A Power Tour of Data Science

Final project presentation

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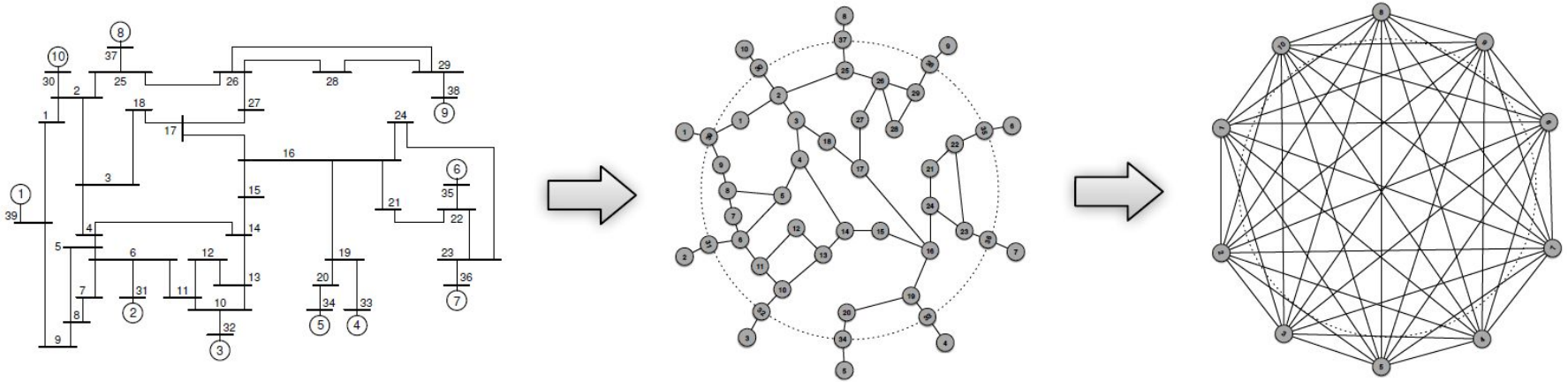
Motivation

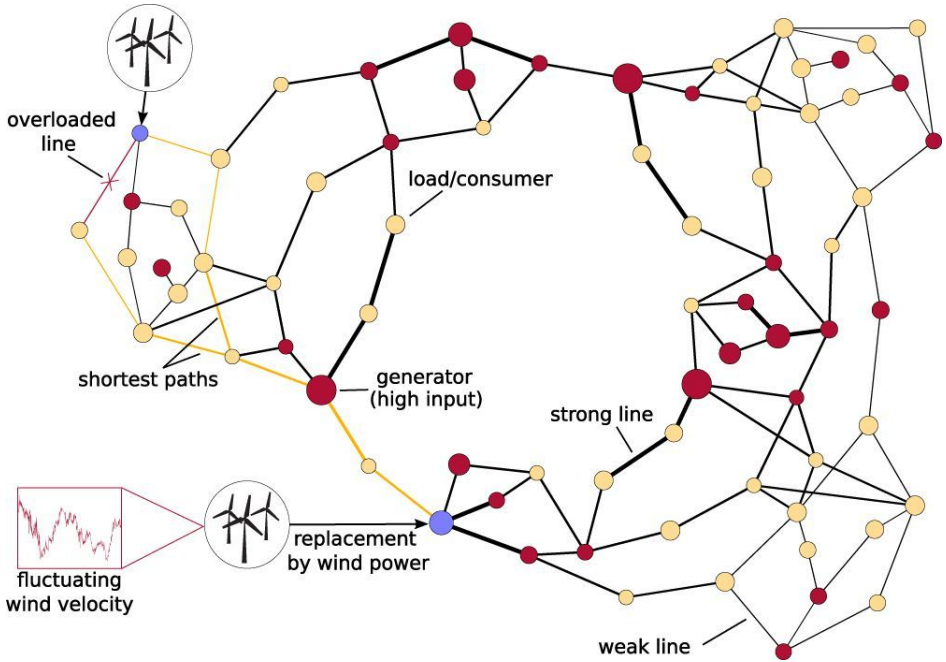
- 1847: Gustav Kirchoff used graph theory to describe electrical networks
- Power grids consist of nodes (generally substations) and edges (transmission lines)
- Can the course topics lead to useful conclusions/tools about power grids?



F. Dörfler, J. Simpson-Porco, F. Bullo. Electrical Networks and Algebraic Graph Theory: Models, Properties, and Applications.

