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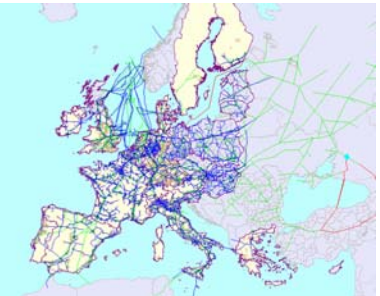
Modelling Distributed Vulnerabilities in a Complex Network

R D Pride, C Di Mauro, C Logtmeijer, S Bouchon, J P Nordvik, A Poucet



Infrastructure I: Methods of vulnerability analysis

19th May 2008

Presentation Outline

- **EU policy & the reasoning behind the current activity**
  - The European Programme on Critical Infrastructure Protection (EPCIP)
    - Identification of European critical infrastructures (ECI)
- **Methodology**
  - Benefits of a model to aid understanding of a complex network
  - Vulnerability and resilience
    - Elements, networks and territories
  - The need for an integrated approach
- **Application to a specific example of a complex network**
  - An international, high pressure, gas transmission pipeline network
  - Data requirements to build a model
- **Scenario development and analysis**
  - Identification and removal of a critical network node
  - Quantitative network behavior
  - Economic impact
- **Conclusion**

European Critical Infrastructure (ECI) Policy context

- **Some infrastructure is becoming increasingly European**
  - eg. energy transmission & transportation systems
- **A National approach is deemed insufficient**
- **Trans-boundary effects need to be minimized**
  - ie. the risk that a member state suffers because another failed to protect their assets adequately
- **Develop cross-cutting criteria to identify ECI**
  - based on severity of consequences of disruption/destruction
- **Owners/operators of ECI will need to establish:**
  - Risk analysis: threat scenarios, asset vulnerability, impact and consequence analysis

National cross-border networks

- Failures may propagate through a network
- Network failure results in:-
  - Effects on the network itself
  - Effects on society

A methodology is required to integrate:

- Vulnerability of the network components
- The consequences on society

Analysis of infrastructure levels

Micro

Physical components
Pipes, substations, etc

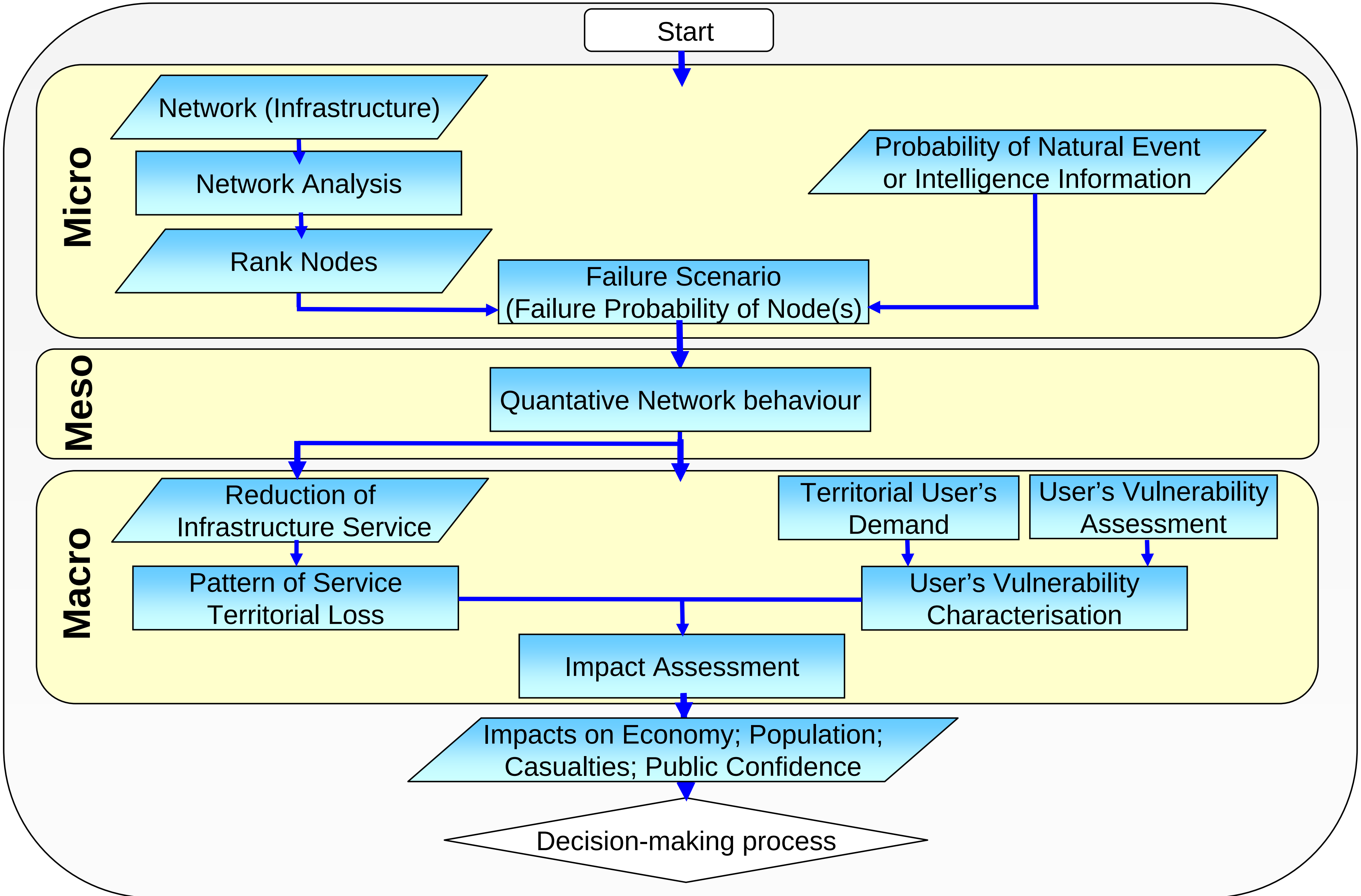
Meso

Edges (Connections), nodes & service flows

Macro

Territory (Local, Regional, National)
Customers, uses & services

Integrated approach to infrastructure vulnerability



The European Gas Infrastructure as an ECI

- **We have considered the European high pressure gas transmission system as an application of the proposed methodology**

- **It provides a key role in supplying energy across Europe**

Major gas movements in 2006 as % of EU27 supplies

Approaching 0.5 million km of high pressure gas transmission pipelines traverse the EU27

