European Commission

ELECTRICITY SECURITY: METHODS AND MODELS FOR SUPPORTING THE POLICY DECISION MAKING IN THE EU

Doctoral Thesis Defence

Supervisors
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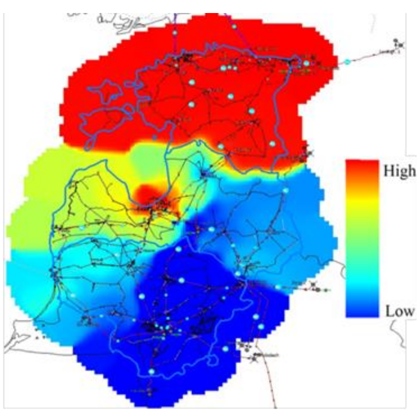
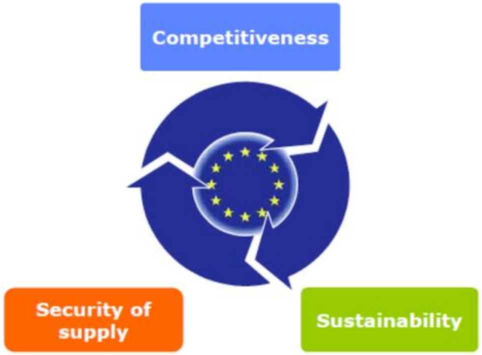
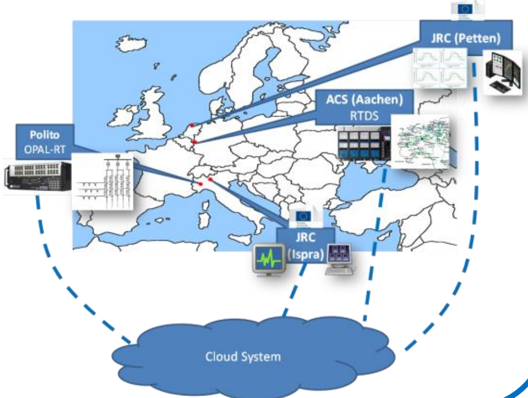
Torino, 26/04/2016







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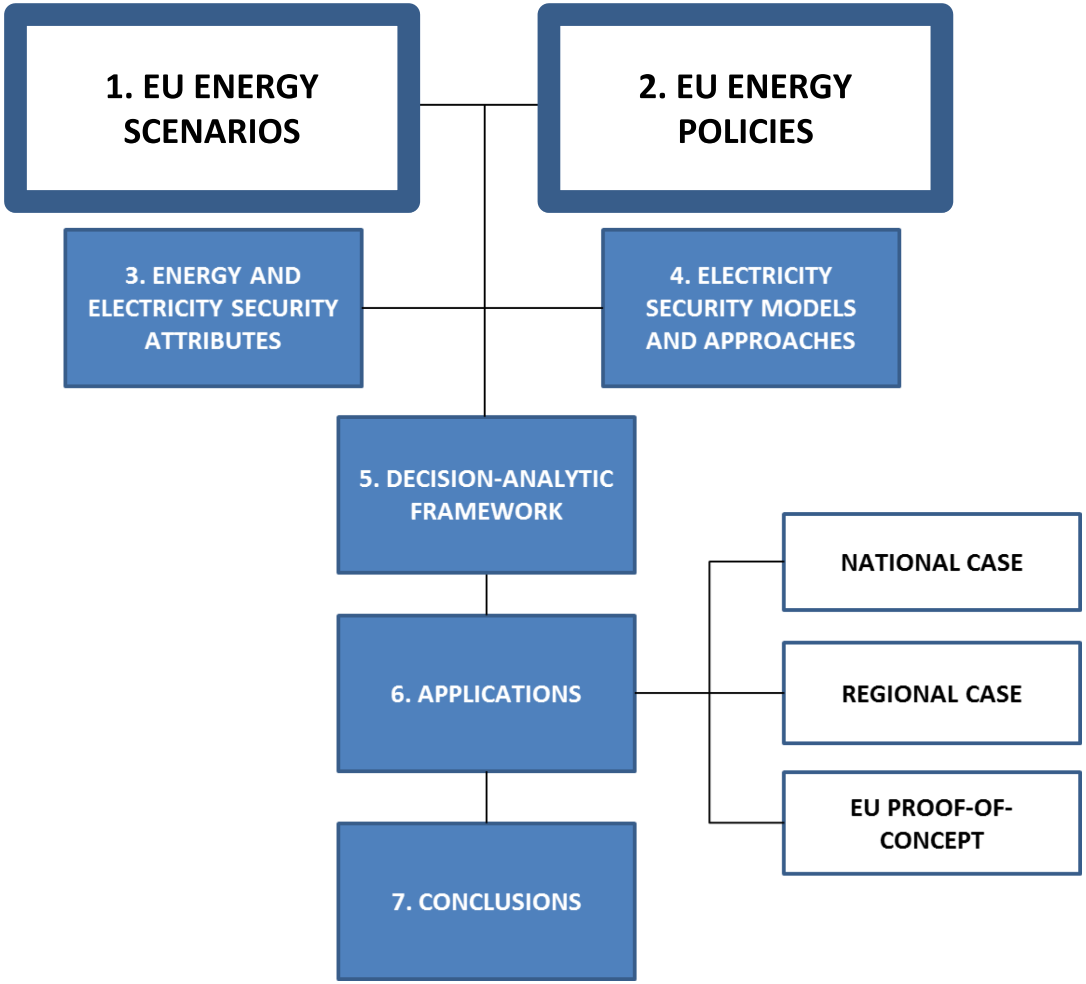
Thesis structure

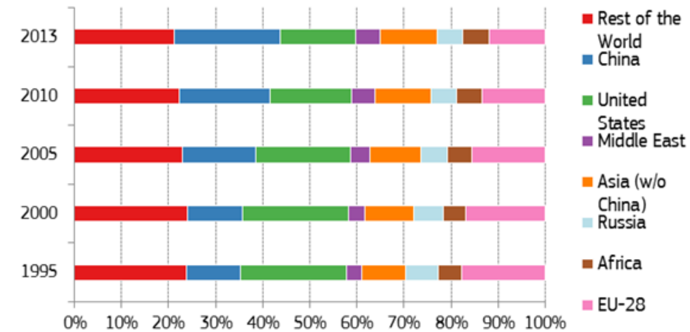


EU's Energy outlook

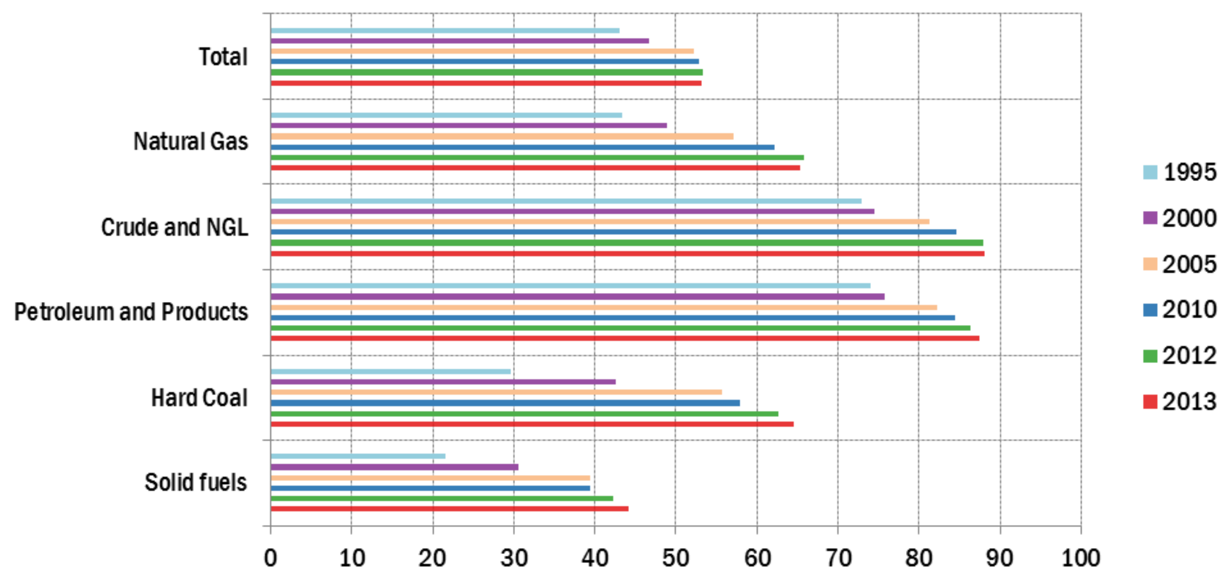
European Commission

Gross inland consumption: EU 4th largest in the world

Year	1995	2000	2005	2010	2013
Rest of the World	2199	2408	2629	2838	2883
China	1055	1174	1788	2483	3036
United States	2067	2273	2319	2215	2188
Middle East	307	356	471	628	689
Asia (w/o China)	868	1039	1239	1523	1655
Russia	637	619	652	690	731
Africa	442	494	596	691	747
EU-28	1645	1692	1787	1721	1626
Total World	9220	10055	11481	12789	13555



Energy import dependency: EU 1st among world economies



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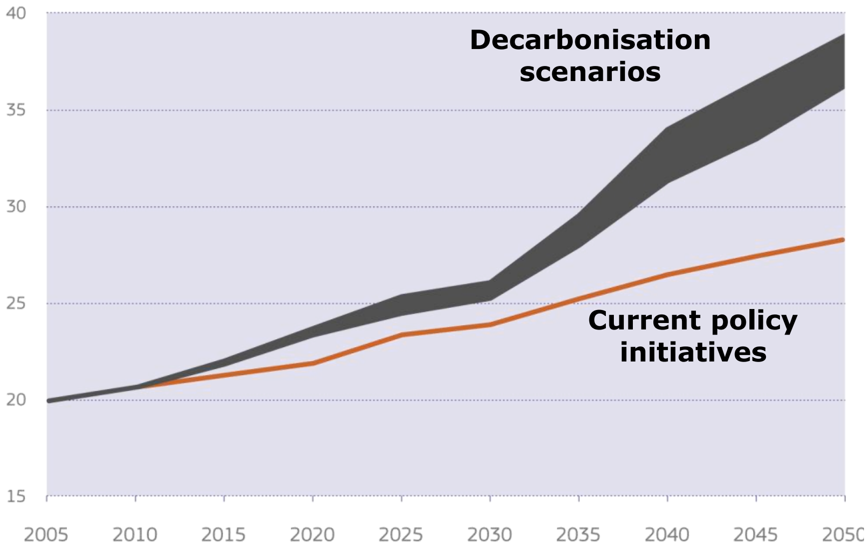
Energy Roadmap 2050

European Commission

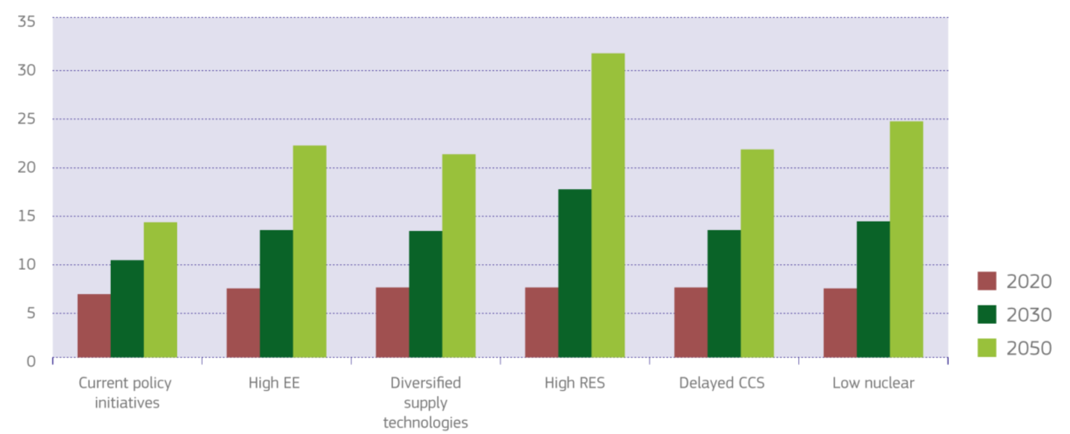


➢ Electricity plays an increasing role

Share of electricity in current trend and decarbonisation scenarios (in % of final energy demand)

