MANMADE

DIAGNOSING VULNERABILITY, EMERGENT PHENOMENA, and VOLATILITY in MANMADE NETWORKS

Project sponsored by nest pathfinder

ECCS'07 CRP Forum

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Interdependent complex structures: MANMADE proposal

- the network of networks that comprise Europe's critical infrastructure; concentrating primarily on different energy supplies

- aim: to assemble network information, develop and apply mathematical methods to analyse ROBUSTNESS of large, man-made multi-element infrastructure systems that exhibit, so-called, complex behaviour

Key questions

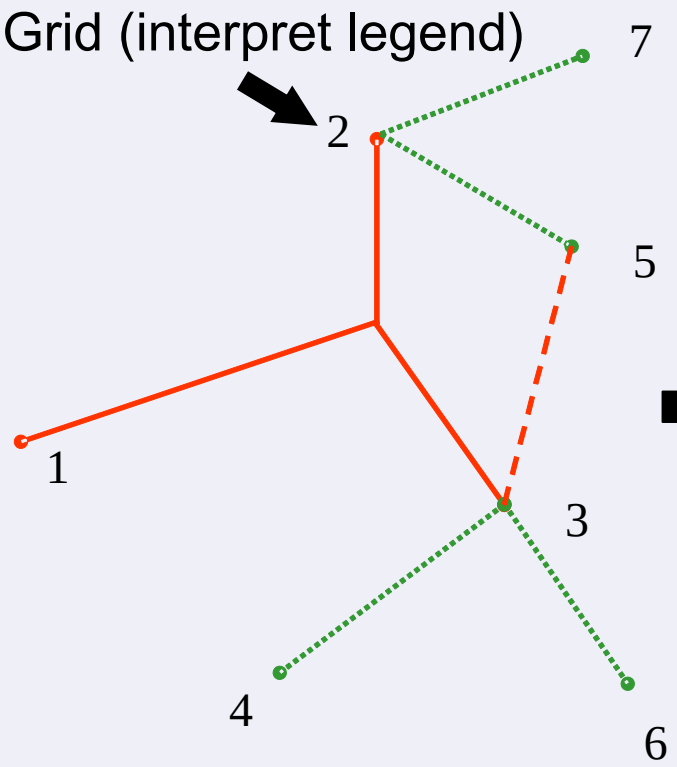
integrity of network model
collation and correction of current network data sets

inter-network coupling
(e.g. vulnerability of interconnected networks to unexpected failures)

volatility and memory
(spot electricity pricing)

instabilities and collapse
both structural (catastrophic failure of network components), functional (electricity grid blackouts, supply chain)

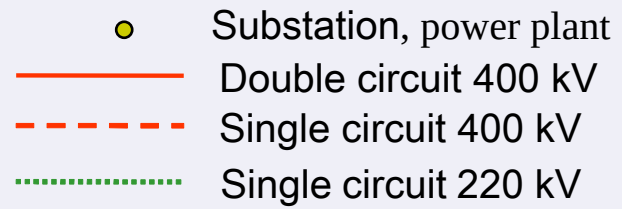
Conversion of HV grid map into a weighted graph

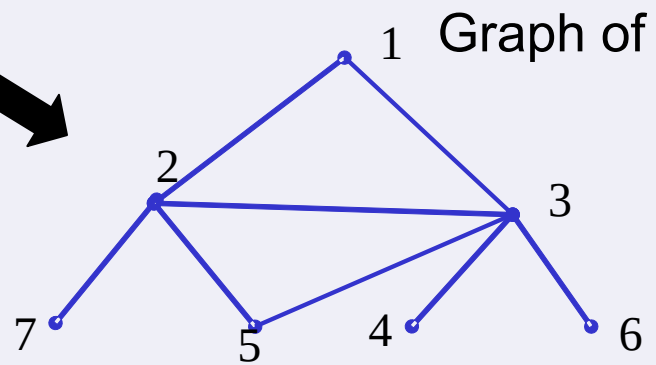


Connectivity matrix

	1	2	3	4	5	6	7
1		400	400				
2	400		400		220		220
3	400	400		220	800	220	
4			220				
5		220	800				
6			220				
7		220					

