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Resilience of critical energy infrastructure and multi-risk approach: addressing existing and emerging risks

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Risk Management in Energy - 2021

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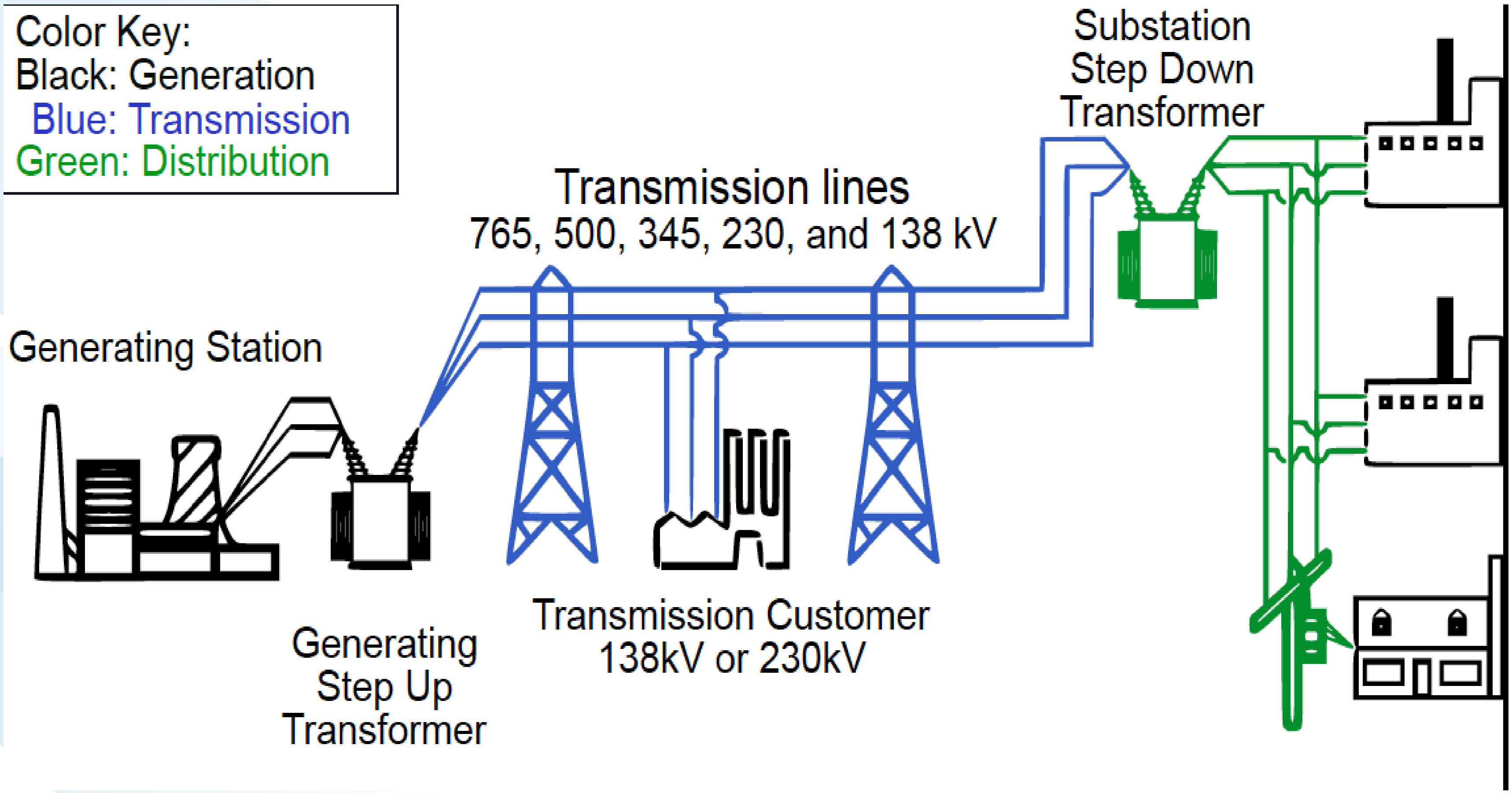
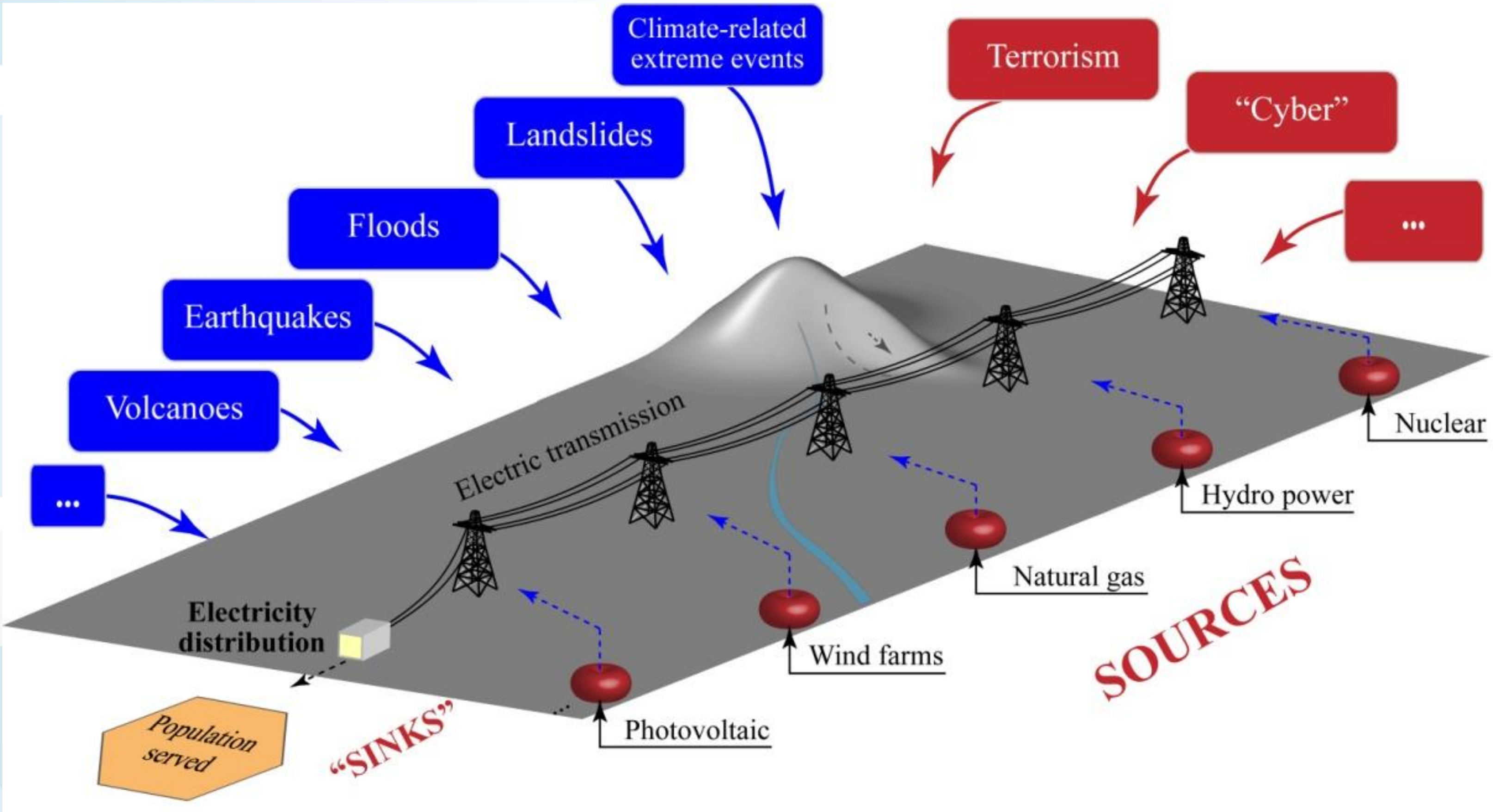
Interconnected and complex infrastructure



