



DIAGNOSING VULNERABILITY, EMERGENT PHENOMENA,  
and VOLATILITY in MANMADE NETWORKS

# Assembly of GIS information to compile the interconnected graph of the European electricity and gas network

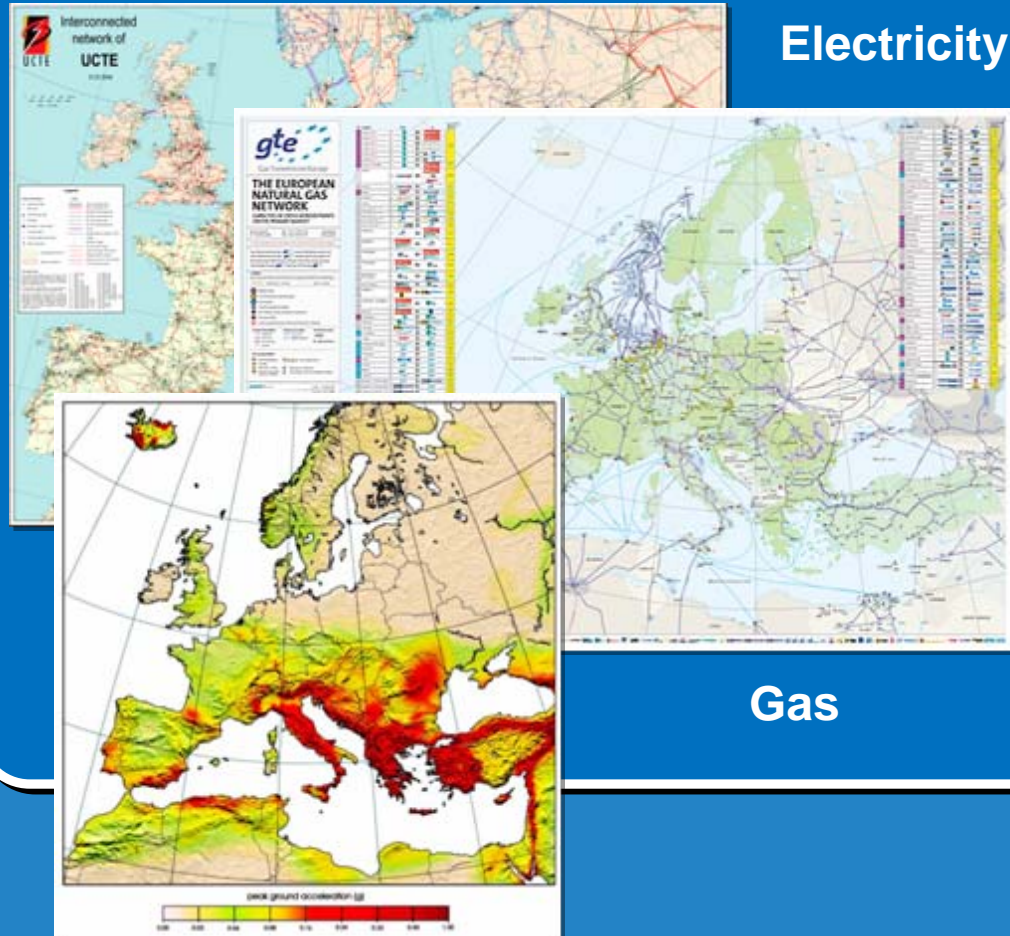
F. Bono

Joint Research Centre, Ispra - ITALY

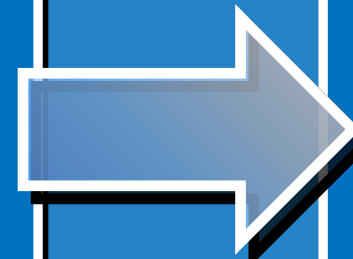
JRC, Ispra 22 of June 2009

# Motivation

## Critical Infrastructures



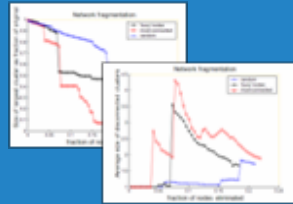
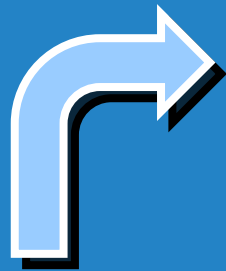
Hazards



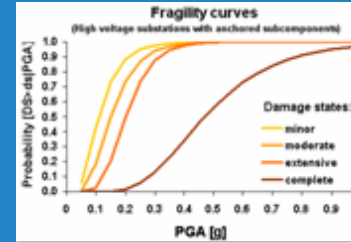
Gas pipeline disruptions  
Complex System  
Vulnerability



