MANMADE

DIAGNOSING VULNERABILITY, EMERGENT PHENOMENA, and VOLATILITY in MANMADE NETWORKS

www.manmadenet.eu

An overview

David Arrowsmith

Queen Mary, University of London

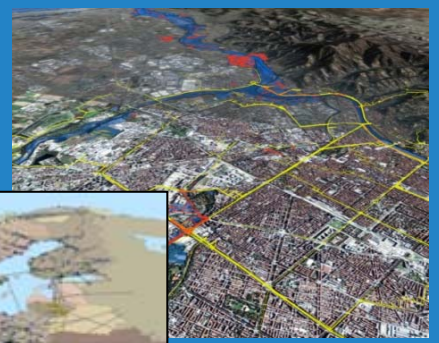
SKOPJE, 24th June 2009

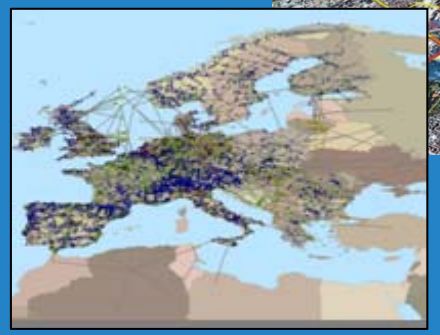
NEST Pathfinder

Man Made

MANMADE EU www.manmadenet.eu

- the project
  - networks that comprise Europe's critical infrastructure
  - primary energy supply
    - assembling data for large manmade multi-element infrastructure systems
    - apply dynamic and static mathematical methods





NEST Pathfinder

Man Made

Collaborators and contributors

- EU Joint Research Centre, ISPRA (data –production and analysis)
- Queen Mary University of London (analysis of data)
- Università Carlo Cattaneo, Castellanza (finance and economics)
- Macedonian Academy of Sciences and Arts (vulnerability)
- Collegium Budapest (wind energy and dynamics of power supply)
- Stakeholders
  - National Emergency Supply Agency, FINGRID, Finland

NEST Pathfinder

Man Made

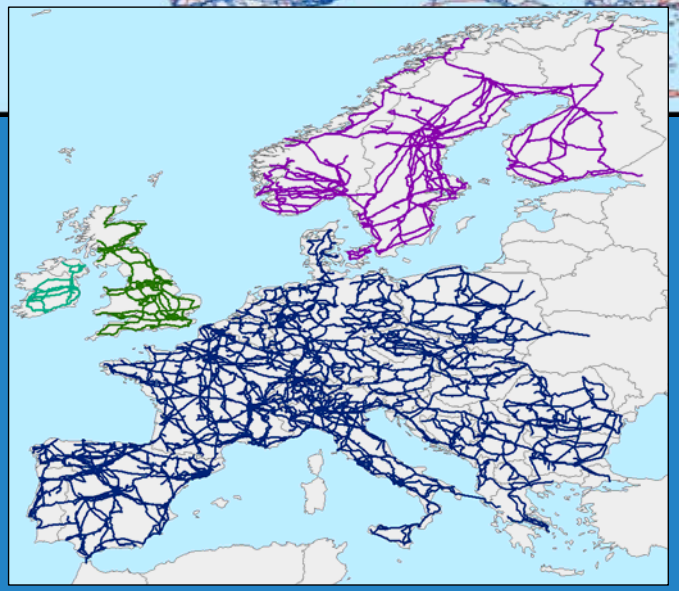
Networks

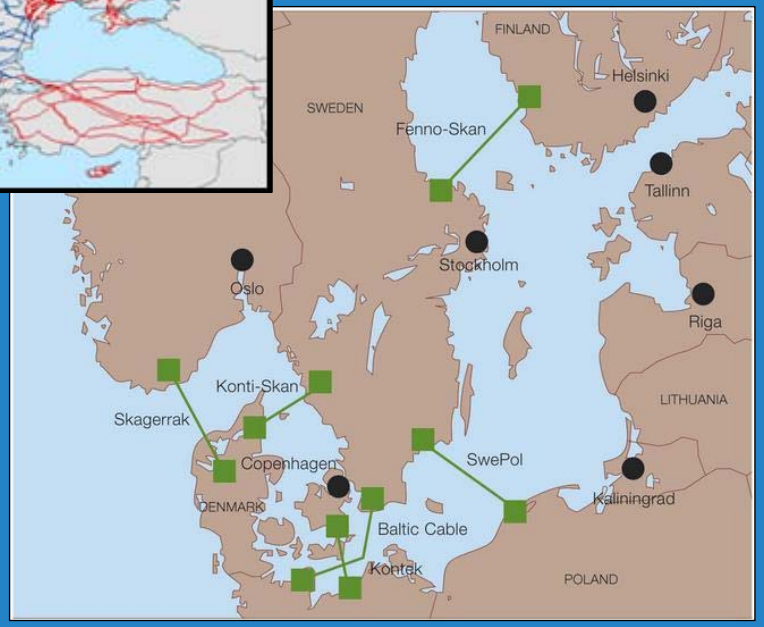
- Energy – *gas and electricity – overlaid networks*
- Transport – city primary routes
- Social networks
  - vulnerability
    - structural (catastrophic failure of network components)
    - functional (electricity grid blackouts, supply chain dynamics)
  - interconnected data sets
    - overlaying of networks – interconnected gas and electricity
    - strategy for vulnerability– green energy inputs
  - volatility and memory in markets and their dynamics
    - spot electricity pricing

Collecting information and producing datasets (JRC)

Data sets of major gas lines and exchange flows	Data sets of major gas lines between and into Western Europe *Platts, etc*.
Datasets of spot price electricity	NORDPOOL time series spot price electricity in European markets
Spatial and topological maps of the road network	Urban street networks – initially Milan, Turin and London
High voltage electricity grid	European Electricity Lines by disconnected Regions UCTE , NORDEL, UK ,National Grid
Wind energy data	ERA-40