Source: ENTSO-E

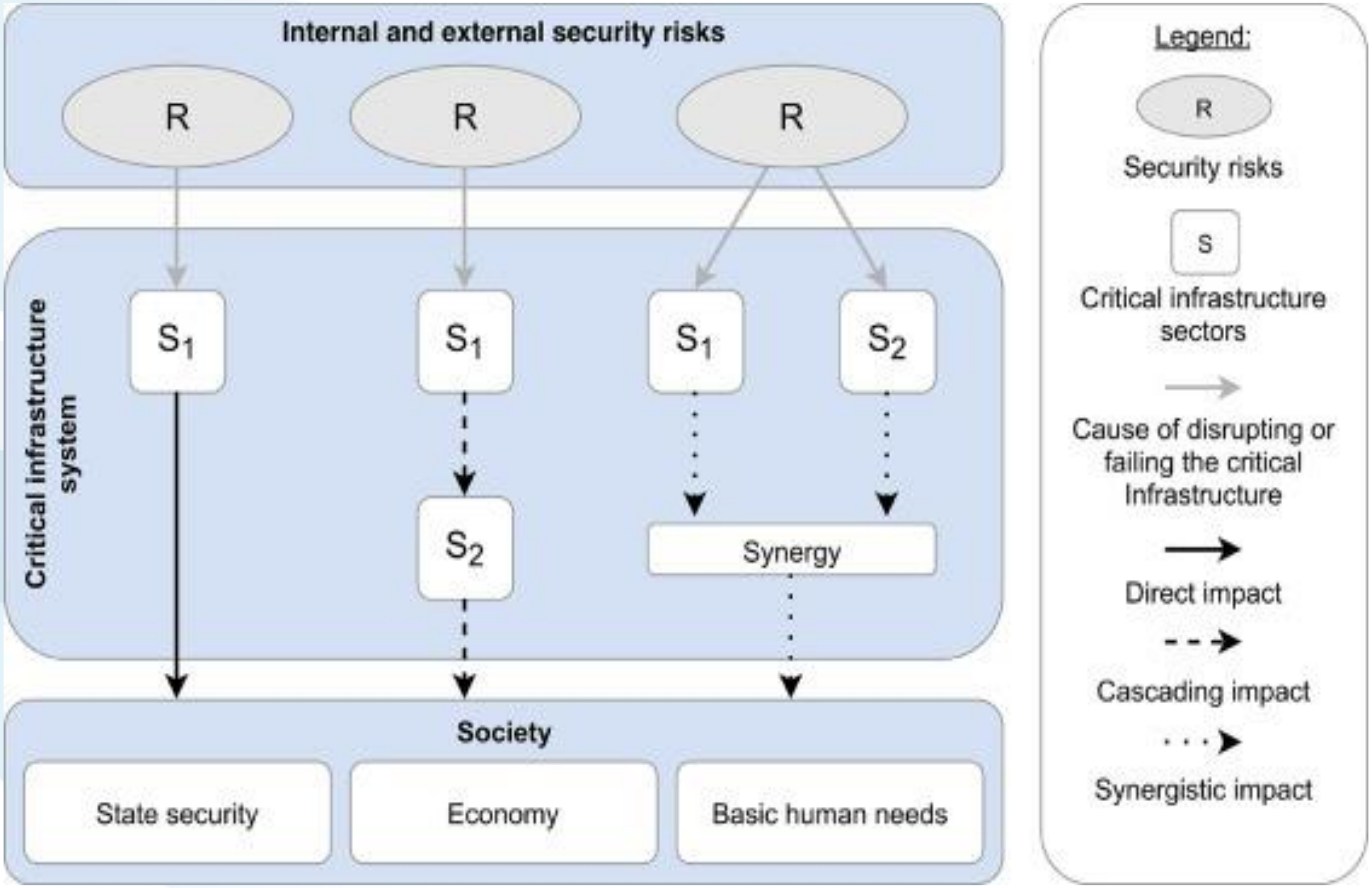
Critical energy infrastructure is a subject to multiple risks



Source: Garcia, AMRA

- Grids are already subject to impacts of natural hazards such as extreme weather and space events, earthquakes, cyclones, storms and heat waves
- Impacts affect physical integrity of electricity transmission grids and decrease transmission capacity
- Increasing impact of emerging risks such as cyber attacks or recent Covid19 pandemic

Cascading impacts on other infrastructures such as transportation, telecommunication etc.