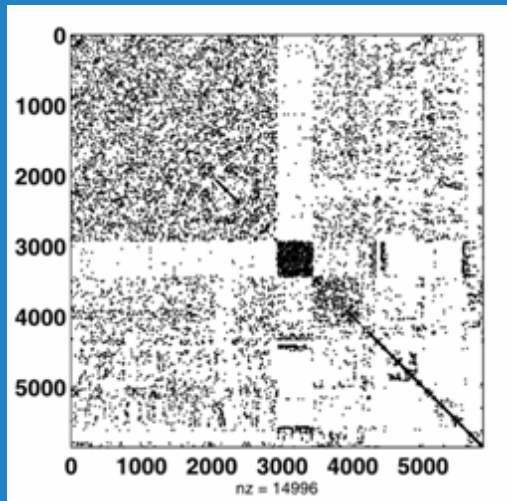
# Approach



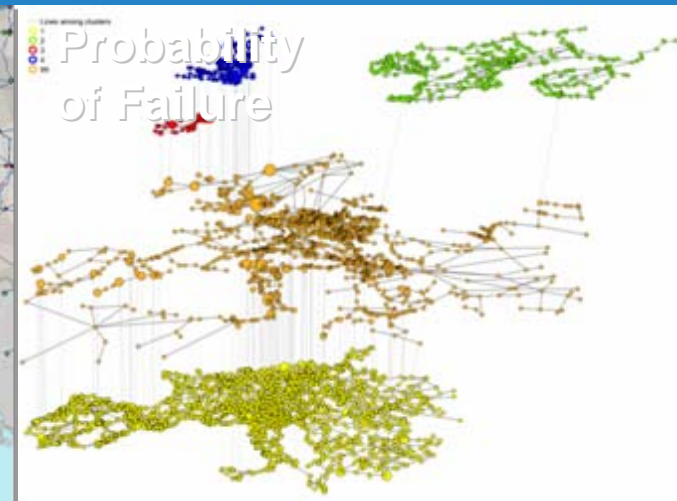
Mathematical Methods



Fragility Curves



Adjacency Matrix



Graph Network

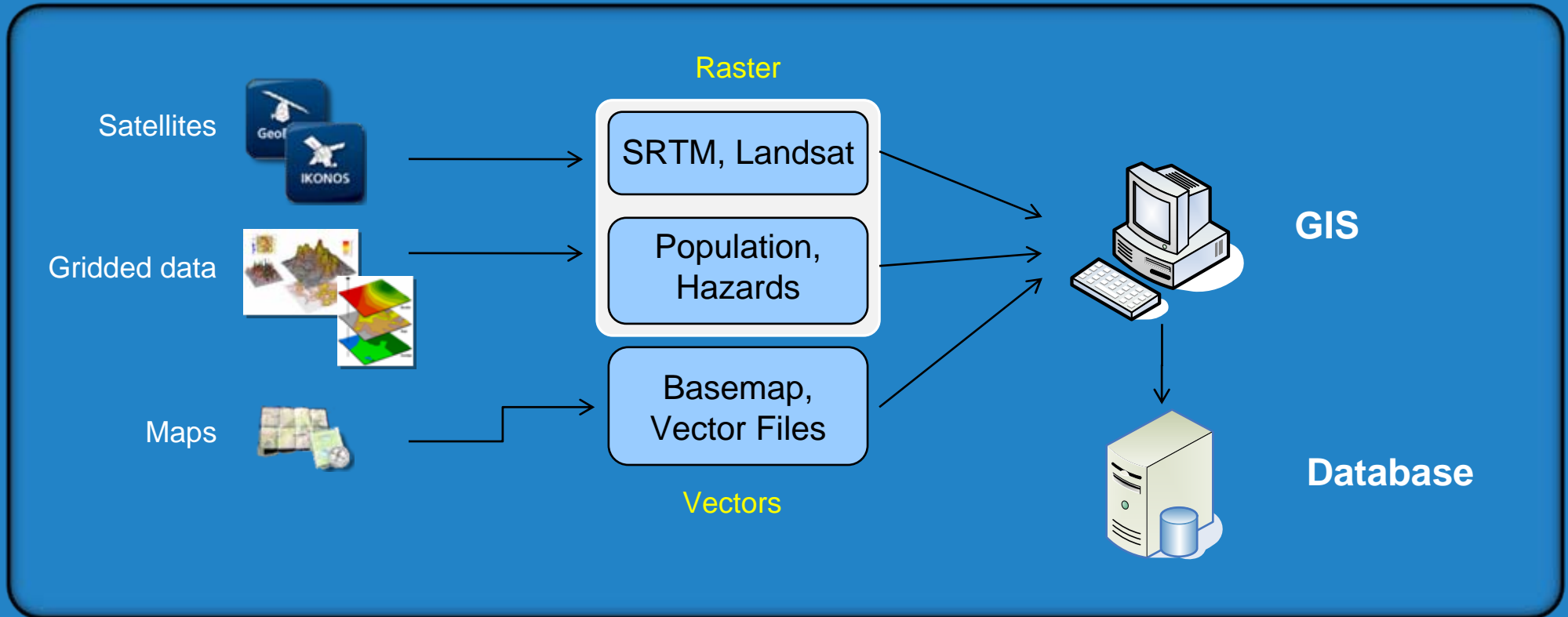
# Overview

- Introduction
- Geographical Information Systems (GIS)
- GIS and networks
- Data processing issues
- The EU interconnected energy network

# Introduction

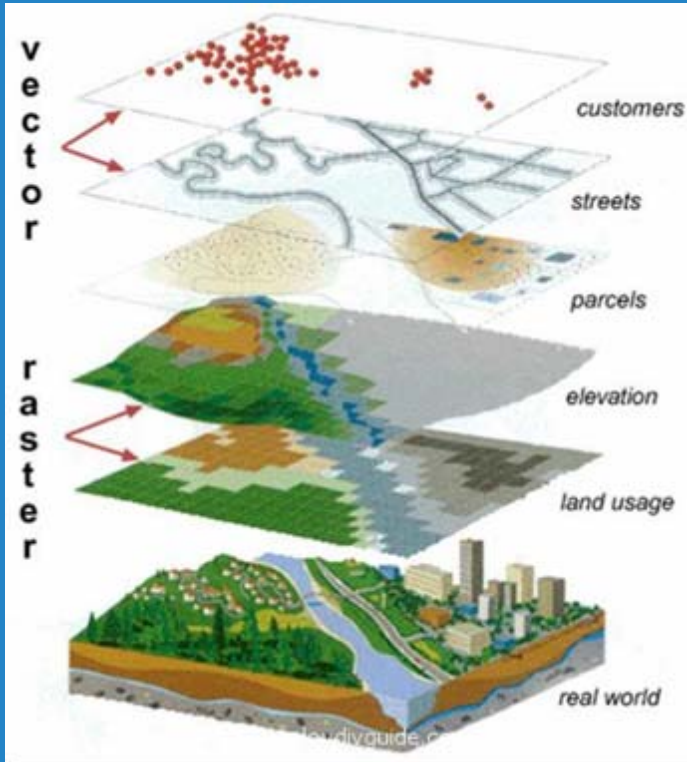
- The recent improvements of GIS has led to the acquisition of massive data sets on territorial and infrastructural elements (transportation, utilities and social networks with a geographical component) that were previously unavailable.
- Georeferenced data are a precious commodity that allows us to compile and study man-made networks, provided that a convenient preprocessing of the data is performed.
- GIS data mining and processing methods to effectively combine heterogeneous data sources into meaningful real-world networks are presented, with an insight into the problems and solutions adopted within the ManMade project.

# Geographical Information Systems (GIS)



A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.

# GIS data



## Vector data model.

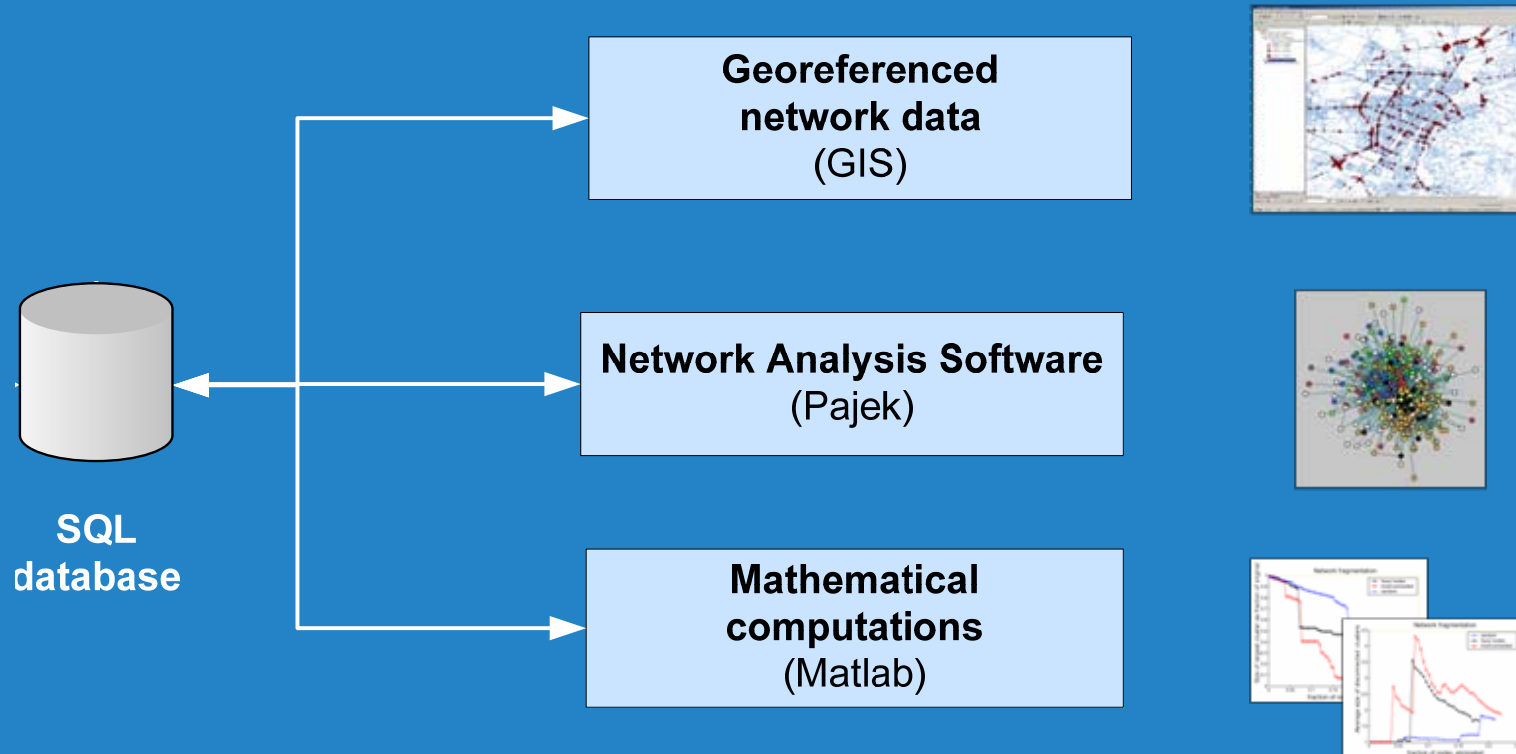
Discrete features, such as infrastructural elements, are usually represented using the vector model.