The European Electricity Grid





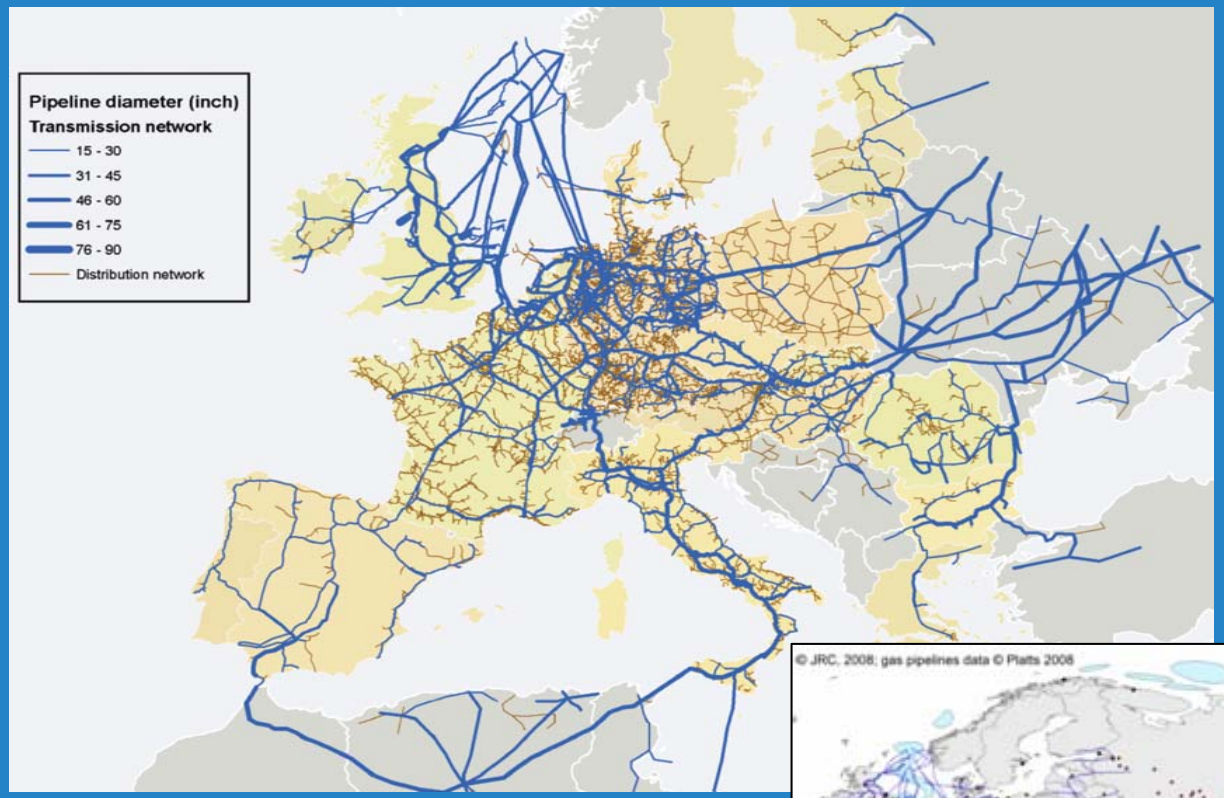
Four independent electricity grids

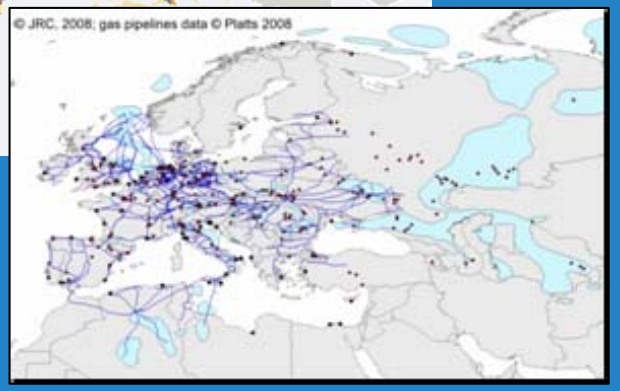
Power exchange between two AC networks, that are not synchronous is by means of high voltage direct current (HVDC) lines
e.g. England-France

NEST Pathfinder

Man made

Euro gas network (QMUL and JRC)





Transmission network

(D >= 15, + interconnections)

2207 nodes, 2696 links

Complete network

24010 nodes, 25554 links

--Gas sources
--LNG terminals
--Pumping stations
--Gas Deposits

www.platts.com

NEST Pathfinder

Man Made

Gas trade movements by pipeline

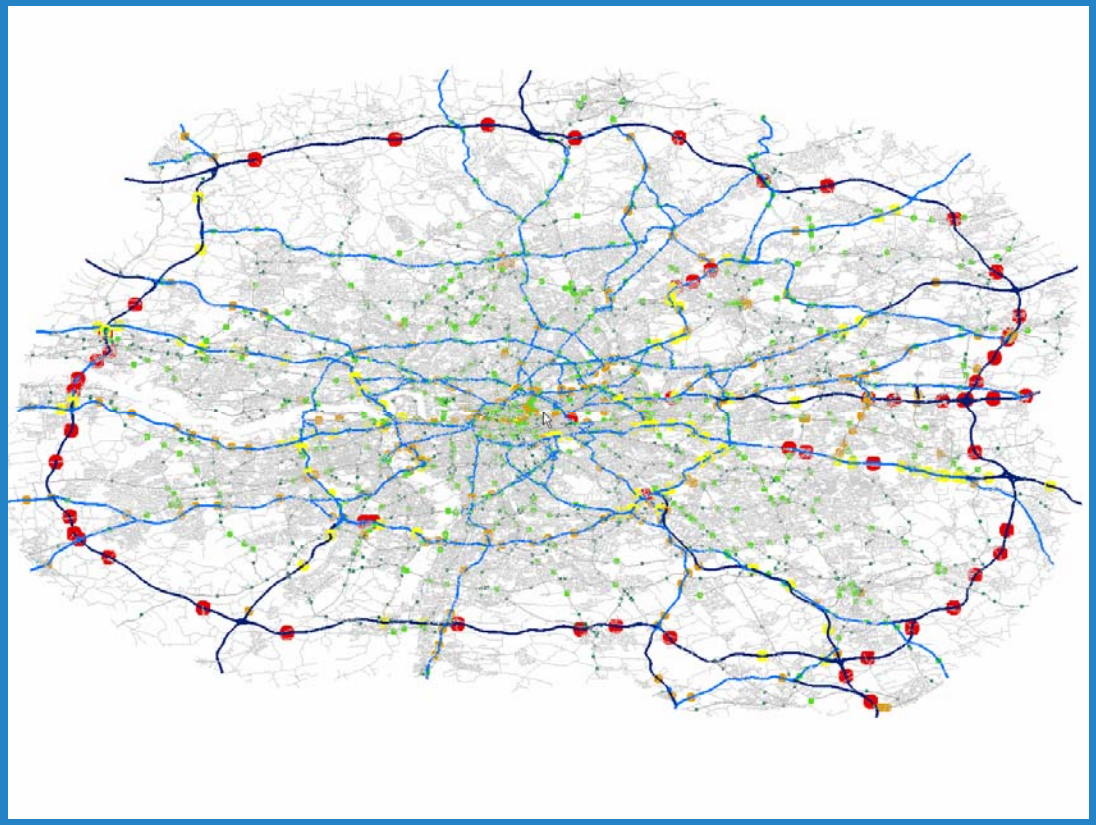
Lack of good information

e.g. directings of all edges of the network – some are obvious!

www.iea.org

www.bp.com

Urban Traffic (JRC)



