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Laboratory for Safety Analysis
INSTITUTE FOR ENERGY TECHNOLOGY

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Risk Analysis of Highly-integrated Systems

VA: Vulnerability and Resilience / Building Robust Systems

Robust and Resilient Energy Infrastructures

Aim: Being capable of coping with "variations" with minimal damage and/or absorbing "impact" and getting back to initial conditions

⇨ Avoid severe accidents and/or disruption of service in case of damaging events, guarantee short recovery times

⇨ Ensure continuation of service, if main system fails

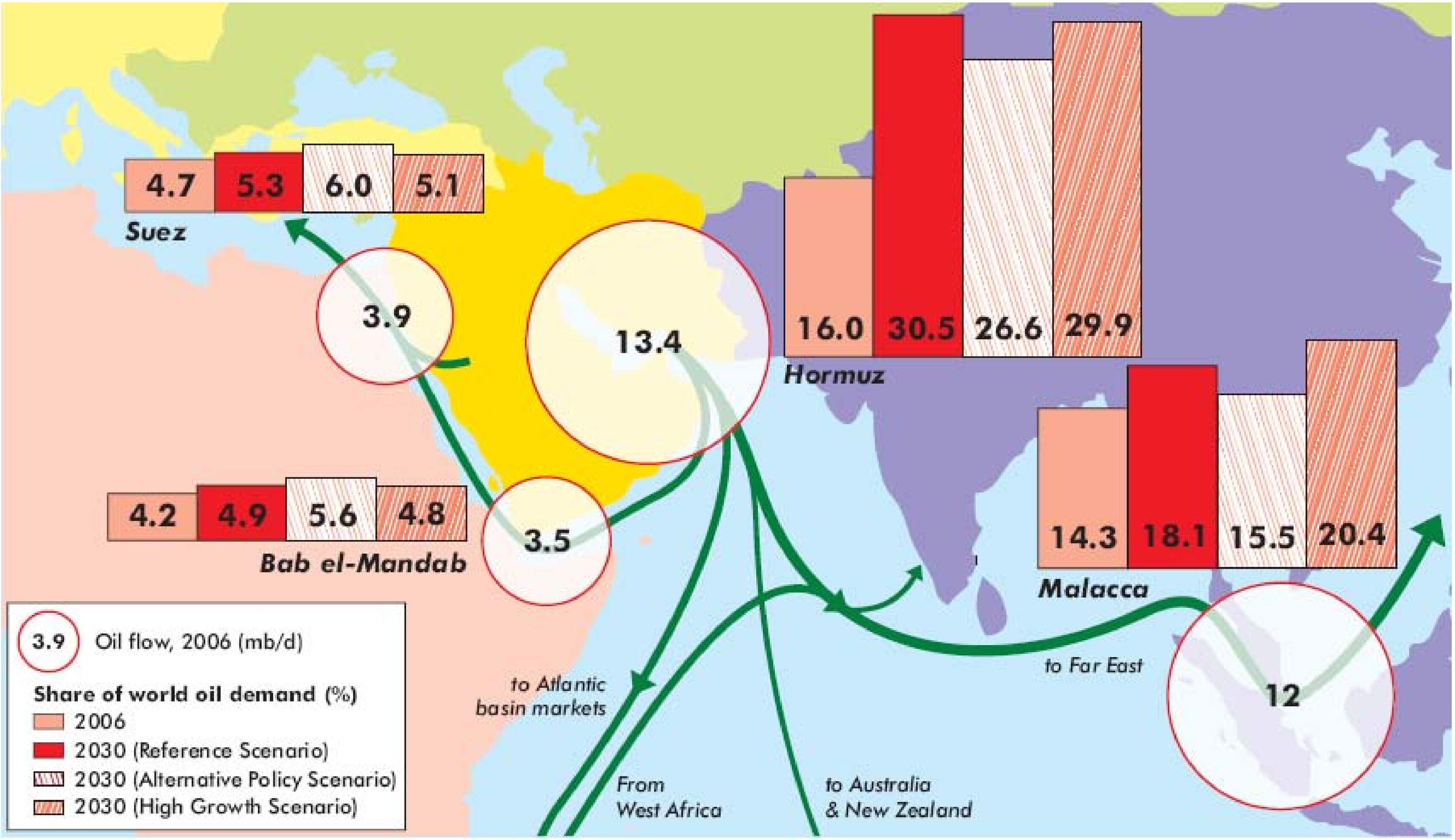
Scope: Entire supply chain from production via transport to consumption; multifaceted set of technical and human failures, natural hazards and various threats including malicious attacks and criminal acts