## Raster data model.

Continuous numeric values, such as elevation, and continuous categories, such as population distribution, are represented using the raster model



# GIS and Network Analysis





# GIS and networks

- GIS Network Analysis basic functionalities
- Topology issues
- Generation of interconnected networks  
from disjoint GIS data

# Topology Issues

## GIS

## Networks

<p><b>Line</b></p> <p><b>Must not have dangles</b></p> <p>Use this rule when you want lines in a feature class or table to consist of one another.</p> <p><b>Must not have pseudonodes</b></p> <p>Use this rule to clean up data with irregularly subdivided lines.</p>	<p><b>Line</b></p> <p><b>Must not overlap</b></p> <p>Use this rule with lines that should never occupy the same space with other lines.</p>
<p><b>Line</b></p> <p><b>Must not self overlap</b></p> <p>Use this rule with lines whose segments should never occupy the same space as another segment on the same line.</p>	<p><b>Line</b></p> <p><b>Must not self intersect</b></p> <p>Use this rule when you only want lines to touch at their ends without intersecting or overlapping themselves.</p>



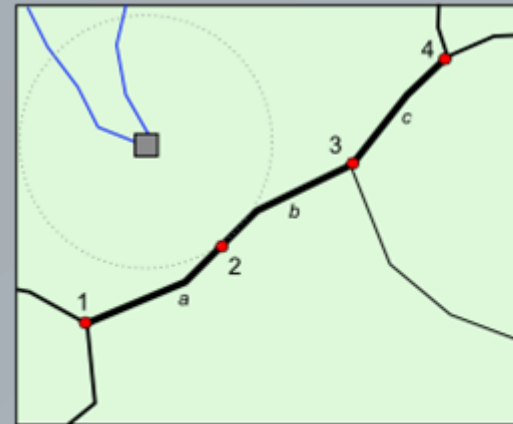
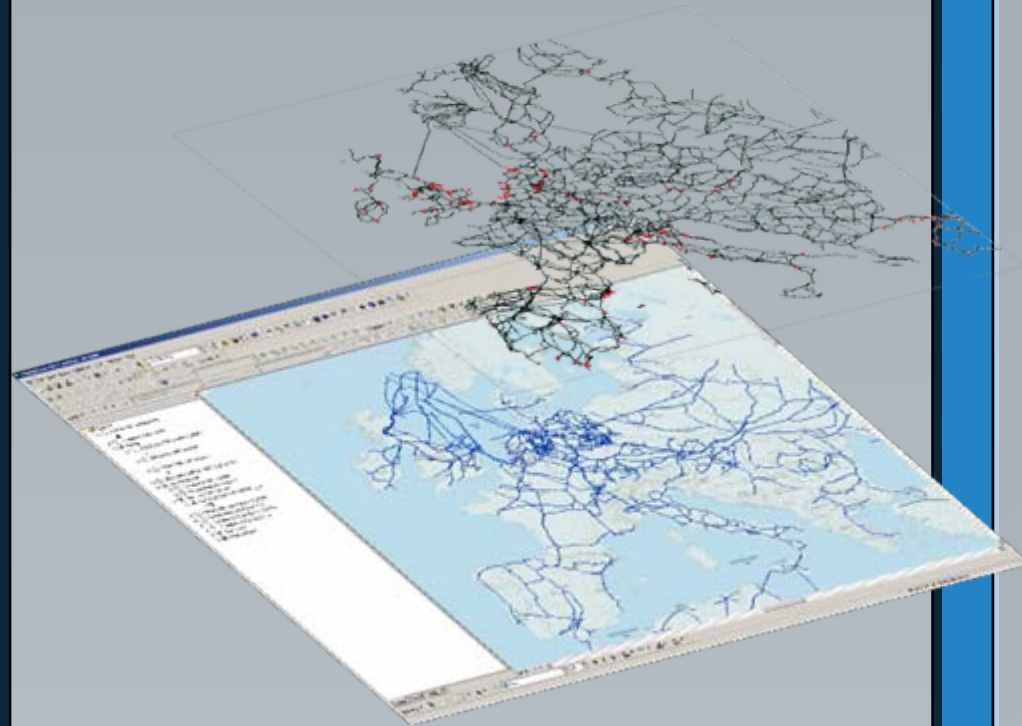
### Network Analysis

- Nodes degree
- Strong Components
- Loops
- Closed Cycles

Map Images georeferencing

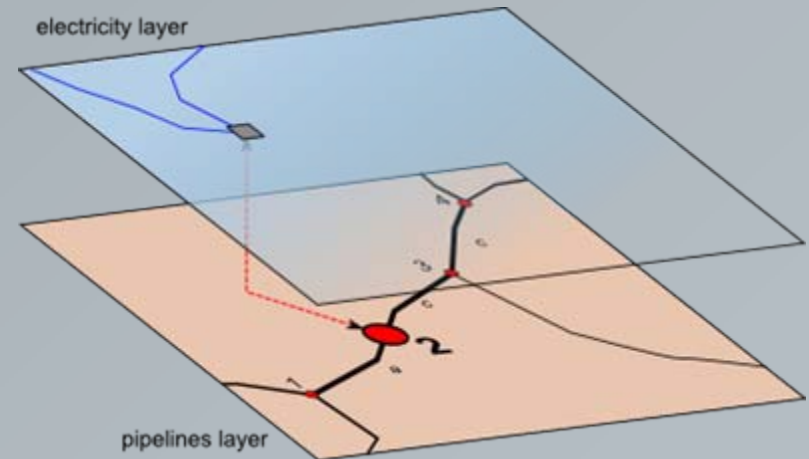
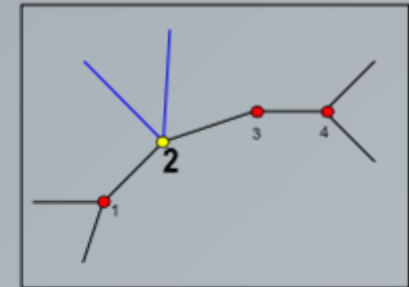
# Relating network elements

