Title of the research project:
Impact of extreme climate events on power grids – Interacting complex networks

Keywords (up to five)
Extreme events, complex networks, climate extremes, renewable energy, power grids

Supervisors (at least two from two different areas):

Supervisor 1: Juergen Kurths (kurths@pik-potsdam.de)
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Expertise: Complex Systems, Climate and Infrastructure

Supervisor 2: Mario di Bernardo (Mario.dibernardo@unina.it)
Expertise: Control theory, Complex Systems, Dynamical systems

Project description (max 5000 characters)

The intensity of extreme climate events has been increased during the very last decades significantly as a crucial part of climate change. This has caused strong impacts on various aspects of our life. One important field are damages of infrastructure. In this project, the influence of such climate events on power grids will be studied; in particular, the break of lines due to strong storms but also failures of underground lines in case of floods. Both systems involved (climate and power grids) will be described as complex networks which are interacting. On the one hand, climate-induced failures of power grids will be modeled, and the most sensitive nodes (troublemakers) will be identified. The findings will be compared with real data and mitigation approaches should be inferred. On the other hand, early warning signals of extreme climate events should be identified and applied to real data for forecasting events with strong impact on the power grid.

In the first step climate networks have to be reconstructed from observational data which requires to further develop existing tools by blending dynamical systems theory and machine learning for network reconstruction applications. Emergent dynamics of climate systems comprise multiple spatial and temporal scales, resulting from a large number of potentially diverse elements coupled via heterogeneous interaction patterns. The dynamics of high-dimensional nonlinear networks is therefore extremely challenging, in particular to address transient dynamics, as well as relevant global dynamics because relevant collective phenomena such as hub synchronization cannot be obtained from local information only. The challenge is that globally the system has complicated heterogeneous dynamical behaviour. While this poses a major challenge
to development of reduced models of macroscopic dynamics based on coarse-graining of structural networks describing microscopic activity, a deeper insight into the relevant substructures of climate systems and underlying connectivity can still be gained by using real-world data sets to construct functional networks. Functional networks reveal hidden structures within the multivariate time series data, enabling us to understand the functional organization of complex systems, segregating them into smaller substructures with specific operational roles. Functional networks can be used to characterize the long-term dynamics by establishing statistical relationships from available datasets, or can describe transient dynamics, such as switching in vicinity of tipping points. Furthermore, machine learning approaches have to advance to develop techniques which use spatiotemporal data to learn the network structure and to predict systems’ behaviour, and to develop of statistical methods to distinguish temporal correlations in climate data to formulate a risk assessment for extreme events.

In the second step, power grids with renewable component have to be designed based on the Kuramoto model of second order with inertia. Additionally, the renewal components lead to algebraic-differential equations which are difficult to solve. Here special techniques of ambient forcing will be applied to identify appropriate initial values. This will be then the basis for a stability analysis of the power grid and to identify critical nodes and connections. Here the concept of basin stability or other probabilistic approaches will be applied and further developed.

The third step is to combine both networks and construct an interacting network. Here the formulation of main interactions between both is an ambitious problem. This combined network will be used to study the influence of selected climate extremes to modern power grids. Based on such real climate events, scenarios of damages will be calculated and the influence of the network architecture on the spreading of damages will be analyzed. Finally, mitigation procedures should be inferred.

Relevance to the MERC PhD Program (max 2000 characters)

**Societal Relevance:**
The increasing intensity of extreme climate events has a huge impact on humans. One important aspect is that we sensitively depend on a functioning infrastructure and in particular on stable working power grids. This study focuses on crucial aspects of damages of power grids due to climate extremes and how to mitigate them.

**Relevance for the MERC PhD program:**
This interdisciplinary project requires a combination of modern network science with climate and infrastructure. The student will apply basic concepts from these fields and will also develop new approaches and techniques to treat the corresponding ambitious problems in an original way.
Key references


Joint supervision arrangements

There will be regular joint supervision meetings.

Location and length of the study period abroad (min 12 months)

This project foresees the need of conducting at least 12 months of activity abroad. It will be in Germany at PIK (Potsdam) under the supervision of Juergen Kurths.
Any other useful information