➢ Decentralised and centralised systems increasingly interact

Share of decentralised electricity in power generation (in %)



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Source: European Commission 2050 Energy Roadmap

EU's energy policies and targets

European Commission

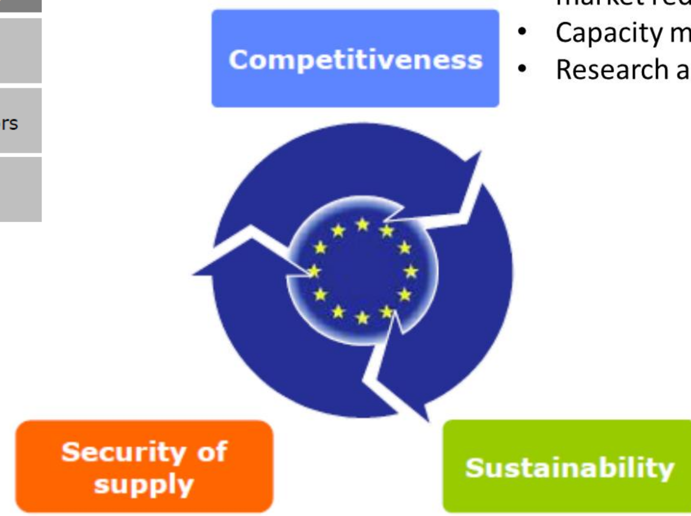
2020

- **20%** greenhouse gas reduction
- **20%** renewable energy
- **20%** energy savings

2030

- **40%** greenhouse gas reduction
- **≥27%** renewable energy
- **Energy efficiency: review in 2014**

Dedicated governance
National plans
Common indicators
Monitoring



Competitiveness

- Market liberalisation
- Wholesale with/vs. retail market redesign
- Capacity mechanisms
- Research and innovation

Security of supply

- Energy resource structure
- Super grid with/vs. smart grid development
- Network infrastructure expansion
- Backup capacity management

Sustainability

- Energy efficiency improvement
- Renewable energy increase
- Emission reduction
- Socio-environmental impact

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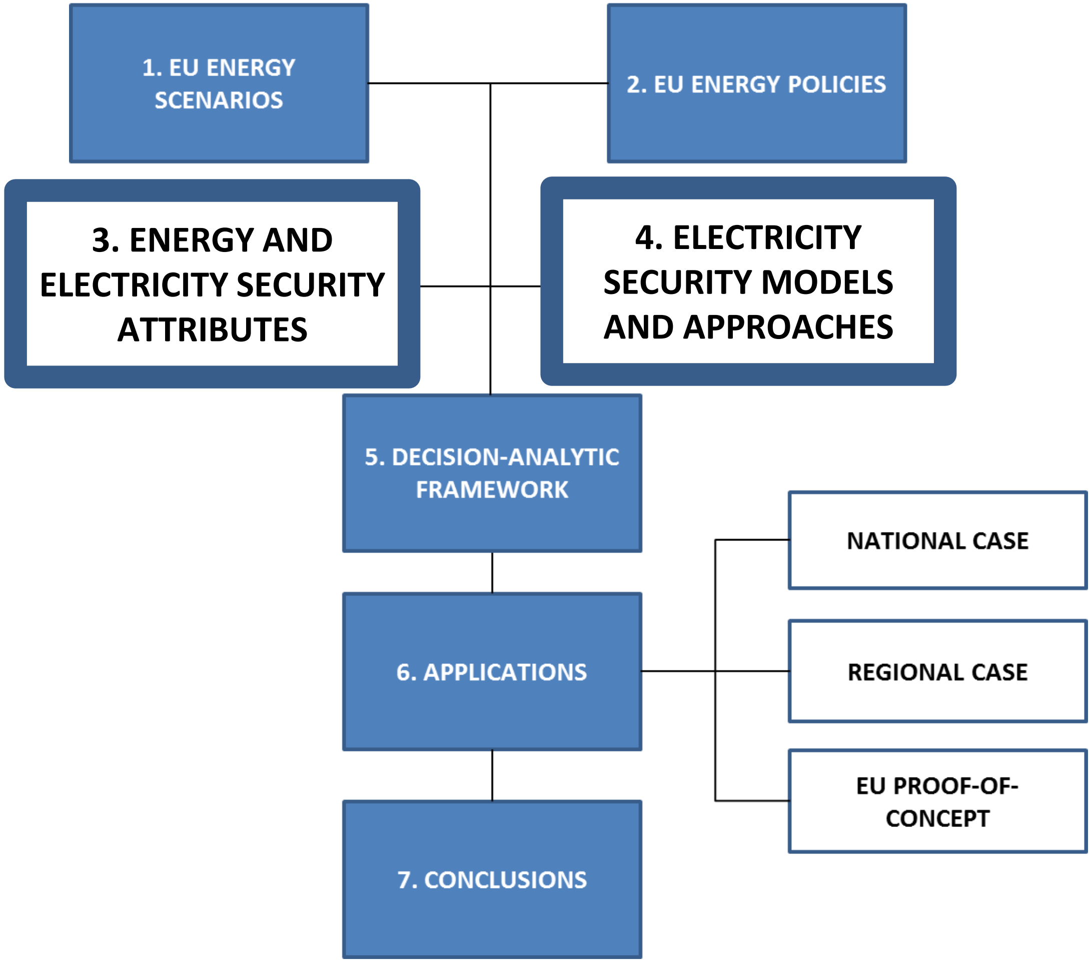
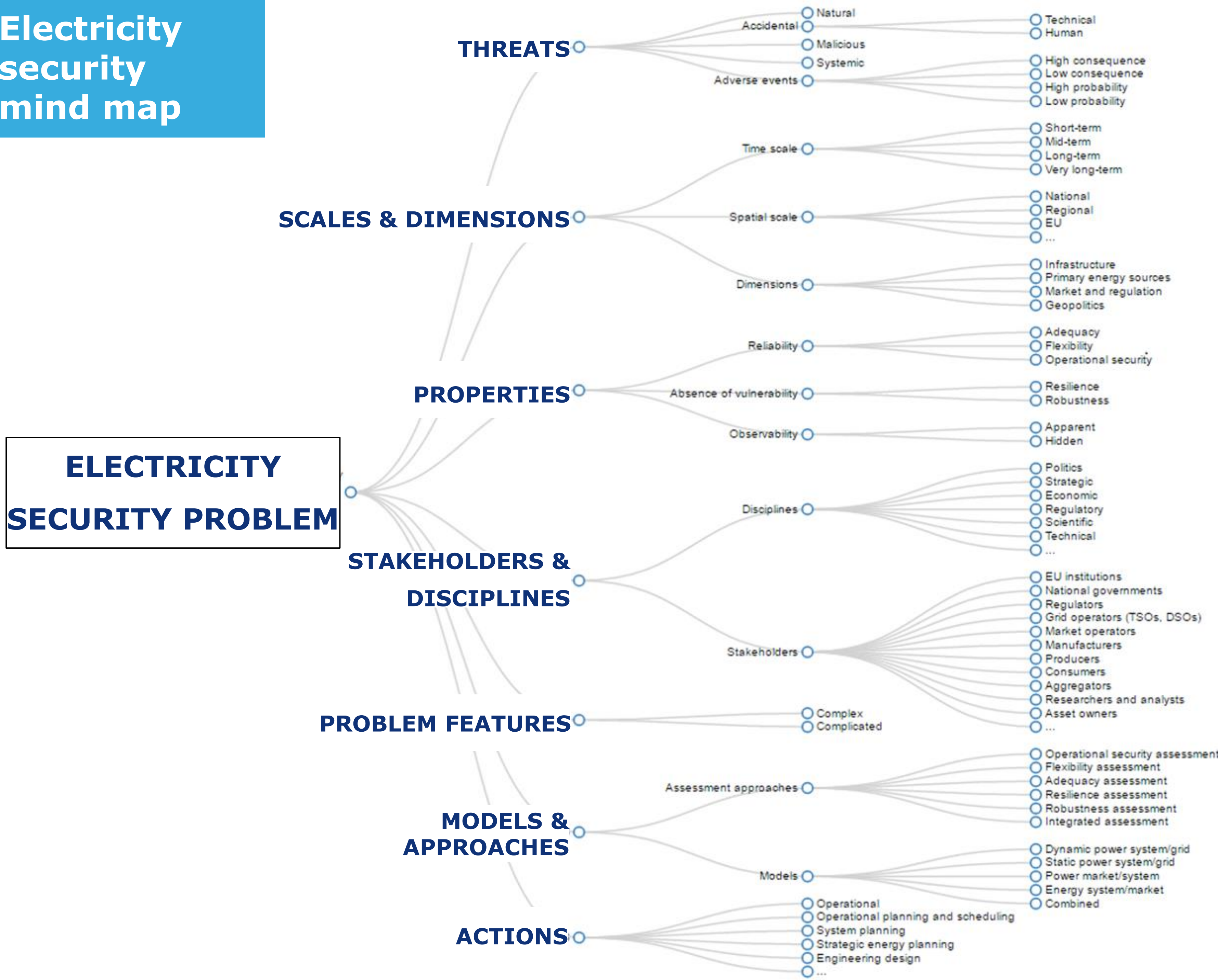
PhD Research question
...and some sub-questions

HOW SHALL ELECTRICITY SECURITY MODELLING AND ASSESSMENT METHODOLOGIES EVOLVE TO ADEQUATELY SUPPORT THE POLICY DECISION MAKING?