## GIS gas and electricity networks

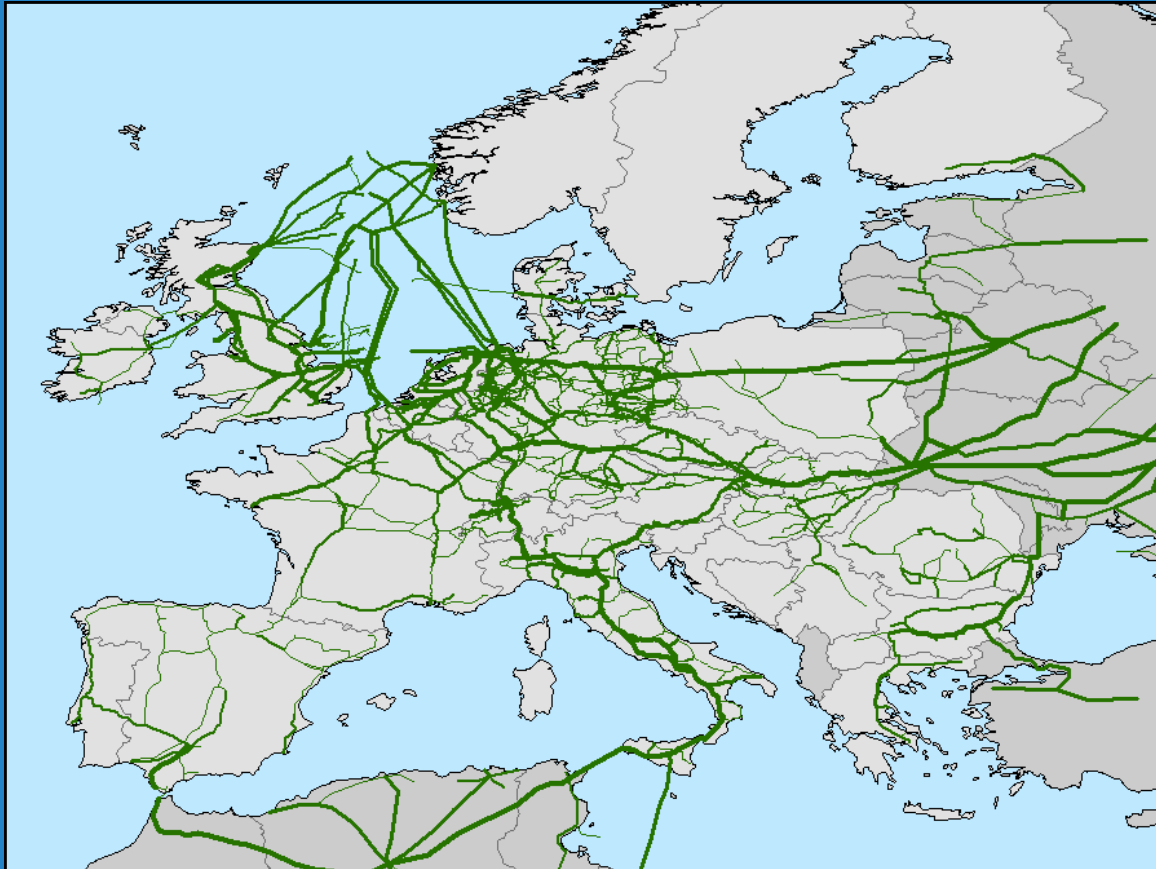


- Main pipelines
- Electricity Lines
- Power Plant
- Node

Resulting Network



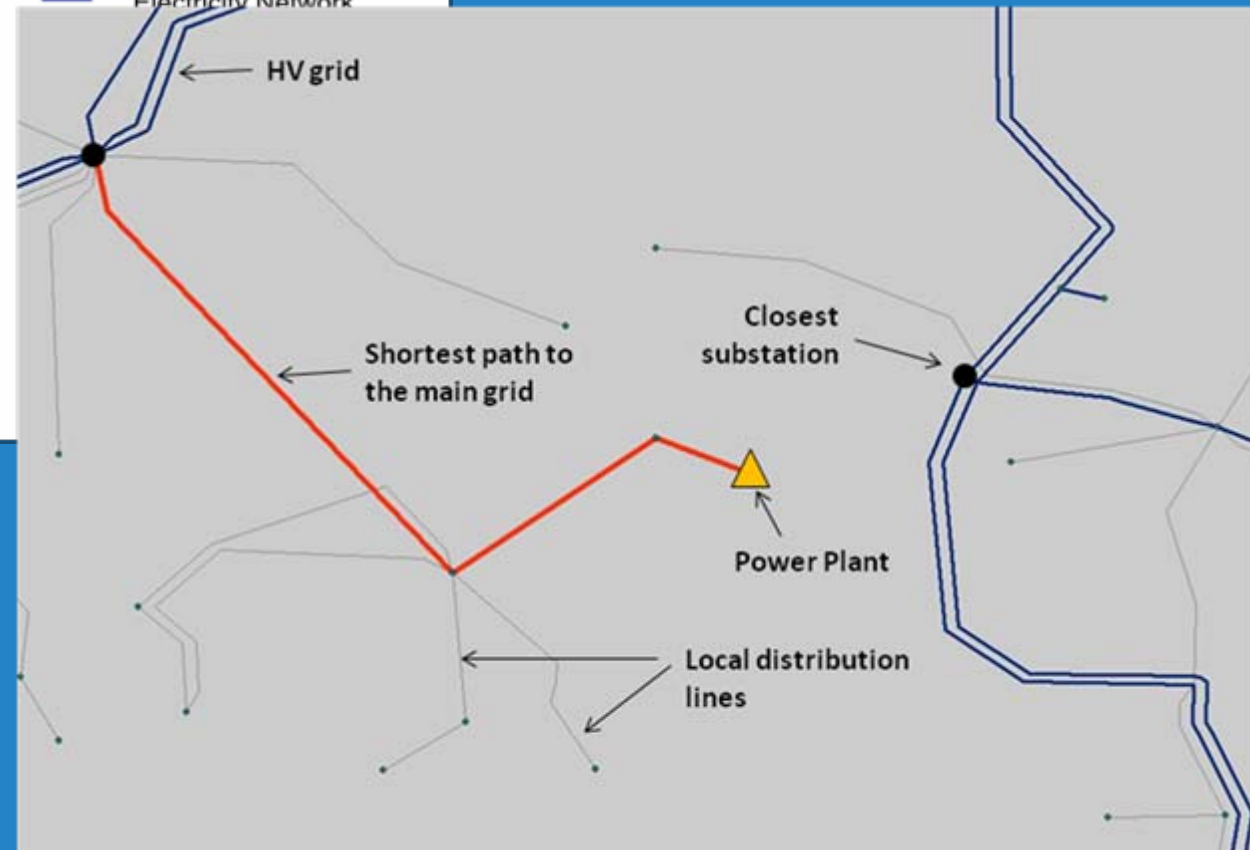
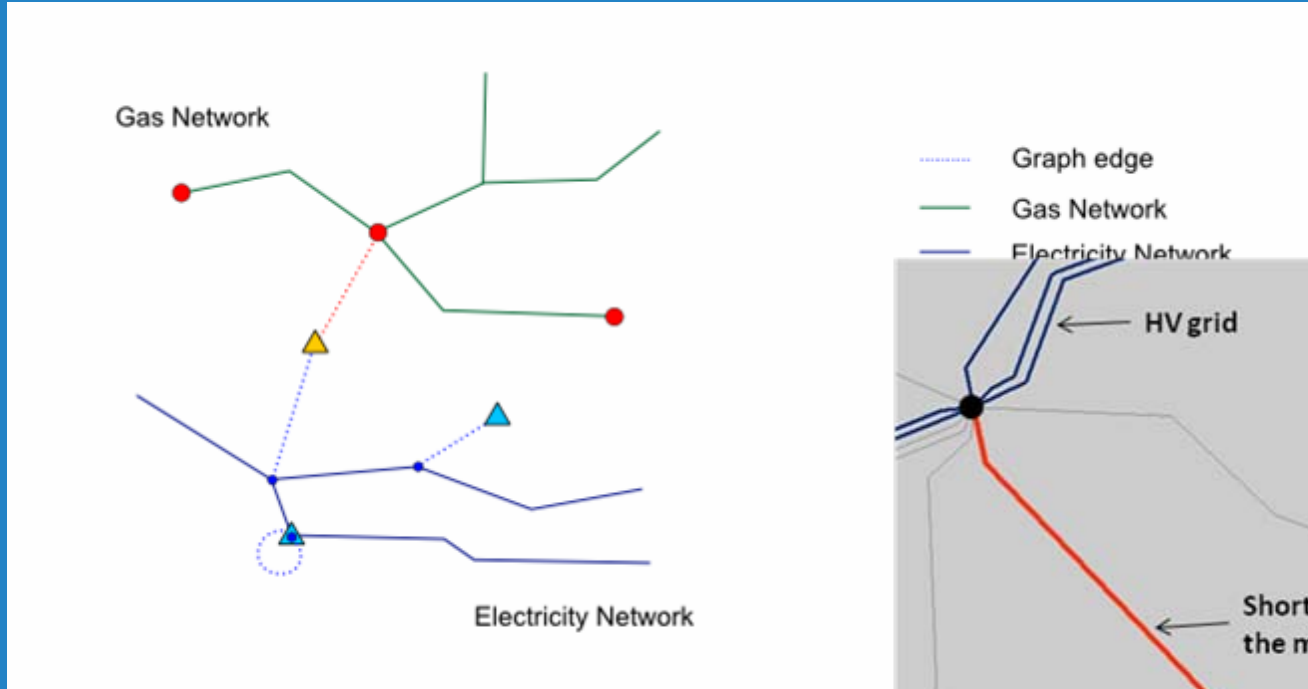
# Condensing the network



