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Designing backcasting scenarios for resilient energy futures

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ABSTRACT

The concept of resilience is a crucial part in crafting visions of desirable futures designed to withstand the widest variety of external shocks to the system. Backcasting scenarios are widely used to envision desirable futures with a discontinuous change from the present in mind. However, less effort has been devoted to developing theoretical frameworks and methods for building backcasting scenarios with a particular focus on resilience, although resilience has been explored in related sustainability fields. This paper proposes a method that helps design backcasting scenarios for resilient futures. A characteristic of the method is to delineate "collapse" futures, based upon which resilient futures are described to avoid the various collapsed states. In the process of designing backcasting scenarios, fault tree analysis (FTA) is used to support the generation of various risk factors and countermeasures to improve resilience. In order to test the effectiveness of the proposed method, we provide a case study to describe resilient energy systems for a Japanese community to 2030. Four expert workshops involving researchers from different disciplines were organized to generate diversified ideas on resilient energy systems. The results show that three scenarios of collapsed energy systems were described, in which policy options to be taken toward achieving resilient energy systems were derived.

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1. Introduction

The current market-based society tends to maximize economic efficiency, but this may lead to undermining the resilience of the system with regard to a variety of sub-system shocks (Lietaer et al., 2010). As is often discussed in the context of climate change, it is crucial to consider the concept of resilience in designing systems and infrastructure with the goal of withstanding various external shocks that might occur in the future (United Nations, 2016). The primary focus of this paper is on energy systems as a typical example of real-world complex systems. In Japan, in response to the Fukushima nuclear power plant accident in the aftermath of the Great East Japan Earthquake in 2011, the resilience of energy systems has been discussed with a particular focus on climate change and energy security (Ministry of Economy, Trade and Industry, Japan (METI), 2014).

In order to envision desirable energy futures (e.g., sustainable futures and resilient futures) on both national and community scales, a number of scenarios have been developed (e.g., Ashina et al., 2012; Gößling-Reisemann et al., 2013; International Energy Agency (IEA), 2012; Mander et al., 2008; Pidgeon et al., 2014; Svenfelt et al., 2011; Upham et al., 2016). Scenarios here refer to narrative stories describing futures, drawing upon which effective policies and actions should be discussed (Foresight Horizon Scanning Centre, 2009; Glenn, the Futures Group International, 2003). While most of the existing energy scenarios are aimed at achieving environmental and economic sustainability, the concept of resilience has yet to be incorporated into visions of desirable energy futures. Resilient energy futures must provide and maintain sufficient services to customers in the case where external shocks (e.g., natural disasters, human error, and political instability) bring about the failure of the energy system (Chaudry et al., 2009; Kharrazi et al., 2015).

From a methodological viewpoint, however, relatively little knowledge has been provided to answer the question of how to design scenarios for envisioning resilient futures in a systematic manner. In order to address this question, a backcasting approach is suitable, since resilience

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is normative and appears to entail drastic and discontinuous changes from the present (Dreborg, 1996; Quist, 2007; Robèrt et al., 2002). The idea of backcasting is to delineate future visions and draw pathways backward from those visions to the present (Dreborg, 1996; Robinson, 1990). If desirable futures are sought, backcasting scenarios facilitate the exploration of technology and policy options that should be taken to reach those futures (Kishita et al., 2016). Although a number of scholars have developed methods and tools for building backcasting scenarios (see Section 2.3 for details), scenario practices are, in general, still undertheorized (Upham et al., 2016; Wilkinson, 2009). In particular, this is the case when designing backcasting scenarios for resilient futures. Therefore, the research question to be tackled in this paper is how to systematically design backcasting scenarios for resilient futures in a workshop environment, often engaging both researchers and stakeholders. The purpose of collaboration between multiple actors (e.g., researchers from different disciplines, policy-makers, and citizens) is to foster mutual learning and co-production of knowledge and values toward crafting shared future visions (Lang et al., 2012; Swart et al., 2004).

This paper aims at developing a method to design backcasting scenarios for envisioning resilient futures, which involve visions and pathways of resilient energy systems. It should be noted that, although the primary focus of this paper is on energy systems, we aim to propose a generalized method that is applicable to any kind of system. In general, scenario design is composed of a series of activities, such as idea generation, idea integration, data gathering, simulations, and appraisal and, moreover, these activities are iterative in order to complete the scenarios (Börjeson et al., 2006; Kishita et al., 2016). For systematic thinking on resilient futures, we define the scenario design process as consisting of two phases; i.e., the first phase is to describe collapse futures due to external shocks and the second phase is to describe resilient futures that avoid or mitigate the collapse states assumed in the first phase. In order to help generate a wide array of ideas for describing plural scenarios, we use fault tree analysis (FTA) (Stamatelatos et al., 2002), thereby enabling the explicit representation of both external shocks to the system of concern and countermeasures to enhance resilience. By drawing on the proposed method, we present the case study of a Japanese community, Suita City, Osaka, Japan with the timeline of 2030. A total of four workshops were organized, where experts from different disciplines were invited, in order to gather as much knowledge and information as possible to put together scenarios.

