An overview

David Arrowsmith
Queen Mary, University of London

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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
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
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
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<th>Data sets of major gas lines and exchange flows</th>
<th>Data sets of major gas lines between and into Western Europe <em>Platts</em>, etc.</th>
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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
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
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)

- AADTF – annual average daily flow
- Network simplification
- Connectivity analysis

EU JRC Data
Interconnected data sets

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

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
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
Ranking in networks (JRC and MASA)

Size of the vertices
Width of the edges

the relative value of the importance

Efficiency

Spectral Analysis

Betweenness

NORDEL
Decay of network - UCTE

Betweeness centrality

NRV – number of removed vertices

Comparison of simulations

Rate of decay is dependent on the selection criteria

NRV = 000

BETWEENNESS CENTRALITY
Measuring the consequences
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)

- Electricity price Model T5.1
- Electric power Model T5.1
- Correlation(T5.2) Analysis(T5.3)
- Energy spot prices Volatility
- Blackouts Volatility
- Supply chain Model T5.1, T5.5
- Coupling models Task5.5
- EWDS of Blackouts T5.4
- Interaction Risk T5.6
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%
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

- Electricity
- Gas
- Electricity

[Diagram showing interconnected network with labels like HV grid, substations, and power plants.]
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