Modes





Weighted graph: oil pipeline capacity – thickness of link

Local topology: GIS vs Map definition

Swiss Laufenburg substation

UCTE

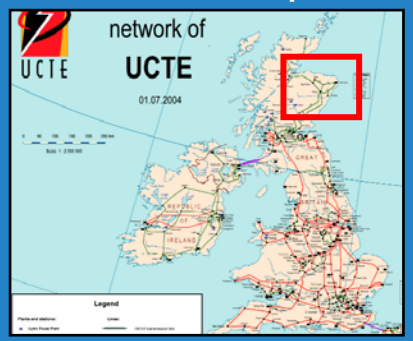
Satellite

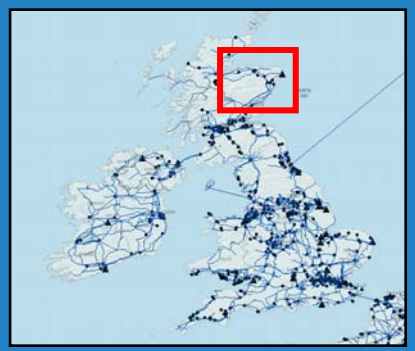
GIS

Geographical information system

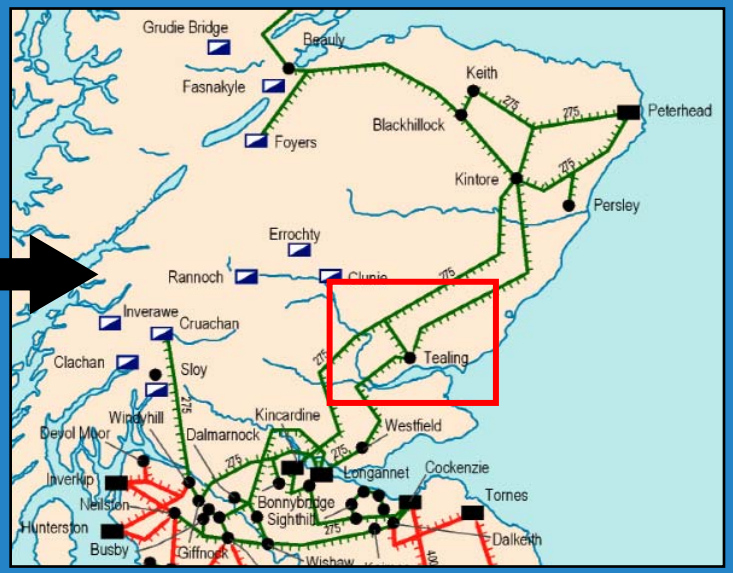
Network description - topological discrepancies