EU JRC Data

AADTF – annual average daily flow

Network simplification

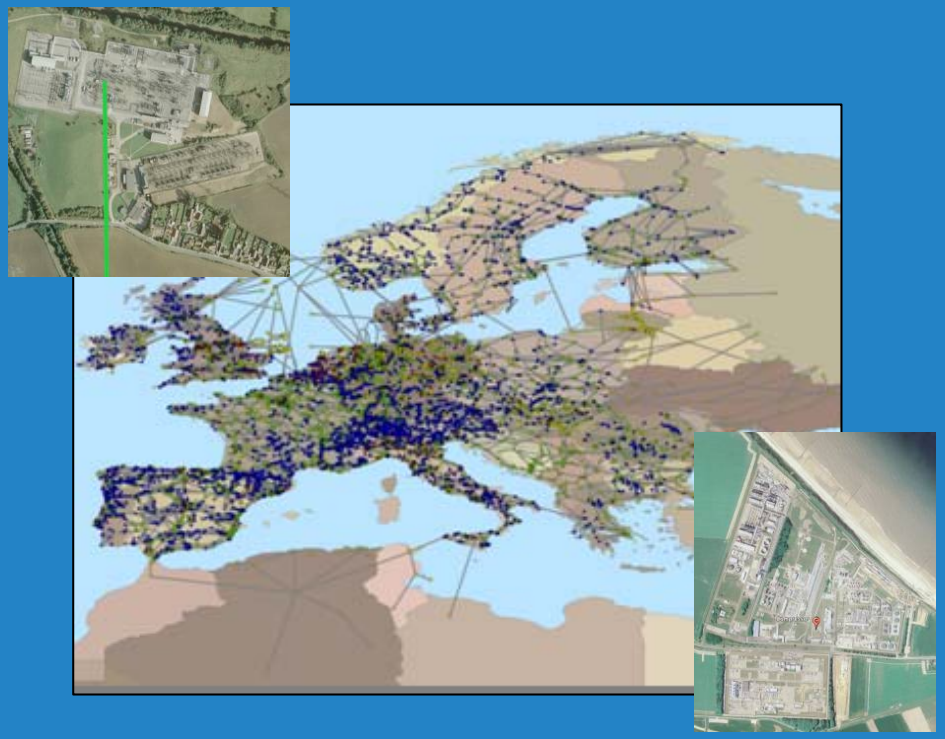
Connectivity analysis

NEST Pathfinder

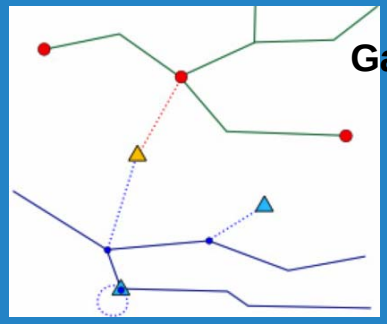
Man Made

Interconnected data sets

Robustness of Trans-European Gas Networks: The Hot Backbone – Carvalho(QMUL), Buzna(ETH), Bono (JRC)



Gas fired power plant



Gas network

Electricity network

Electricity Network

Nodes (10494) - power stations, power plants
Links (15413) - power lines
Node attributes - position, power plant capacity,
Link attributes - voltage level, length

Gas network (primary)

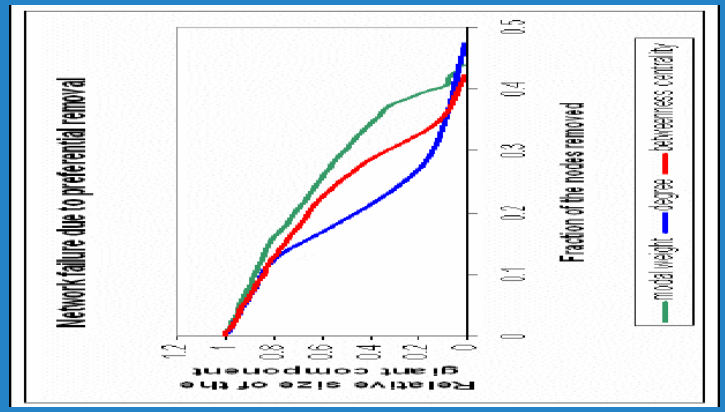
Nodes (2207) - compressor stations, LNG terminals, city gates
Links (2696) - pipelines
Node attributes - position, storage and LNG terminal capacities,
Link attributes - length, diameter

NEST Pathfinder

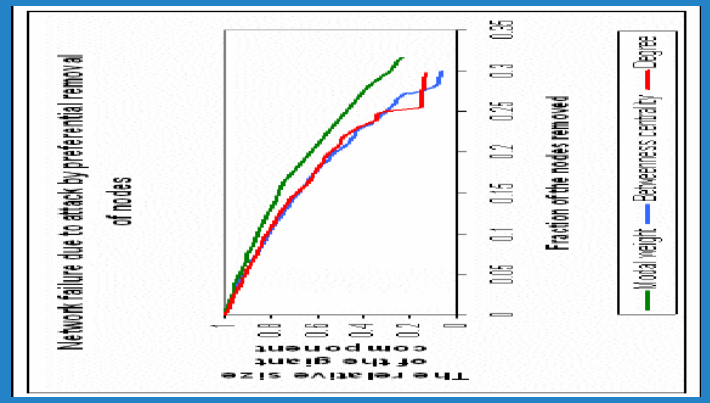
iTanMade

Network analysis (JRC,MASA,QMUL)

- **Different topologies were investigated**
  - Random graphs (Erdos – Renyi model)
  - Scale – free (Barabasi – Albert)
  - Manmade - segments of the European power grid



- **Attack strategy – nodes deletion according to**
  - Degree
  - Betweenness centrality
  - Modal weight
  - *low correlation between the different ranking criteria*
- **Adaptive and non-adaptive strategy**



NEST Pathfinder

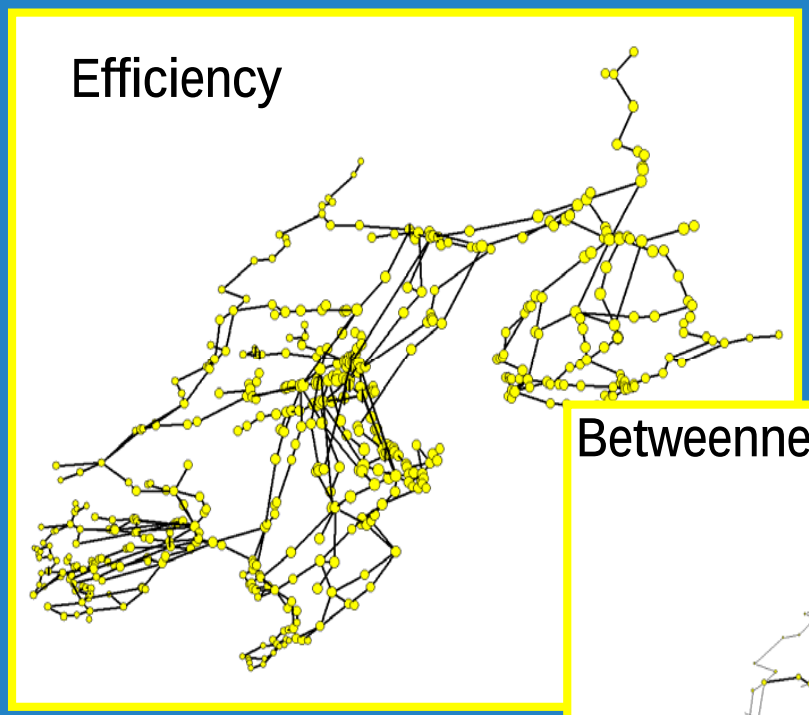
Man Made

Ranking in networks (JRC and MASA)