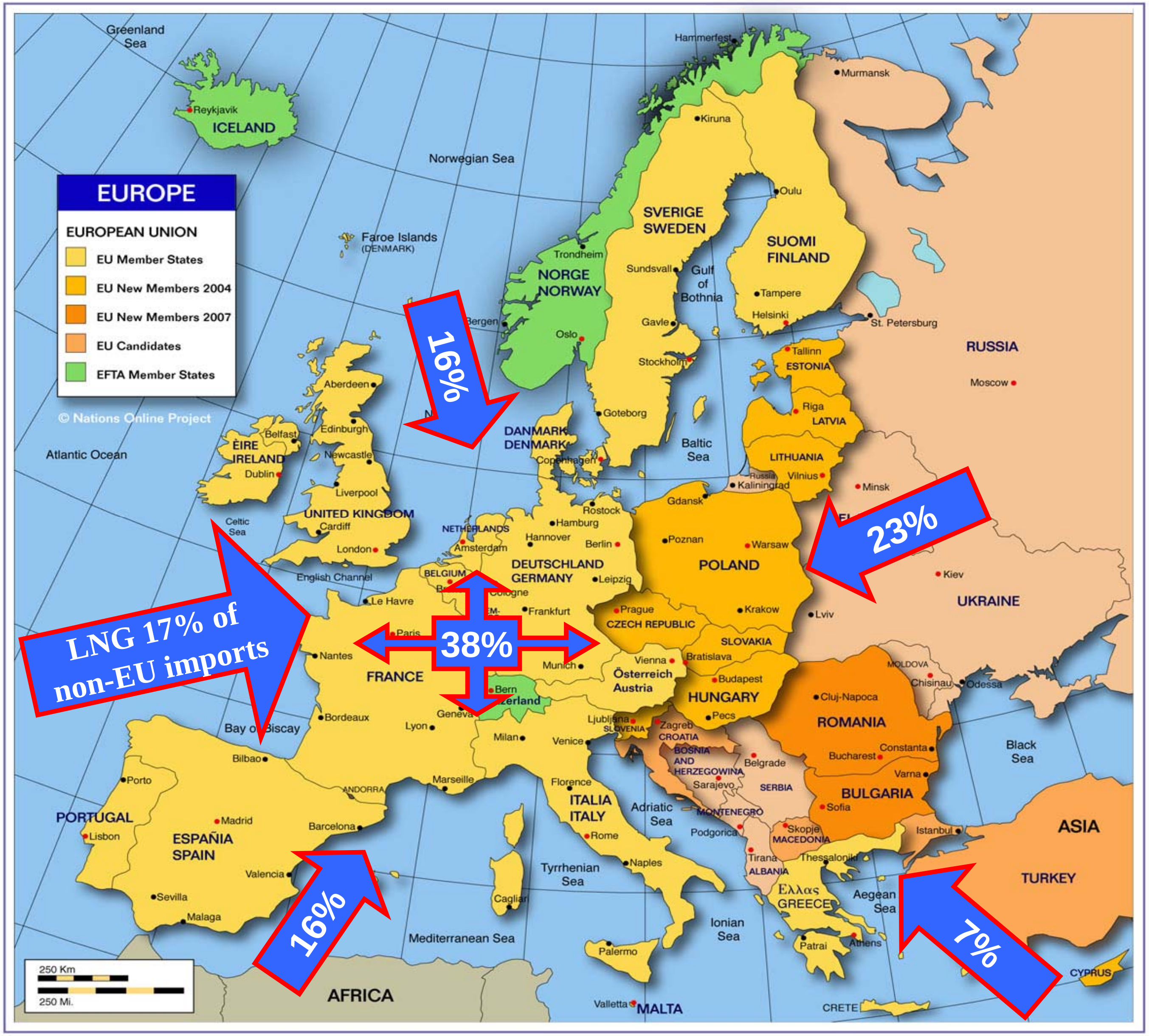
Net supplies

~ 507 billion m^3

Imports 62%

~ 315 billion m^3

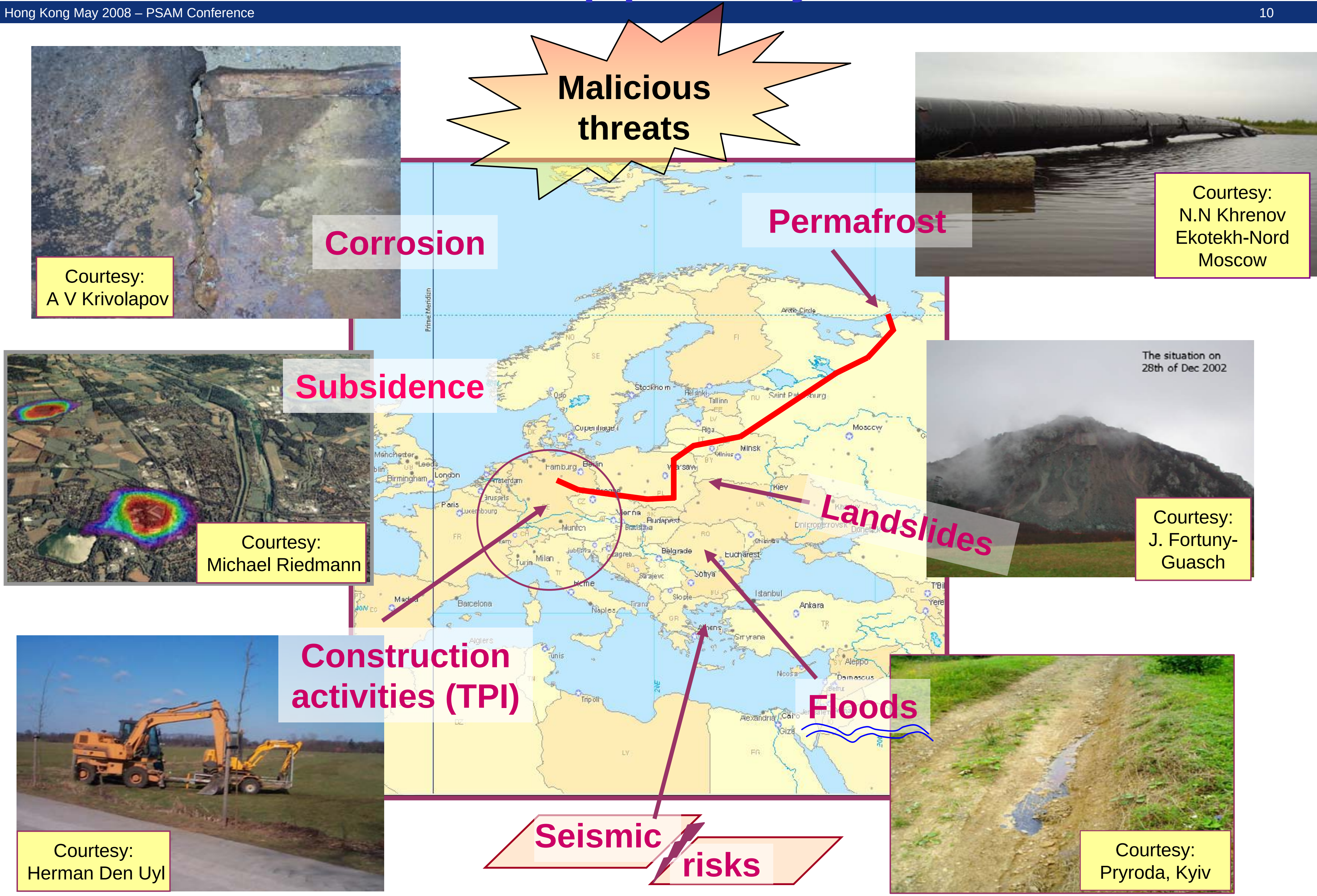
Imports shown as percentages of net supplies



The European Gas Infrastructure as an ECI

- We have considered the European high pressure gas transmission system as an application of the proposed methodology
- It provides a key role in supplying energy across Europe
- **The system is subject to both natural and man-made threats**