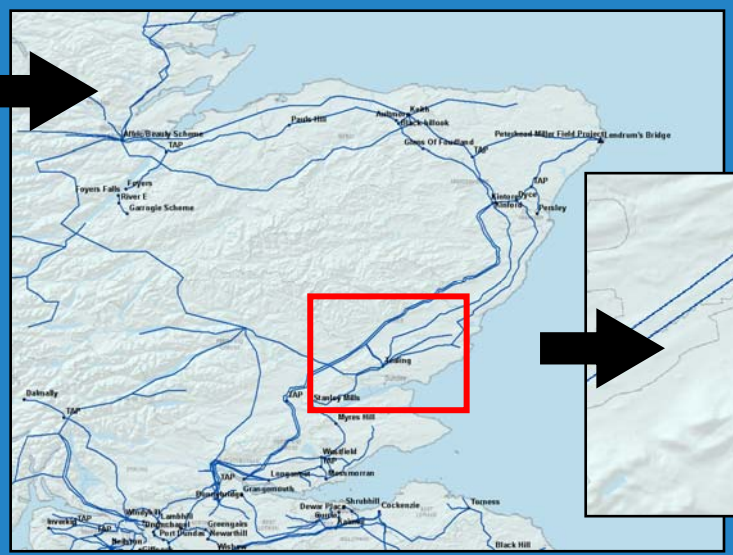
UCTE map

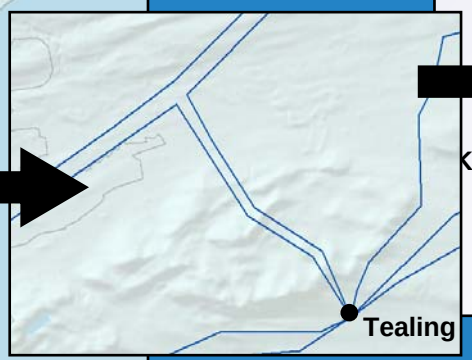


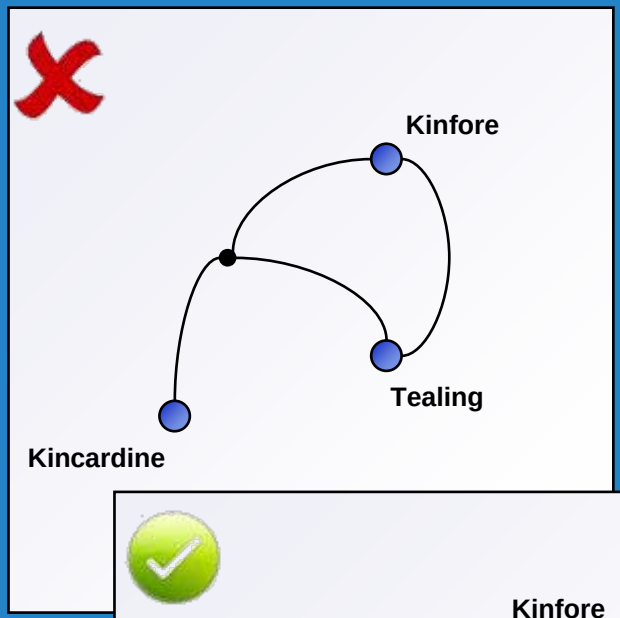


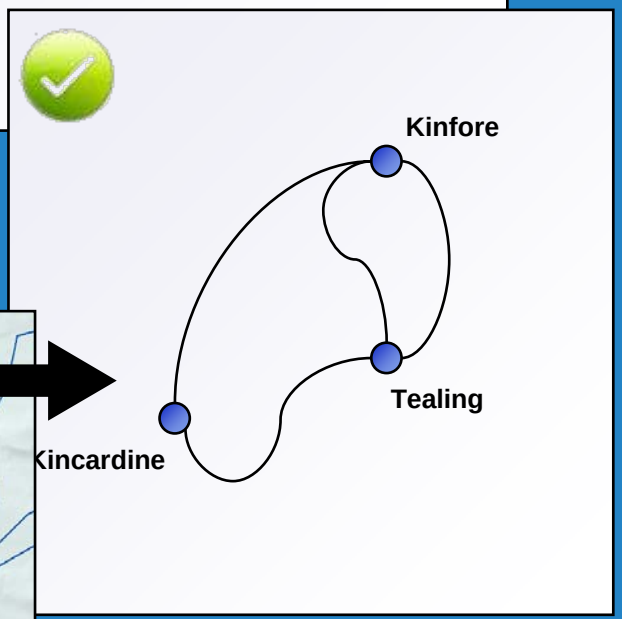
GIS dataset





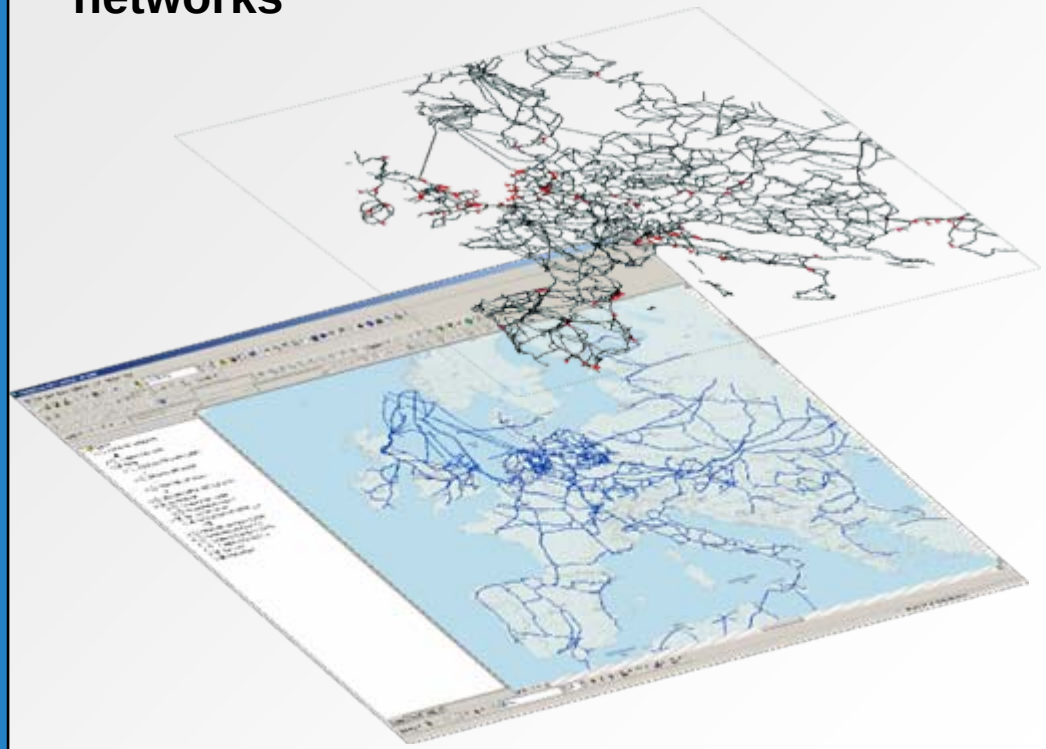


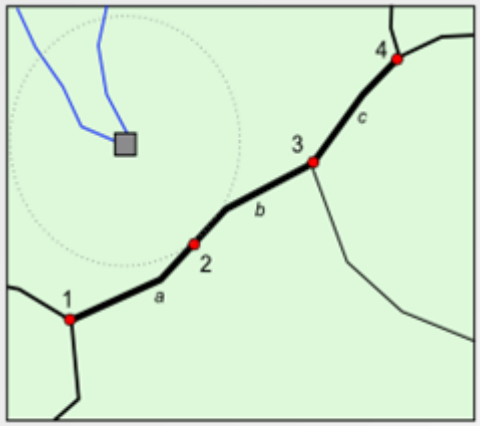


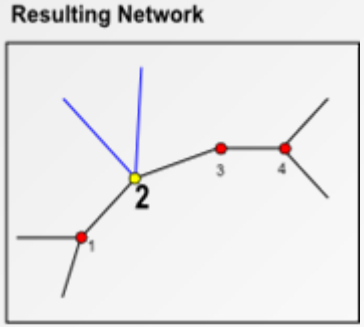


Interconnected Networks - overlaying

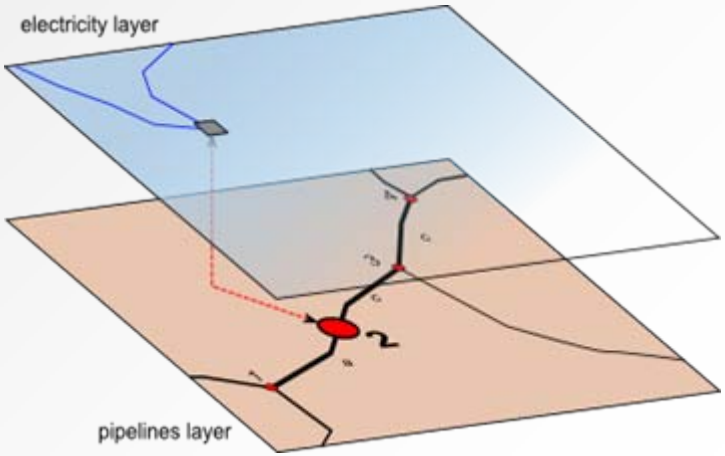
GIS
gas and electricity networks





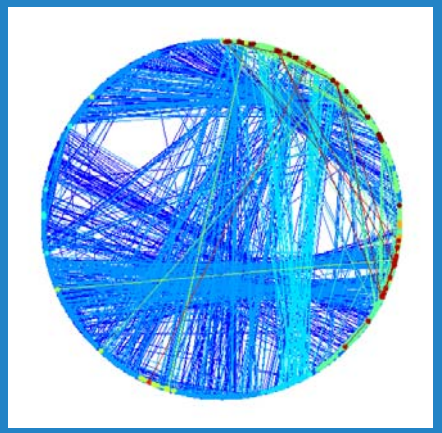