Motivation

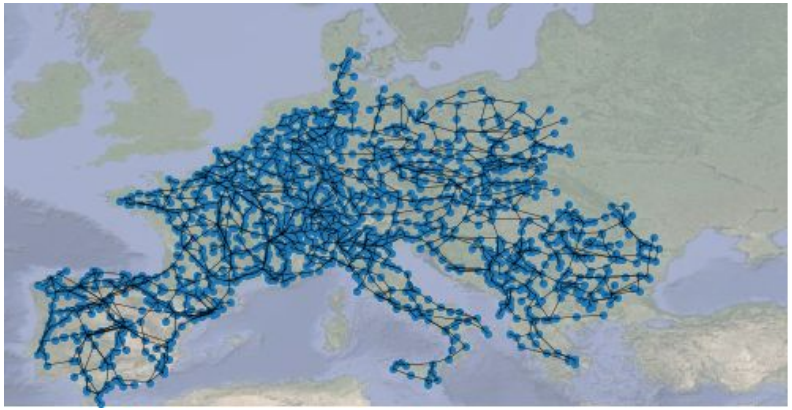
- Power systems are **networks**
- Increase of renewable energies poses challenges:
  - Modelling
  - Analysis
  - Generation predictions: cheaper to plan
- Objectives:
  - Use tools studied in the course to analyse power grids
  - Develop useful product for the integration of non-dispatchable renewable energies

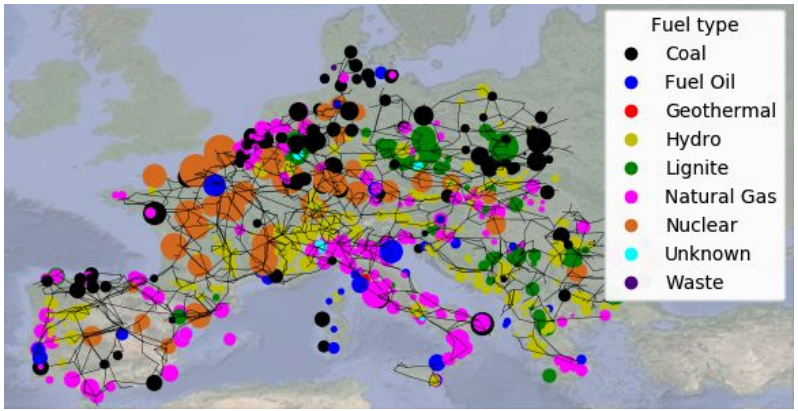


C. Schiel, P. Lind, P. Maass. Resilience of electricity grids against transmission line overloads under wind power injection at different nodes.

The Data-set: RE-Europe[1]

- 1494 Nodes
- 2156 Transmission lines (high voltage)
- 969 generators with location, type of fuel, and operation costs
- Time series (01.01.2012 - 31.12.2014)
  - Hourly demand per node
  - Hourly wind & solar production per node
  - Wind and solar forecast per node
- Geographic Coordinates of the nodes



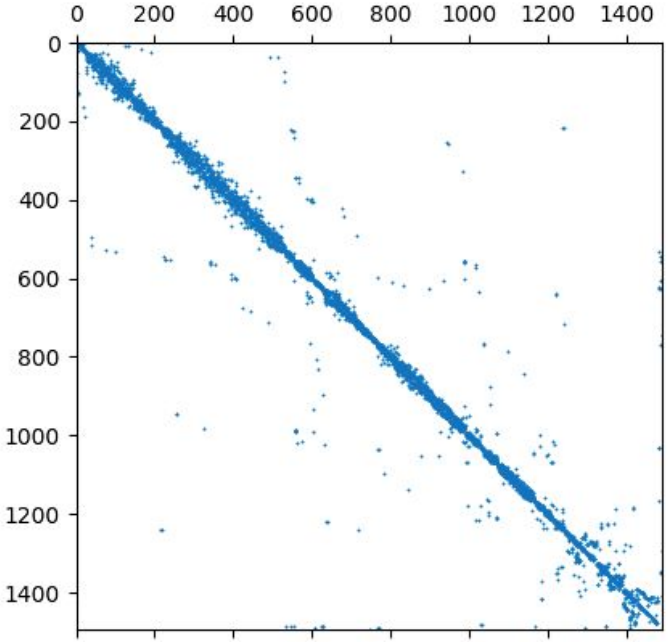


[1] T.V. Jensen & P. Pinson, “RE-Europe, a large-scale dataset for modeling a highly renewable European electricity system", SCIENTIFIC DATA, vol. 4, Nov. 2017.

Exploration

Features of the graph that have been evaluated:

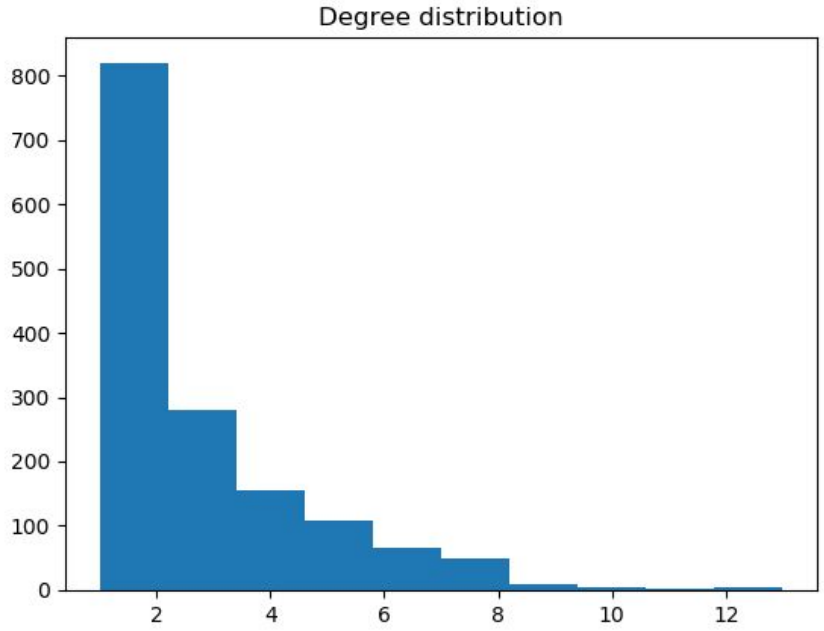
- Connected components: 1
- Adjacency matrix (sparsity)
- Diameter: 48
- Degree distribution
- Clustering coefficient: 0.105975
- Laplacian eigenvalues
- Fourier Transform of power consumption signals for each node

