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Strategies against shocks in power systems – An analysis for the case of Europe

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ABSTRACT

Electricity systems are constantly exposed to geopolitical, techno-economic and natural uncertainties that may endanger security of supply. Therefore, it is crucial that policy makers concerned about it consider a variety of possible futures — and not only the one that is perceived as the most likely. In particular, they should account for the possibility of sudden shocks in their decisions with the goal of making the system more "robust". However, long-term power system models which are an important pillar of policy decision making are typically designed to determine the cost-minimal power system for a specific expected future; such a system is not necessarily the most robust one. By combining the classic investment optimization approach with the tools of Robust Decision Making we analyze the viability of different strategies that may potentially increase the robustness of a power system. For the case of the European power system we pursue a dedicated analysis with the European power system model LIMES-EU. Based on a total of more than 40,000 model runs, we find that strategies promoting the ability of countries to always produce at least 95% of their electricity demand domestically significantly help to reduce the loss of load in case of shocks. Such a strategy is not cost-optimal for the expected future without shocks; but the additional costs (about 0.1% of total system costs) are low compared to the benefits of significantly increasing the power system's robustness.

1. Introduction

In order to decide on new energy policies, decision makers frequently rely on scientific advice (European Commission, 2014a; IPCC, 2014). An important pillar of this policy advice consists of long-term energy scenarios based on numerical optimization models that inform about the cost-efficient future development of today's power systems (Chiodi et al., 2015). The calculation of a cost-optimal investment pathway is based on an expected development of external parameters such as fuel prices and investment costs. Though their future development is uncertain, possible deviations from the expected future are often neglected, for example in the European Commission's Impact Assessments (European Commission, 2011, 2014a). But with the electricity system being constantly exposed to geopolitical, techno-economic and natural uncertainties, it is crucial to design the system in such a way that it performs well under a variety of possible futures — not only the one that is perceived as the most likely. In this context, sudden short-term shocks that do not allow for an adaptation of the capacity stock are particularly challenging. Policy making based on studies that disregard the possibility of shocks may lead to serious vulnerabilities of the electricity system and – given the various uncertainties about the future – may actually not be as cost-efficient as the studies suggest.

So what are viable strategies, beyond pure cost-minimization, for ensuring that an envisioned power system also performs well under shocks? This question addresses the issue of energy security, an aspect typically not considered in long-term optimization models but prominently covered both in policy debates and scientific literature. Energy security is a multi-faceted issue with various different definitions and indicators depending on the respective context.[1] In the Global Energy Assessment energy security is defined as the "uninterrupted provision of vital energy services" (GEA, 2012). In line with this definition Cherp and Jewell (2011) discern three different perspectives of energy security: robustness, resilience and sovereignty. The concept of robustness stems from a technological point of view on the danger of technical failures and natural disasters; resilience refers to broader societal attributes such as the ability to build and increase the capacity for

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Abbreviations: CCS, Carbon Capture and Storage; CSP, Concentrated Solar Power; NTC, Net Transfer Capacity; PV, Photovoltaic; RDM, Robust Decision Making; VOLL, Value of Lost Load.

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[1] See Månsson et al. (2014) and Winzer (2012) for reviews of different energy security indicators.

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reorganization and adaptation (Anderies et al., 2013; Walker et al., 2004); sovereignty covers political concerns about foreign dependency. In this paper we focus on robustness, which can more generally be defined as a reduced sensitivity of output to shocks (Anderies et al., 2013). Reaching robustness implies diverging from the strategy that would be optimal in the case of absolute certainty, and instead engaging in a strategy that yields near-optimal outcomes for a large variety of possible futures (Rosenhead et al., 1972).

In order to determine which strategies are viable to increase the robustness of power systems against shocks, we combine the classic optimization approach of power system planning with the tools of Robust Decision Making (RDM) (Lempert et al., 2006). According to RDM a system is considered to be robust when it performs well for a large variety of possible futures. We consequently analyze how a power system that is determined by a typical cost-optimization model performs under shocks and compare its performance with systems based on different design strategies other than pure cost-minimization, namely increased fuel diversity, self-sufficiency and redundancy, as well as excess transmission and storage expansion. Focusing on the case of Europe, our analysis is based on more than 40,000 model runs with the long-term power system model LIMES-EU. We thereby focus on short-term but large-scale shocks that could possibly affect the entire European power system and cover shocks on both thermal and RES-based[2] power generation, on the transmission system, as well as on the fuel supply. Though we focus on Europe, the tools we use are applicable to other regions of the world.

In the following section, we provide an overview of existing tools for decision making under uncertainty and elaborate on our approach in more detail. We also describe the strategies and shocks considered in our analysis of the European case. The robustness of the power systems resulting from the different strategies is assessed in Section 3 and our conclusion is presented in Section 4. In the appendices, we provide a general overview of the applied optimization model LIMES-EU (Appendix A), state the model equations for implementing the strategies (Appendix B), give a detailed overview about the modeled shocks (Appendix C) and provide an analysis how the performance of the strategies depends on the assumed value of lost load (Appendix D).