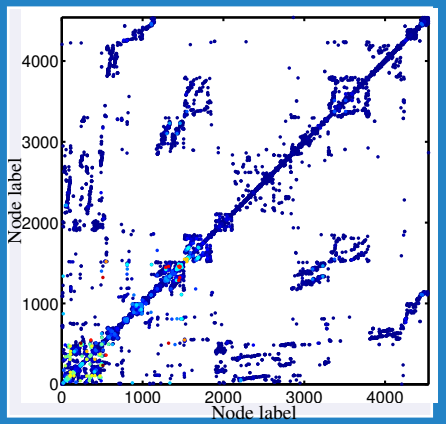
Main pipelines
Electricity Lines
Power Plant
Node

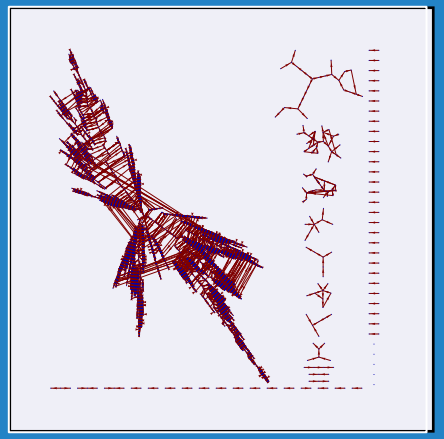


Network classification

- Network classification (regular, random, small-world, scale-free







- Various measures (average path length, clustering or transitivity, node betweeness/centrality, community structure
- Resilience and robustness of networks
  - Robustness with respect to topology change
  - Reliability and efficiency
  - Black-outs