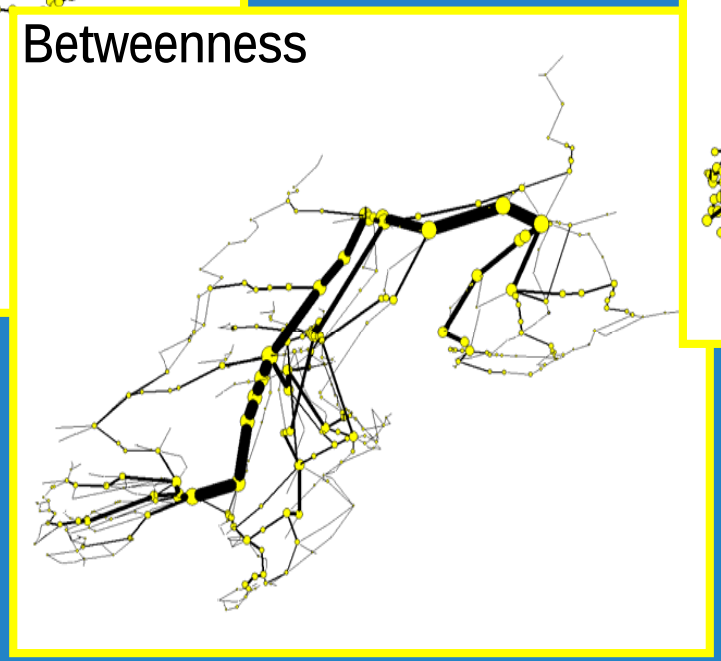
Size of the vertices
Width of the edges

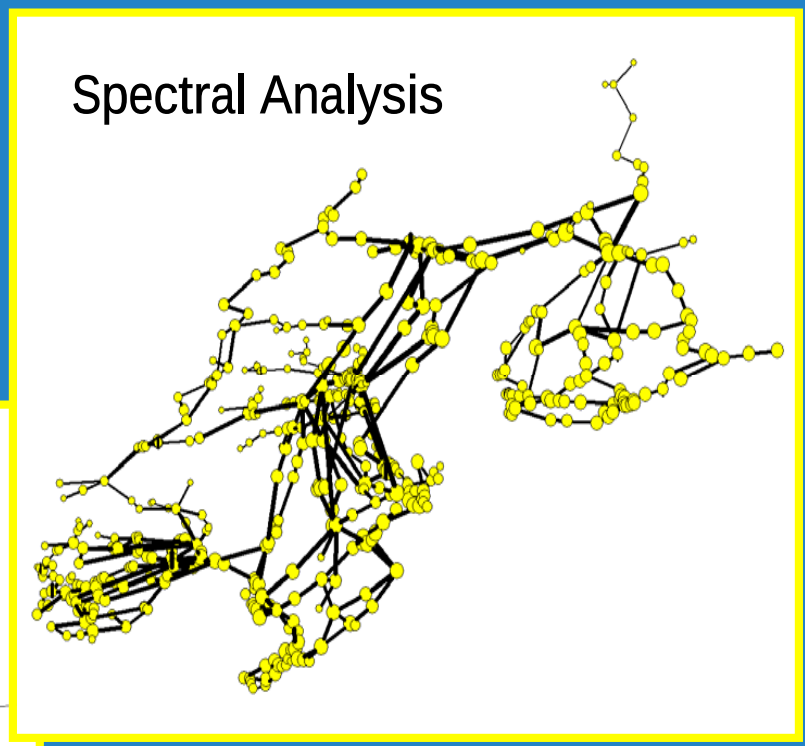
→

the relative value of
the importance



NORDEL

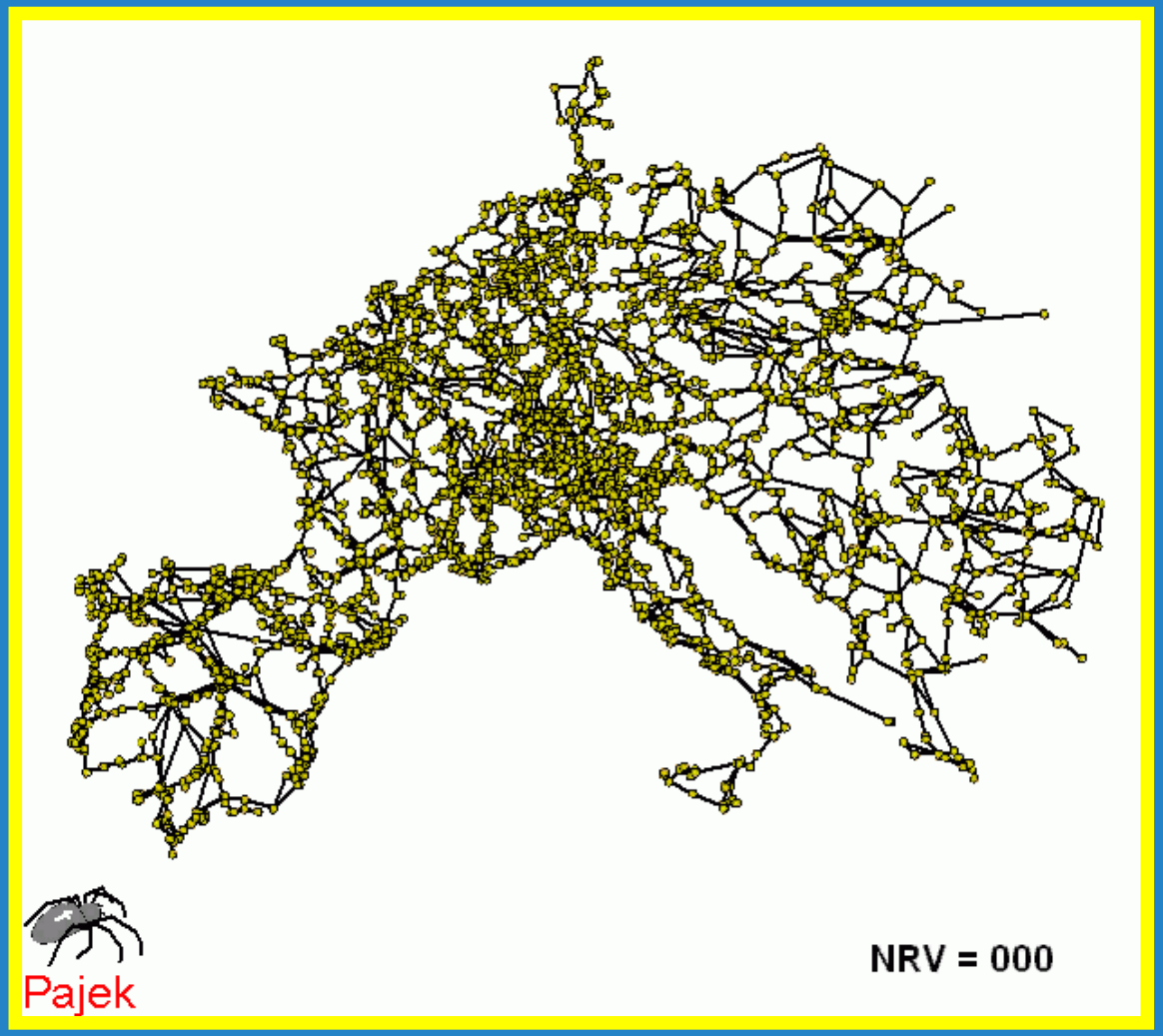




NEST Pathfinder

Man Made

Decay of network - UCTE



Betweeness centrality

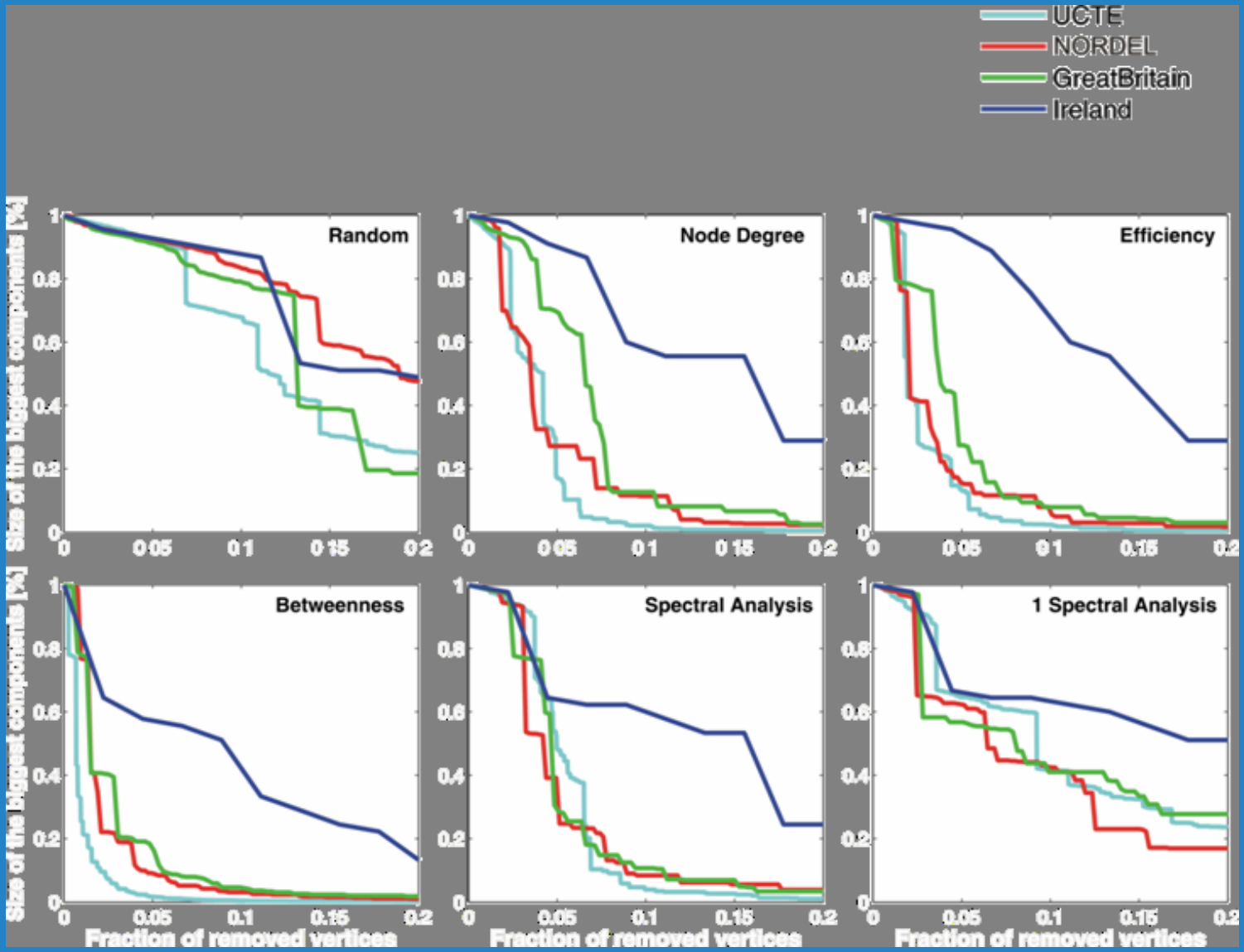
NRV – number of removed vertices

Comparison of simulations

Rate of decay is dependent on the selection criteria

BETWEENNESS CENTRALITY

Measuring the consequences



NEST Pathfinder

Man Made

Complementary activity (MASA and JRC)

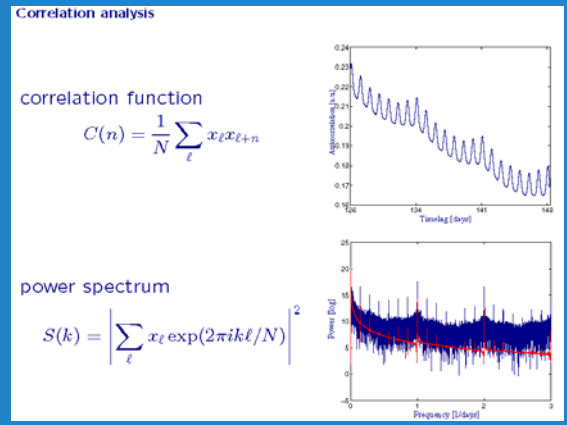
- Influence Model approach (MASA)
  - Method for deriving Interoperability matrices from networks' graph.
  - Quantitative rating of a node's vulnerability (importance) in interdependent infrastructures.
  - Model for analytically tracking various spreading phenomena like failures in power grid
- Modal analysis approach (MASA with JRC)
  - Investigation on the application of Modal weight analysis in assessment of network vulnerability
- Game theory approach (MASA)
  - link vulnerability
  - identify the weakest links in complex networks

Complementary activity(LIUC and QMUL)

- Volatility and blackouts in market dynamics (LIUC)
  - Time series analysis of spot price data
    - correlation analysis
    - persistency, fluctuations and