- Working with networks at continent level
- Focus on major networks
- Relating objects connected via the minor network

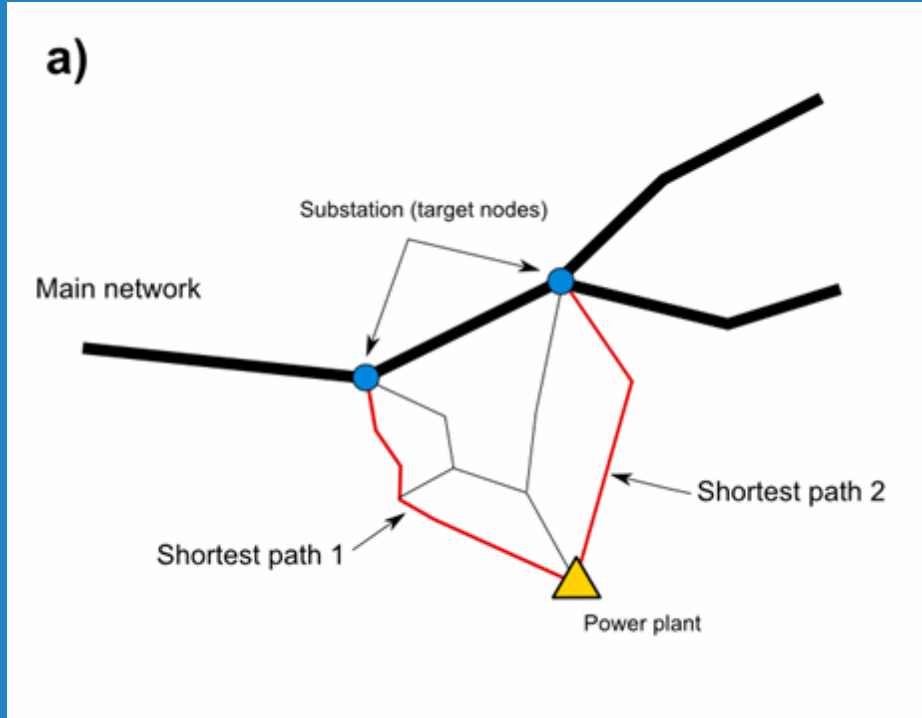
# Inter-network connectivity

## Plants and grids connections

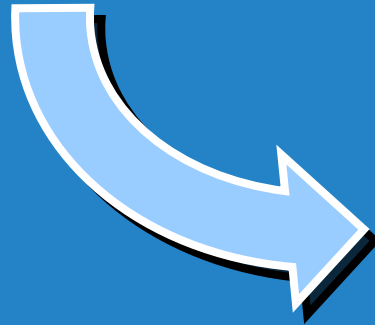
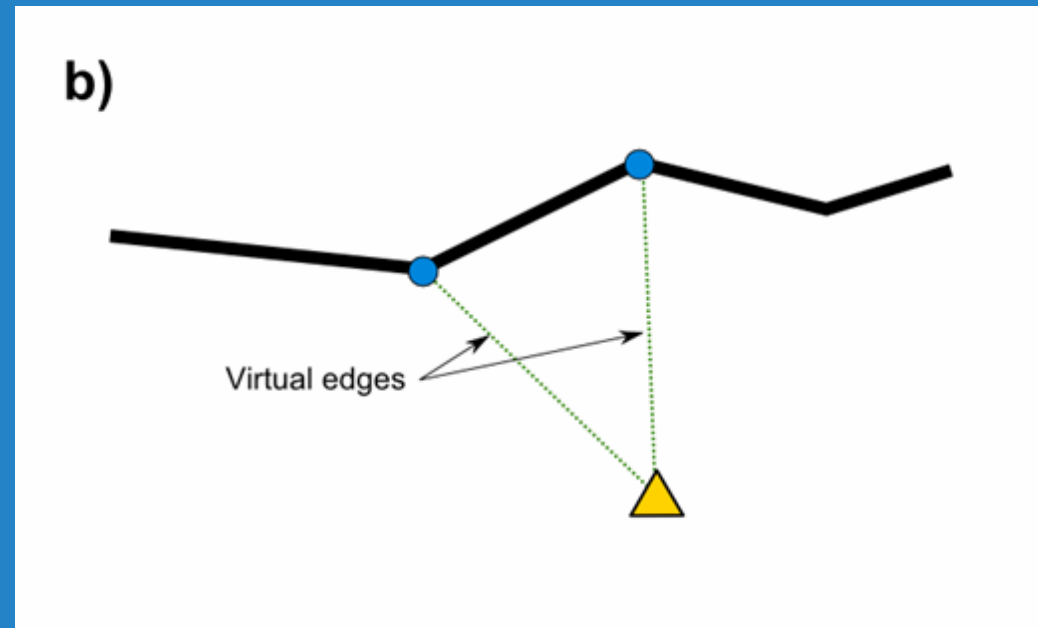


Shortest path (red line) between a power plant and the substation on the main network; the geographically closest substation is not the one to be associated with the plant