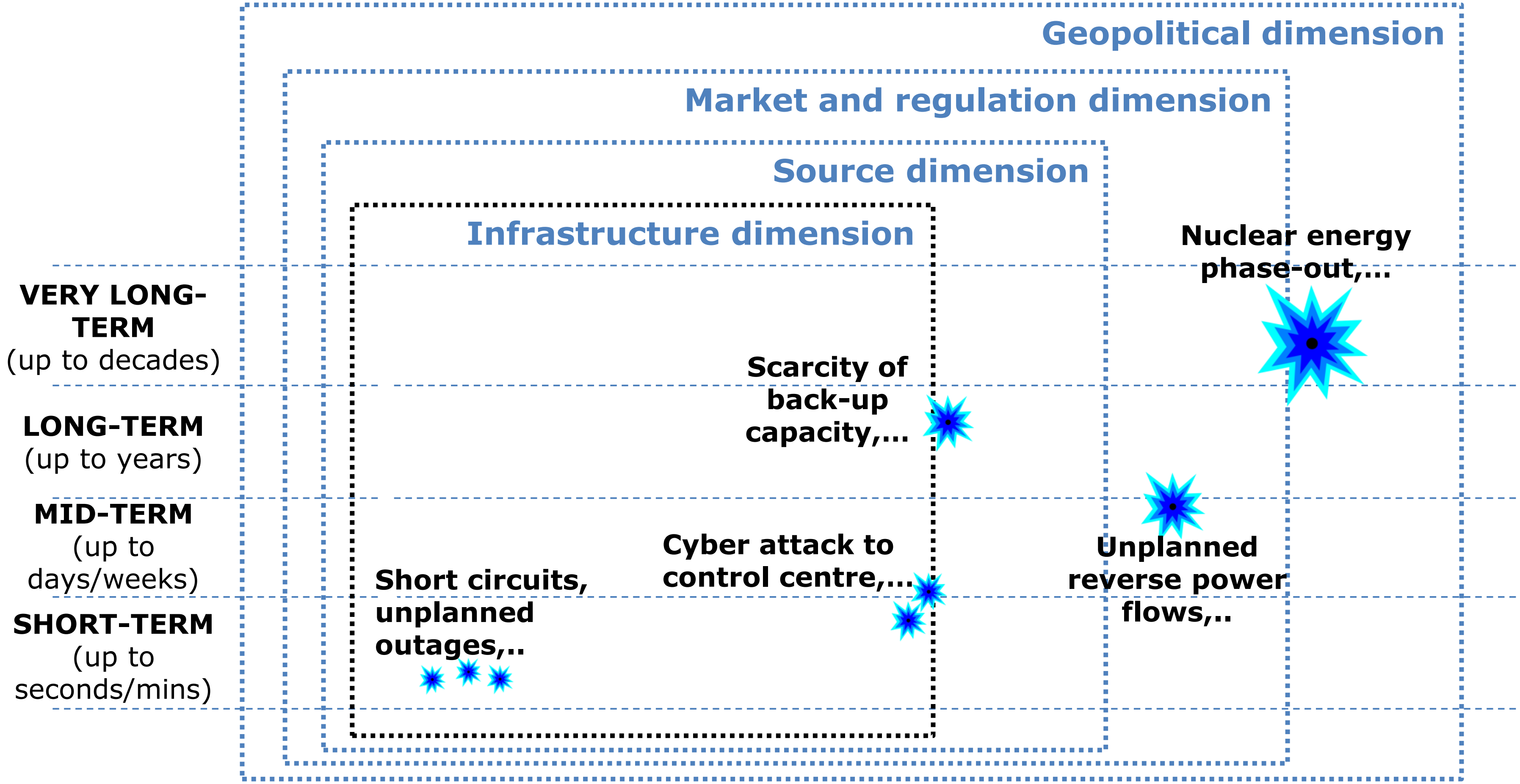
1. How to **define electricity security**?
2. What **models and methodologies** are **available**?
3. **What works and what doesn't** in the current approaches?
4. How to **improve** electricity security **policy decision making**?


1. EU ENERGY SCENARIOS
2. EU ENERGY POLICIES
3. ENERGY AND ELECTRICITY SECURITY ATTRIBUTES
4. ELECTRICITY SECURITY MODELS AND APPROACHES
5. DECISION-ANALYTIC FRAMEWORK
6. APPLICATIONS
7. CONCLUSIONS
NATIONAL CASE
REGIONAL CASE
EU PROOF-OF-CONCEPT

Electricity security mind map



Electricity security: threats and dimensions



Threats: natural, accidental, malicious, system

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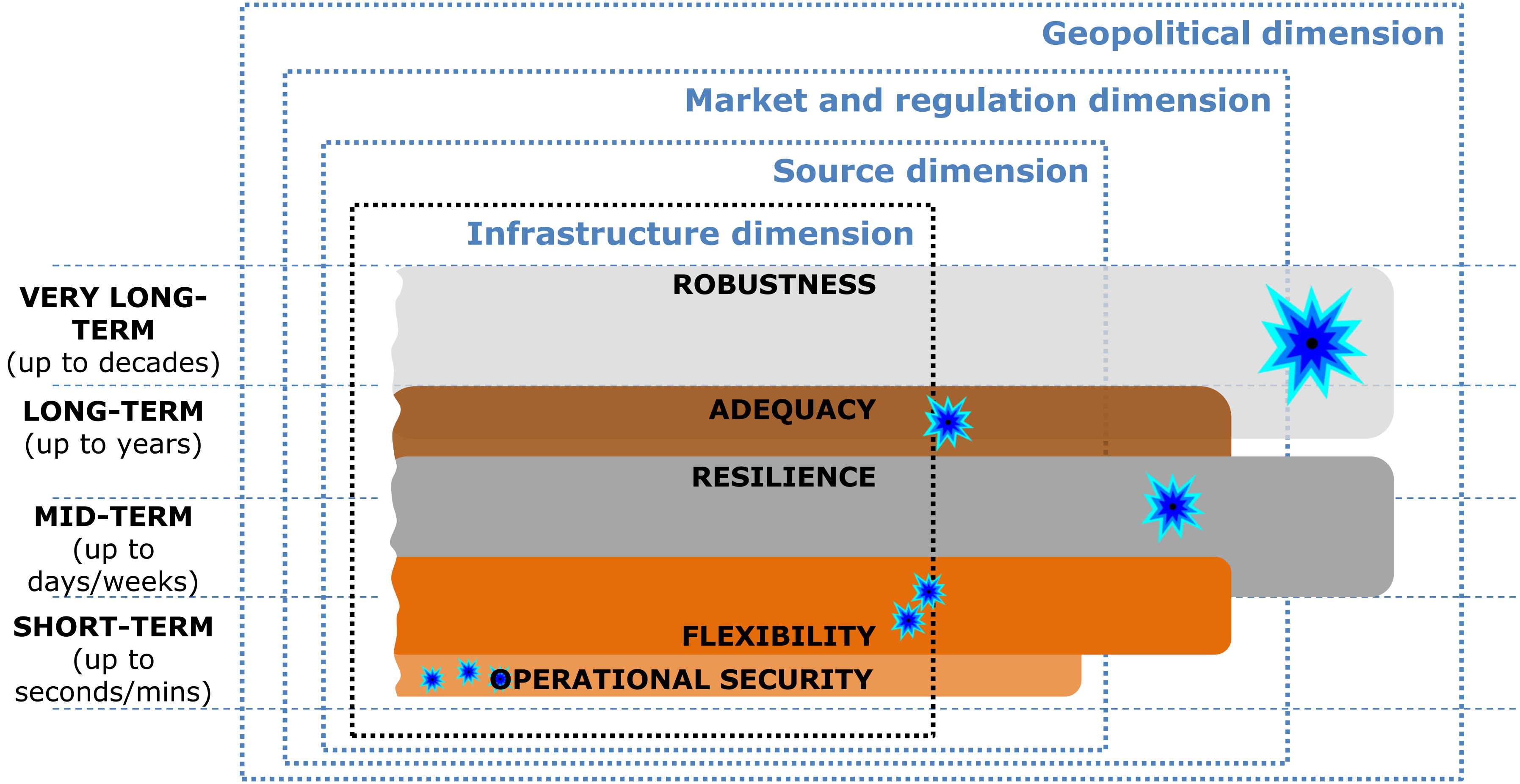
Electricity security: properties



Robustness: long-term capability of the power system to cope with constraints/stresses originating outside the infrastructure dimension.

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Four electricity model clusters:

- **Dynamic** power system/**grid** models: detailed short-term description of the power system, grid and protection components
- **Static** power system/**grid** models. They offer detailed representations of the power grid (component by component)
- **Power market**/system models: demand-supply equilibrium representation, and simplified grid representations
- **Energy system**/power market models: whole energy system representation, and selected portions of the power system/market

FEATURES / MODEL CLUSTER	TIME HORIZON				SYSTEM REPRESENTATION DETAIL		
	SHORT TERM	MID TERM	LONG TERM	VERY LONG TERM	ENERGY SYSTEM	POWER MARKET	POWER SYSTEM / GRID
DYNAMIC POWER SYSTEM / GRID MODELS	X	-	-	-	-	-	H
STATIC POWER SYSTEM / GRID MODELS	X	X	X	-	-	M	H
POWER MARKET / SYSTEM MODELS	X	X	X	-	-	H	M/L
ENERGY SYSTEM / POWER MARKET MODELS	-	X	X	X	H	H/M	-

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Which approaches assessing which electricity security properties?

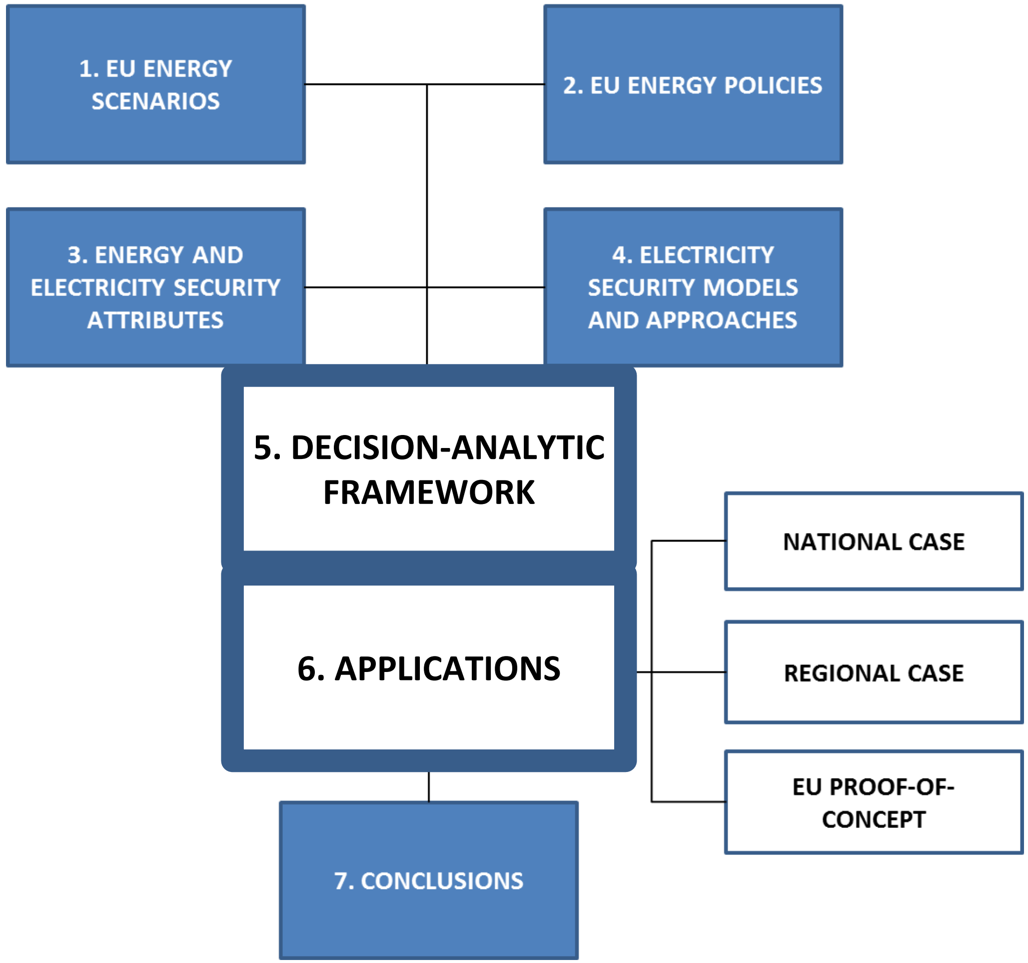
- **RELIABILITY** (op. security, flexibility & adequacy):ability of the system to perform its intended function → ENGINEERING

  "how things should work": higher probability-lower impact

- **VULNERABILITY** (lack of resilience & robustness): inability of the system to withstand strains and failures → COMPLEX SCIENCE