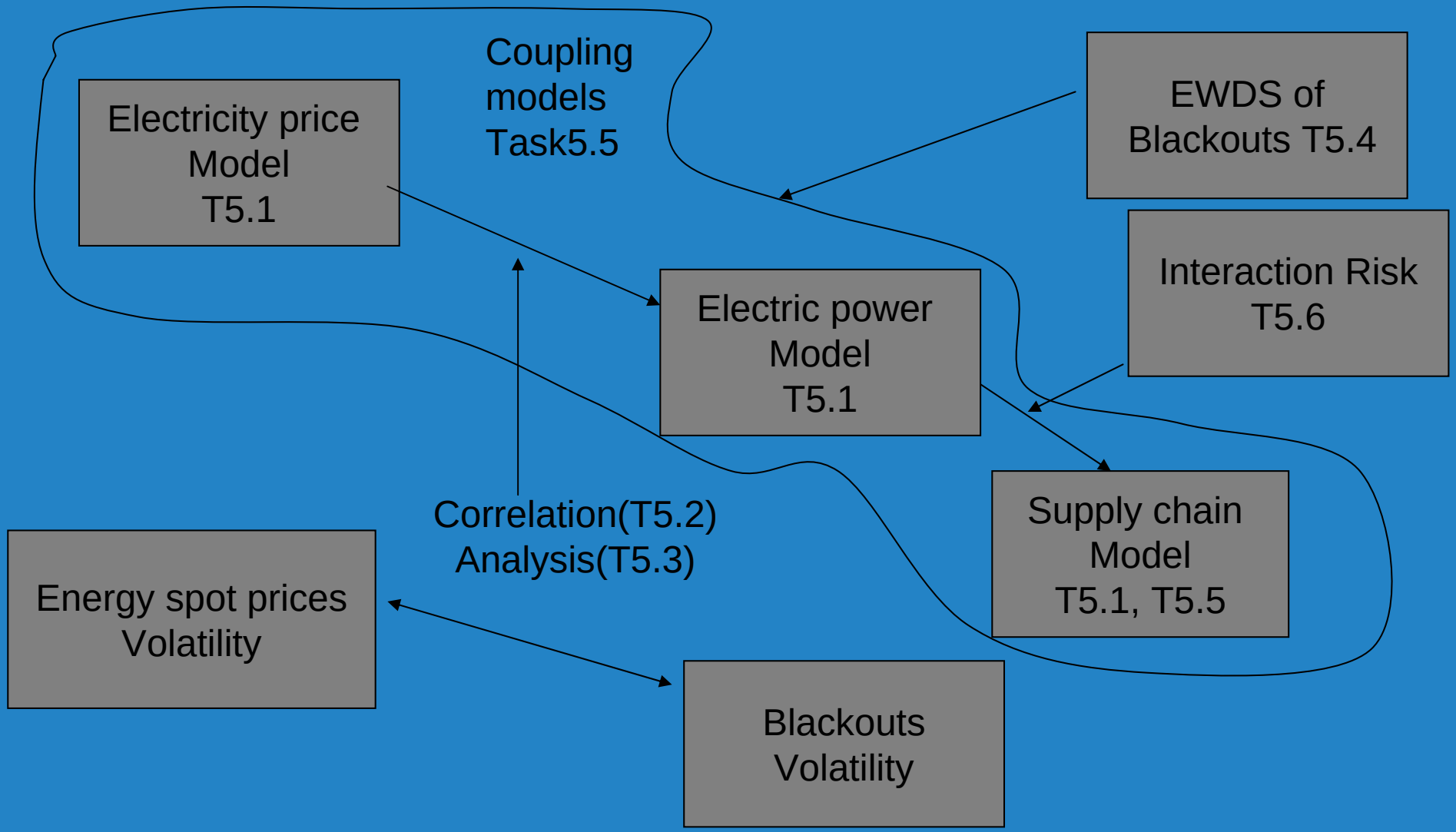
      Hurst exponent - determinism and recurrence

      quantification analysis
  - Supply chains and production networks
    - coupled Markov chain models



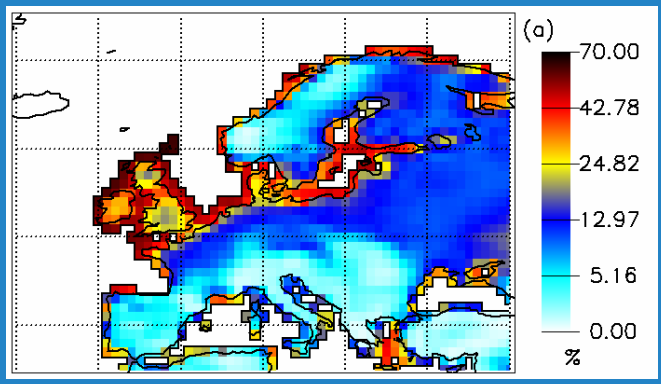
NORDPOOL ELECTRICITY SPOT PRICE DATA

Supply chain models in WP5– complexity (LIUC)

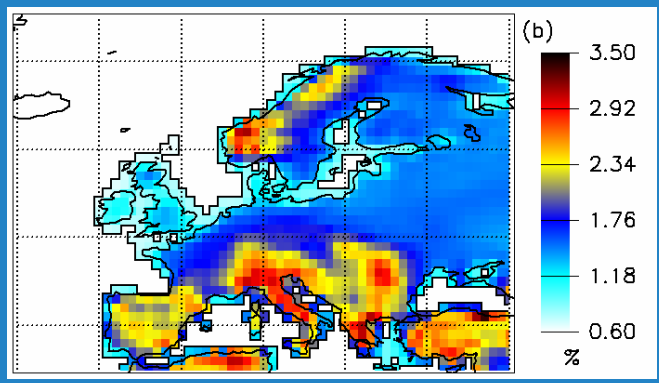


Wind power (COLB)

- New energy sources and network capacity dynamics (COLB)
  - Wind data – clear implications at the political level (pan European investment)
  - Useful first steps on dynamic programming for cascade breakdowns from overload



