

Evolution of the Global Energy Network: Shocks and Resilience

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Overview

Global sustainable development critically depends on a fundamental transformation of current energy-intensive systems along both socio-economic and environmental dimensions. These two dimensions of energy transitions are closely related as energy is required for economic growth and development, and poverty often coincides with limited access to energy and a high vulnerability to the effects of climate change. The rising global demand for energy has increased the energy flows between countries, leading to an increasing connectedness of the global energy system. In addition, increasing price volatility, geopolitical instability and the shift to renewables lead to considerable changes in the global energy system. In a globally connected energy system changes or disruption in national energy systems may create instabilities and energy security concerns on the global scale. However, energy security issues and other energy system indicators mostly studied at national level. The aim of this paper is to present an integrated network model that allows us to study energy security issues in a global level. More specifically, we analyze how countries recover from energy shocks, that is, what the characteristics of resilient energy systems are.

Despite being a key priority of most energy policies, there is no single definition of energy security. A review by Ang et al. (2015)¹ of 104 research and policy papers found most definitions highly context dependent and specific to analyzing the energy security of a country or region. Most energy security indicators focus on the four A's: Availability, Affordability, Accessibility, and Acceptability (APEREC). Availability of energy supplies has thereby long been the center of energy security discussion, triggered by the very first energy security discussion in the 1970s²⁻⁴. Energy security indicators aim to capture these dimensions of energy security but are also used to quantify the (potential) impact of energy crises on the economy⁵ and/or the environment⁶. However, as most energy crises are exogenous to the energy system and may destroy vital parts of the energy system, these energy security indicators are of little value when predicting (resilience to) energy crises. In this paper we present a network-based analysis of the resilience of energy systems in relation to the existing security indicators.

In ecology, resilience refers to the state or quality of a system's responsive capacity⁷ to perturbations or disturbances in terms of damage resistance or rapid recovery. High resilience is generally characterized by diversity and redundancy in a system's structure. Some – such as diversity of energy sources - but not all (such as the pace and the extent of recovery) of these aspects are taken into account in traditional energy security indicators⁸.

Methods

The study draws on a network graph representation of the global energy system, where energy flows i.e., energy commodity trade between countries) are the links in the network. The global energy network is constructed using data of global energy flows between 1990 and 2013. Through network analysis, we study how various perturbations to the system (such as natural/political energy events shift to renewables) propagate and lead to changes throughout the global energy system or be absorbed and be neutralized. We identify 14 such perturbations each of which are defined as 'energy crises' (such as the 2011 Fukushima disaster and the 2006 and 2009 Russia – EU Gas disputes that particularly affected Bulgaria and Poland) in the Platts energy market dataset⁹.

We analyze the time-series of various energy security indicators, both prior and after the system is getting hit by an external shock. For example, a resilient system should be able to maintain energy prices and availability following the shock whereas a less resilient system will undergo (long-term) price increases and settle to a fairly new equilibrium. Accordingly, we estimate lag in the energy prices that best indicates the recovery time after each shock.

Using the network representation of the global system, we can calculate further (pre and post-crisis) indicators of resilience, such as the diversity of energy sources, and link these to the post-crisis energy prices. We also analyze the propagation of the impact over the system (geographically and/or over the network of energy flows) on the basis of spatial autocorrelation in the motion of our various indicators of resilience.

Results

In terms of network structure, our preliminary findings indicate a shift from an oil-dominated market to diverse energy carriers. We also observe the emerging significance of Non-OPEC countries in the global energy market in addition to rapid increasing of natural gas and electricity trade within countries compared to the early 1990's. The study also shows increasing connectivity between countries as measured by the average degree distribution which grows from 15.3 to 19.6 and the diversity of commodities in the network showing the global energy market is becoming less reliant on oil as evidenced by a 11% decrease of its share in global energy market trade flows. The shift in the energy market is also shown by the increasing share of gas and coal in the energy mix at the expense of oil. This situation creates pathways for the development of non-oil exporting organizations such as increasing importance of natural gas producers in the global energy market and the creation of the Gas Exporting Countries Forum (GECF). Moreover, Germany increasingly appears to be a significant energy player in the region due to its growing renewable energy production and the increasing connectivity of the European electricity market.

With respect to the ability to recover from crises, our initial panel data test results indicate that energy systems differ before and after a crisis. Our panel data analysis shows that three energy security indicators are particularly important for assessing resilience; the median household energy prices, the Shannon-wiener indicator for the energy mix as well as import sources, and the energy demand per capita. We observed that countries affected by an energy crisis show an increasing import source diversity post-crisis. In addition, energy prices went up following the increasing diversity. We observe that the Japanese median electricity prices took almost three years to show relatively stationary behavior after the Fukushima events while in Bulgaria and Poland gas prices became stationary again in less than a year after the Russian gas dispute in 2006 and 2009. Furthermore, we observed increasing energy import sources diversity in the EU member countries as respond after the 2009 Russian gas dispute even for countries with limited exposure. This raises an interesting the question of whether energy systems benefit from (intermittent) perturbations in a way described by Taleb (2012) as *anti-fragile*¹⁰.

Conclusions

The emergence of GECF and the German significance in the energy market indicate that the energy system is evolving from an oil-dominated system to a more diverse system. Additionally, crisis also plays a large role in the development of the energy network because countries tend to increase the diversity of their import sources after crisis creating new connections in the global energy network.

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