  "how things might fail": lower probability-higher impact

- **INTEGRATED: cost-benefit analyses, multi-criteria analyses and indicators**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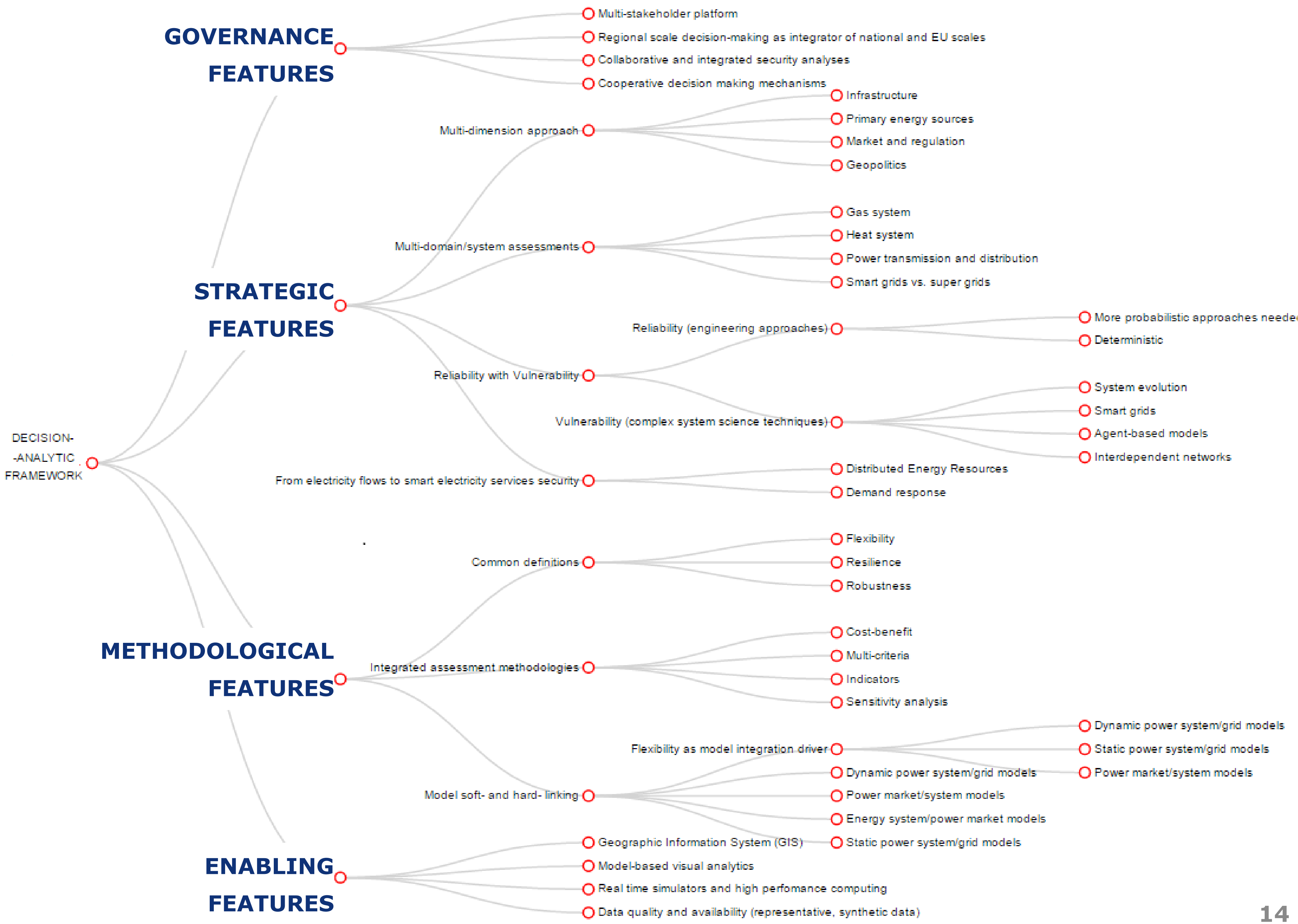
Decision-analytic framework



Framework applications

NATIONAL CASE:

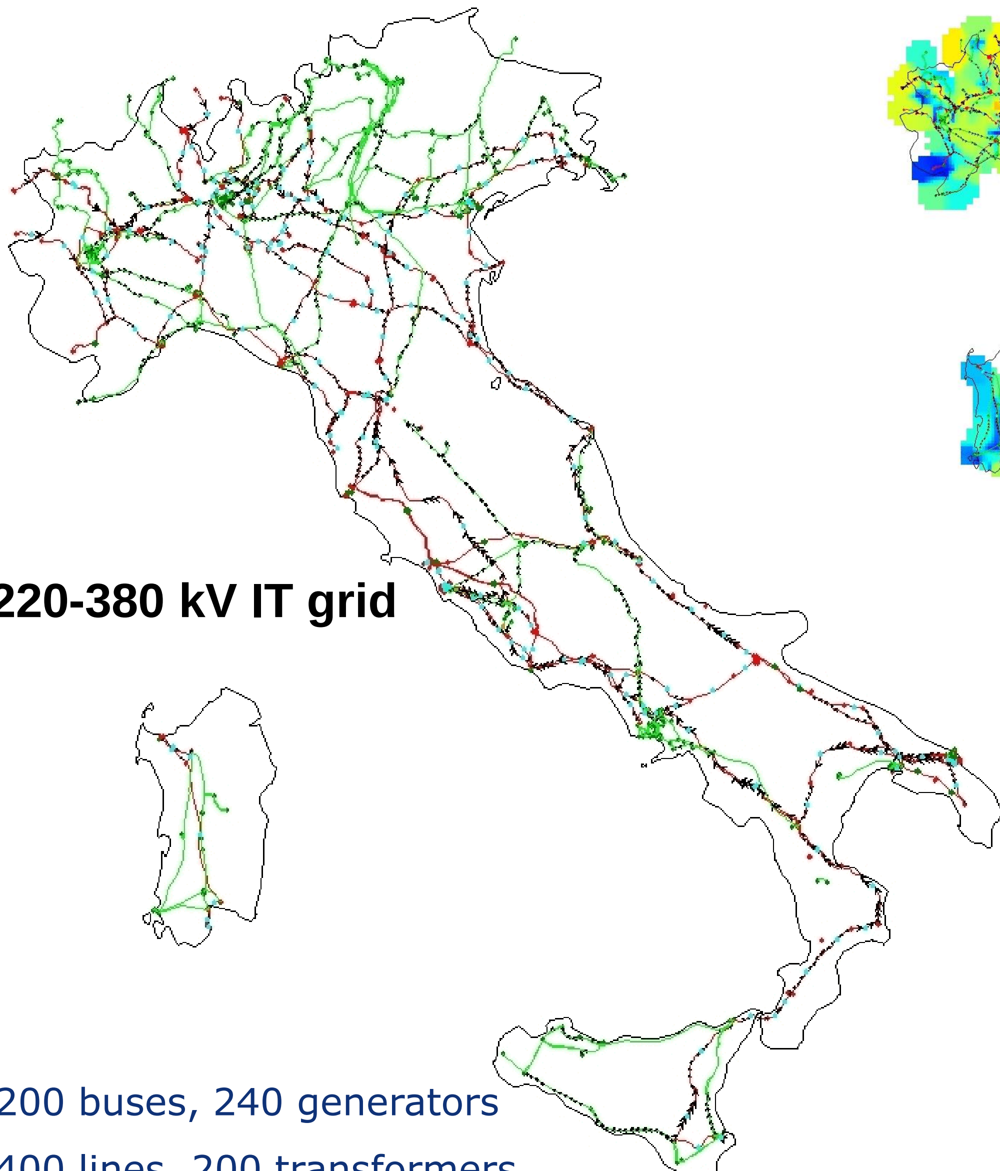
ITALY

ELECTRICITY SECURITY DIMENSIONS — INFRASTRUCTURE

ELECTRICITY SECURITY PROPERTIES — OPERATIONAL SECURITY, ROBUSTNESS

ELECTRICITY SECURITY MODELS — STATIC POWER SYSTEM/GRID MODELS

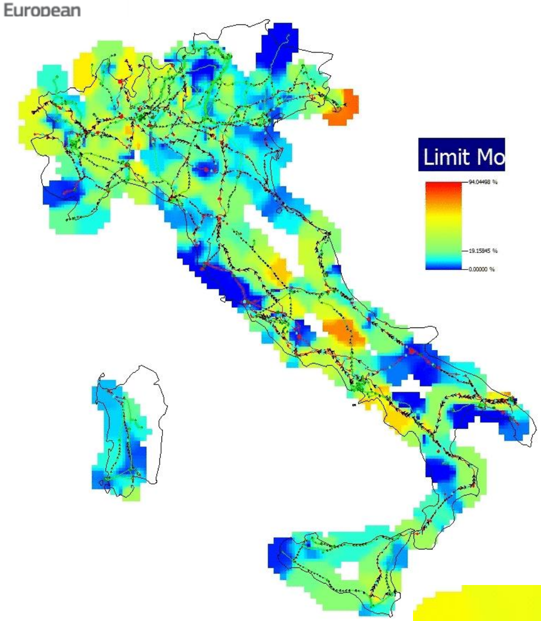
Georeferenced model for the Italian 380-220 kV transmission grid



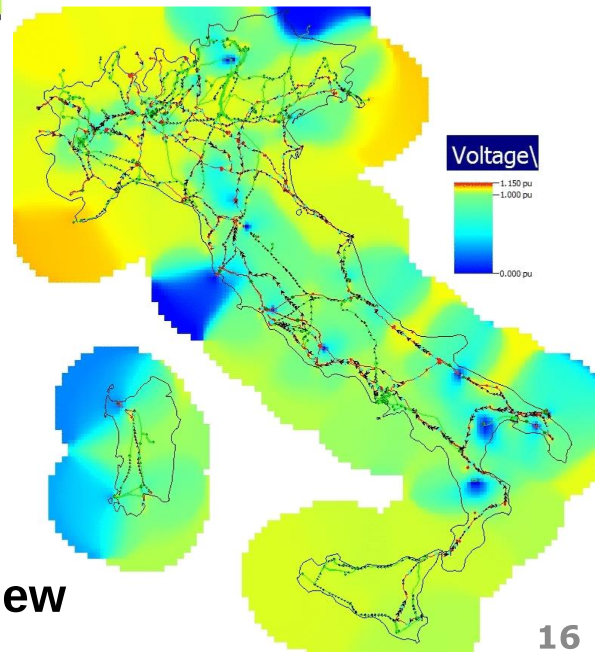
220-380 kV IT grid

1200 buses, 240 generators

1400 lines, 200 transformers



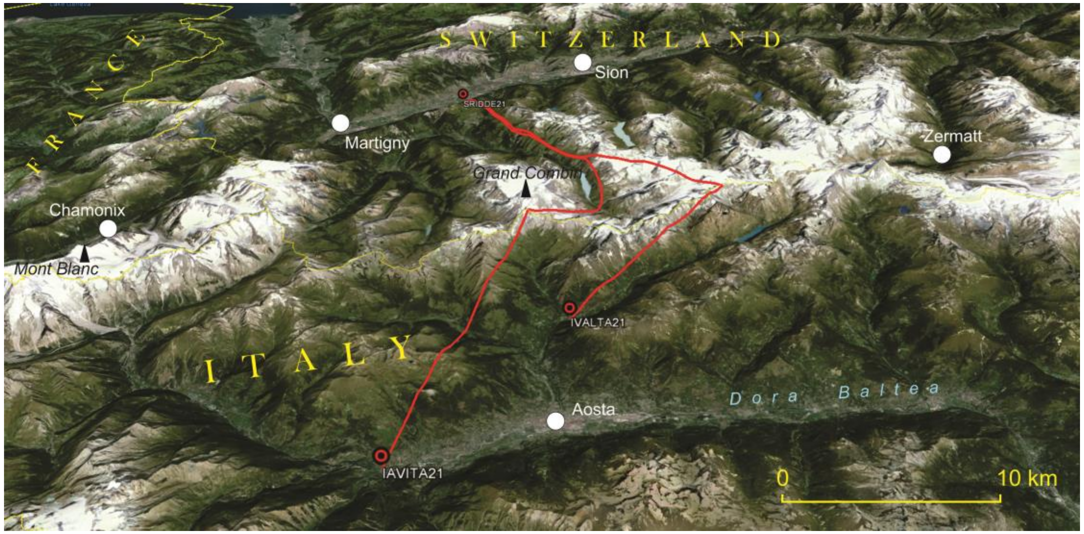
Power flow view



Voltage view

Contingency analysis example: extreme weather scenario design

- Extremely cold days of winter in the Alps, and the temperature reaches -45 ° C (record lowest temperature in the Alps)
- The highest recorded snowfall on the Alps 11.5 m assumed
- 220 kV interconnection lines between Switzerland and Italy disrupted by snow/ice (3500m average altitude)