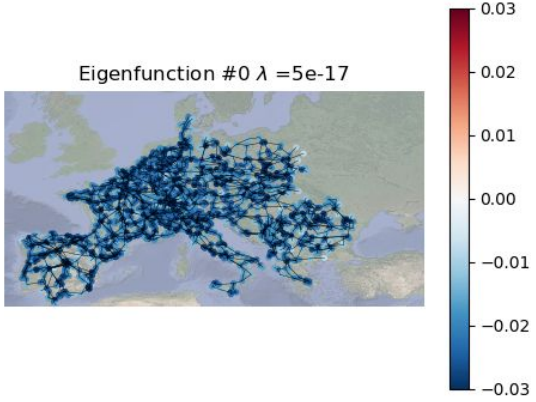


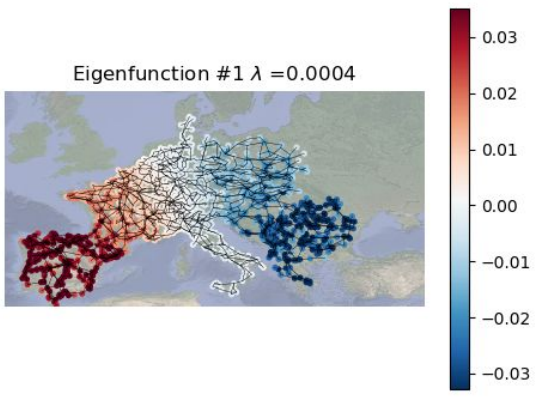
Adjacency matrix of the graph

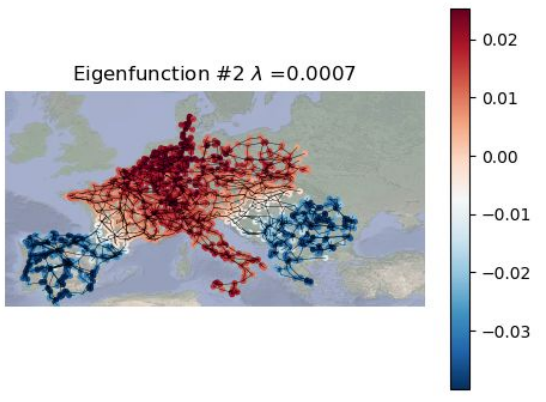
Exploration (2)

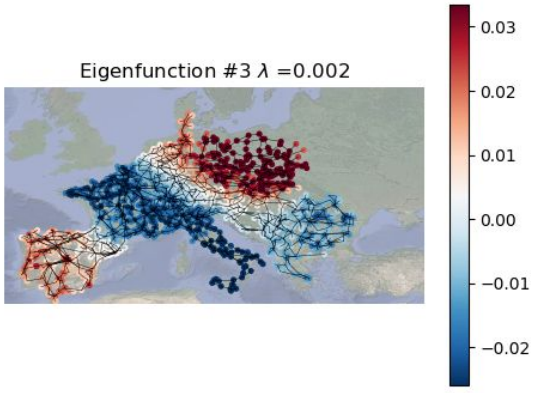
- The graph appears to be a power law model, as it can be seen from the degree distribution and the small clustering coefficient.
- The eigenvalues are consistent with the other features of the graph.