Diagnostic parameters calculated from time series

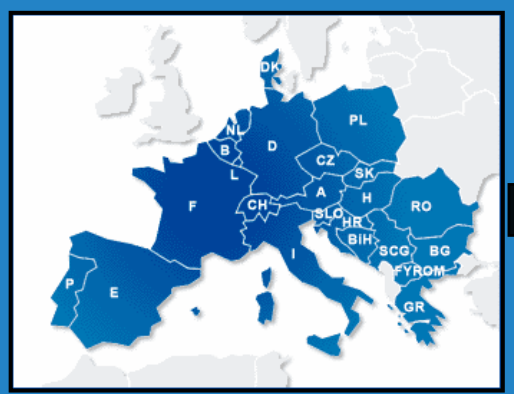
Hurst exponent

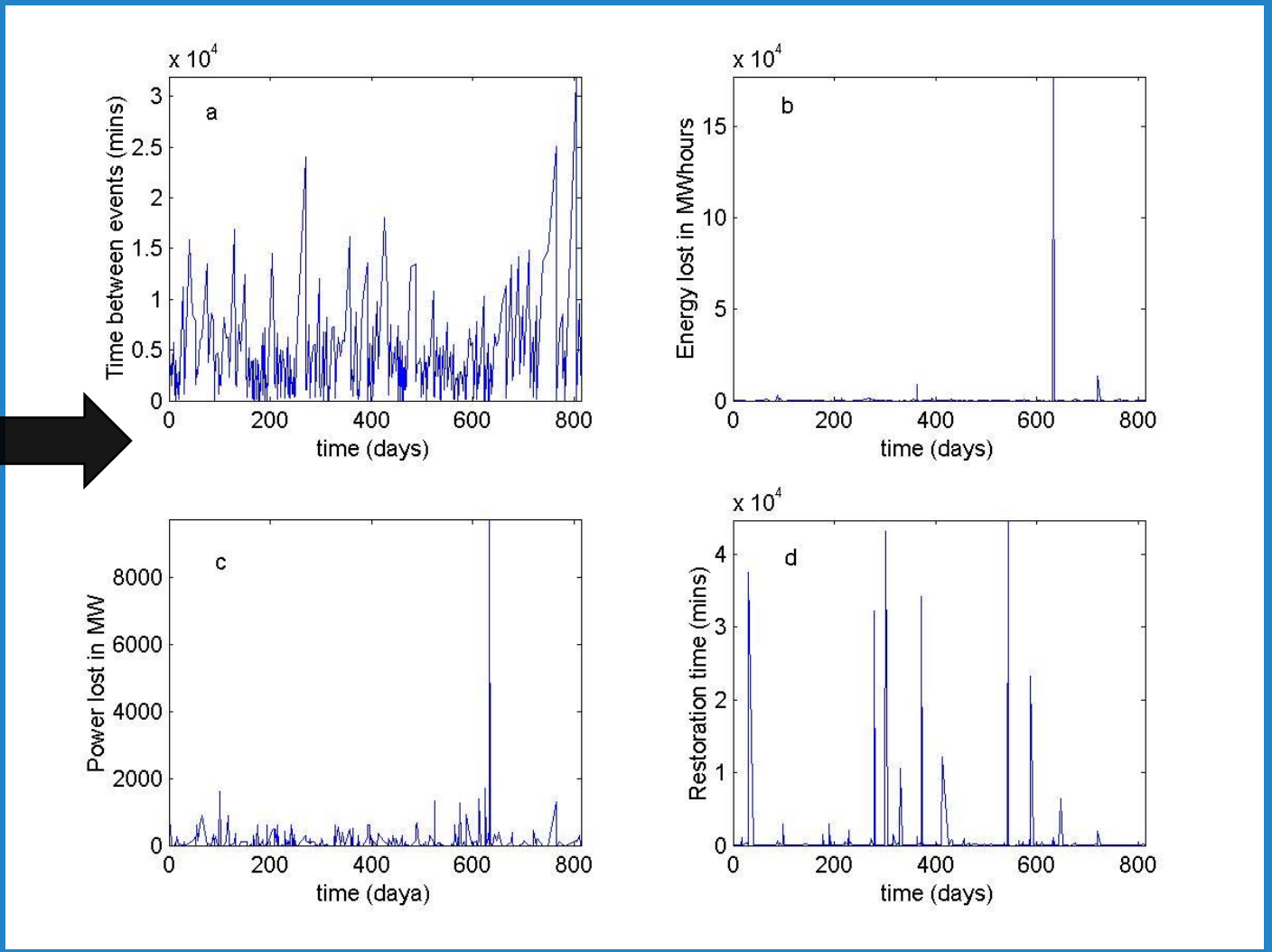
A means of detecting long-range dependence in the presence of noise

Cumulative frequency distribution

The tail of the cumulative frequency distribution provides information on the rate of decay of perturbations as a function of the blackout size.

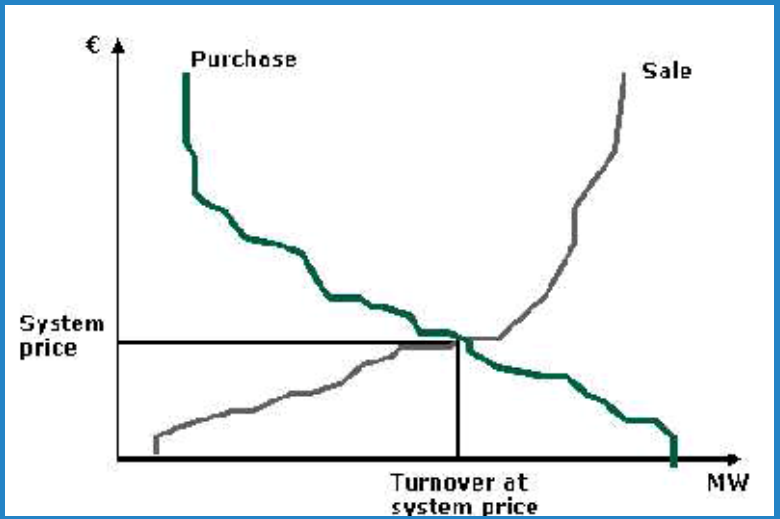
Time series of UCTE disruption blackouts