Relevance of technical fixes to reduce vulnerabilities against terrorist and cyber attacks

most sensitive areas	avoid, reduce	redun-dancy	reserves	robust topology	extended respond times	'island solutions' (cyber)	physical protection	spatial se-paration	other
choke points (tankers)	n.r.	-	(X)	-	-	-	-	-	political / military
wide-area gas & oil pipelines	n.r.	X	X	X	-	n.r.	n.r.	X	
large storage & treatment facilities	X (remote siting)	-	X	-	-	-	n.r.	n.r.	
hydro dams	n.r.	-	-	-	-	-	X (?)	-	military (?)
NPPs	n.r.	X*	-	-	X	X	X	X*	
distribution networks (UCTE)	-	X	X	X	X	X	n.r.	X	

n.r. not realistically * at systems' level

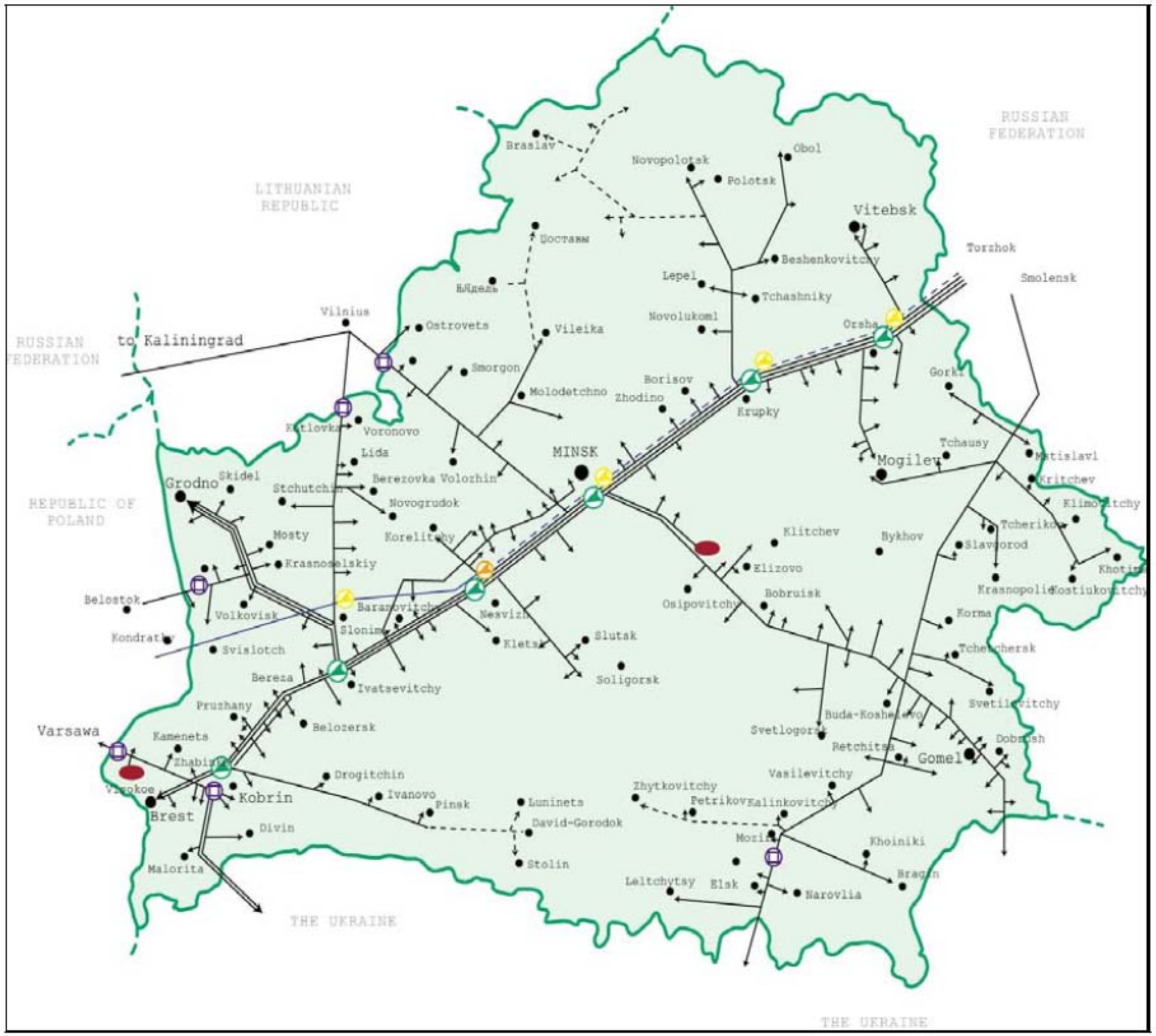
Obvious Vulnerabilities: Oil exports through critical choke-points