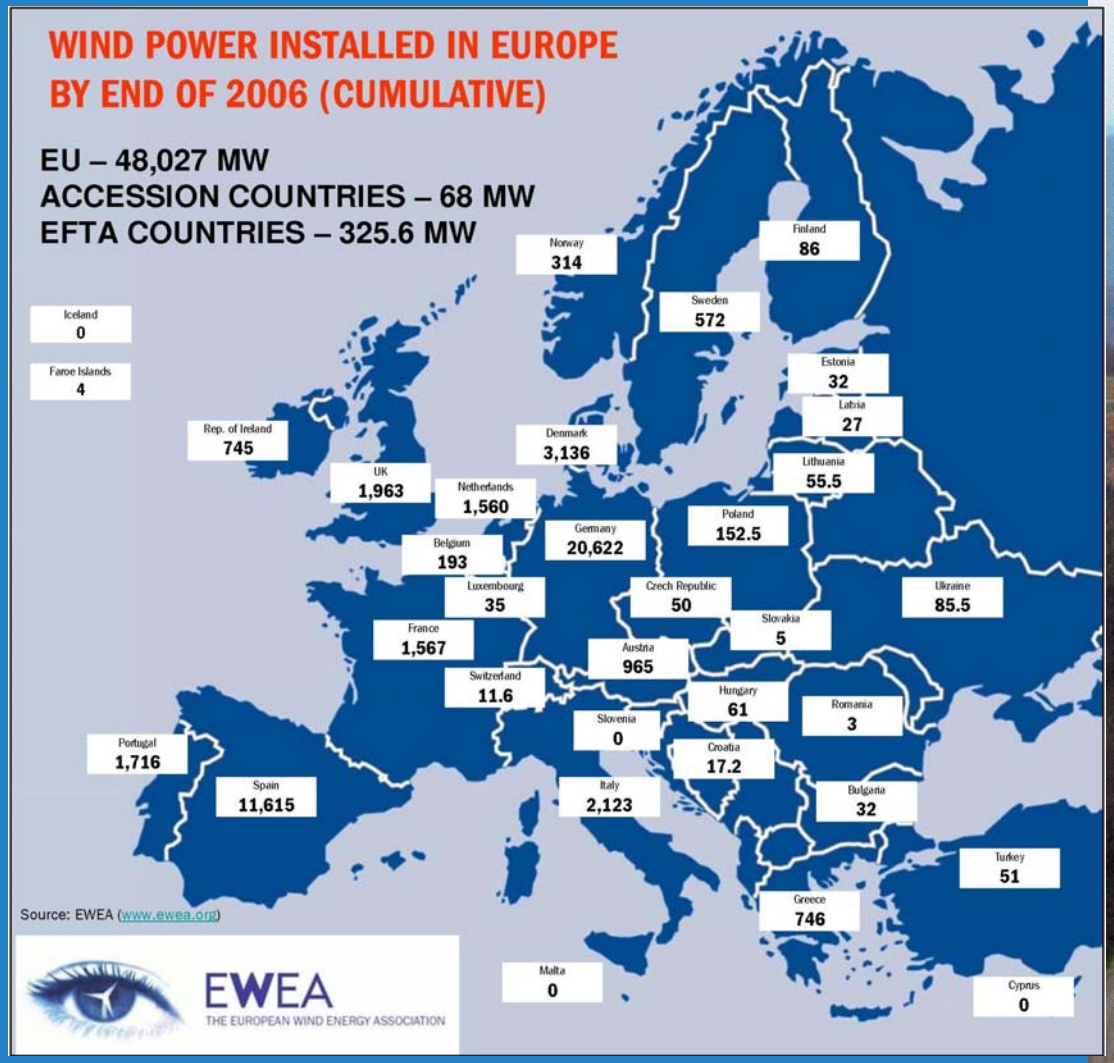
Average wind speed



Variance of wind speed

Wind field construction

and maps of potential wind energy production over Europe



wind energy

as a %

of total energy

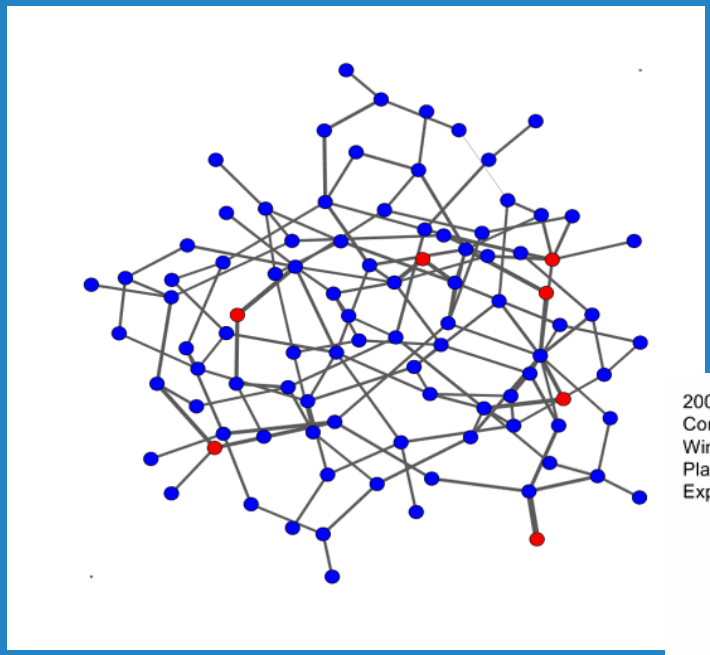
in EU

7-8%

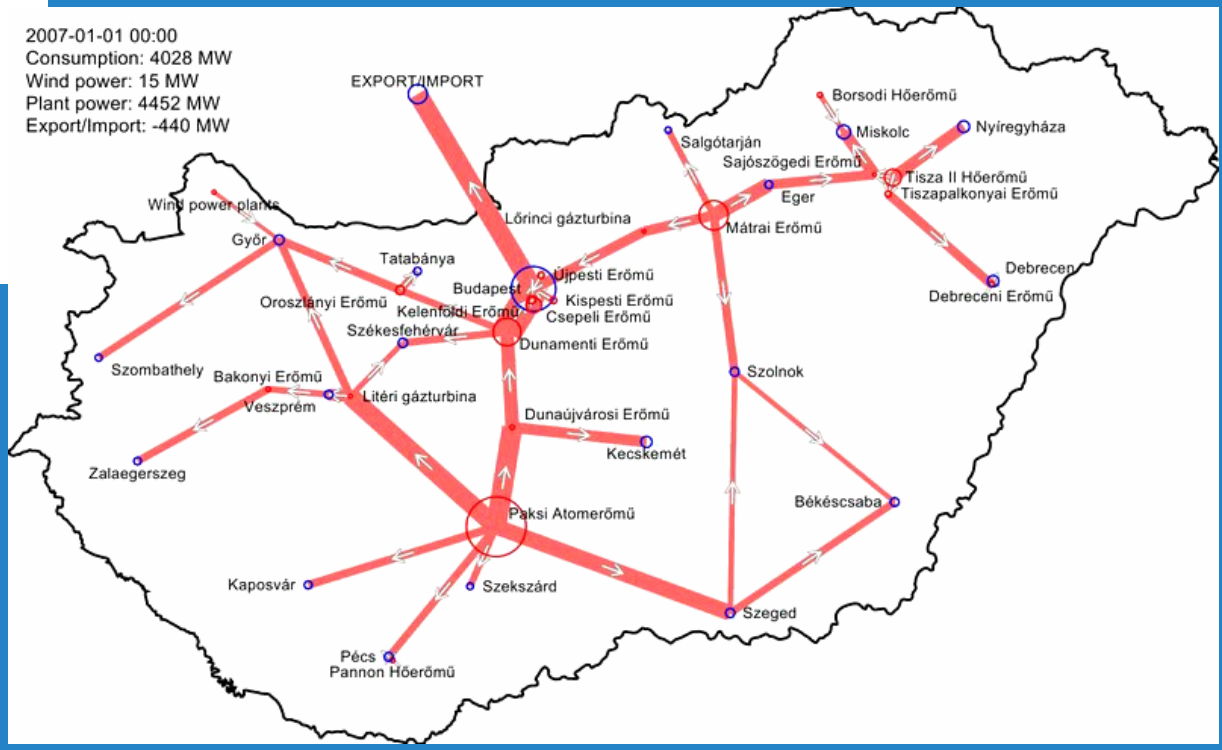
NEST Pathfinder

Man Made

Dynamic capacity model (COLB)