Source: Rehak et al., 2018

Multi-risk governance to address existing and emerging risks

Today

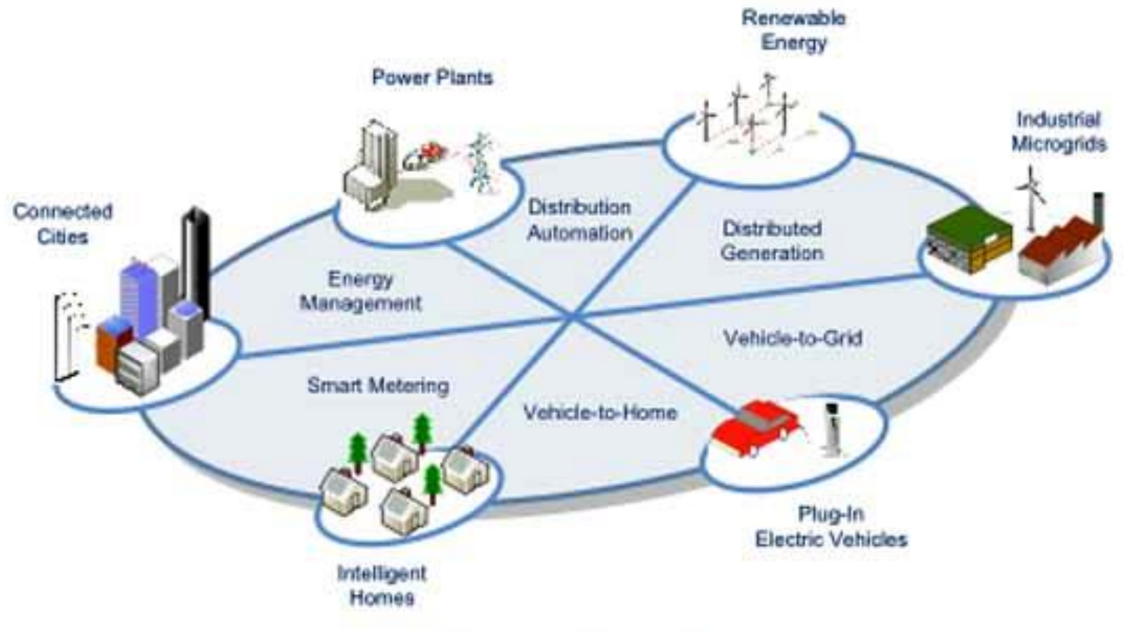
- Frequent prioritization of risks which can be significantly reduced and not necessarily risks with highest impacts
- Single risk centered regulation and institutional frameworks
- Absence of systematic consideration of cascades and associated impacts

Benefits of multi-risk approach

- Multi-risk approach – comparing and ranking of different risks, holistic view of interactions and conflicts of risks
- Improvement of spatial planning, emergency management and multi-risk governance
- Cost reduction, improvements in efficiency of risk mitigation and management measures and better identification of actions priorities

In Europe the multi-risk governance approach for protection of energy critical infrastructure is influenced by following vulnerability factors

- Aging of energy infrastructure
- Diversification of electricity supply located in different areas
- Transboundary risks
- Multiplicity of stakeholders

