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Identifying the main uncertainty drivers of energy security in a low-carbon world: The case of Europe

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ABSTRACT

This analysis contributes to recent efforts to better understand the evolution of energy security in a low-carbon world. Our objective was to assess how energy security may change over the course of the century, and to what extent these changes depend on the uncertainty of the factors that drive the evolution of energy systems, including future technologies, improved energy efficiency, fossil fuel resources and markets, and economic growth. To this end, we focused on Europe and on a set of energy security indicators based on three perspectives: sovereignty, robustness and resilience. A database of scenarios allowed us to account for the large uncertainties surrounding the determinants of future energy systems. We then analyzed the way energy security indicators evolve over time, and how their trajectories vary across scenarios. We identified the indicators that vary the most between scenarios, i.e., the indicators whose future evolution is the most uncertain. For these indicators, we performed an analysis of variance to estimate the contribution of each driver to the uncertainty of the indicators. The paper shows that the European double target of significantly decreasing CO_2 emissions and increasing the security of the supply of energy may be difficult to reach. Nevertheless, some levers could facilitate the transition to a low-carbon society while improving energy security, or by limiting its degradation. The results emphasize not only the importance of policies in favor of low or zero carbon technologies in power generation but also the differences in their contributions to the complete uncertainty of the indicators. Policies promoting energy efficiency also play a role but only in the resilience of TPES. These policies are thus important levers for mitigating the negative impacts of climate policies on energy security.

1. Introduction

In 2008, the Lisbon Treaty launched new climate and energy policies in the European Union with the aim of significantly decreasing CO_2 emissions, while increasing the security of the supply of energy in the Union, at reasonable costs in order to maintain competitiveness. Since then, climate policy and energy security policy have been closely linked in the EU, as detailed in the European Energy Roadmap 2050 (European Commission, 2011).

Today, it is clear that the two issues are intertwined. They share a common root cause, the demand for energy, but the solutions for improving energy security and reducing greenhouse gases (GHG) are not necessarily the same and may involve some contradictions. For instance, the deployment of renewable energies led to greater dependency on natural gas for peak load and back-up, especially on Russian gas. The recent geopolitical crises between Russia and Ukraine revealed the vulnerability of European energy on this respect.

Energy security does not only refer to geopolitical risks or dependency on primary fuels but is multi-faceted. Several recent contributions proposed an analytical framework to evaluate the concept by incorporating different dimensions or perspectives of energy security (APERC, 2007; Cherp et al., 2012; Winzer, 2012). In this paper, we use the framework developed by the Global Energy Assessment (Cherp et al., 2012). The starting point of this approach is to work with a definition of energy security that incorporates the likely radical transformations of energy systems in the long term. Energy security is defined as the low vulnerability of vital energy systems. Even if the security of oil supplies remains important, contemporary energy security policies must also address other energy systems. This point is crucial in the current context in which many stakeholders call for speeding up the energy transition. Vital energy systems thus refer to different energy carriers (electricity, hydrogen, liquid, and synthetic fuels), or to the total energy supply.

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Several papers recently used this framework to explore the consequences of climate policies for energy security from a long-term perspective (Cherp et al., 2013; Jewell et al., 2013, 2014; Guivarch et al., 2015). These analyses show that the implementation of ambitious climate policies affects vital energy systems differently. They also emphasize the importance of the time dimension. For instance, Guivarch et al. (2015) showed that the impact of climate policies is mixed in the short term and globally good in the medium term, whereas in the long term, there is a risk of degradation of energy security, especially related to the electricity system.

The objective of this paper is thus to highlight levers that could improve energy security, or limit its degradation, if ambitious climate policies are implemented. This is a companion paper to Guivarch et al. (2015). In the present paper, we take a close series of energy security indicators and analyze their dynamics over the course of the present century in a low-carbon world. We aim to identify the main drivers of these dynamics among key low and zero carbon technologies, the evolution of energy efficiency, fossil fuel resources, and markets and economic growth. The positive or negative impacts of ambitious climate policies on energy security may depend on the evolution of some drivers of the uncertainty of future energy systems.[1] For instance, the availability and affordability of carbon capture and storage (CCS) technologies would make the use of coal possible in a low-carbon world, while improving energy security for coal-producing countries. Without being sure of succeeding in developing low-carbon technologies, public policies will play a crucial role in their future availability and cost. This is also true of energy efficiency and for economic growth.