Electricity grid of Belarus (220-330-750 kV lines)

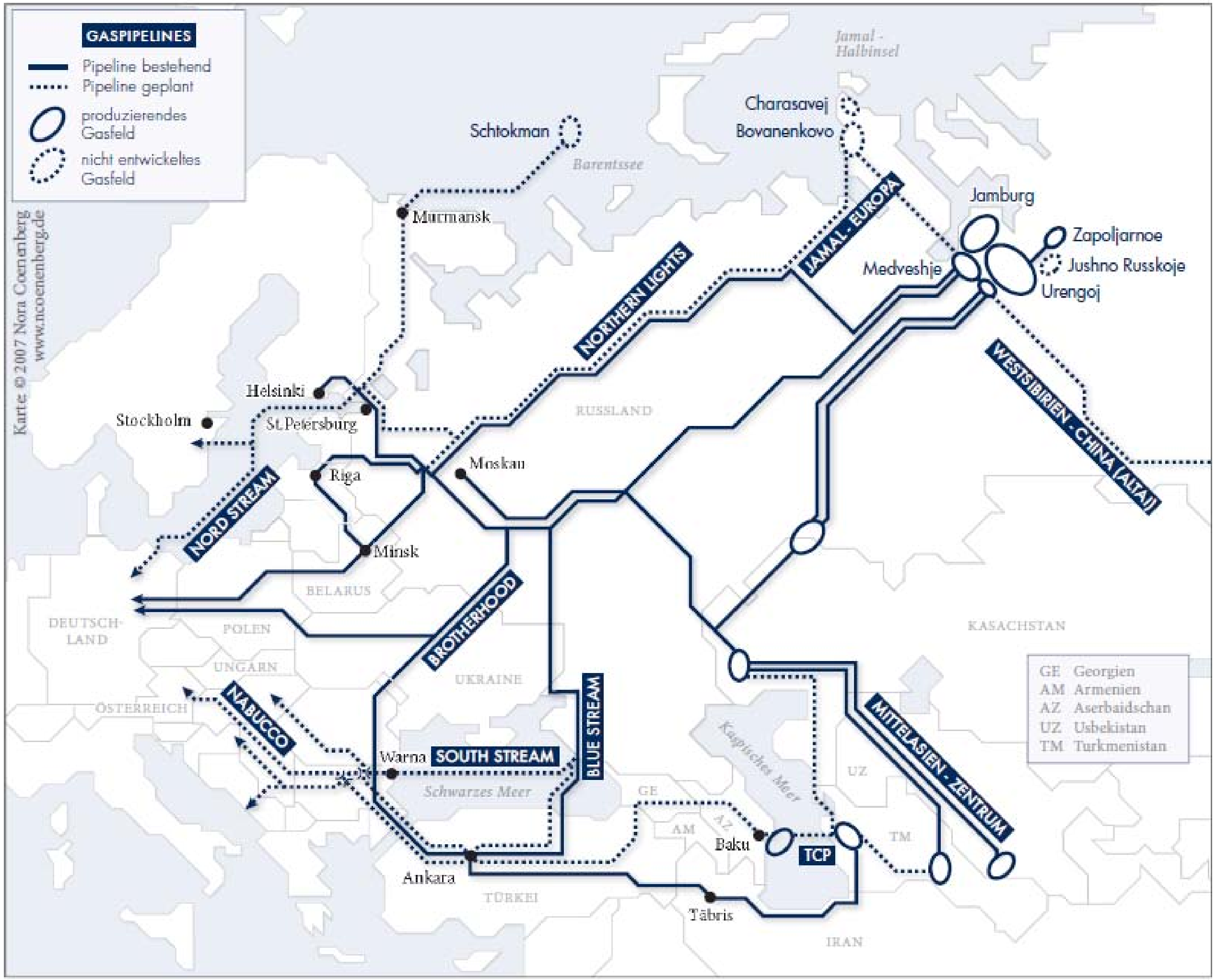
Source: http://www.eees.ee/FAILID/PDFid/Erialapaev111207/Baltic%20grid%202025.pdf