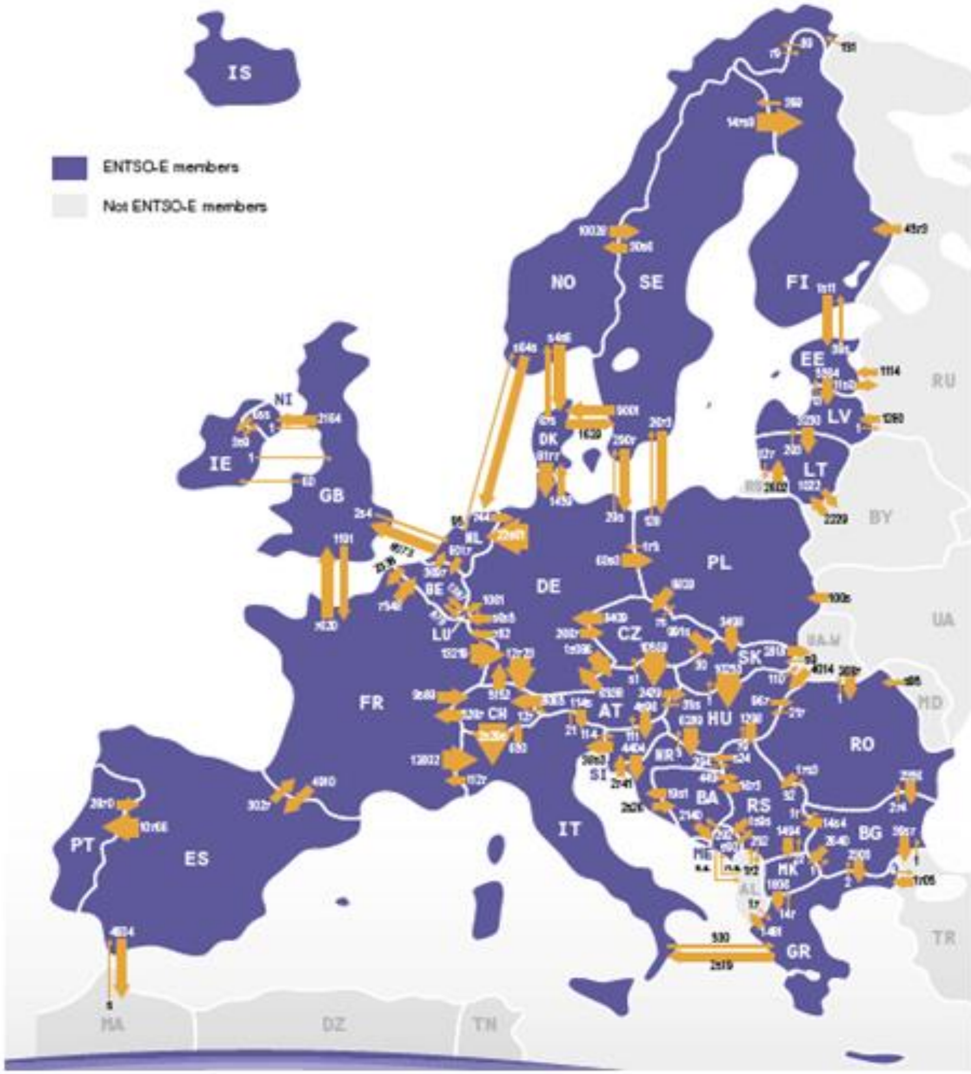


Smart Grid building blocks

Grids at the border of their capacity to integrate growing volumes of renewable energy electricity

Several new km need to be constructed to secure market integration, security of supply and accommodate renewable energy expansion

Example: European electricity transmission system is grouped in 5 synchronous areas and is managed by 41 TSO from 34 countries