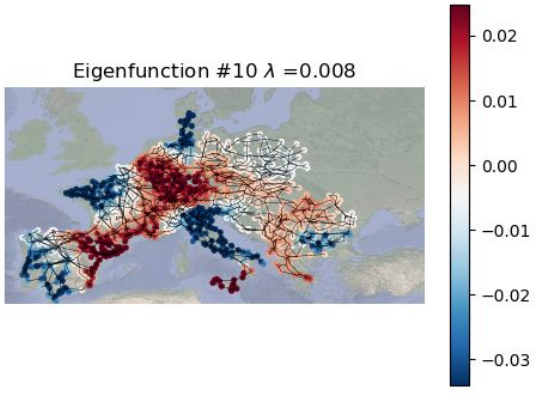


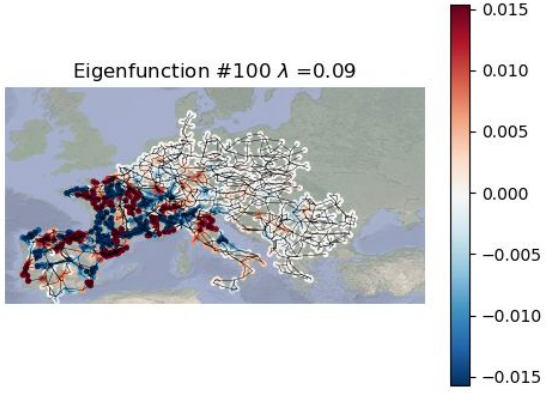








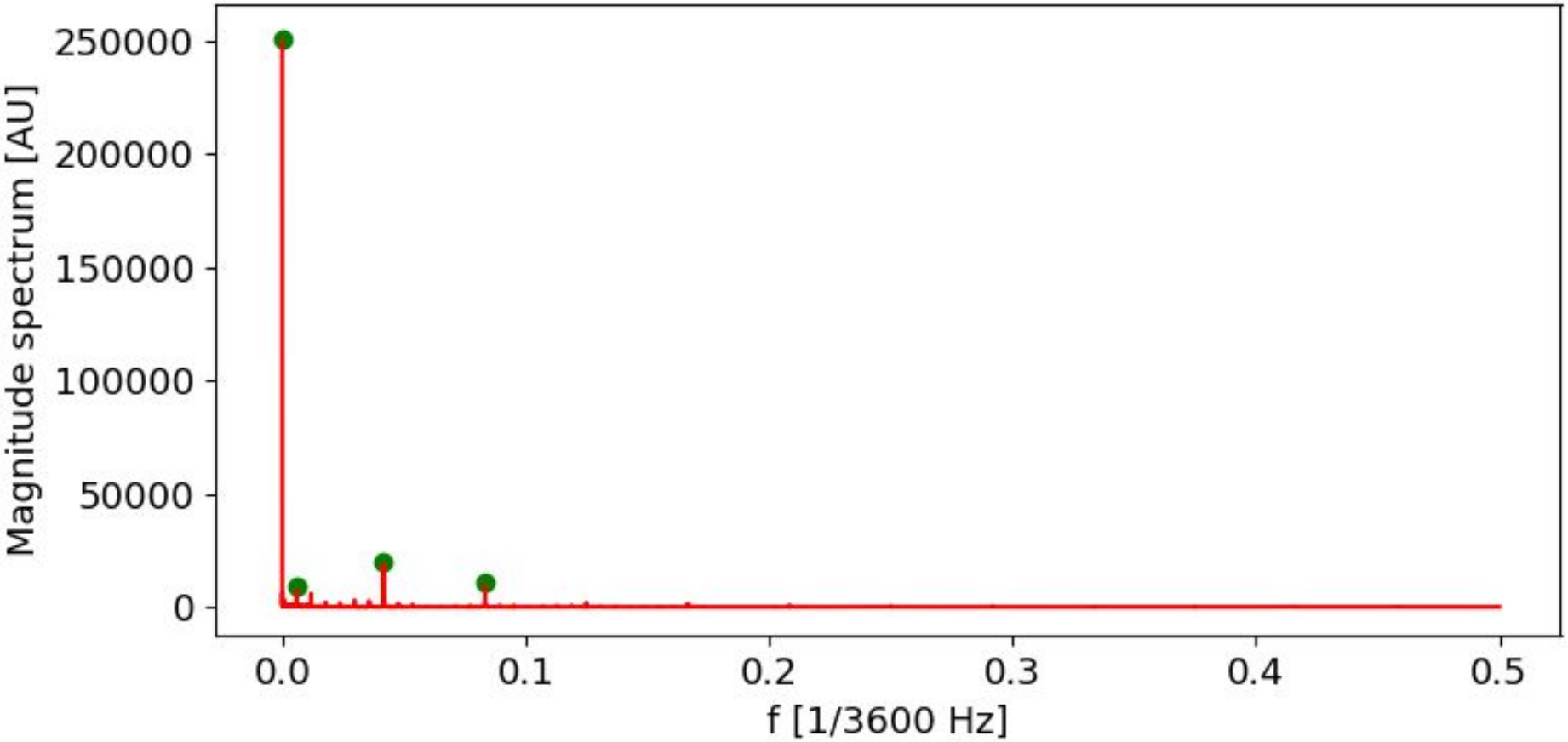




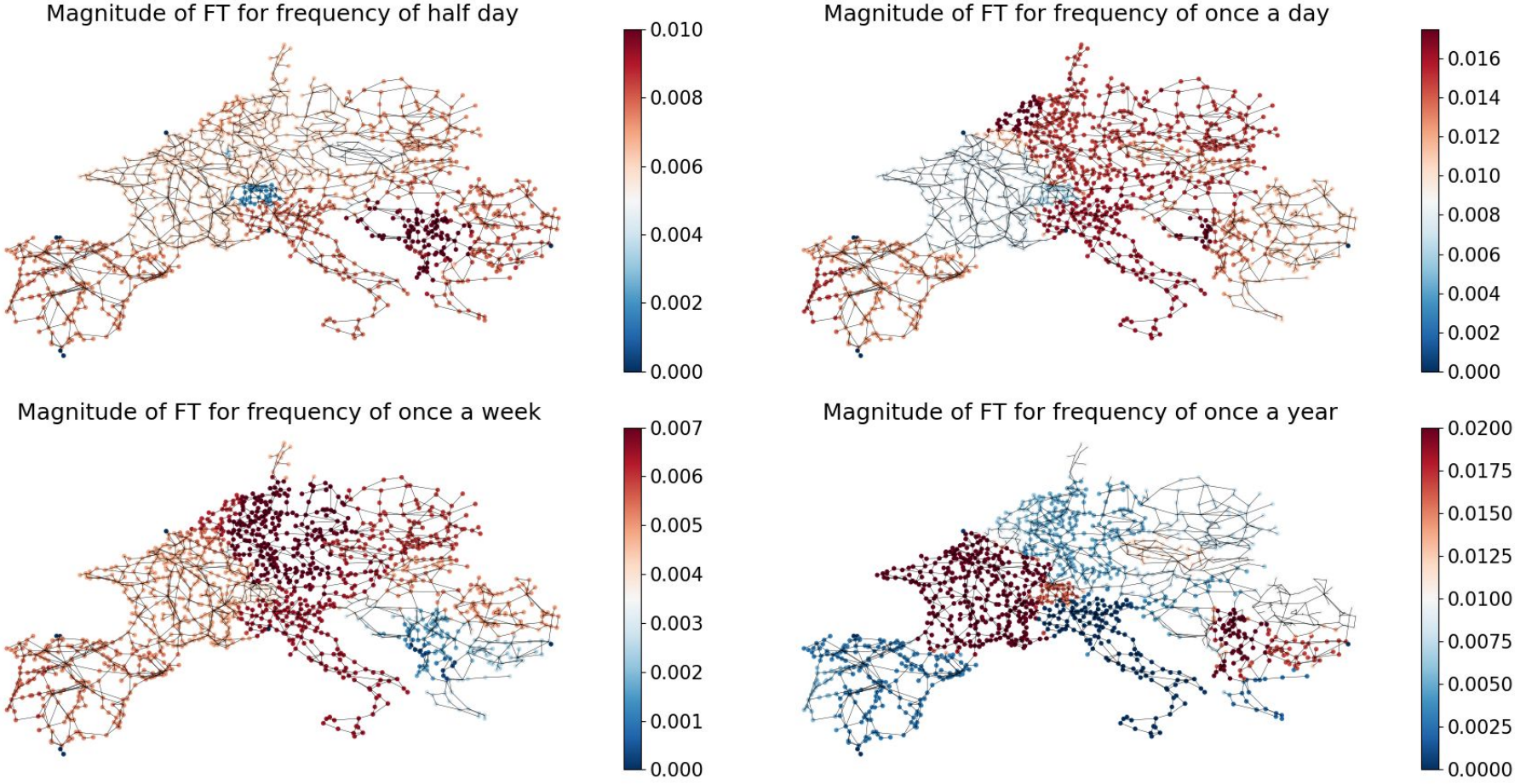
Some eigenfunctions of the graph with respective eigenvalue

Exploration (3): Fourier Transform

- The Fourier Transform of the power consumption signal of all nodes was performed
- Four frequencies were expected to be meaningful :
  - every 12 hours
  - once a day
  - once a week
  - once a year



Fourier transform of the consumption of node



Magnitude of FT of power consumption corresponding to selected frequencies

Observation about the FT component graph signal

- Half day graph : Switzerland in blue
- Day graph : France and Switzerland in blue
- Week graph : Balkans in blue
- Year graph : France in red

Why this might be ?

- Hourly electricity rate in Switzerland

  The day-ahead market is organized as a uniform auction with hourly contracts. It opens 45 days before delivery time and is cleared the day before at 11:00 determining contracts for hourly delivery for each hour of the following day. [1]

- Night rate and electric heating combination in France and Switzerland
- Less industry in the Balkans?
- Policy to encourage heating houses with electric radiators in France that works in synergy with their investment in nuclear energy