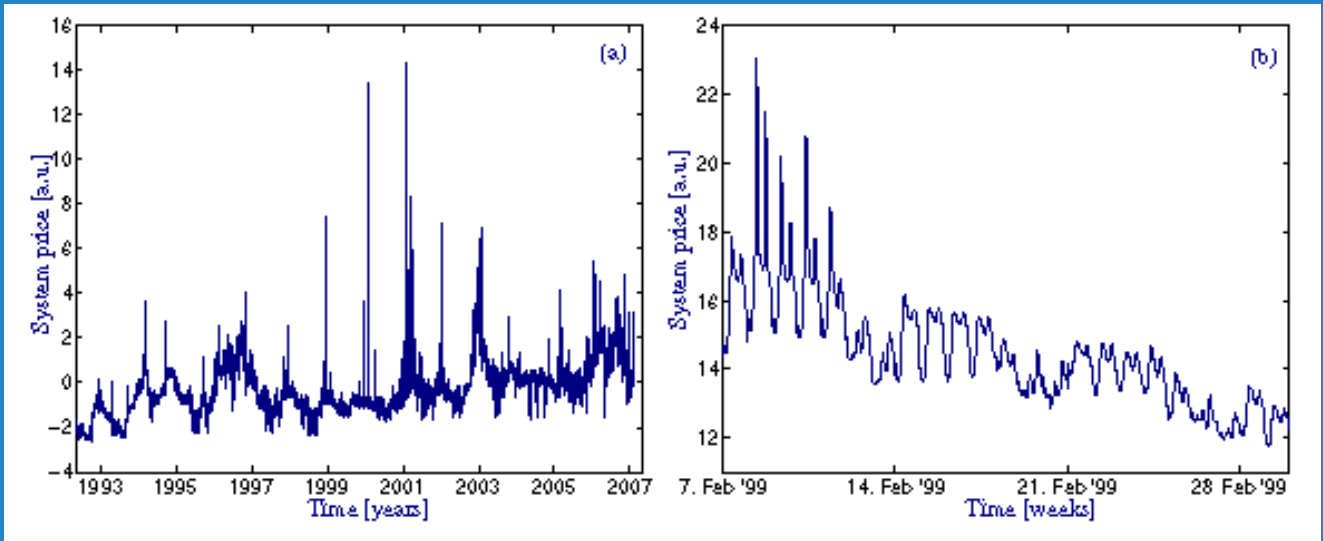




Time series analysis: Norwegian electricity spot prices

Electricity spot price
market data (used in WP2)