# Virtual Edges

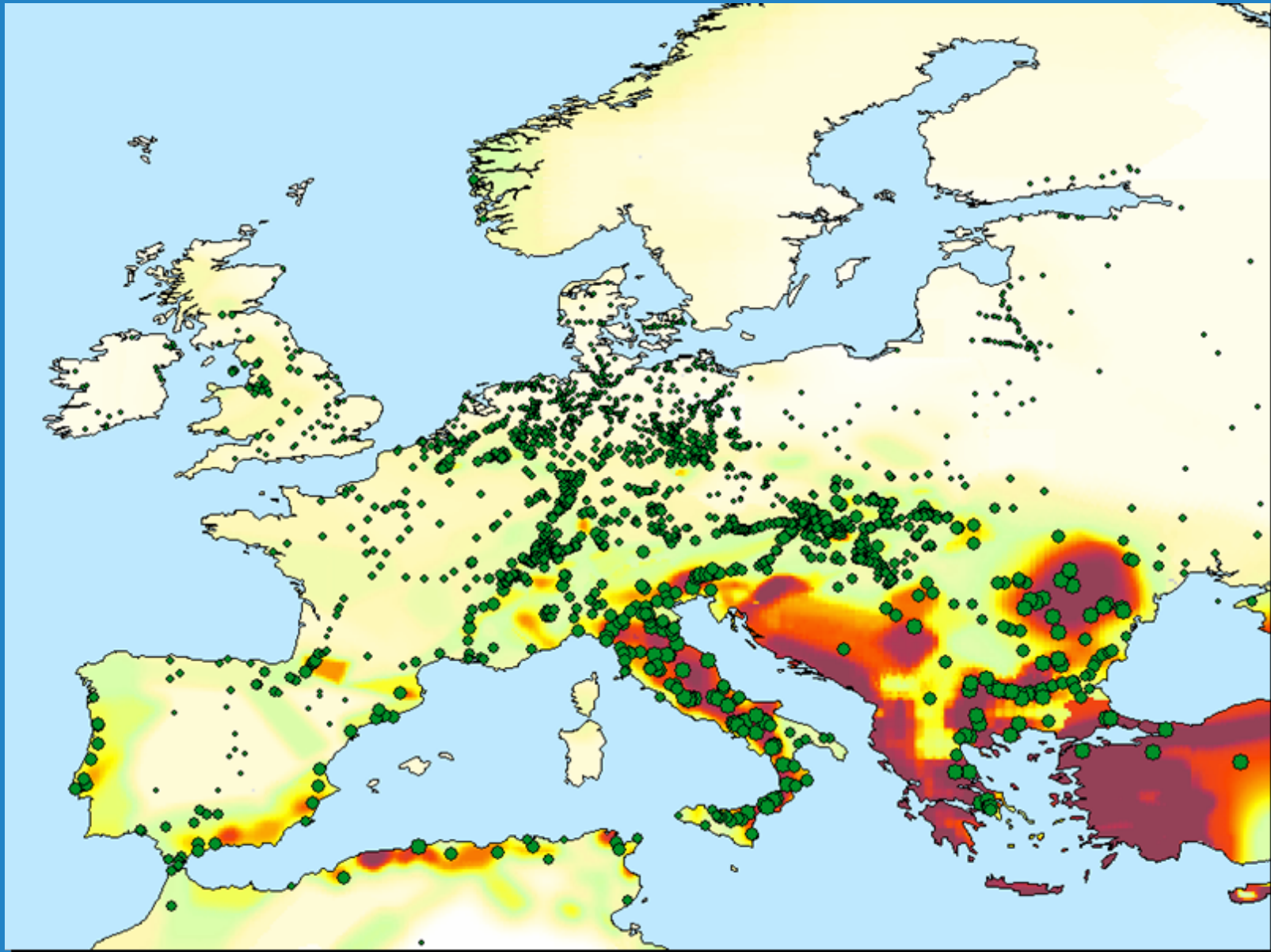


Breadth first search of the shortest paths between a power station and the substations on the main network