[1] J. Abrell, "The Swiss Wholesale Electricity Market", SCCER CREST, May 2016

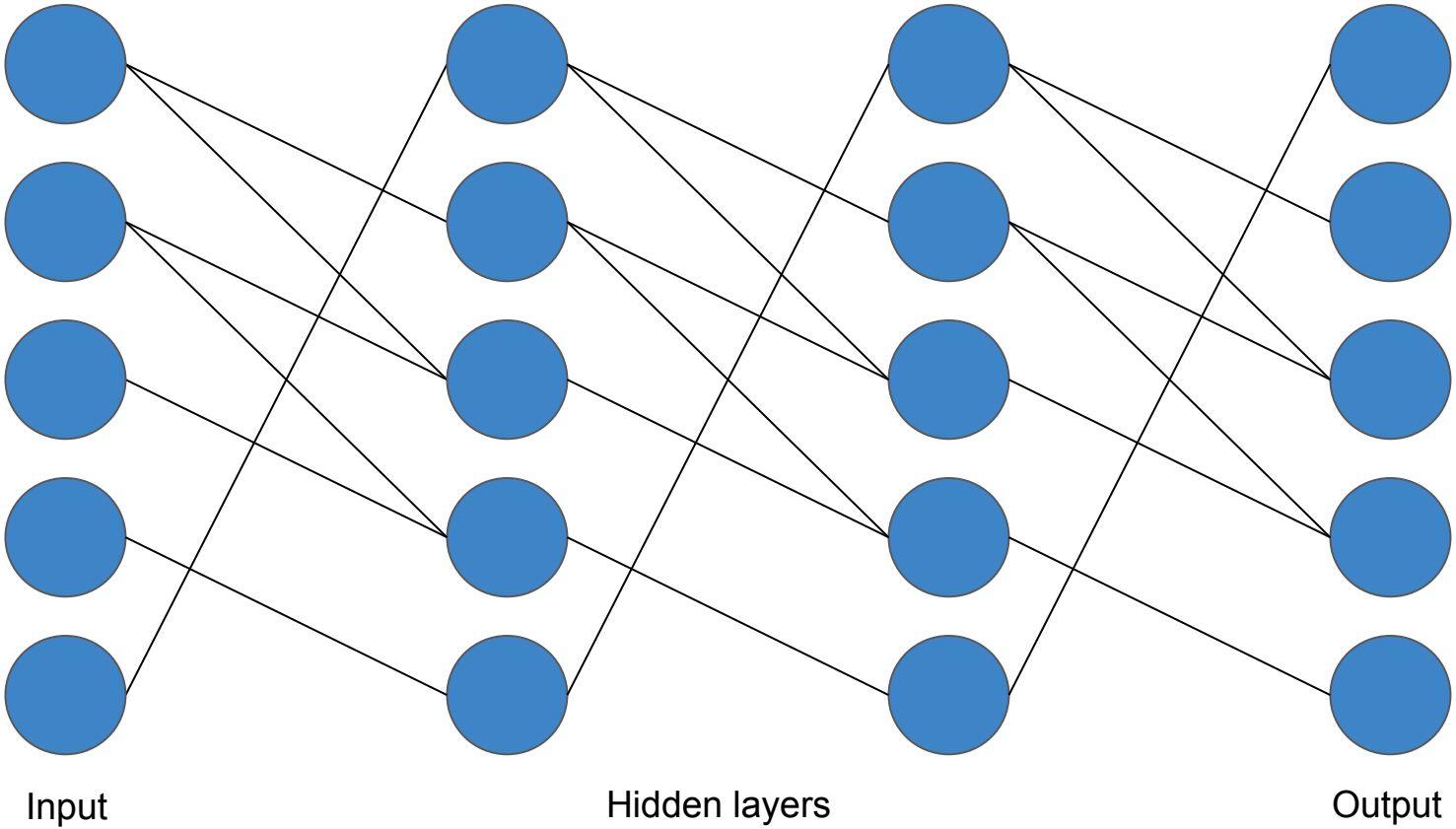
Exploitation: Graph Convolutional Network (GCN)

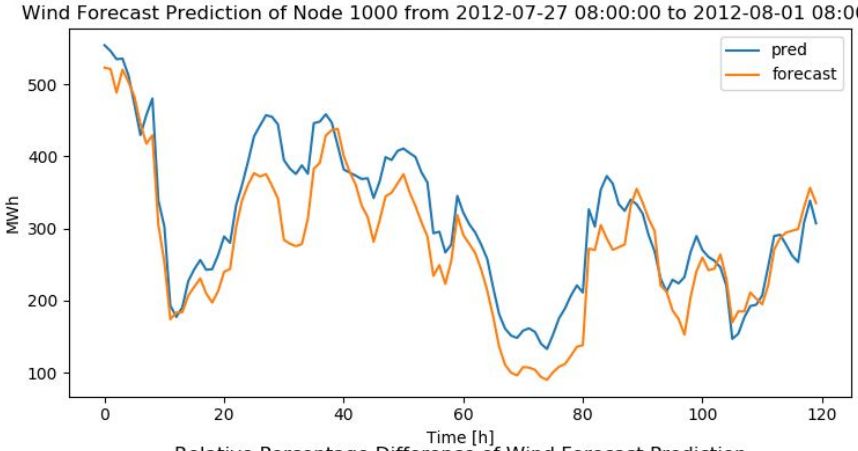
- Improve robustness of renewable energy forecast
- Predict the energy output of missing nodes
- Assure stability of the power grid

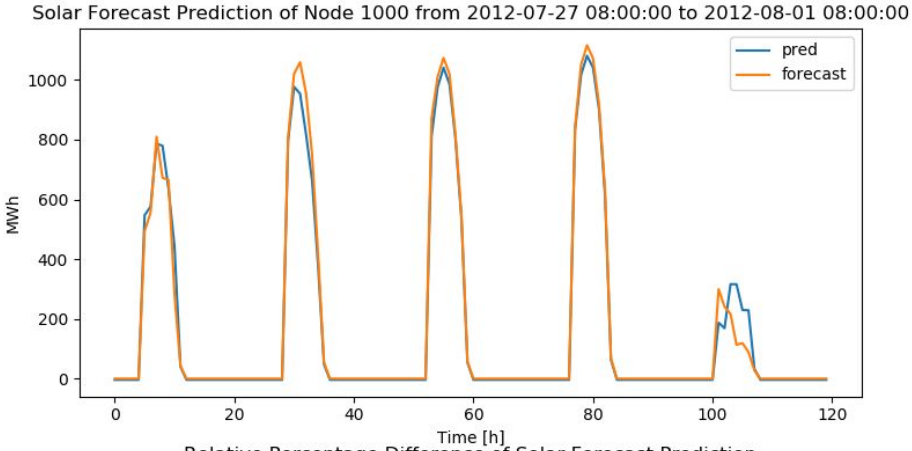
Structure:

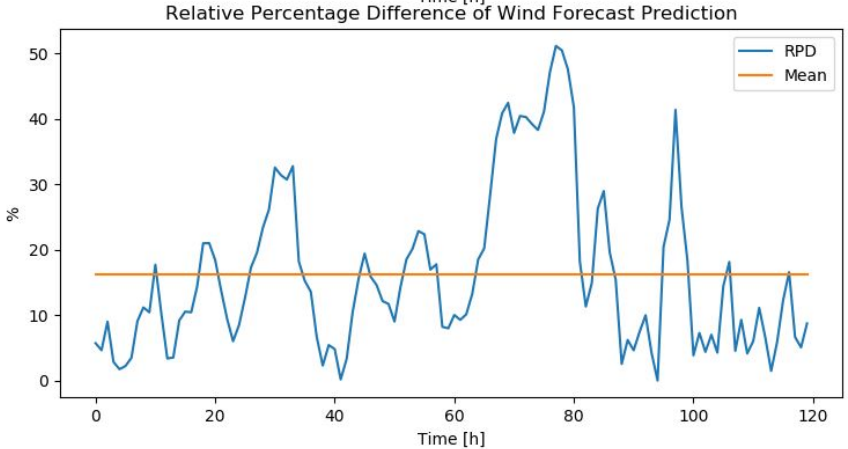
- 3 layers with 1494 nodes each (+ bias node)
- Includes graph structure (adjacency matrix)
- prediction from the neighboring nodes (max 3 edges away)
- layer calculation: $$X^{(t+1)} = D^{-1} A W X^{(t)}$$