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Tripping of 380 kV line in Central Italy: line flows violation

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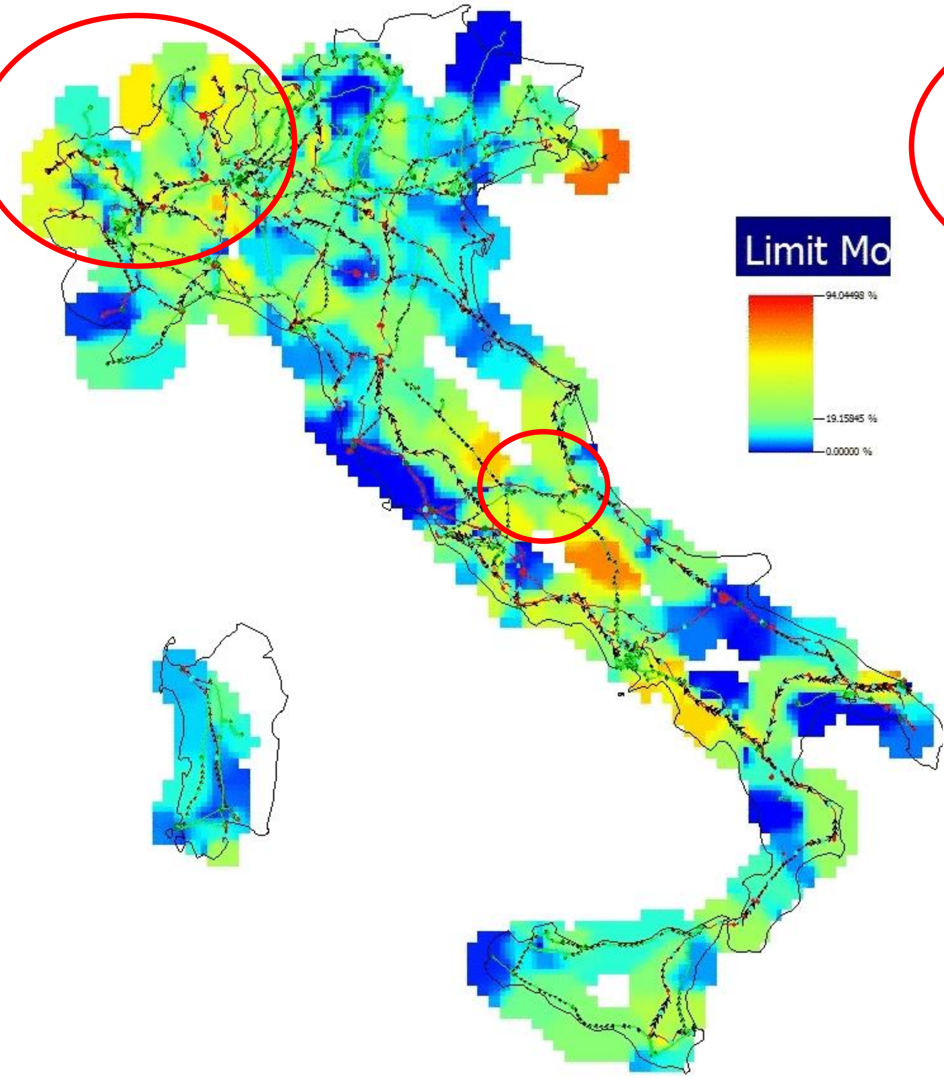
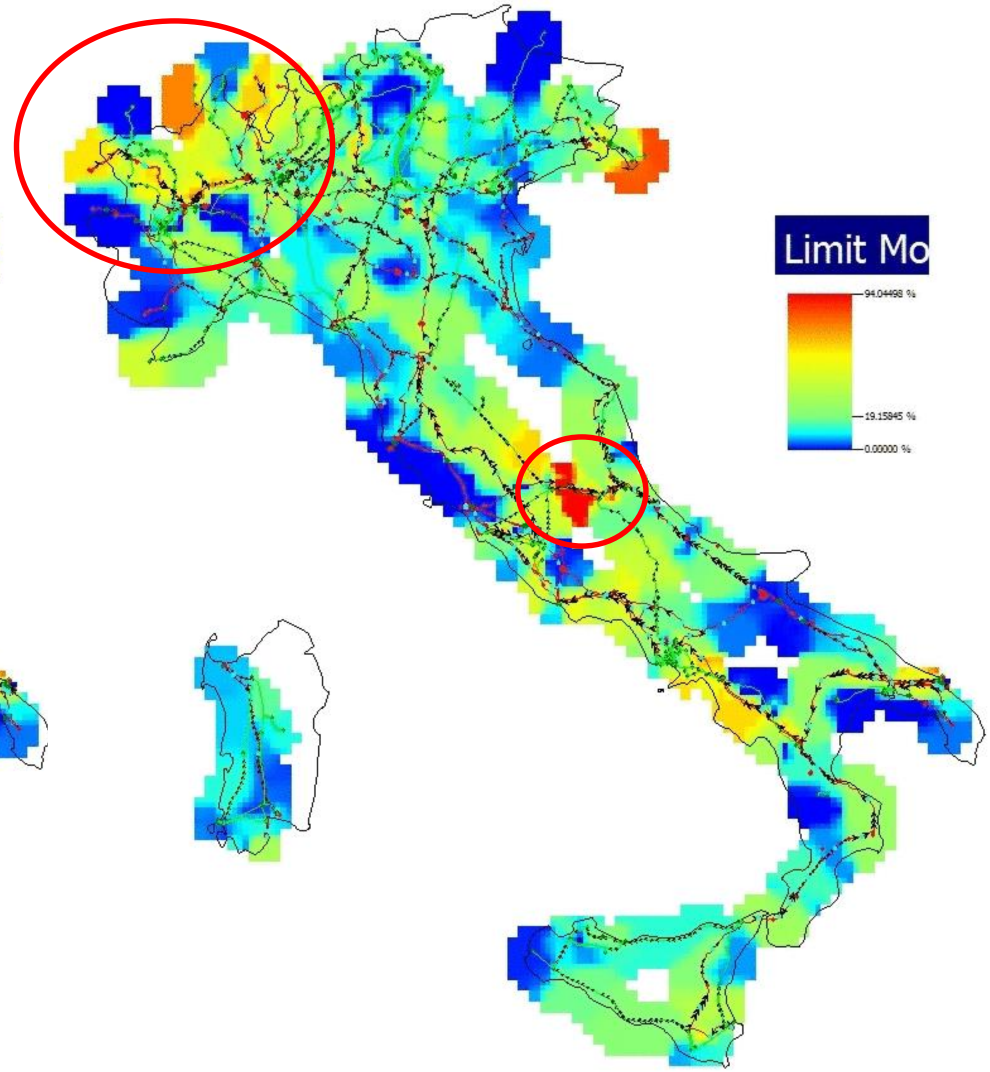


normal state



After tripping

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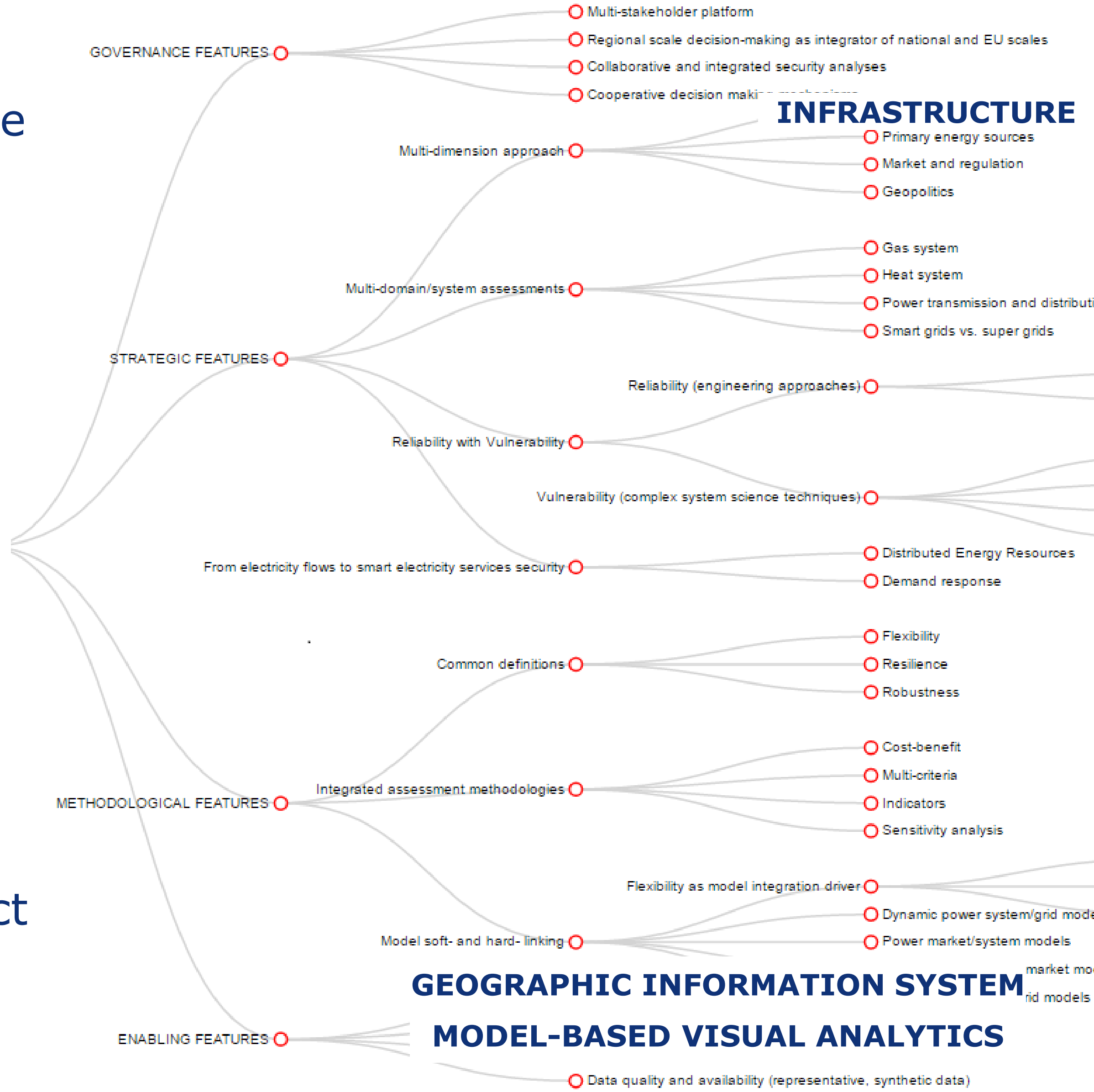
The Italian national case

European

This test case showed how the decision makers (the system operator in particular), via **Geographic Information System** and model-based **visual analytics**:

- could gain quicker awareness of potentially critical system conditions
- and this would more speedily allow them to react



