerable part of this literature focuses on

[2] Scopus (www.scopus.com) is an important database of scientific literature covering a wide range of journals. See Falagas et al. (2008) for a comparison to other popular databases.

[3] The final search query in Scopus was ("climate change" OR "global warming") AND infrastructure AND energy AND transport AND (impact OR adaptation). The search was limited to title, keywords and abstract.