The rest of this paper is organized as follows. Section 2 discusses resilience and the design of resilient energy systems and gives a review of backcasting scenario methods. Section 3 develops a method for designing backcasting scenarios for resilient futures. Section 4 shows a case study of resilient energy systems of a Japanese community. Based on the case study results, Section 5 discusses the effectiveness of the proposed method and policy implications for resilient energy systems. Finally, Section 6 concludes the paper.

2. Backcasting approach to designing resilient energy futures

2.1. Requisites for designing resilient energy systems

The concept of resilience originates from ecology for understanding the dynamics of ecological systems (Holling, 1973). Resilience is defined as the capacity of a system to absorb external shocks and reorganize while undergoing change in order to retain essentially the same function (Folke, 2006; Liu et al., 2007; Walker et al., 2004). Differentiated from sustainability, the emphasis of resilience is on how the system responds to disturbance or non-linear dynamics (Folke, 2006).

Since the 1982 book "Brittle Power" by Lovins and Lovins (1982), discussions on resilience have been deployed to the design of energy systems in relevant literature (e.g., Afgan, 2010; Chaudry et al., 2009; Hirose, 2013; O'Brien and Hope, 2010). Although there are no universal definitions of the term energy system, an energy system in this paper refers to a system that comprises energy supply infrastructures, human activities, and ecological systems (see Fig. 1). Given the definition of resilience, the focus is on the interaction between the energy system and external factors, such as technological developments, lifestyles, energy policies, economic situations, and natural disasters. A resilient energy system has the capacity to speedily recover from external shocks and to provide alternative means of maintaining an acceptable level of services to consumers in the event of external disturbances (Afgan and Veziroglu, 2012; Chaudry et al., 2009). The essential characteristic is not the continuation of energy supply for its own sake, but maintaining quality and quantity of services for human activities.

Lovins and Lovins (1982) advocated the importance of ensuring the resilience of energy supply because energy supply infrastructures have vulnerability to large-scale failures caused by unpredictable disruptions, such as natural disaster, technical failure, and malice. In the end, Lovins and Lovins (1982) suggested diverse, dispersed, inter-compatible, and redundant energy sources. However, visions of resilient energy systems are still blurred and have not yet been investigated by looking at all the elements in Fig. 1. Difficulties in designing resilient energy systems stem from the following two problems. One is that visions of resilient energy systems vary critically between stakeholders, targeted regions, and time frame of interest — the issue of competing temporalities is discussed for the case of resilience in cities by Moffatt (2014). The other is that the interaction between the energy system and various external factors is complex and not necessarily explicitly represented, thereby making it difficult to understand such interaction among stakeholders involved in a systematic manner. Therefore, these problems should be addressed to derive profound knowledge toward resilient energy futures by taking into account, at least, environmental-friendliness, energy security, and economic performance.

2.2. Lessons from beyond energy systems

In the field of water, backcasting (discussed in Section 2.3) has been effectively coupled with adaptive management for sustainable groundwater use (Gleeson et al., 2012) and climate adaptation in a coastal region (van der Voorn et al., 2012). Van der Voorn et al. (2012) proposed a methodology for linking adaptive management to backcasting in a way that integrates actions across local, provincial, and nation levels. The structured approach to identifying links between specific actions at specific levels has similarities to the Fault Tree Analysis used later in this paper. The difference is that, whereas van der Voorn et al. (2012) proposed linked actions to achieve a vision, our current paper explores the cause–effect chains in a stepwise manner to delineate futures that might be resilient or fragile (collapse futures).

Although adaptive management and resilience are not synonymous, the process of adaptive management has been associated with building resilience (Olsson et al., 2004) and underscores the importance of explicitly connecting backcasting scenarios and resilient futures. There are many discourses in the context of socio-ecological resilience (Moore et al., 2014; Smith and Stirling, 2010). In particular, a number of studies addressed adaptive management focused on climate change (Bollinger et al., 2014; Park et al., 2012; Reed et al., 2013).

2.3. Related work on backcasting scenarios

In the context of energy policy design, a number of backcasting scenarios have been studied (e.g., Ashina et al., 2012; Giurco et al., 2011; Robinson, 1982; Svenfelt et al., 2011). Backcasting is often used to consider a drastic change from the present, partly because desirable energy futures must satisfy long-term goals of CO_2 reduction (e.g., 25% reduction to 2030) and the lifespan of energy infrastructures is relatively longer (e.g., 40 to 50 years). Many researchers have proposed methods for developing backcasting scenarios (e.g., Banister et al., 2000; Carlsson-Kanyama et al., 2008; Mander et al., 2008; Mizuno et al., 2012; Quist and Vergragt, 2006; Robinson, 1990; Svenfelt et al., 2011). One of the most famous methods is Robinson's method (Robinson,

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