	NATIONAL CASE: ITALY	REGIONAL CASE: BALTICS
ELECTRICITY SECURITY DIMENSIONS	INFRASTRUCTURE	GEOPOLITICAL, SOURCE, INFRASTRUCTURE
ELECTRICITY SECURITY PROPERTIES	OPERATIONAL SECURITY, ROBUSTNESS	OPERATIONAL SECURITY, ADEQUACY
ELECTRICITY SECURITY MODELS	STATIC POWER SYSTEM/GRID MODELS	STATIC POWER SYSTEM/GRID MODELS POWER MARKET/SYSTEM MODELS

The Baltic case – models and scenarios

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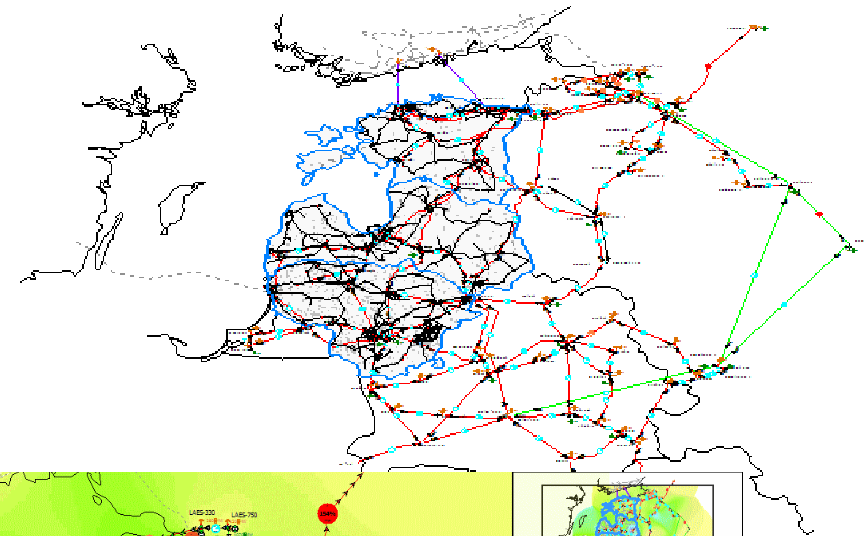
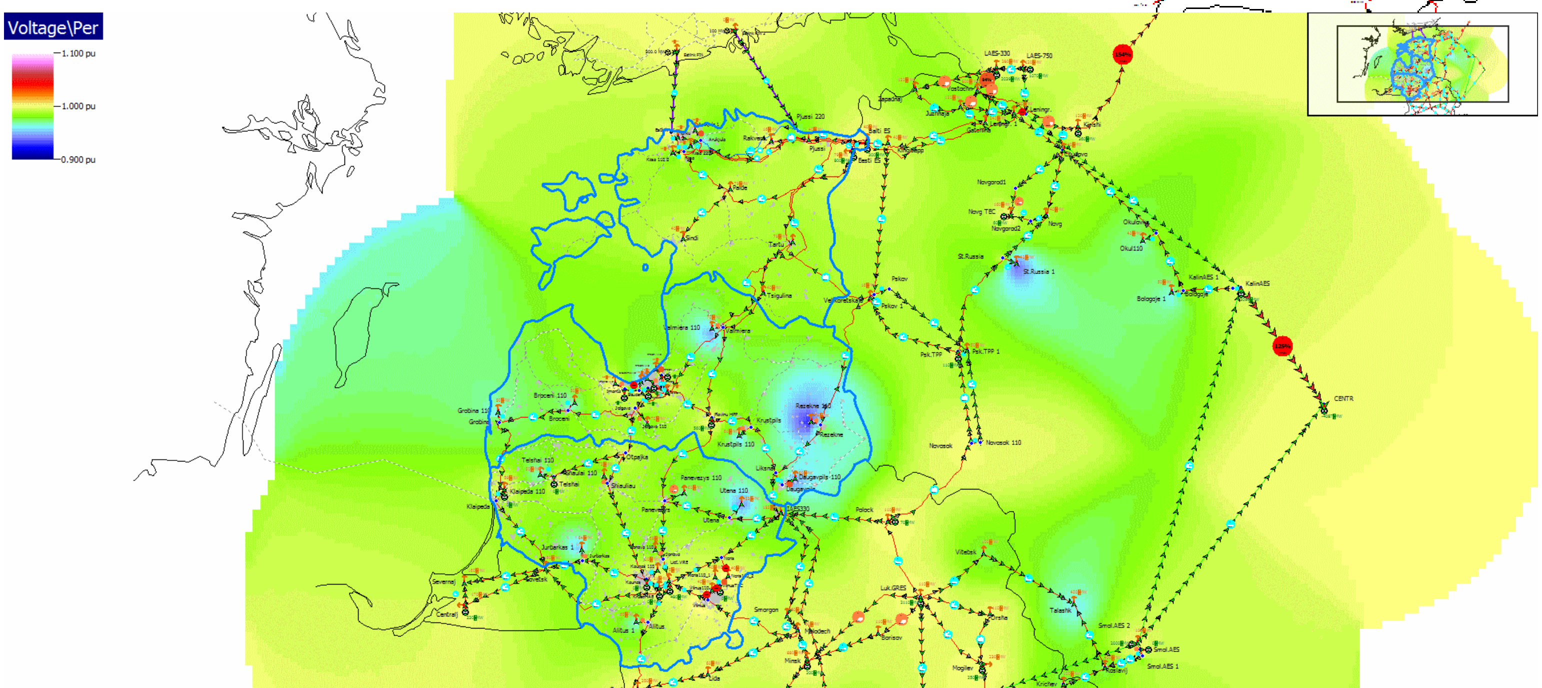
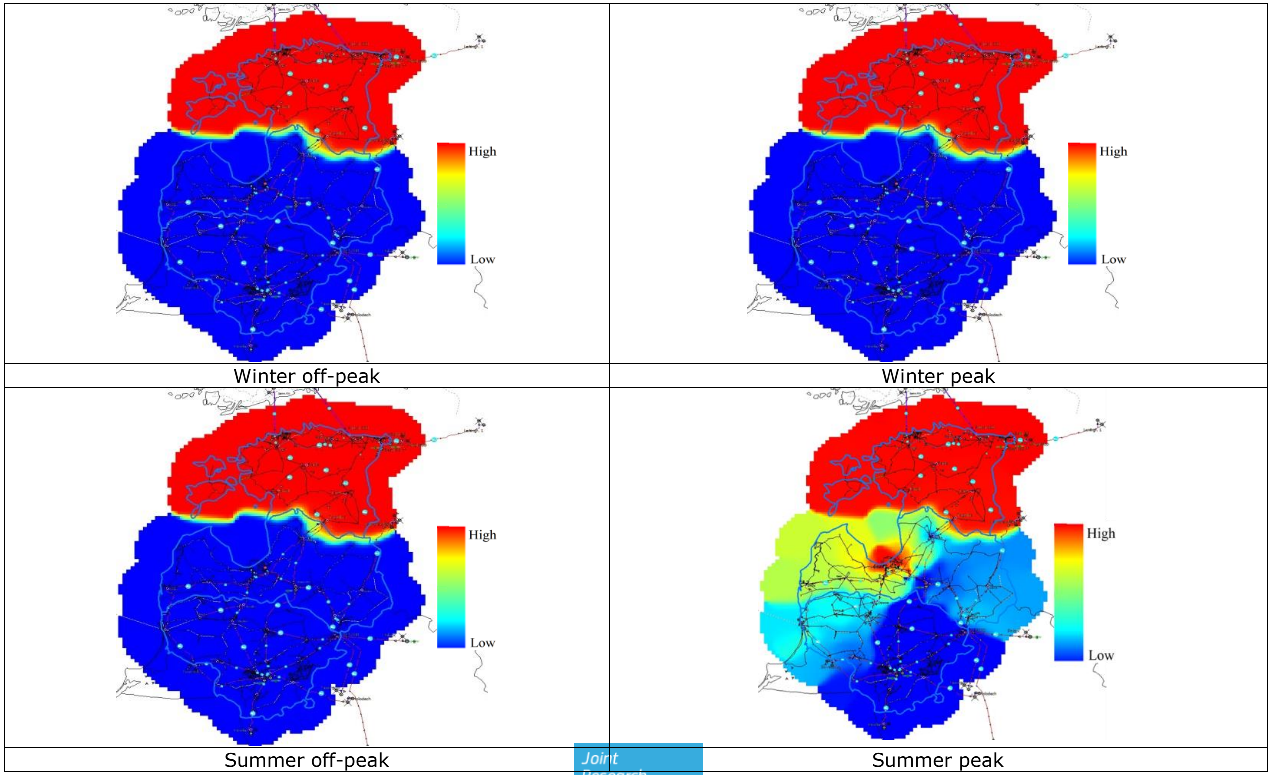
Detailed steady-state models of the electricity infrastructure are built to perform security and preliminary (market) adequacy analyses in the Baltic and adjoining regions in a set of anticipated **scenarios**





The Baltic case – techno-economic analyses

- The objective of the optimal power flow is to minimise generation cost considering grid constraints
- Locational marginal costs are provided for each Baltic power system (so that market zonal splitting due to congestion can be identified)



The Baltic case: steady-state and contingency analyses

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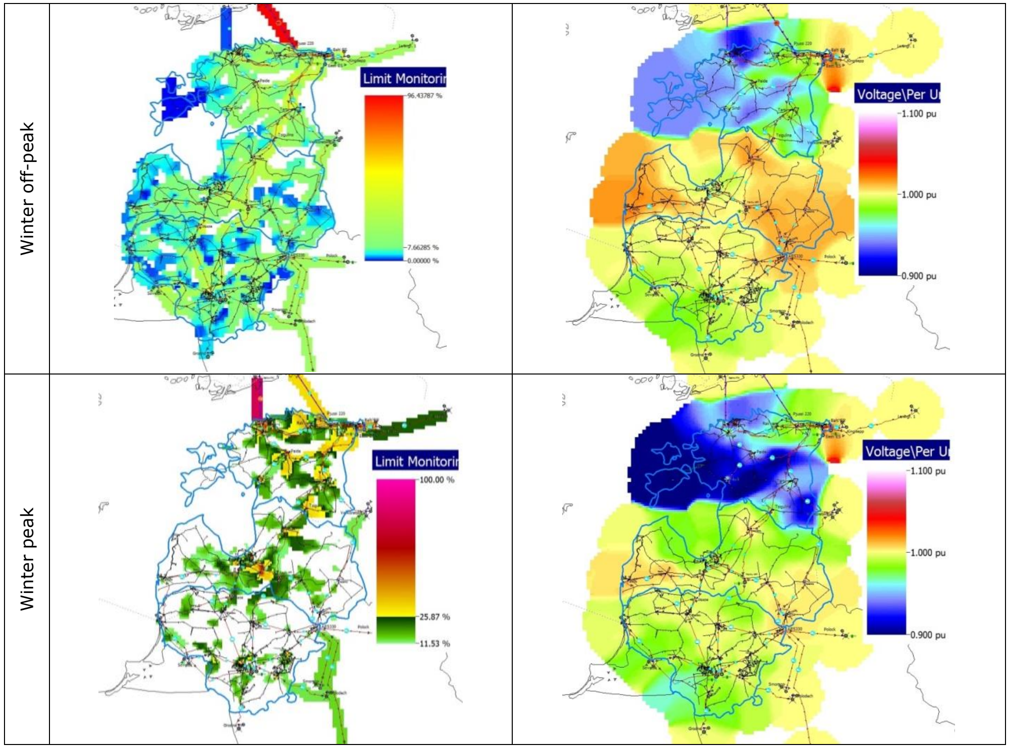
- Contingency analysis performed on four scenarios to check the **operational security** of the systems, and the adequacy of resources available to the TSO to handle such contingencies.