2. Method

Our analysis focuses on the possibility of low-frequency, high-impact events. The rarity of these events complicates the task of ensuring energy security as the majority of the established risk management tools are not applicable (Nepal and Jamasb, 2013). The following subsection presents existing tools for decision making under uncertainty and motivates the application of Robust Decision Making in our context. In Section 2.2 we describe our approach in more detail. Section 2.3 presents the strategies considered in our analysis of the European power system and Section 2.4 provides an overview of the shocks that we analyze.

2.1. Existing tools for decision making under uncertainty

There is a large variety of tools designed to account for risks and uncertainties about the future in energy sector investment decisions, system planning and policy making (cf. Andrews, 1995; Hickey et al., 2010; Zeng et al., 2011). The applicability of individual approaches depends on the level of knowledge, i.e. whether there is risk, uncertainty or ignorance. In the case of risk, both the possibility and the probability of future states are known; under uncertainty – sometimes also termed “deep uncertainty” – only the possibility is known; and ignorance exists when even the possibility of events is unknown (cf. Stirling, 1994).

Stochastic tools are widespread in order to account for political and fuel price risks in individual investment decisions.[3] For overall system planning (the subject of our analysis), the use of deterministic approaches is more common but has been repeatedly criticized and the importance of a variety of scenarios has been stressed (McDowall et al., 2014; McJeon et al., 2011; Wachsmuth, 2014). Recent literature that discusses risk and uncertainty in light of policy making includes Pye et al. (2015) and Watson et al. (2015). Most influential is the work by Awerbuch and his colleagues (e.g. Awerbuch and Berger, 2003; Awerbuch and Yang, 2007; Awerbuch, 2006), who apply portfolio theory for policy planning. The use of portfolio theory in the electricity sector is highly contested, however, because of the existing technological restrictions and high transaction costs compared to assets that are purely financial (cf. Hickey et al., 2010). The long lead times of power sector investments and the abrupt character of shocks also reduce the suitability of other approaches such as sequential decision making which involves the constant adjustment of decisions based on learning by the decision makers: Once a shock happens, the system should be prepared as there is no time left for adaptation.

In addition, all of the probability based stochastic approaches have an important caveat when it comes to the consideration of shocks: As shocks are low-frequency phenomena it would be rather difficult to assign meaningful probabilities (Nepal and Jamasb, 2013). Furthermore, they would only have a small impact “on the average”, but they have a high impact if they occur (Gorenstin et al., 1993). It is therefore important to analyze each future scenario separately (Meristö, 1989) and assume uncertainty rather than risk. Beyond that, Stirling (1994) points out that we are not able to anticipate every possible contingency and outcome affecting the electricity sector, and it is therefore ignorance that dominates real electricity investment decisions. However, the assumption of ignorance would preclude any numerical analysis of possible futures which could provide meaningful insights. We therefore reduce the strict necessity of knowing about *all* possible future states and assume that the viability of a strategy under uncertainty is a good indicator for the strategy's performance in the real world that offers shocks not deemed possible beforehand.

Robustness is a valuable concept for decisions under uncertainty as it does not require the assumption of probabilities (Rosenhead et al., 1972). The aim is not to find the optimal decision for an expected future, but rather to find a robust strategy that performs reasonably well across many scenarios. In this way, it also differs from the often applied sensitivity analysis which determines cost-minimal future power systems for varying input assumptions but which does not give any guidance on how a specific system performs if external parameters change.

The concept of robust decisions has been covered in earlier electricity sector literature (Burke et al., 1988; Gorenstin et al., 1993; Linares, 2002) and gained further attention in the context of uncertain climate change (Hallegatte, 2009; Heal and Millner, 2014; Kunreuther et al., 2013). Heal and Millner (2014) highlight two general tools for making robust decisions: The “maxmin”-rule and the “minmax regret”-rule. The first one results in picking the strategy whose worst possible outcome (“min”) is the least bad (“max”). Its use necessarily results in conservative decisions, as it is based on the anticipation that the worst might well happen (Rosenhead et al., 1972). Instead of using absolute values (such as total costs) of the different considered futures as an indicator for the decision making process, the “minmax regret”-rule is based on the regrets of the strategies, i.e. the additional costs of a strategy compared to the best-performing strategy for a specific future (Savage, 1954). This rule is less conservative as it sets the performance of a strategy under a specific future into perspective with the performance of other strategies and thus gives weight to missed opportunities

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[2] Renewable energy sources.

[3] Such risk management tools include two-stage models (Bistline and Weyant, 2013; Hu and Hobbs, 2010; Usher and Strachan, 2012; van der Weijde and Hobbs, 2012), real-options analysis (Agusdinata, 2008; Fuss et al., 2012; Kettunen et al., 2011; Yang et al., 2008) and portfolio theory (Fuss et al., 2012; Vithayasrichareon et al., 2009).