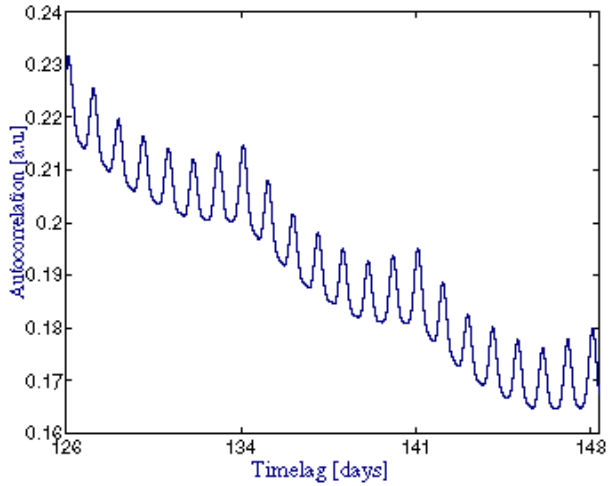




Time series analysis

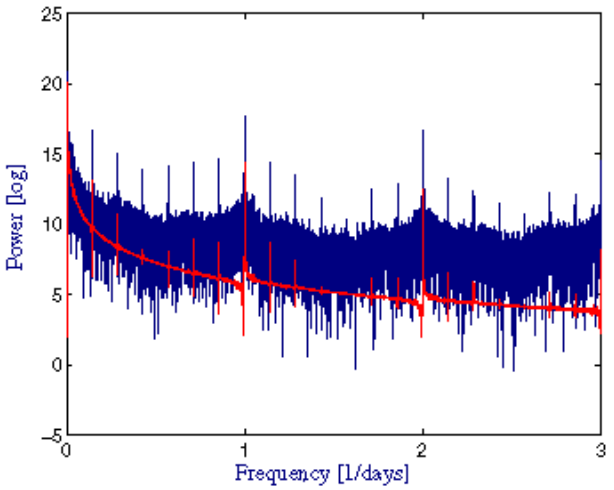
correlation function

$$C(n) = \frac{1}{N} \sum_{\ell} x_\ell x_{\ell+n}$$



power spectrum

$$S(k) = \left| \sum_{\ell} x_\ell \exp(2\pi i k \ell / N) \right|^2$$

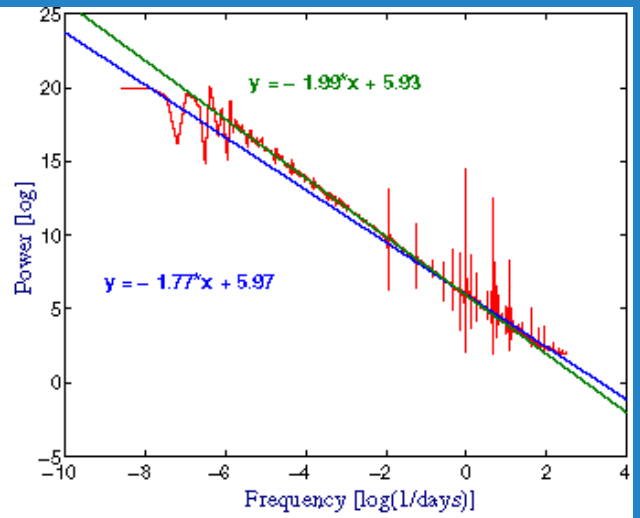


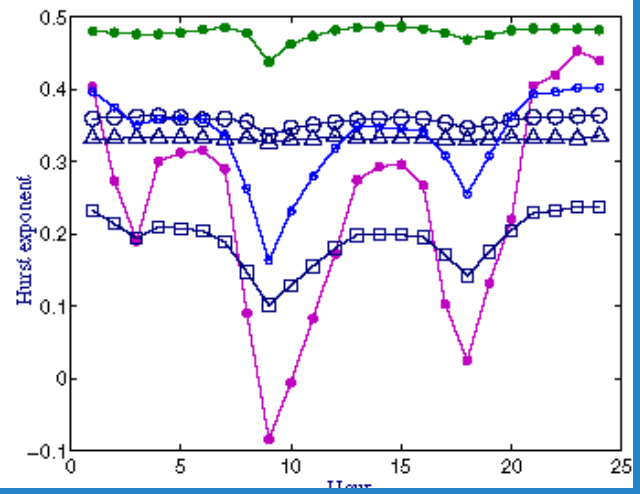
Multifractal analysis

Hurst exponent ($\longrightarrow$ D3.1)

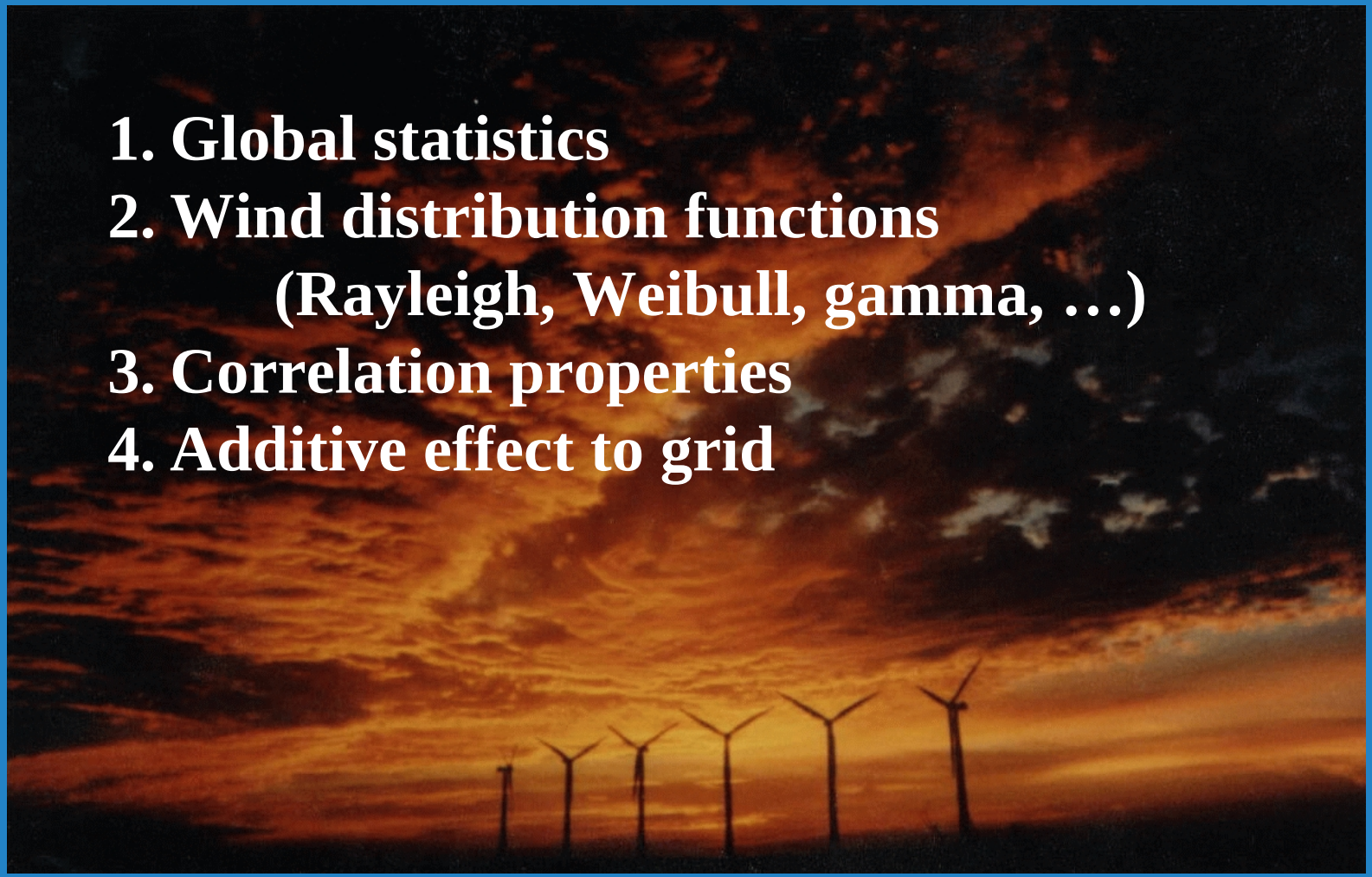
$$x(t) \sim \lambda^{-H} x(\lambda t)$$
$$\langle x^2(t) \rangle \sim t^{2H}$$
$$S(\omega) \sim \omega^{-1-2H}$$