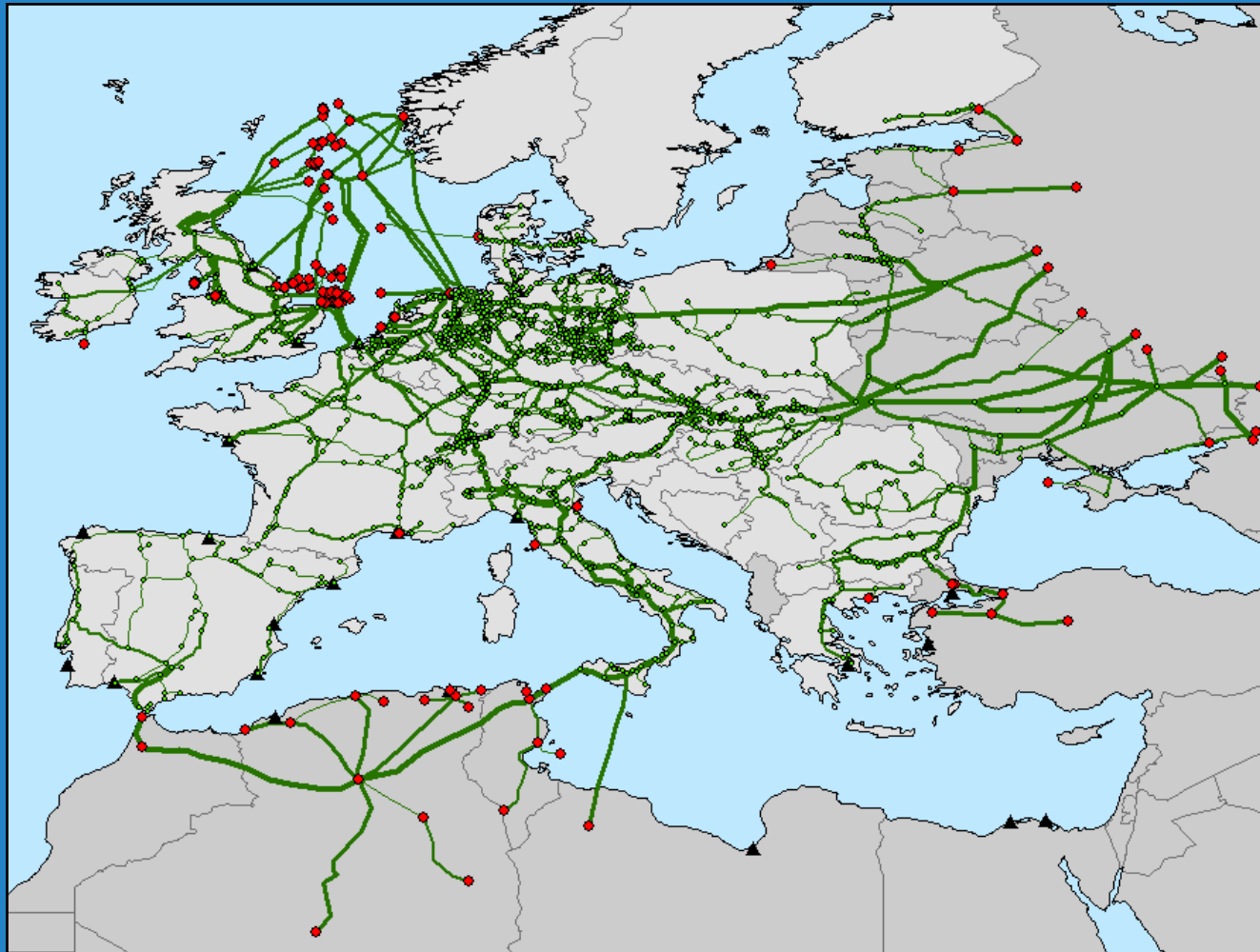


# Setting the hazard level on the networks' elements

**SOURCE:**  
The Global  
Seismic Hazard  
Assessment  
Program  
(GSHAP)



# Gas Sources



LNG Terminals

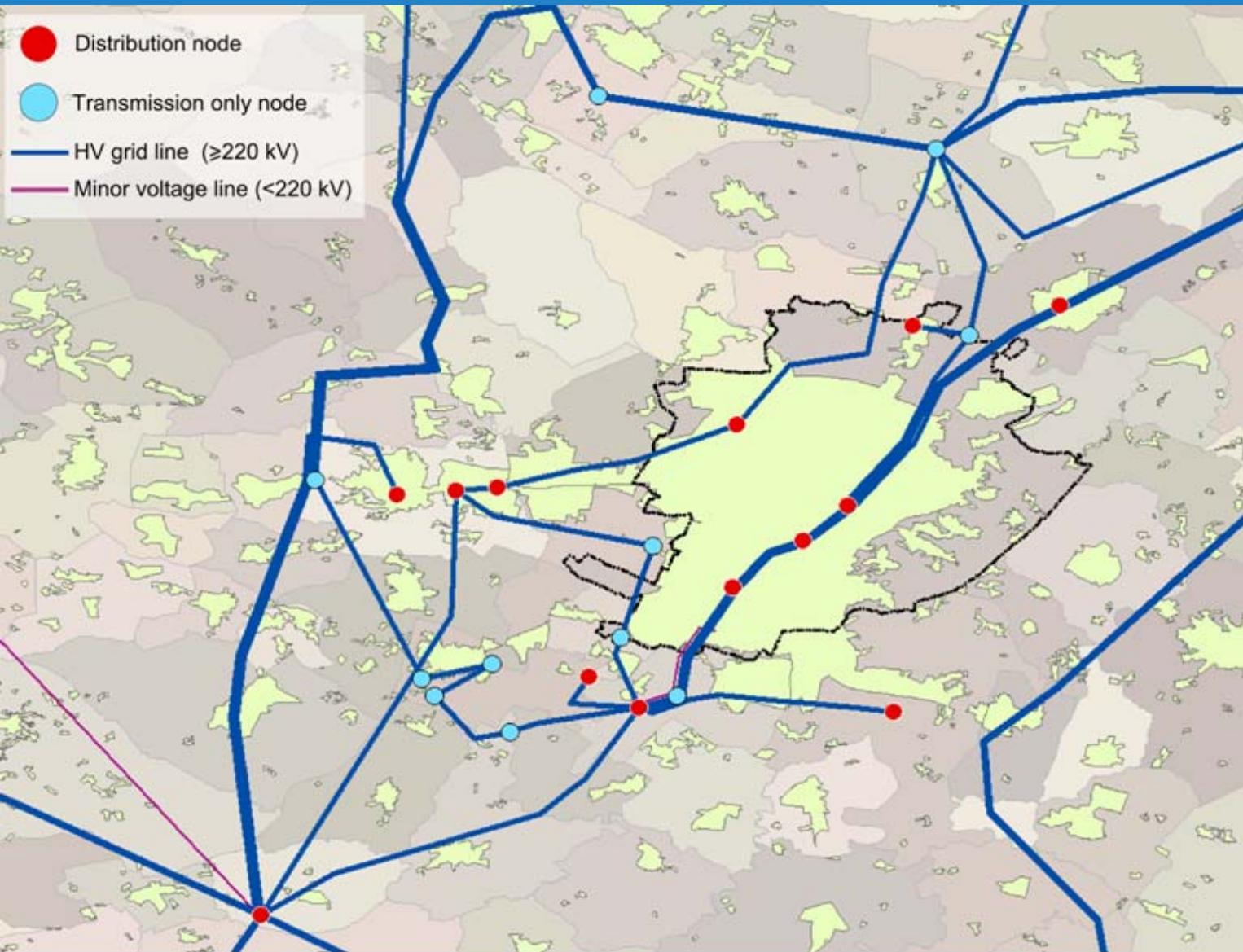
Natural Gas  
Production Regions

Natural Gas  
Producing Countries

Open Sea gas nodes



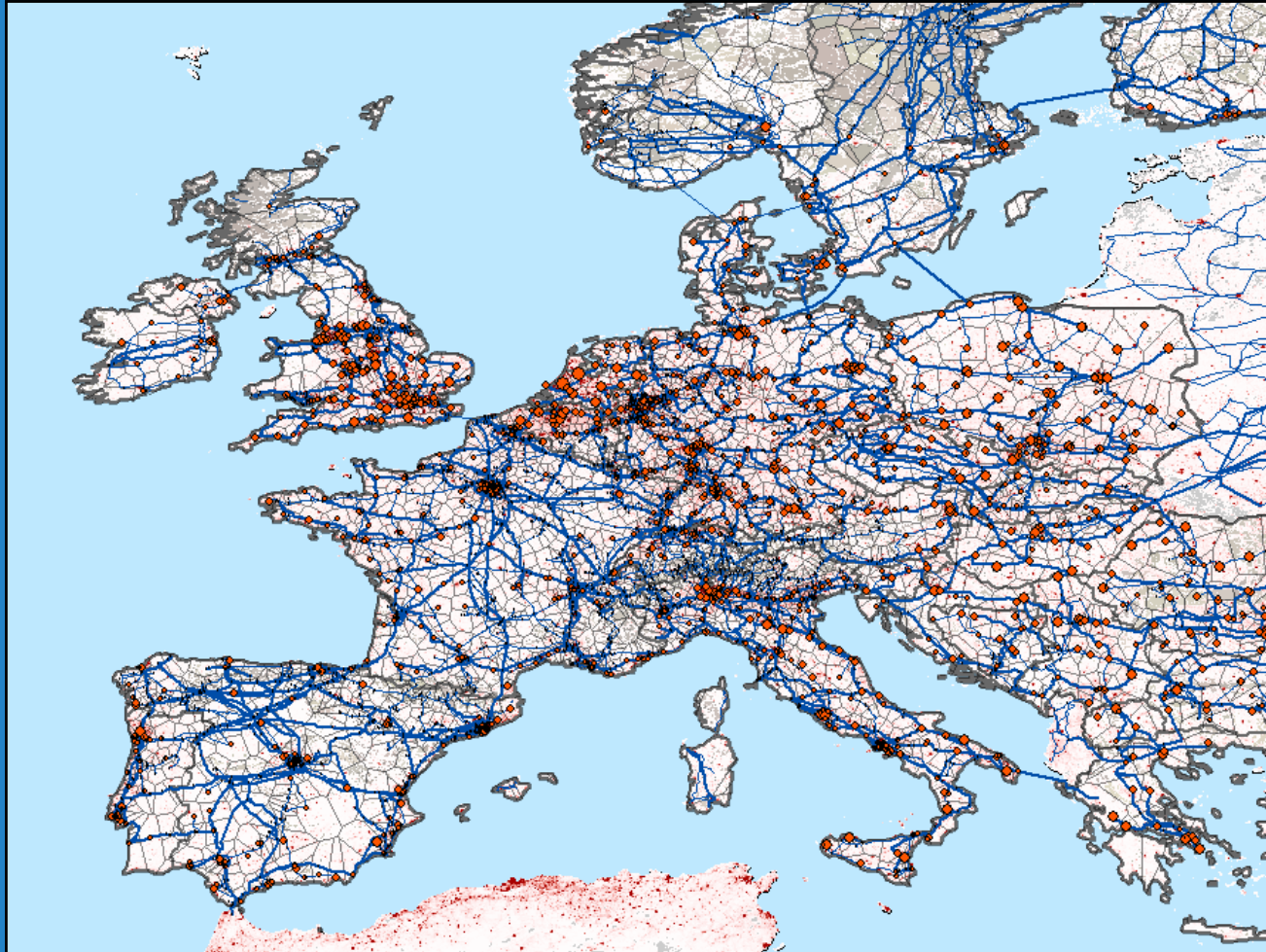
# Electricity Transmission/Distribution



The original electricity grid dataset is composed of transmission lines and substation of the whole Europe.

The problem to distinguish between the nodes serving the distribution network and those that belongs to the high voltage transmission lines only, led to the definition of a set of rules in the GIS

# Population



Distribution substation (red dots), population and served areas (polygons).

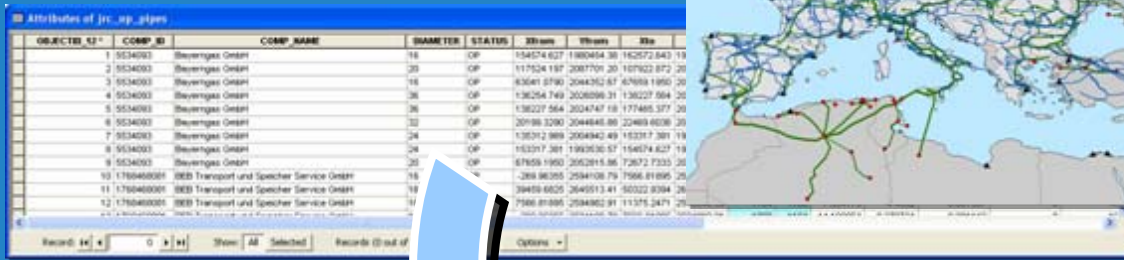
In order to evaluate the population affected in case of hazard-induced damages to the electricity network, the customers served by each distribution substation was computed.