Example potential threats to a pipeline system



Requirements for a detailed network model

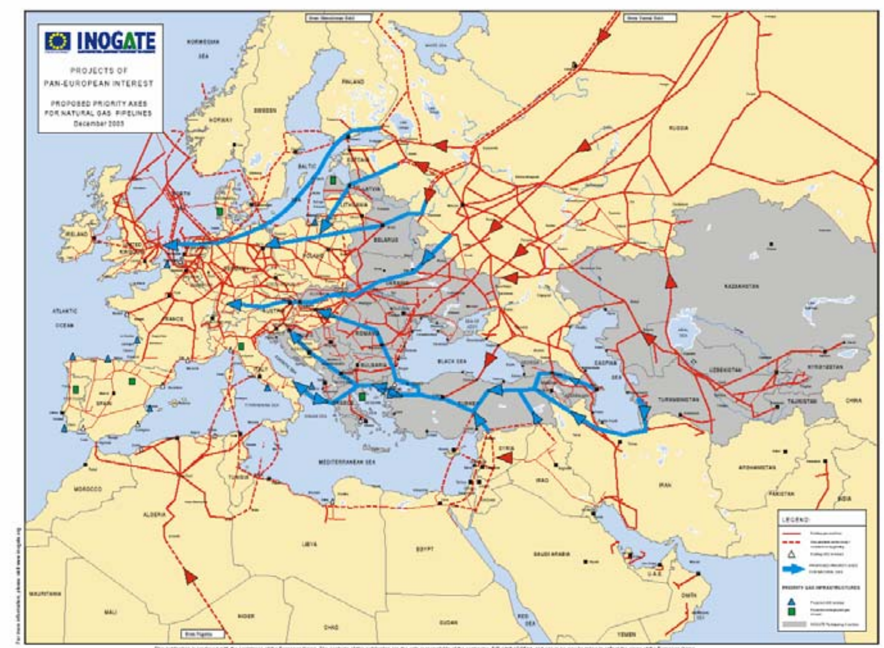
- **A detailed model - to explore cross-border system interactions**

- **Modeling software**
  - Requires high degree of technical functionality applicable to gas industry
  - Initial requirement for steady state only
  - Calculates all unknown pressures and flow rates in the network from input data

- **Limit model size to a representative supply route to central Europe**
  - Select a major supply route
  - Include several countries

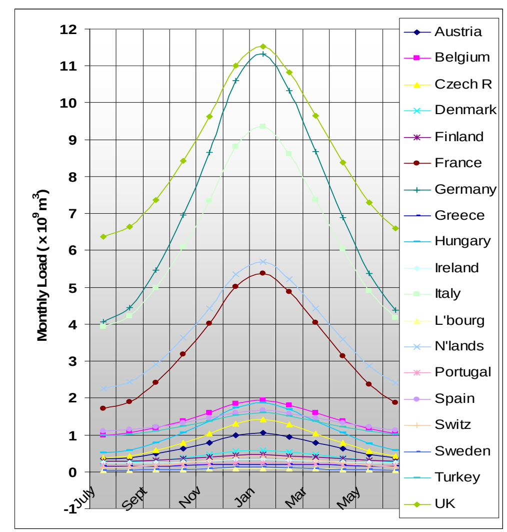
- **Limit model to worst case conditions**
  - Use winter peak demand