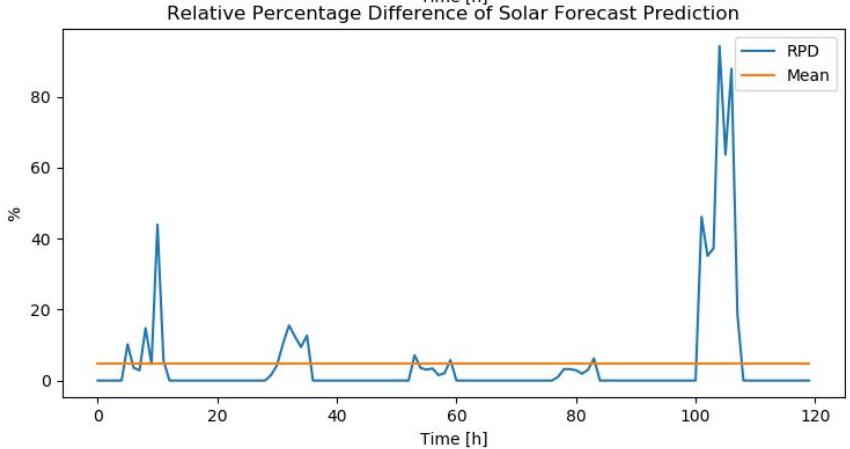
GCN Structure





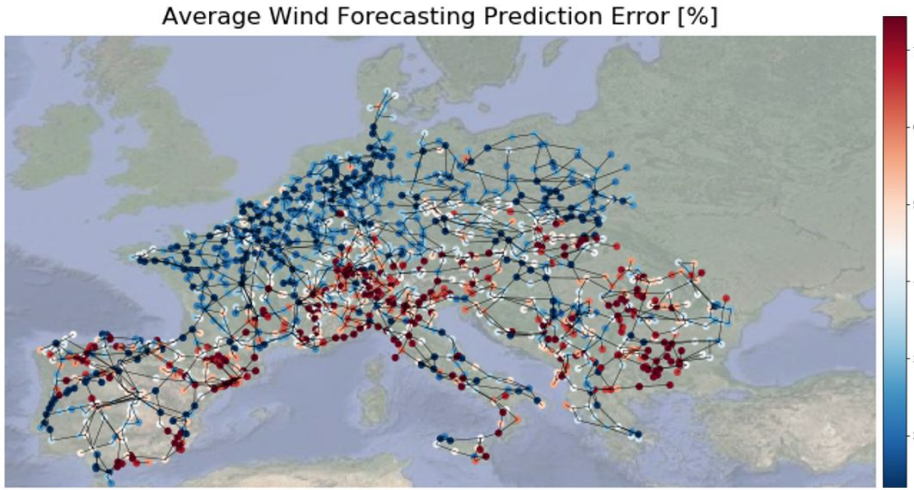


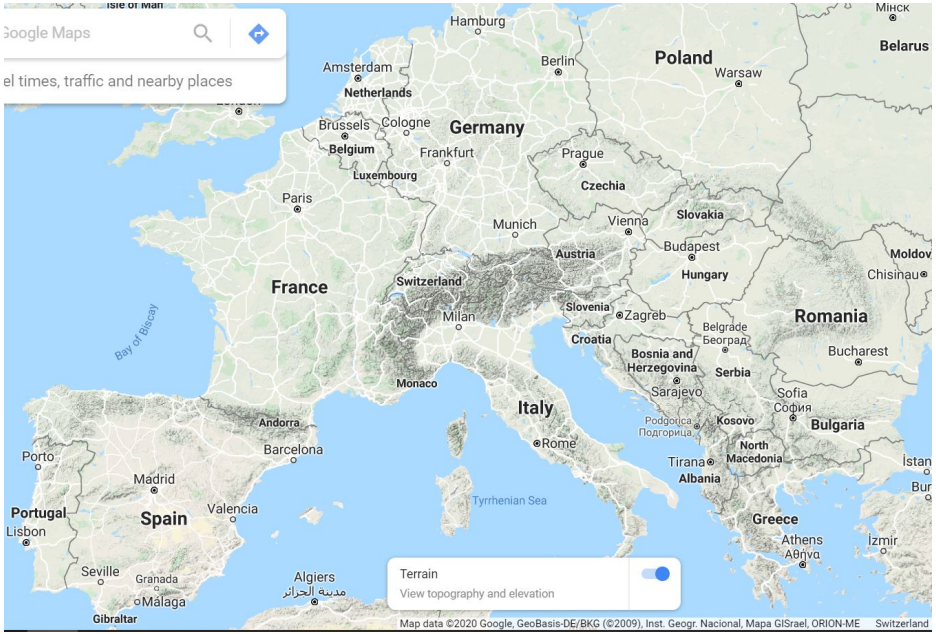




GCN prediction on one of the nodes during a five day period

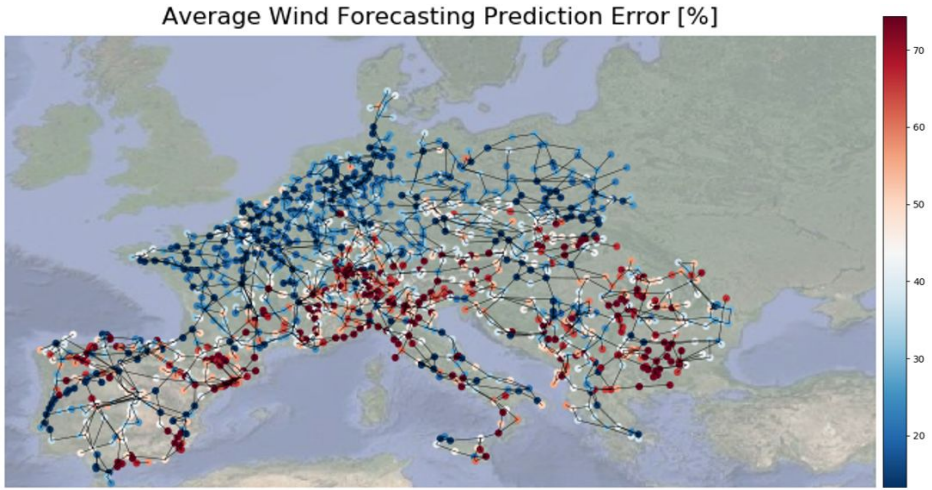
Exploitation: average prediction error

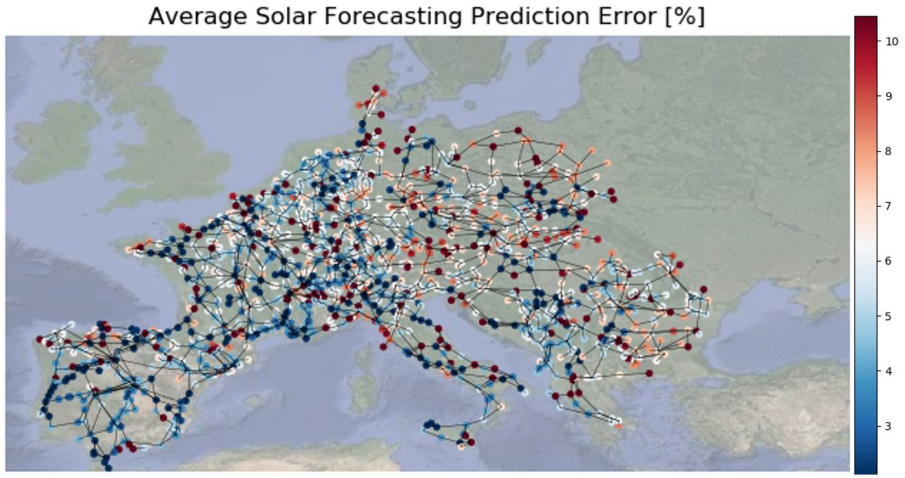




Average prediction error for the entire graph

Exploitation: average prediction error





Average prediction error for the entire graph

Conclusions

- Graph Theory is a useful tool to model and study power grids.
- The Fourier Transform of power signals can be useful to understand impact of energy policies and regulations in each country.
- The Graph Convolutional Network can be a useful product to obtain a full renewable energy forecasting given limited data, especially for solar energy.

Any questions?