The number of customers is computed generating Thiessen polygons for the distribution substations.

Thiessen polygons define individual areas of influence around each set of points; each polygon therefore defines the served area of each substation.

# Generation of adjacency matrices

1. GIS data extraction



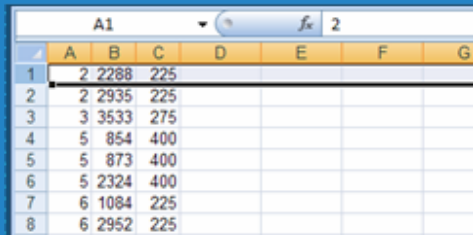
OBJECT_ID	COMP_ID	COMP_NAME	DIAMETER	STATUS	Xfrom	Yfrom	Xto
1	5534093	Steuerigas Gaset	16	OP	134574.627	1880454.38	162572.643
2	5534093	Steuerigas Gaset	20	OP	117524.187	2083701.20	167922.872
3	5534093	Steuerigas Gaset	16	OP	83641.8790	2044292.67	67688.1890
4	5534093	Steuerigas Gaset	26	OP	136254.749	2020590.31	136227.864
5	5534093	Steuerigas Gaset	36	OP	136227.564	2024747.18	177485.377
6	5534093	Steuerigas Gaset	32	OP	20188.2290	2044845.88	22489.6038
7	5534093	Steuerigas Gaset	24	OP	136212.989	2004842.49	153217.381
8	5534093	Steuerigas Gaset	24	OP	153217.381	1992530.57	154574.627
9	5534093	Steuerigas Gaset	25	OP	87859.1990	2052815.86	72672.7225
10	176048005	SEB Transport und Speicher Service Gaset	18	OP	289.88205	2584108.79	7066.81895
11	176048005	SEB Transport und Speicher Service Gaset	18	OP	39459.6625	2640513.41	50222.8084
12	176048005	SEB Transport und Speicher Service Gaset	17	OP	7980.81895	2584802.91	11376.2479



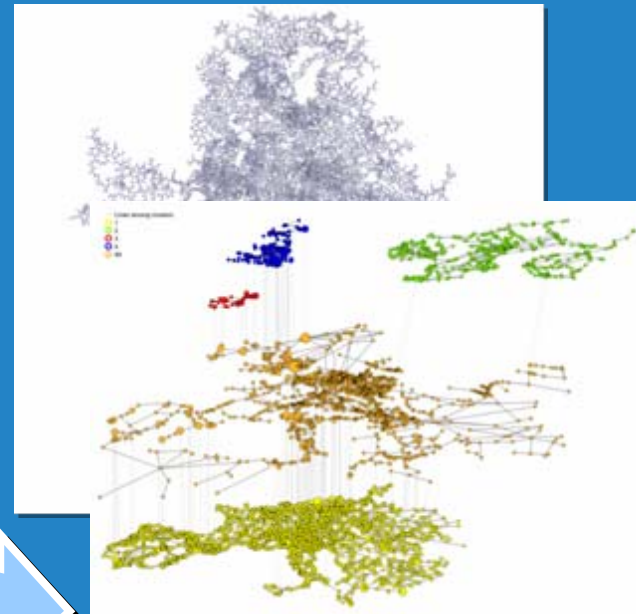
4. GIS import of computed values



2. Network grid compilation  
(IDfrom, IDto, value)



	A	B	C	D	E	F	G
1	2	2288	225				
2	2	2935	225				
3	3	3533	275				
4	5	854	400				
5	5	873	400				
6	5	2324	400				
7	6	1084	225				
8	6	2952	225				



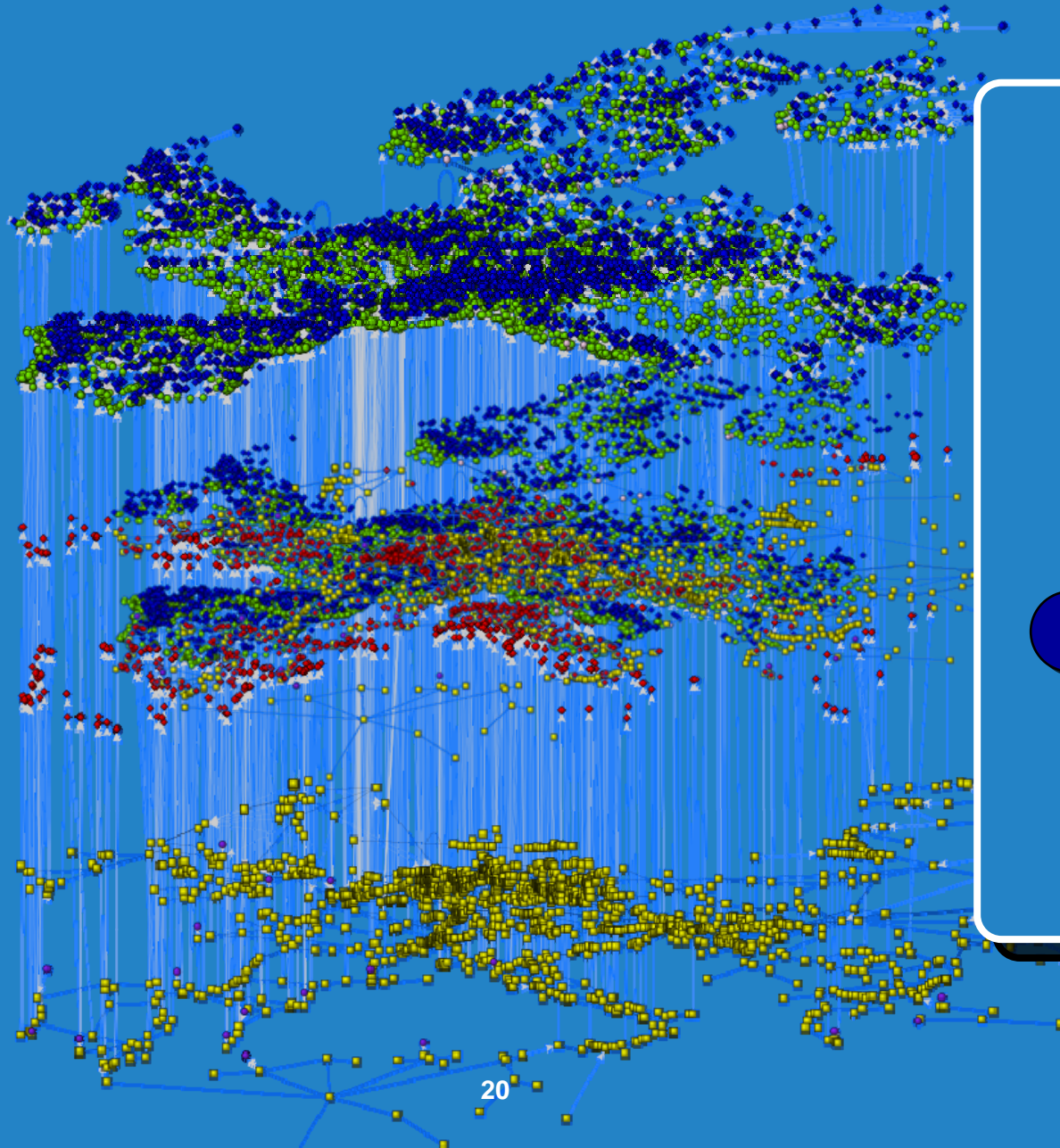
3. Matlab and Pajek data import and processing

# The interconnected Network

Gas pipelines  
2212 nodes  
2644 edges  
75 Arcs  
21 LNG terminals

Electricity grid  
5127 subs  
6726 edges

Power plants  
998 Natural Gas  
4383 Others



## Directed Network