- **Develop model using publicly available data**

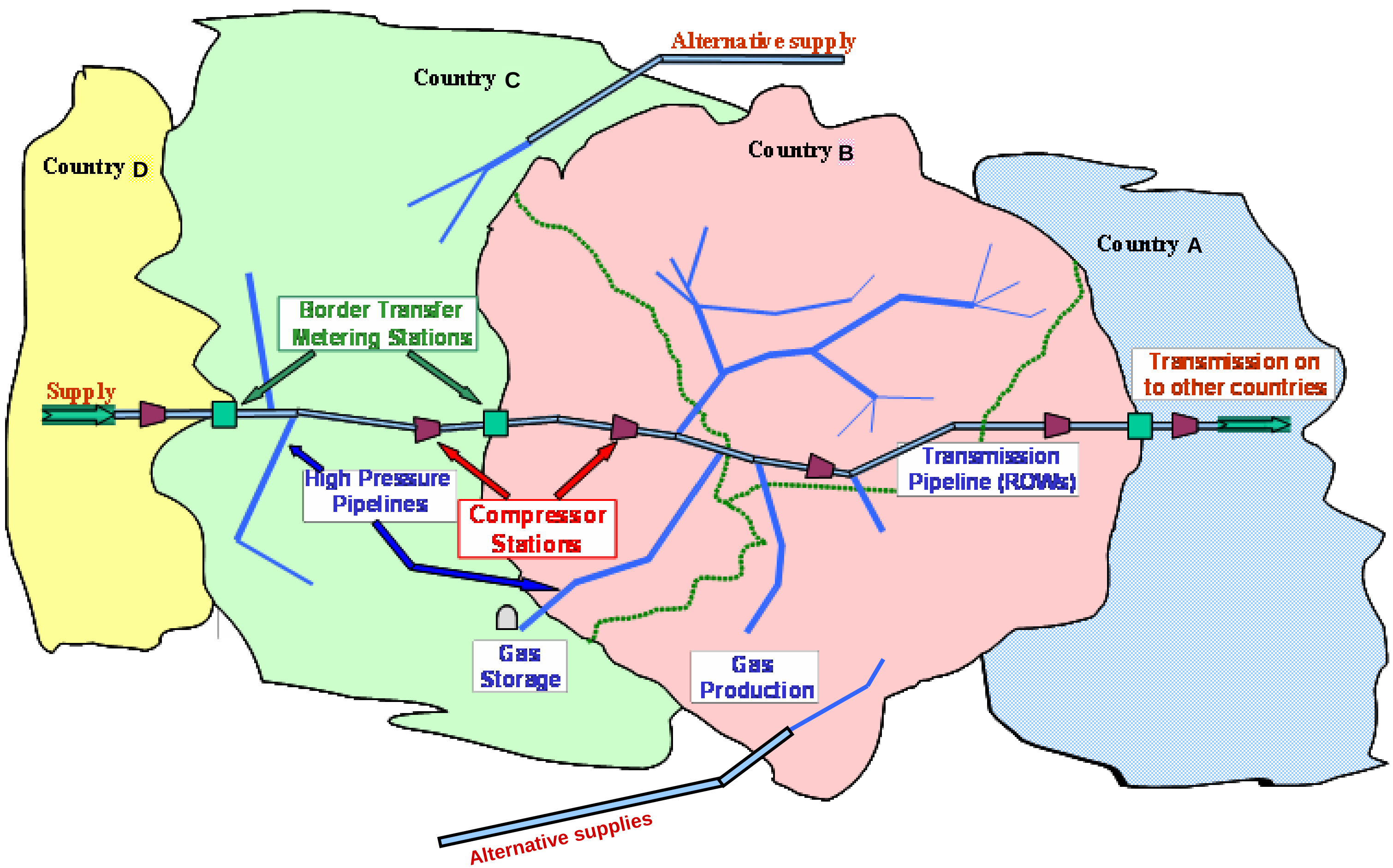


Requirements to build a detailed model

- **High pressure pipeline routes in & beyond Europe**
  - **Transmission pipelines** - GIS locations
    - Internal diameters; off-take locations, etc
- **Physical infrastructure – key items**
  - **Supply sources** – Known locations & pressures, etc
    - Storage fields • LNG supplies • Production sources
  - **Compressor stations; Metering transfer stations**
    - Locations & technical details
- **Theoretical requirements**
  - **Flow equations • Gas properties**
- **Country annual consumption**
  - **Peak demand profiles**
- **Gas customers**
  - **Numbers known by category:-**
    - Domestic; Commercial
    - Industrial; Power generation
    - Individual daily consumption profiles
- **Regional demand profiles**
  - **Allocation of gas flows to off-takes**



➢ A four country scenario (Countries A, B, C, D)