National Gas Transportation System of Belarus

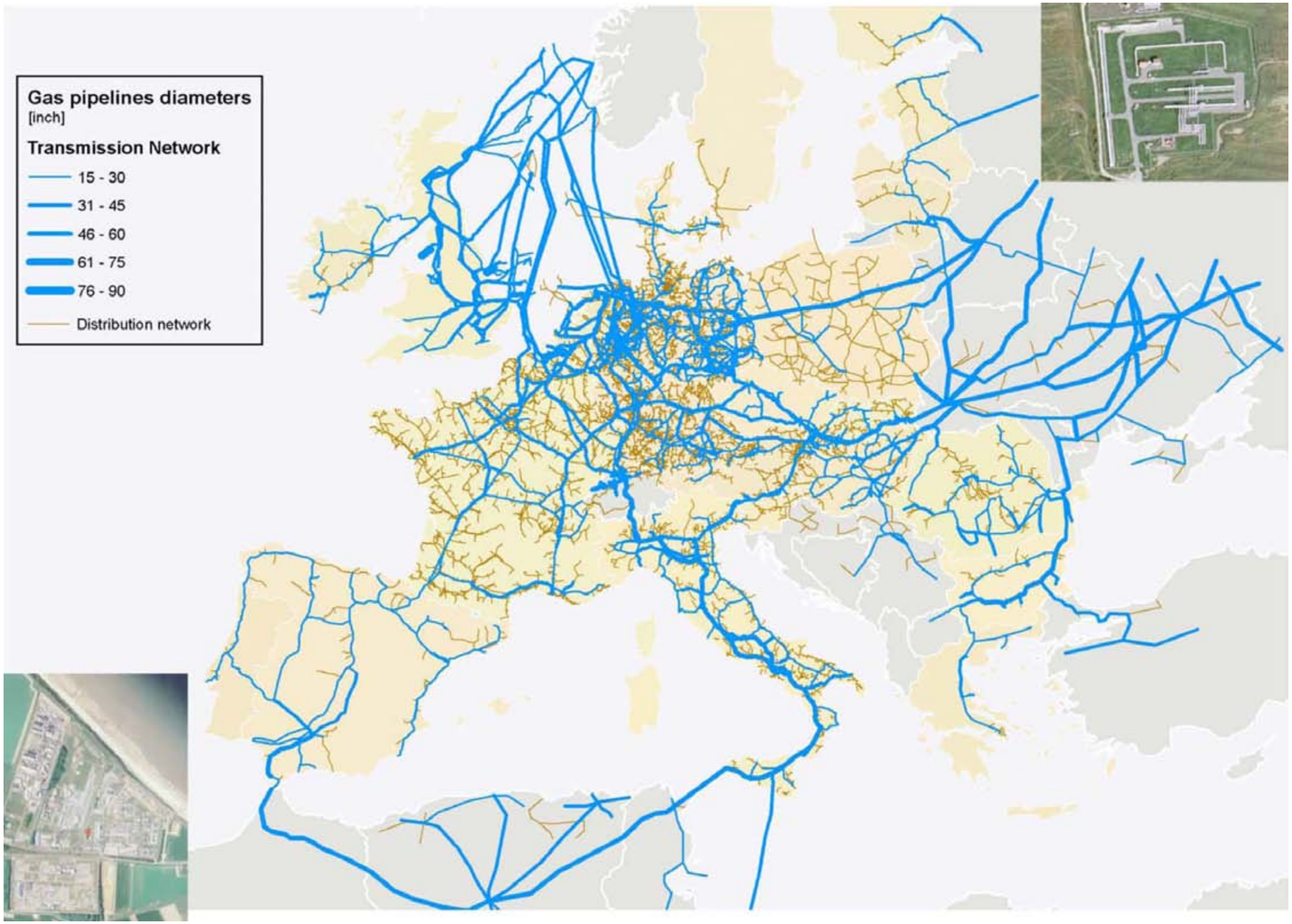


Source:
http://www.encharter.org/fileadmin/user_upload/document/Belarus_ICMS_2007_ENG.pdf