- R/S
- DMA
- MF-DFA

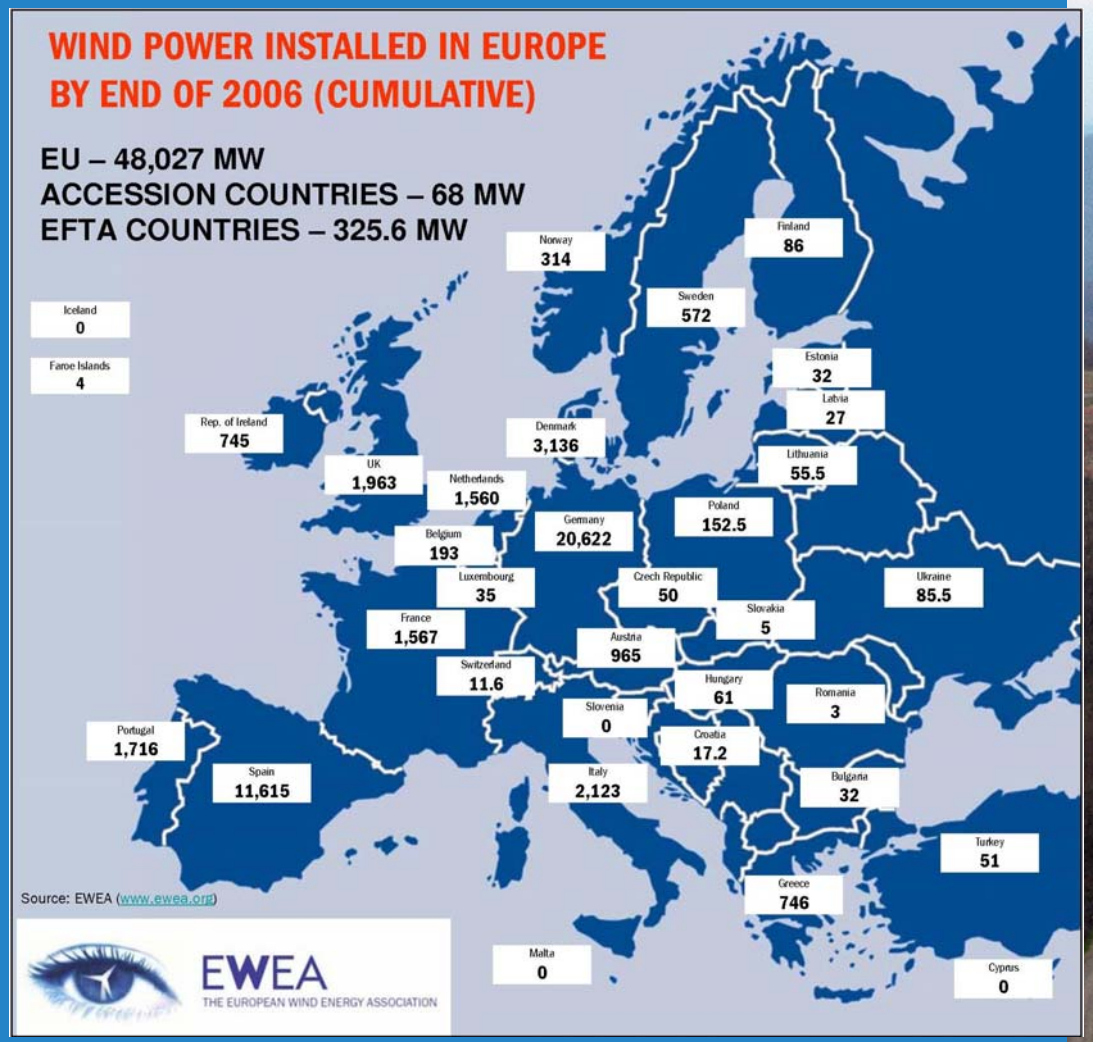




Wind energy resource



Wind power contributions - MW



wind energy

as a %

of total energy

in EU

7-8%

Analysis of Networked Systems: energy distribution

- Different energy distribution systems are independently large, but also interconnected
  - interconnected, networks coupled by non-trivial dependencies
- A key task is to analyze energy networks at the macro-scale
  - what can be said of their failure rates?
  - what can be said of the vulnerability of the whole network?
- Manmade documents on network data electricity spot pricing, and statistical interpretations are now available.