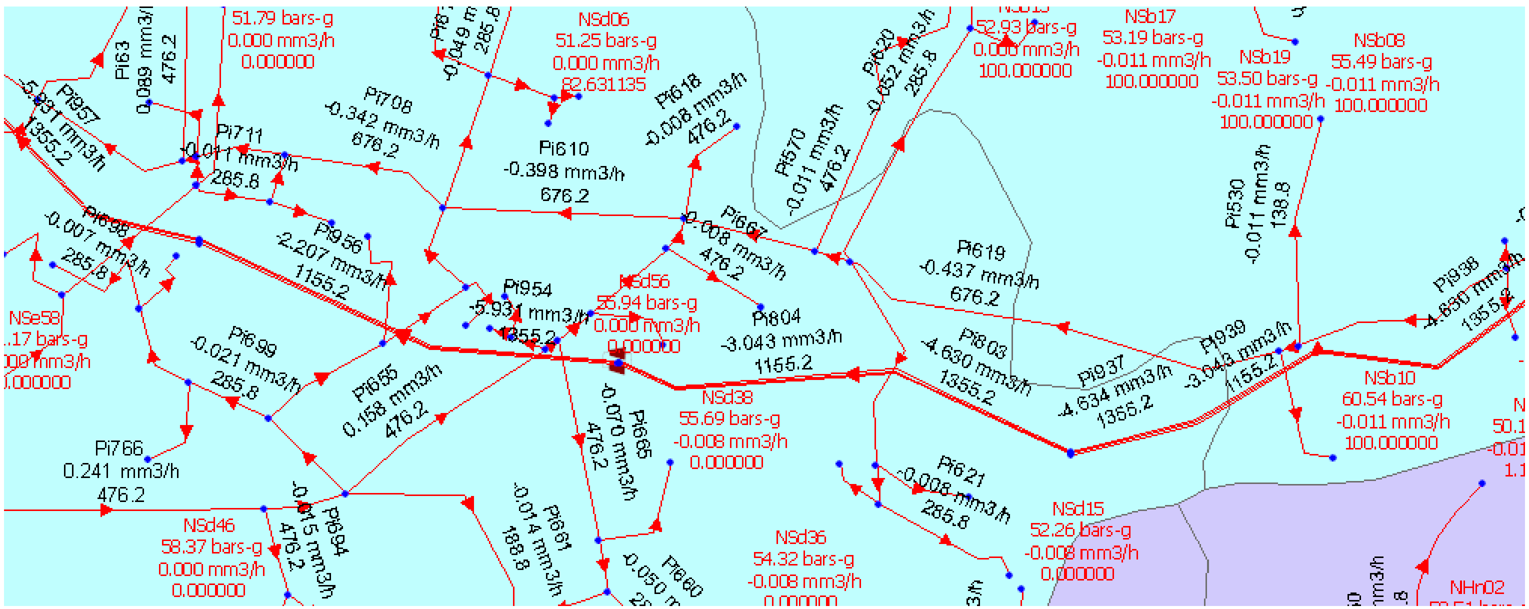


The final gas network model

➢ The current model contains the following:

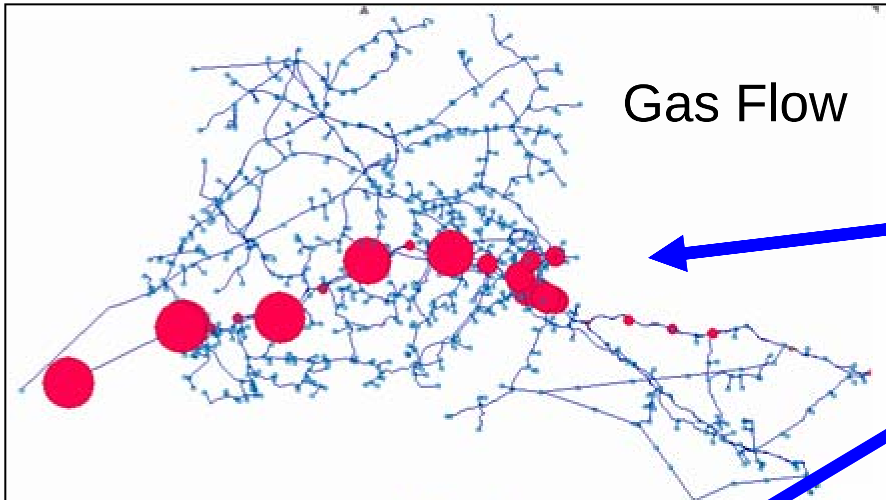
No. of pipes >> 1064
No. of nodes >> 974 (where pressures & flows are calculated)
No. of facilities >> 15 Compressor stations
No. of sources >> 13 Stores; 7 Production sites

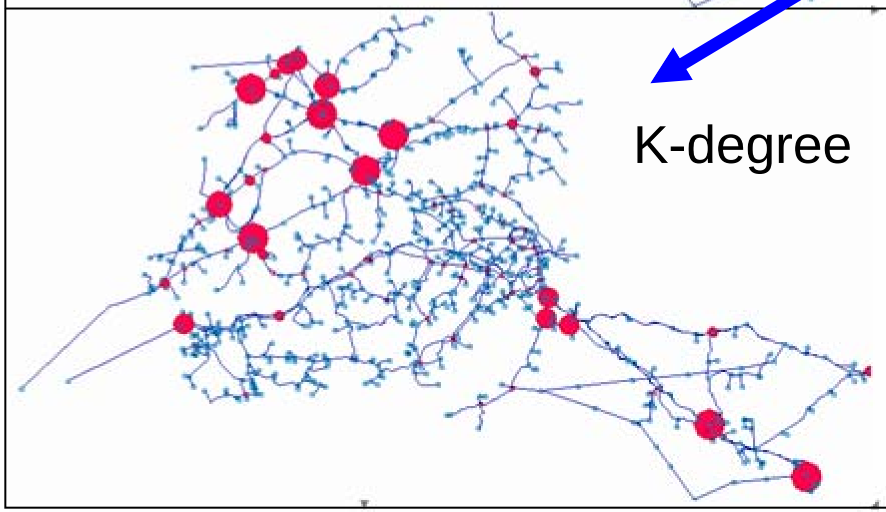
➢ The software solves simultaneous equations iteratively for each component in the system