The paper describes an original methodology to investigate these issues. Using the energy-economy-environment model, Imaclim-R, we created a database of long-term scenarios in which different determinants of future energy systems, on both the supply and demand side, are considered. Each scenario describes a possible future in terms of economic growth, fossil fuel availability, energy efficiency and the cost and the availability of different low-carbon technologies. For each possible future, we imposed a global CO_2 emission trajectory leading to the stabilization of the concentration of CO_2 in the atmosphere at 550 ppm CO_2-eq. A set of indicators that capture the multi-faceted aspect of the energy security concept were assessed in each scenario, enabling us to analyze the evolution of the indicators in all possible future worlds, and their dispersion over the course of the century. By focusing on the indicators with the widest dispersion, and by applying a multi-factor analysis of variance (ANOVA), we identified the main explanatory factors. The analysis was applied to Europe and identified the most important drivers of energy security indicators in a low-carbon world. The method identified some levers that could be used to improve energy security if ambitious climate policies are implemented.

Section 2 is a brief review of the literature exploring the impacts of climate policies on long-term energy security. In Section 3, we explain our contribution and detail the method we used. We present the series of indicators used for the analysis and the energy-economy-environment model, Imaclim-R, used for the simulations. We explain how we built our database of scenarios and the tools we used to analyze the results of the simulations. In Section 4, we present the results: first, the dynamics of the indicators in all the scenarios for the whole century and the assessment of their dispersion; second, the contributions of the different drivers to this dispersion with an analysis of variance. In Section 5 we discuss our results and conclude.

2. Climate policy and energy security: recent advances

Although the issue of energy security is high on the policy agenda and pervasive in the discourse, it is seldom accompanied by a clear definition of the term. As explained in Winzer (2012), the concept of energy security is "blurred," "elusive," or "slippery." This is partly due to its multi-faceted nature. The assessment of energy security thus implies developing an analytical framework to identify the different dimensions of the concept. Several recent contributions proposed different frameworks (APERC, 2007; Cherp et al., 2012; Winzer, 2012).

In this paper, we use the framework developed by the Global Energy Assessment (GEA) in a series of recent papers that specifically examined the effect of climate policies on energy security worldwide and in different regions (Cherp et al., 2013; Jewell et al., 2013, 2014; Guivarch et al., 2015). The aim of the analytical framework is to assess the "new" energy security dealing with tensions in the supply of natural gas in Europe, the increasing demand for energy in Asia, and the transition toward low-carbon societies that began in the 2000s. The analytical framework is based on a definition of energy security that is sufficiently flexible to include the likely future transformation of energy systems in the long term. Energy security refers to the low vulnerability of vital energy systems. These systems comprise not only primary fossil fuels but also different energy carriers (electricity, hydrogen, liquid and synthetic fuels), which will play an increasing role in a low-carbon world. The GEA approach aims to identify the vulnerabilities of these systems, from three perspectives: sovereignty, robustness, and resilience. The sovereignty perspective refers to threats posed by external actors and the exposure of a region/country to such threats (Cherp and Jewell, 2011). It is related to past events such as energy embargoes or price manipulations and to foreign control of energy resources. From this perspective, energy security is generally evaluated through the reliance of a region on imported energy sources or, at a more global level, through international trade in energy. The robustness perspective deals with natural and technological to energy systems. Historically, it is related to major accidents, electricity blackouts and resource scarcity. The resilience perspective focuses on the ability of the energy systems to resist diverse disruptions caused by social and economic factors that are difficult to predict and control (political instability, price volatility, etc). From a resilience perspective, the future is unpredictable. This future uncertainty can be related to markets, technologies, and societies. From this perspective, energy security can be apprehended in terms of the range of energy options. The risks apprehended by the framework we use refer not only to traditional ones, like geopolitical risks, but also to new challenges, for instance those posed by the development of electricity systems.

Cherp et al. (2013) envisaged different levels of ambition in reducing world GHG emissions and introduced uncertainties by considering different levels of GDP growth and of the availability of fossil resources. These different scenarios were simulated in two different integrated assessment models. These authors found that climate mitigation policies will increase the resilience of energy systems as reflected in their diversity and will improve sovereignty around the middle of the century when low-carbon and fossil energy source co-exist. Climate policies will enable deep penetration of solar energy in the electric sector and of bio-fuels in the liquid fuel sectors, which will reduce diversity by the end of the century.

Jewell et al. (2013) examined the future evolution of energy security in major economies: China, India, the European Union, and the United States of America. Their analysis is based on results of six integrated assessment models. In each model, two temperature limitation targets are considered: an increase of 3 °C and an increase of 2 °C. Their results conclude that different regions share common trends. For instance, climate policies reduce energy imports and increase the diversity of energy options. However, the major economies would also be exposed to specific changes. For instance, in the EU, climate policies would decrease dependence on imports, while increasing the diversity of energy options in the transport sector. With climate policies, China would not completely exhaust its oil and gas reserves, thereby allowing

[1] The term uncertainty is used here like Saltelli (2002), who defined it as "Sensitivity analysis is the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input."