Natural Gas Pipeline Routes from CIS to Europe

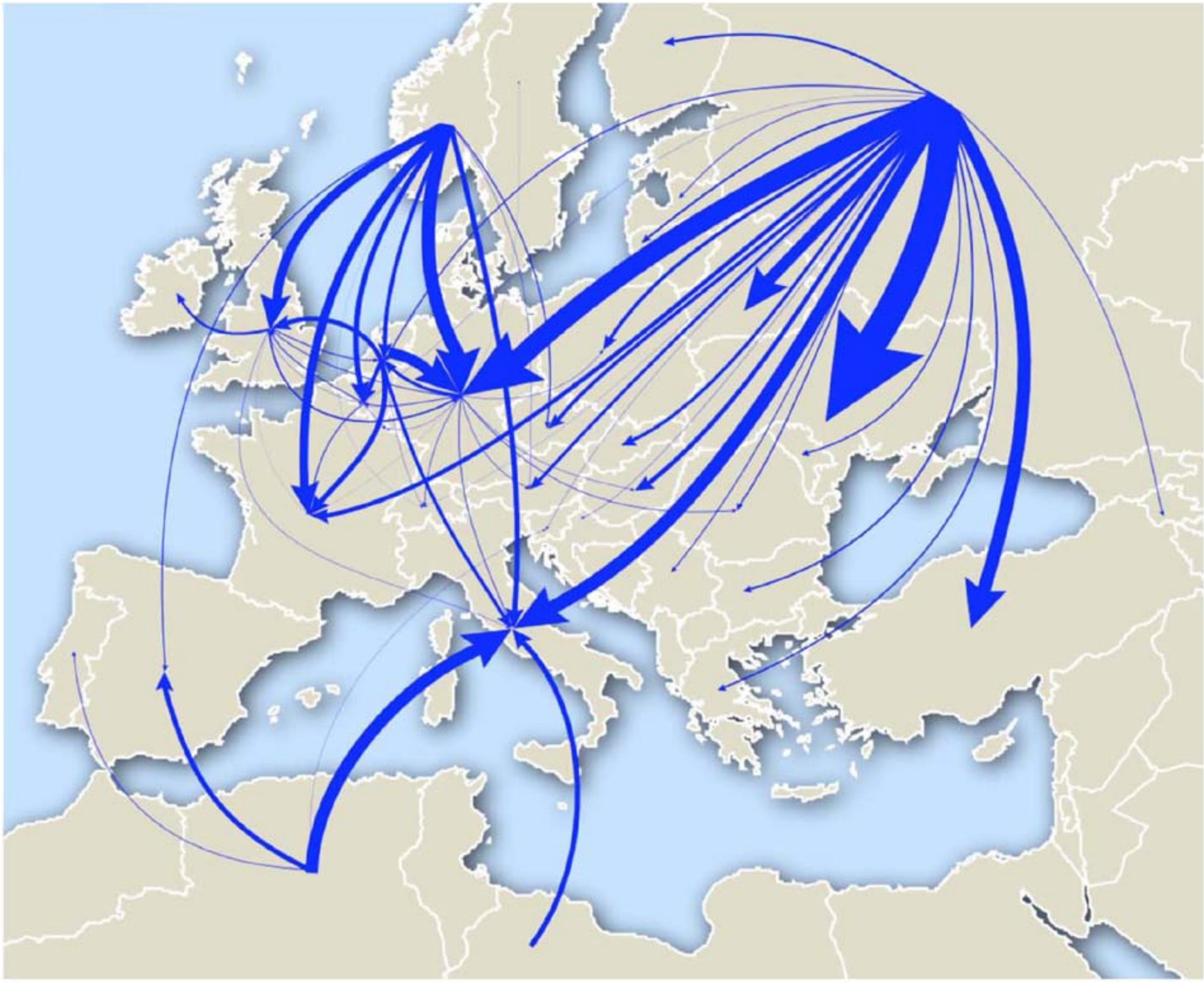


European gas network



Carvalho et. Al., Robustness of trans-European Gas Networks, Physical Review E 80, 016106 (2009)

Natural gas trade movements by pipeline for 2007



88% of natural gas imported in Europe comes from three countries: Russia, Norway and Algeria.