Extract from detailed map

Ranking importance of Nodes by connectivity & flow rate





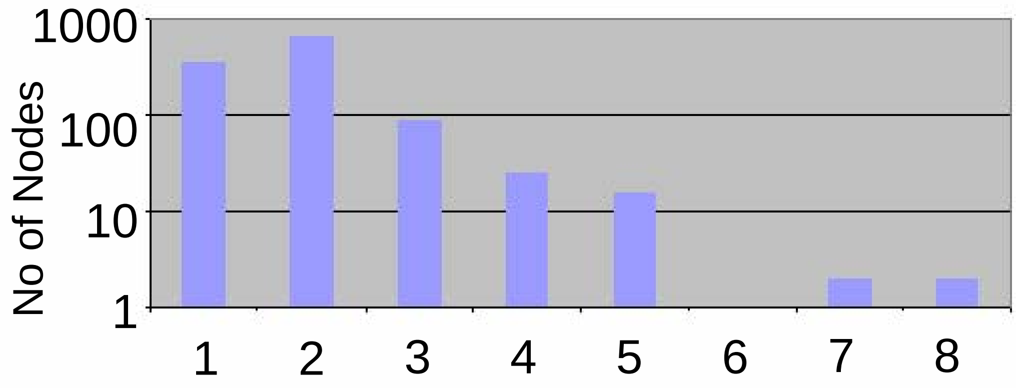
Ranking of Nodes

Ranking of Node Criteria:

- By Gas Flow:
- large diameter indicates large flow;

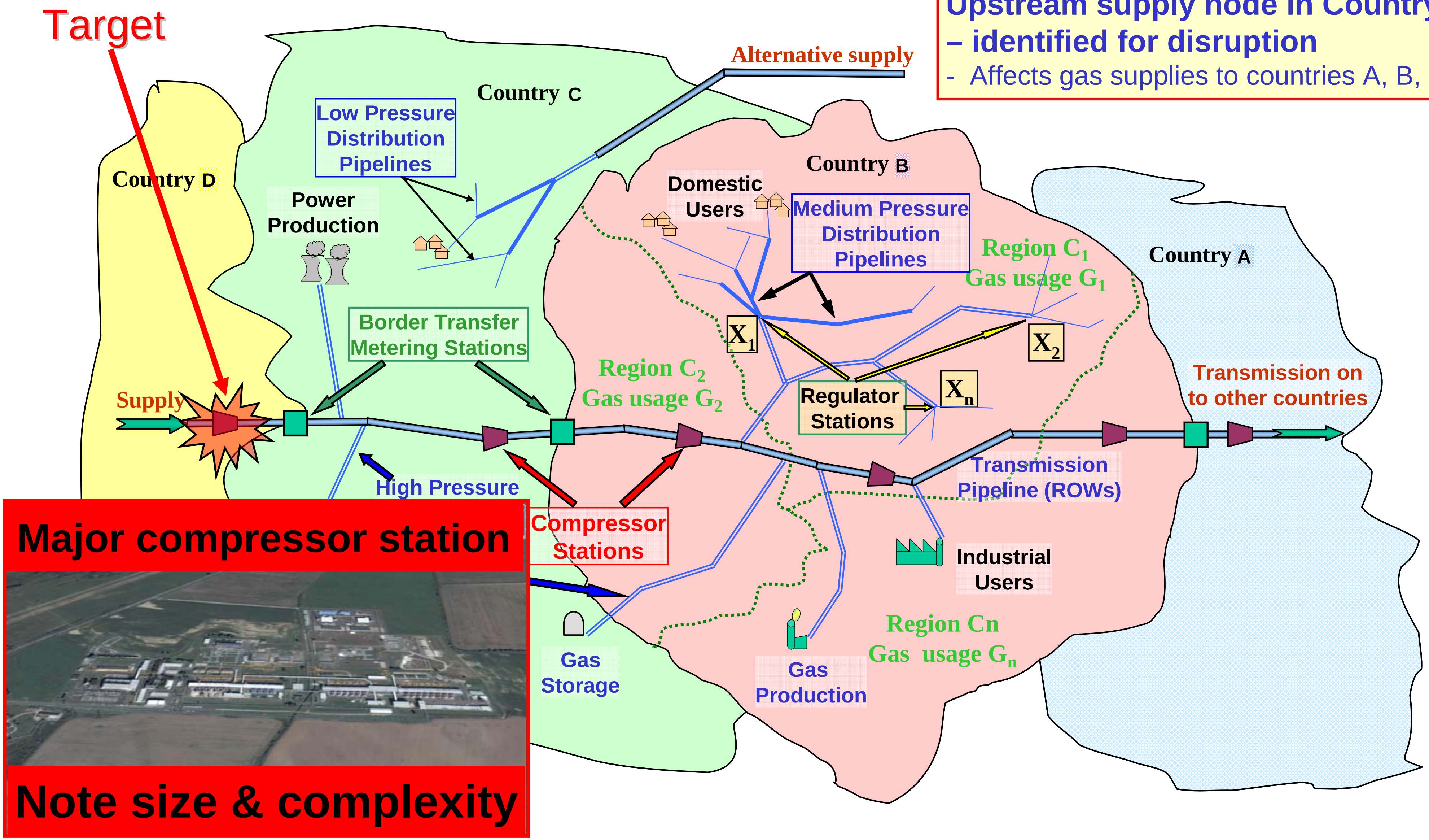
- By degree (K) of connectivity:
- large diameter indicates high connectivity