Realization of cascading breakdown

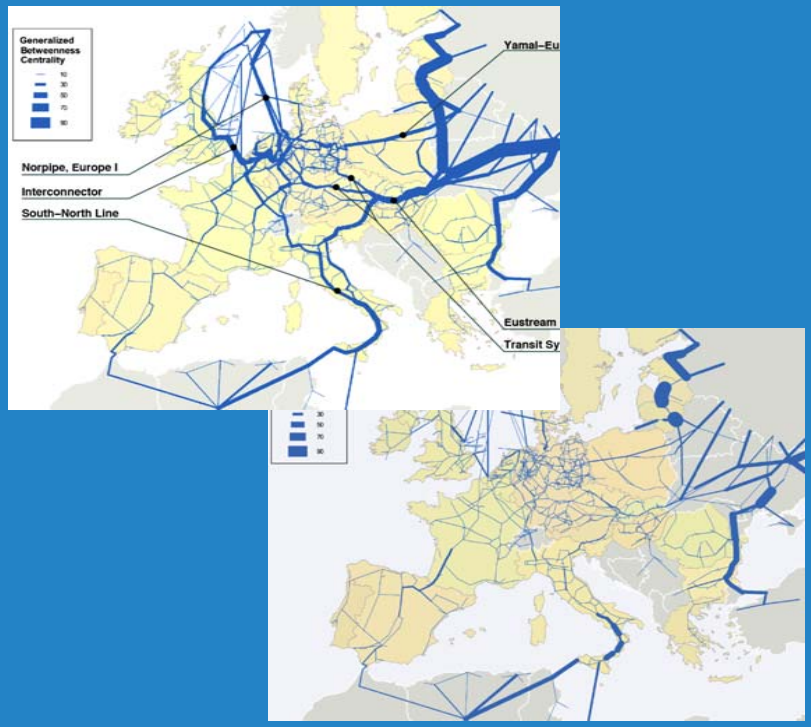


Composite energy model for Hungary

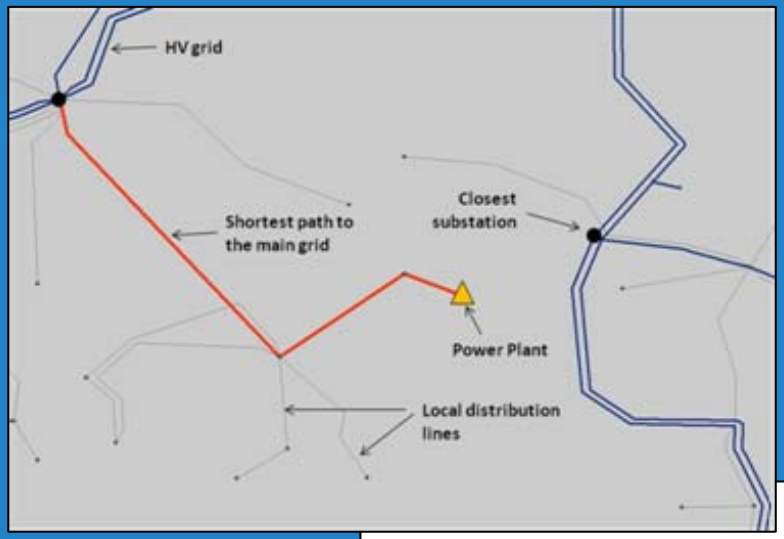
Vitality of networks (QMUL and JRC)

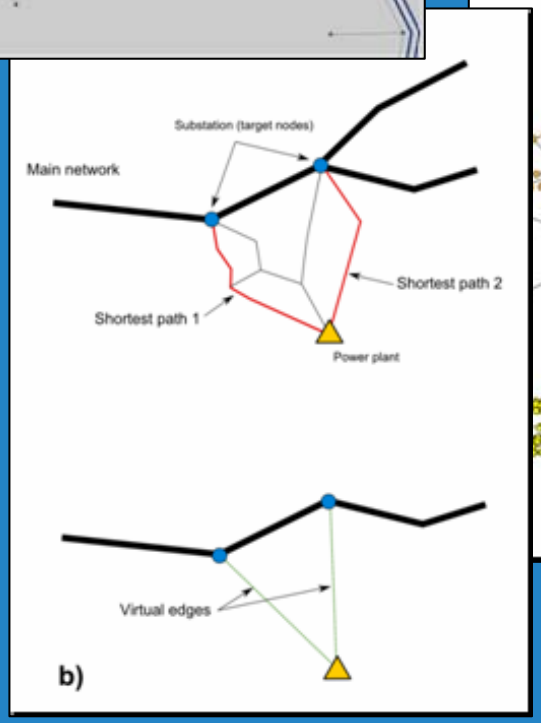
- Network quantification and vulnerability (QMUL, JRC, MASA)
  - Spectral analysis, betweenness centrality, modal analysis
  - Different vitality approaches –
    - maximum flow and
    - betweenness centrality

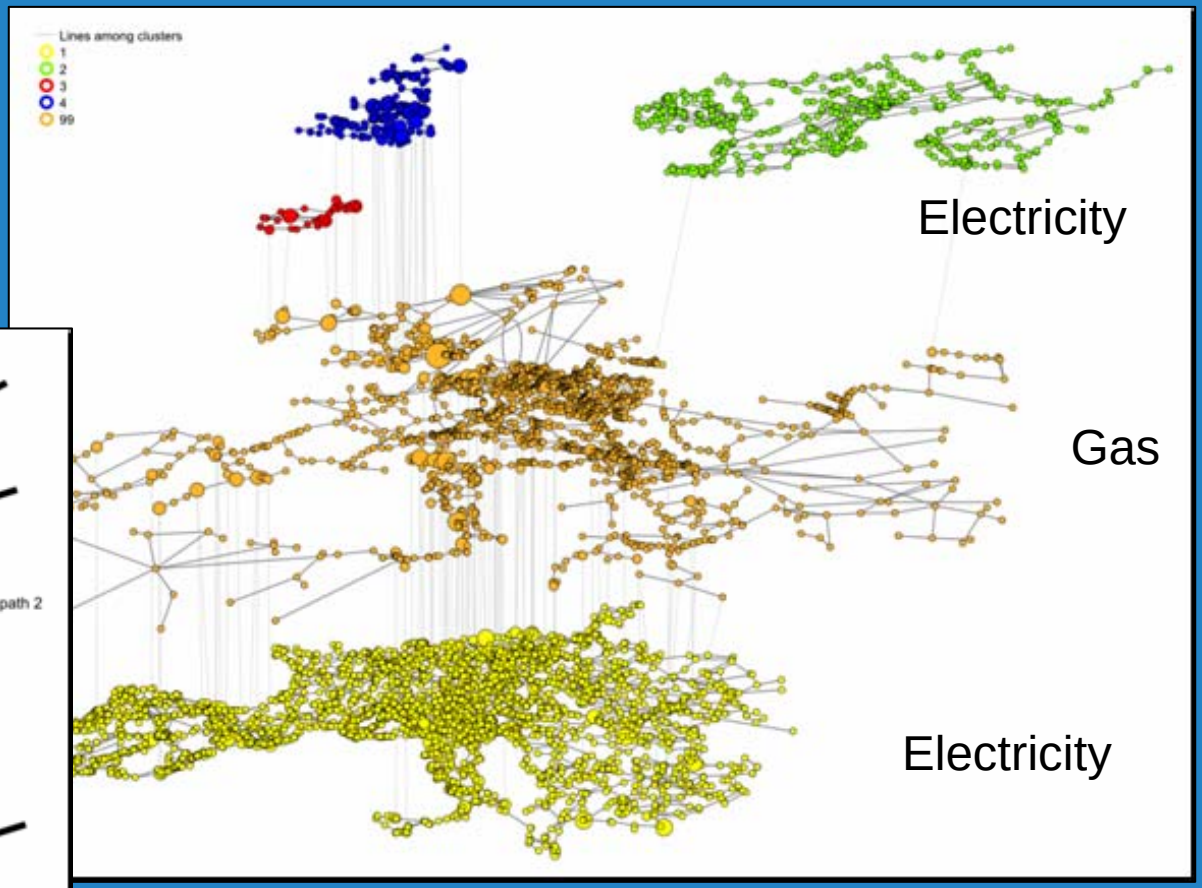
    for international borders



The Interconnected Network







NEST Pathfinder

Man Made

MANMADE Observations

- Significant collection of data and synthesis
- Use of the data to obtain significance in terms of vitality and importance
- Dynamic modelling on networks– probabilistic and dynamic - financial, economic and physical
- We now need to:
  - Bring more of the work together in the remaining part of the project
  - disseminate this work not only scientifically, but also in the media/social arenas
  - MANMADENET.EU Web pages have to be fully loaded

NEST Pathfinder

Man Made

MANMADE

DIAGNOSING VULNERABILITY, EMERGENT PHENOMENA, and VOLATILITY in MANMADE NETWORKS