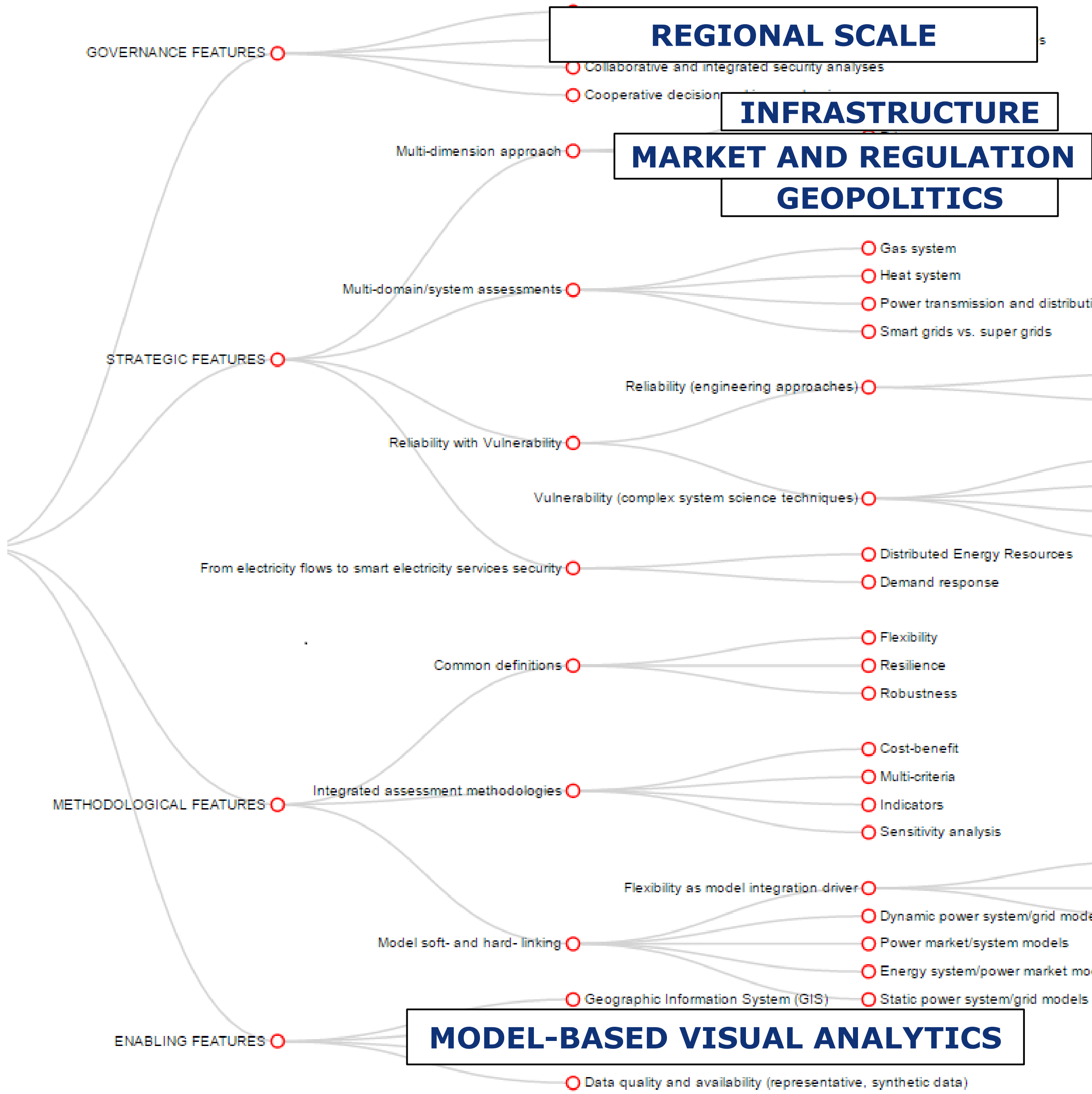
- Results useful to identify the criticalities of the system under different generation and load conditions.



The Baltic regional case

This test case showed how

- **coordinated regional security analyses** can be conducted across Member States, targeting multiple security properties and
- electricity security models can be used to support decisions beyond the techno-economic aspects and including the **geopolitics**

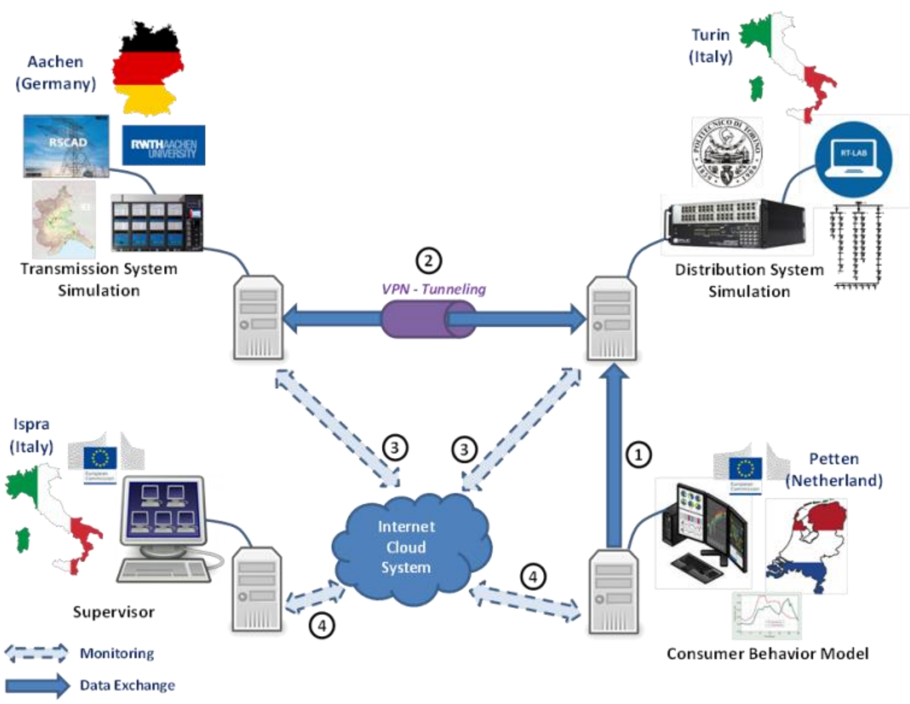


	NATIONAL CASE: ITALY	REGIONAL CASE: BALTICS	EU-WIDE CASE: ERIC NETWORK
ELECTRICITY SECURITY DIMENSIONS	INFRASTRUCTURE	GEOPOLITICAL, SOURCE, INFRASTRUCTURE	GEOPOLITICAL, SOURCE, MARKET AND REGULATION, INFRASTRUCTURE
ELECTRICITY SECURITY PROPERTIES	OPERATIONAL SECURITY, ROBUSTNESS	OPERATIONAL SECURITY, ADEQUACY	PROOF OF CONCEPT FOR CROSS-CUTTING, INTEGRATED ELECTRICITY SECURITY ASSESSMENT
ELECTRICITY SECURITY MODELS	STATIC POWER SYSTEM/GRID MODELS	STATIC POWER SYSTEM/GRID MODELS POWER MARKET/SYSTEM MODELS	

Real time co-simulation platform proof of concept

- **Real-time co-simulation** of a transmission-distribution system between 4 laboratories in Europe
- **Real-time remote access** to high-performance computing, data and infrastructure
- **Perspective integrated analyses** of different domains/systems: market, generation, transmission, distribution, consumers,…