K-degree Classification of Nodes



Schematic diagram of physical network entities

Upstream supply node in Country D – identified for disruption
- Affects gas supplies to countries A, B, C



Gas disruption scenario basis

- **3 months required to repair/re-instate supply node in D**
- **All countries can maintain required supplies for 2 months**
  - Either from:
    - Storage gas - but has an additional cost
    - Alternative supply sources and routes and temporary arrangements
- **During the third month**
  - All countries assumed to have lost supply from country D
  - All countries retain sufficient gas supplies for electrical power production
  - A, B & C retain supplies from alternative sources
  - Country D has no other alternative supply sources

Final patterns of territorial gas losses

Months	Country >>	A	B	C	D
1 & 2	% of demand capacity (from storage & production)	90	100	73	80
	Maximum time (weeks) at this capacity {but due to uncertainties in distribution - assume to 2 months supply for all countries}	9	10	7	8
3	Final gas deficit (based on 3rd month assumptions)	75	77	57	100

Economic Assessment

- **The objective of a socio-economic analysis is to assess the impact of an event on the economy of a member state, to estimate the net national cost of an event**

- **When discussing economic damage due to infrastructure failure, the aim is to evaluate the <u>economic value of the loss of service</u>, based on:**

  - **intensity of use of a certain service provided through an infrastructure, and/or alternatives**

  - **reduction in productive capacity by users of a service**

  - **indirect effect this reduction in productive capacity has on the rest of the economy**

Input - output method of economic analysis

- **The input - output approach includes detailed information for a given year on the following:**
  - production activities
  - supply and demand of goods and services
  - intermediate consumption
  - primary inputs
  - foreign trade

- **The tables (available from Eurostat) include:**
  - structure of production and the value added in the production process
  - inter-dependencies of industries
  - flows of goods and services produced within the national economy
  - flows of goods and services with the rest of the world

- **Impacts are modeled by formulating:**

A. Resilience of the sectors, based on real impact and alternatives
B. Value of lost production based on intensity of use
- based on Eurostat statistics
C. Industry linkages
D. Loss

(A) (B) (C) (D)

$$\begin{bmatrix} Va \\ Vb \\ Vc \\ Vd \end{bmatrix} \times \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \times \begin{pmatrix} 1.14 & 0.22 & 0.13 & 0.12 \\ 0.19 & 1.10 & 0.16 & 0.07 \\ 0.16 & 0.16 & 1.16 & 0.06 \\ 0.08 & 0.05 & 0.08 & 1.09 \end{pmatrix} = \begin{bmatrix} Loss \end{bmatrix}$$

I/O analysis vulnerability & economic loss

➢ For the loss of gas the following assumptions were made:

- Production sectors dependent on gas would stop production
- Where appropriate, electrical production from gas would have maximum priority and would be maintained
- Economic losses resulting from the service sector excluded
- Economic losses resulting from domestic gas use excluded

➢ Estimated economic losses for the 4 countries

Country >	A	B	C	D
Economic Loss by Sector	**Millions Euro**			
Energy sector	0	0	0	9075
Industrial sector	39393	37785	0	15701
Transport sector	6452	4414	1968	2813
Household & service sector	0	0	0	0
Total loss	**45845**	**42198**	**1968**	**27590**

➢ The values in the above table may then be compared with pre-set criteria to identify the criticality of the supply loss to each of the individual countries' economies

Future work linked to ECI

- **The current analysis was based on a worst-case scenario analyzed at national level**
  - With improvements to the gas model, future analysis will consider national consequences integrated from regional levels
- **The current model only addresses economic impacts**
  - Future work is anticipated to include other areas of impact, including number of casualties, public and environmental consequences

Conclusion

- **A need to develop methods for assessing consequences of failures in European Critical Infrastructures (ECI) that form parts of complex networks has been identified**
- **An interdisciplinary methodology has been developed to address disruptions in such complex networks that includes an assessment of the territorial economic impacts**
- **An international gas transmission pipeline network has been used to demonstrate the principles of the methodology**
- **Added value has been created that aims to assist decision making processes in evaluating the importance of ECI**

Thank you for your attention

jean-pierre.nordvik@jrc.it

russell.pride@jrc.it

Statistics on industrial linkages are used to derive the model

Table: Transactions in a Three Sector Economy

Economic Activities	Inputs to Agriculture	Inputs to Manufacturing	Inputs to Transport	Final Demand	Total Output
Agriculture	5	15	2	68	90
Manufacturing	10	20	10	40	80
Transportation	10	15	5	0	30
Labor	25	30	5	0	60

Table: Input-Output Model for Hypothetical Economy Total requirements from regional industries per dollar of output delivered to final demand

Purchasing Industry	Agriculture	Transport	Manufacturer	Services
Selling Industry				
Agriculture	1.14	0.22	0.13	0.12
Transportation	0.19	1.10	0.16	0.07
Manufacturing	0.16	0.16	1.16	0.06
Services	0.08	0.05	0.08	1.09
Total	1.57	1.53	1.53	1.34