Carvalho et. Al., Robustness of trans-European Gas Networks, Physical Review E 80, 016106 (2009)

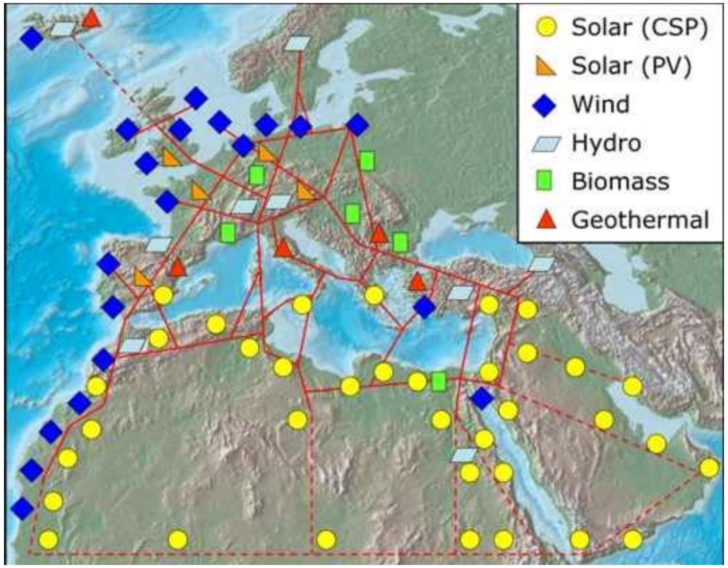
Integration of Renewable Energy Sources in the European Power Grid

• In December 2008, the so-called climate package was adopted at EU level.

• Ambitious goals were adopted by the EU, with a commitment to reduce greenhouse gas missions by 20% and to generate 20% of its electricity from renewable energy sources, all of it by 2020.

➡ Projects of massive renewable energy sources are currently under development.

• Develop offshore wind energy in the North Sea and connect it to a DC "supergrid" that would link offshore wind farms to European countries.



• Massive development of photovoltaic units in North Africa (Sahara desert) and unroll a "supergrid" composed of submarine cables through the Mediterranean Sea to develop the interconnection with European & Middle East countries.

Europe plans a North Sea Super-grid

• Nine European countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, UK) agreed to build a power grid of high-voltage cables under the North Sea.

• The cable project, estimated to cost the nine countries more than $40 billion over 10 years.

• It would be the first multinational grid designed to address the fluctuating nature of green power generation.

• The grid will transport energy generated by a mix of wind, solar, and tidal power between Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway (the only non-EU participant), and the United Kingdom to better balance supply and demand.

• Energy produced at night in UK wind farms, for instance, could be stored in Norway's hydropower facilities and released the following day. Around 100 GW of offshore wind power are currently planned by European power companies.

Sahara Solar Project

- The Desertec Industrial Initiative aims to supply Europe with 15% of its energy needs by 2050, as well supplying the growing energy needs in North Africa and the Middle East.

- It plans to cover 16,900 square kilometers of desert with solar thermal power stations - which use the sun to generate heat which is then used to generate electricity.

Members of the Consortium

ABB
ABENGOA Solar
Cevital
Deutsche Bank
E.ON
HSH Nordbank
MAN Solar Millennium
Munich Re
M+W Zander
RWE
SCHOTT Solar
SIEMENS

The New Challenges of Grid Development in the 21st Century

New projects have large consequences for grid developers:

• The large-scale changes in generation type and their location (integration of renewables), as well as the modified power grid network structure will consequently affect the load flow patterns.

• For example, a sudden change of wind in Northern Europe, where the most of wind power capacity is installed, is likely to completely modify power flows at the European scale and threat the robustness of the European power grid.

<u>Mitigation of the variability of the wind power.</u>

The smoothing effects of aggregation and geographical spread can be dramatic.

Grid development, effectively leading to supergrids.

Smoothing can be further augmented by aggregating different types of energy source, including other renewable energy sources. Incorporating tidal energy, for instance, would add a source which, although variable, is highly predictable.

An important way to reduce the need for reserve and back-up capacity is to improve wind forecasting methods.

Recommendations based on vulnerability assessments (for Western power grids)

- Avoid operating the system at its limits (undue “stress”/overloading) Reasons might be:
  - lack of investment, (technical obsolescence, bottleneck, etc.);
  - safety criteria traded-off against other (economic) factors;
  - inadequate integration of stochastic energy sources;
- Acknowledge key role of system operators and available time for response actions (about 10-20‘);
- Establish a CIP program in cooperation with other countries;
- Do not use open-access communication systems (Internet) for any vital control function unless it is sufficiently secure;
- Check adequacy of network topology (role of hubs) and balance advantages (mutual help, access to broader market) and disadvantages (potential of cascades) of integration into larger systems.