http://www.eric-lab.eu/

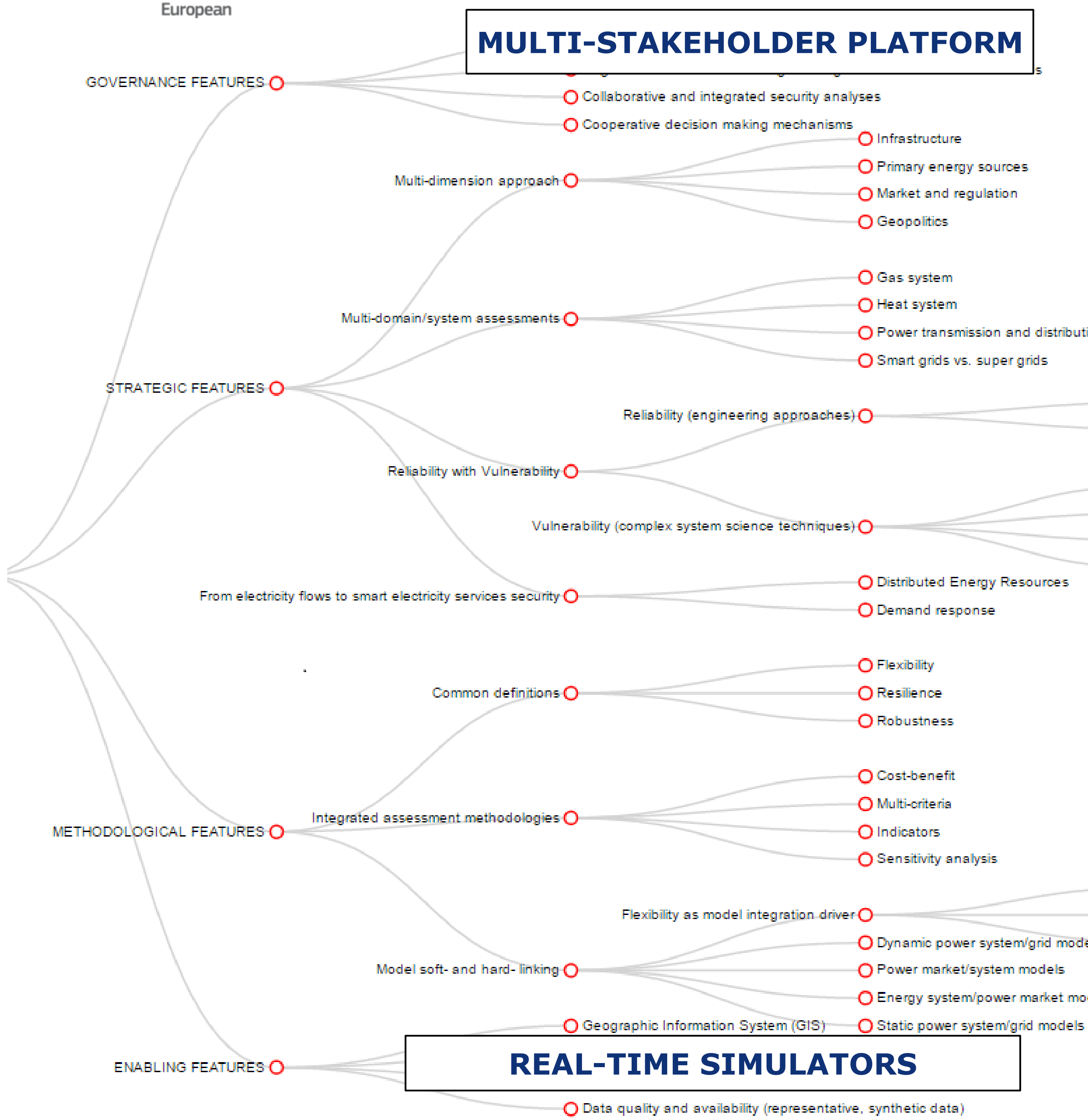


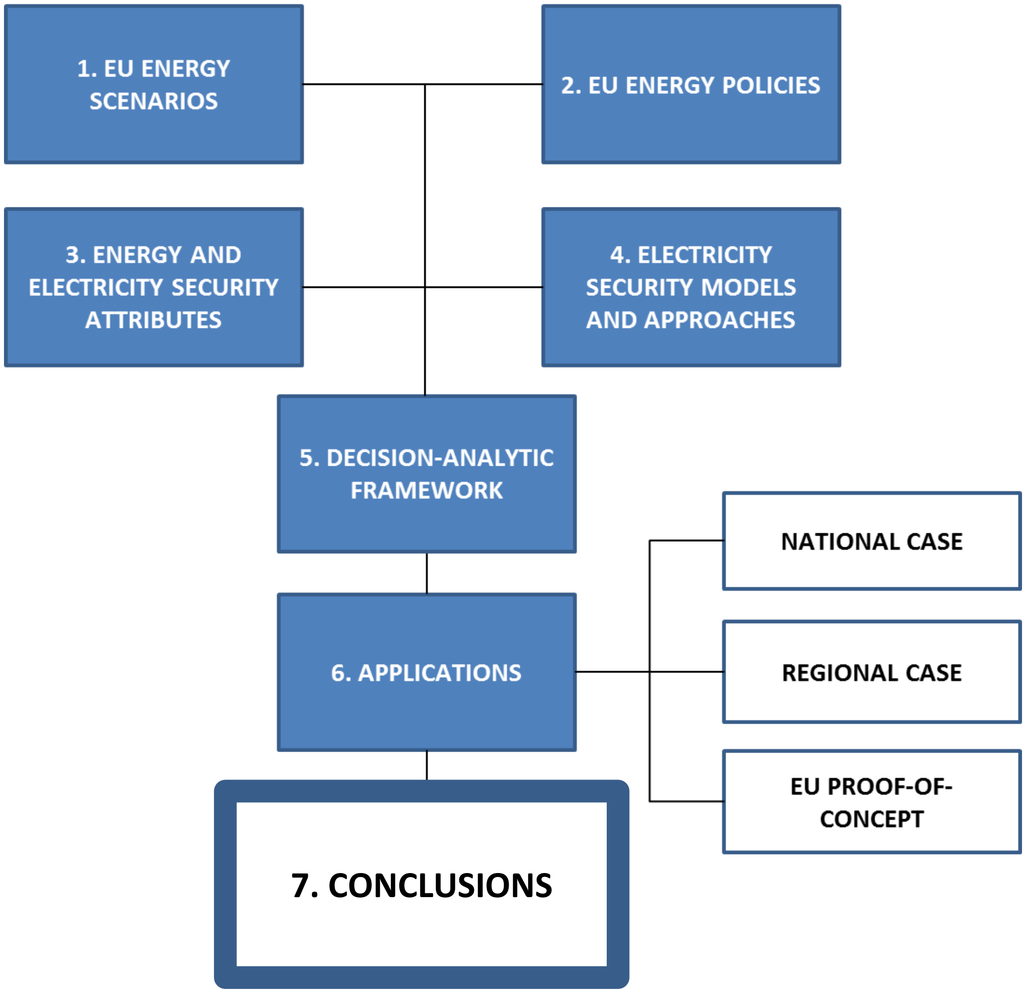
The platform proof-of-concept

This proof of concept showed how a real-time simulation platform can **overcome**

- **computational** power **constraints**
- **data confidentiality constraints**

towards accurate cross-national security analyses





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Conclusions (1/2)

1. How to define electricity security?

Taxonomy at the cross-roads of science and policy for electricity security properties

2. What models and methodologies are available?

Classification, clustering and mapping of electricity security models and assessment methodologies

Conclusions (2/2)

3. What works and what doesn't in the current approaches?

Critical review of electricity security models, procedures and actors in the framework of the EU energy transition

4. How to improve electricity security policy decision making?

Novel decision-analytic framework for electricity security and applications at national, regional and EU-wide scale

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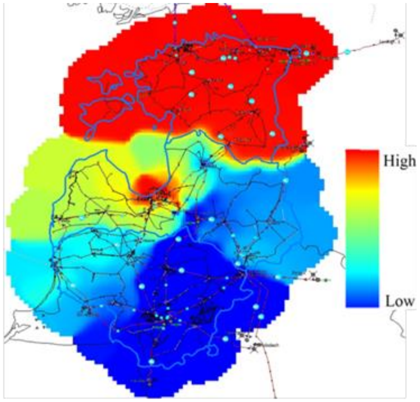

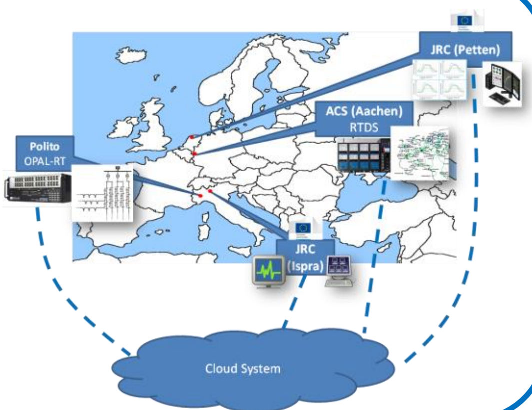

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2013-2016 Scientific output: Peer-review papers

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Co-authorship of 12 ISI-listed journal papers, 2 magazine papers, 5 conference papers, 5 book chapters and 4 EC-JRC Reports

6 ISI-listed papers more directly linked to this PhD research

1. Bompard, E.; Estebsari, A.; Huang, T.; Pons; E.; Fulli, G.; *A Framework for Analyzing Cascading Failure in Large Interconnected Power Systems: a Post-Contingency Evolution Simulator*, 2016, *International Journal of Electrical Power & Energy Systems*, in press
2. Colak, I; Sagiroglu, S.; Fulli, G.; Yesilbudak, M.; Covrig, C.F.; *A survey on the critical issues in smart grid technologies*, 2016, *Renewable and Sustainable Energy Reviews*
3. Colak, I; Fulli, G.; Bayhan, S.; Chondrogiannis, S.; Demirbas, S.; *Critical aspects of wind energy systems in smart grid applications*, 2015, Renewable and Sustainable Energy Reviews
4. Bompard, E.; Fulli, G; Ardelean, M.; Masera, M.; *It's a bird, it's a plane, it's a … Supergrid*, 2014, *IEEE Power and Energy Magazine*
5. Brancucci Martinez-Anido, C.; Vandenbergh, M., de Vries, L.; Alecu, C.; Purvins, A.; Fulli, G.; Huld, T.; *Medium-Term Demand for European Cross-Border Electricity Transmission Capacity*, 2013, *Energy Policy*
6. Brancucci Martínez-Anido, C.; L'Abbate, A.; Migliavacca, G.; Calisti, R.; Soranno, M.; Fulli, G.; Alecu, C.; de Vries, L.J.; *Effects of North-African electricity import on the European and the Italian power systems: a techno-economic analysis*, 2013, *Electric Power Systems Research*

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Electricity security analyses - improvement areas

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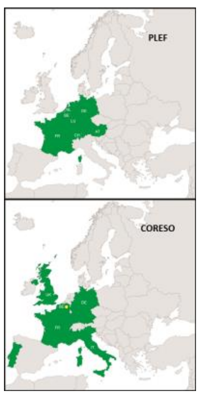
National scale:

- model **interlinking** across domains/systems: the electricity distribution & transmission, gas, heat,…
- incorporate **probabilistic/complex system** approaches in decision making process

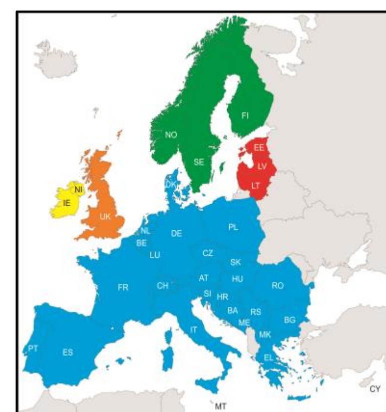


Regional scale:

- better defining **roles** and **responsibilities** of the actors
- expanding security analyses in the **vulnerability** area and in modelling the **interfaces** with other energy systems

EU-wide scale:

- transmission-distribution **interfacing** issues
- streamlining **EU-wide & regional** modelling/analyses
- **dynamic** system representation (real-time simulation)



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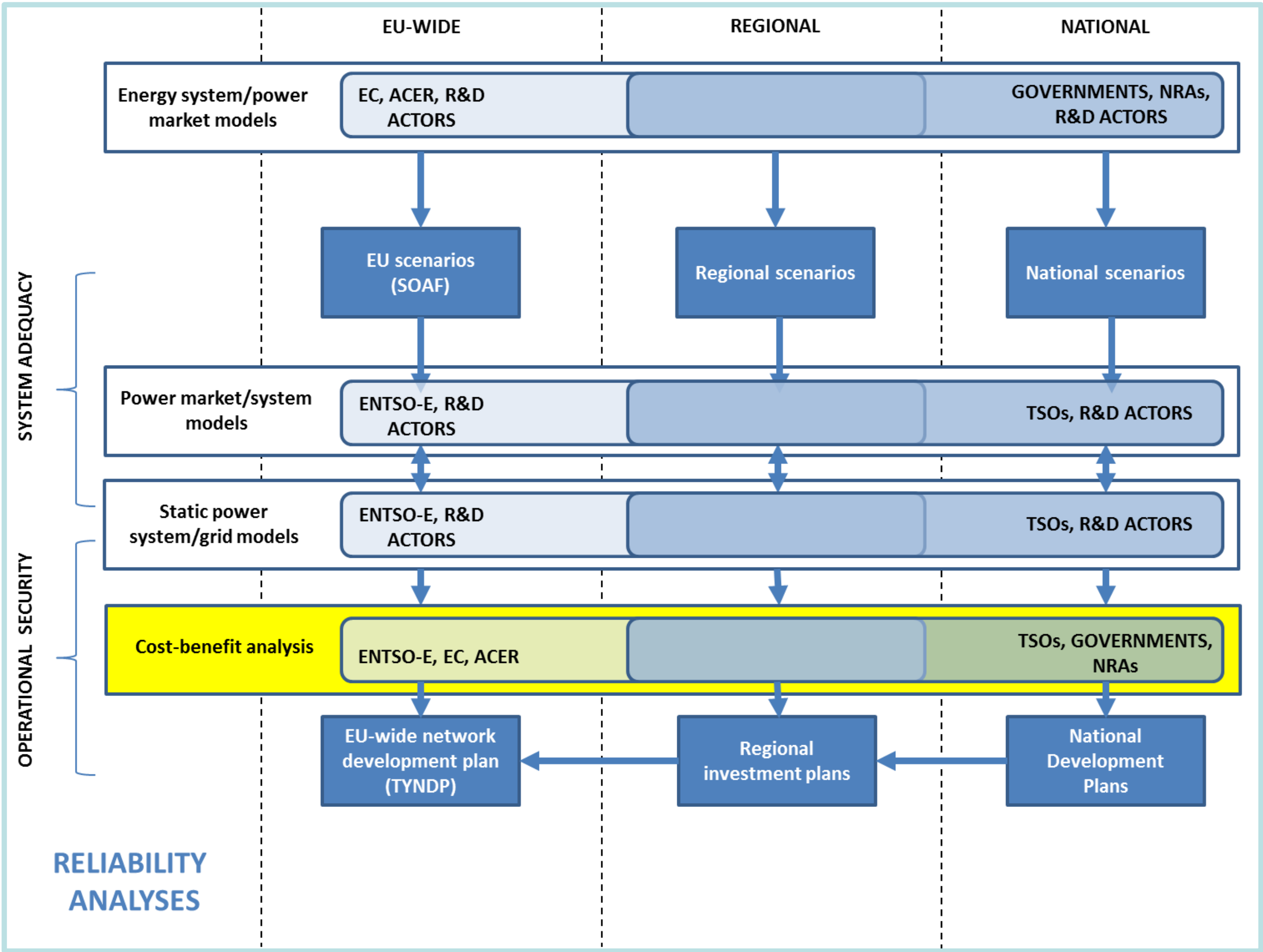
Current power system security and planning decision making



Framework contextualization in the planning process