Source: ENTSO-E Memo 2012, values in GWh

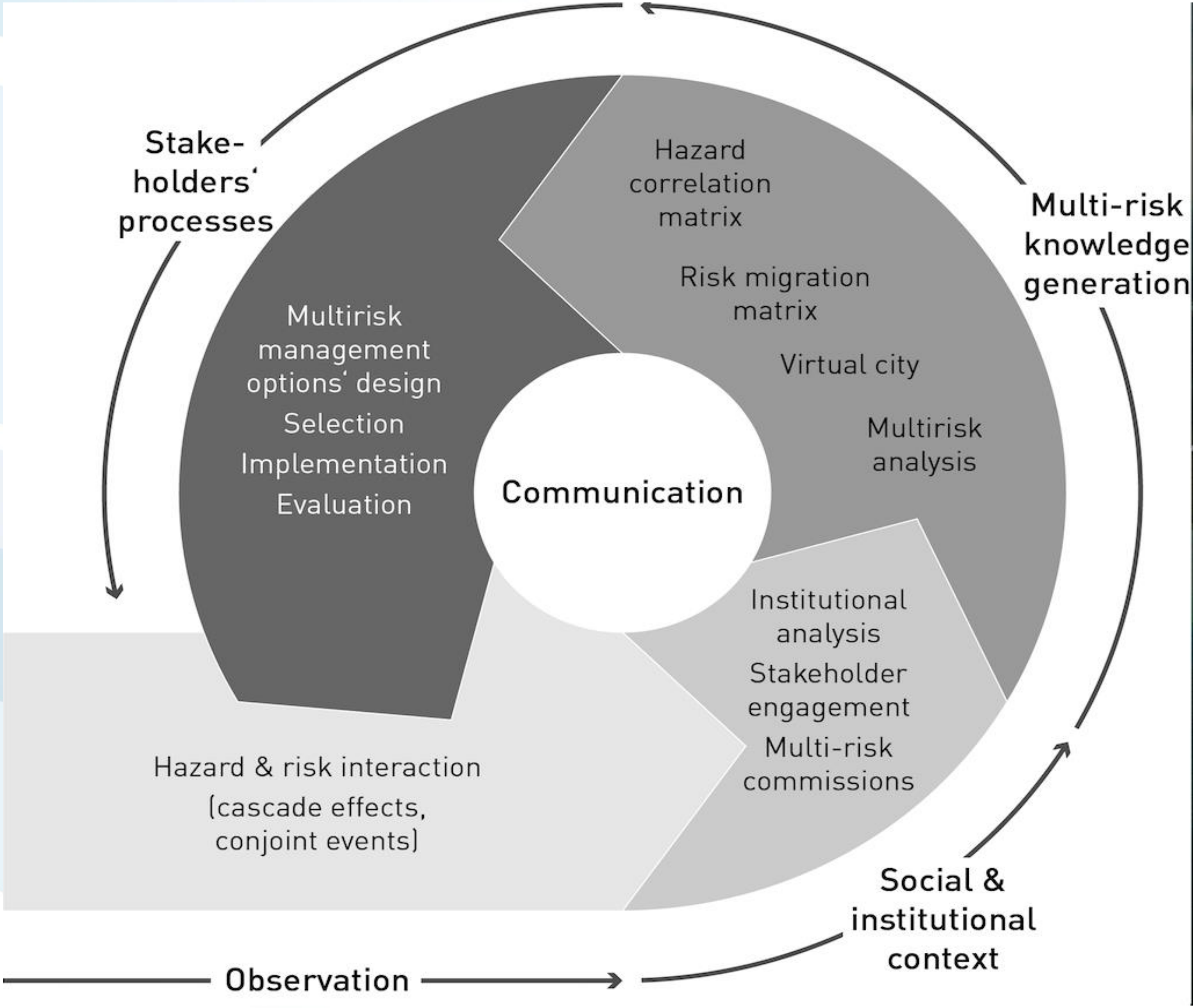
Key figures (2012):

- 5 synchronous areas
- Network of 41 TSOs from 34 countries
- Serving 534 million citizens – 3'300 TWh consumption, 13% cross-border
- 305'000 km of transmission lines

Main goals:

- Security of supply, reliable operation
- Efficient and competitive market
- Optimal management and sound technical evolution of the system

Multi-risk governance framework



Source: Scolobig, A., Komendantova, N., Mignan, A. *Geoscience*

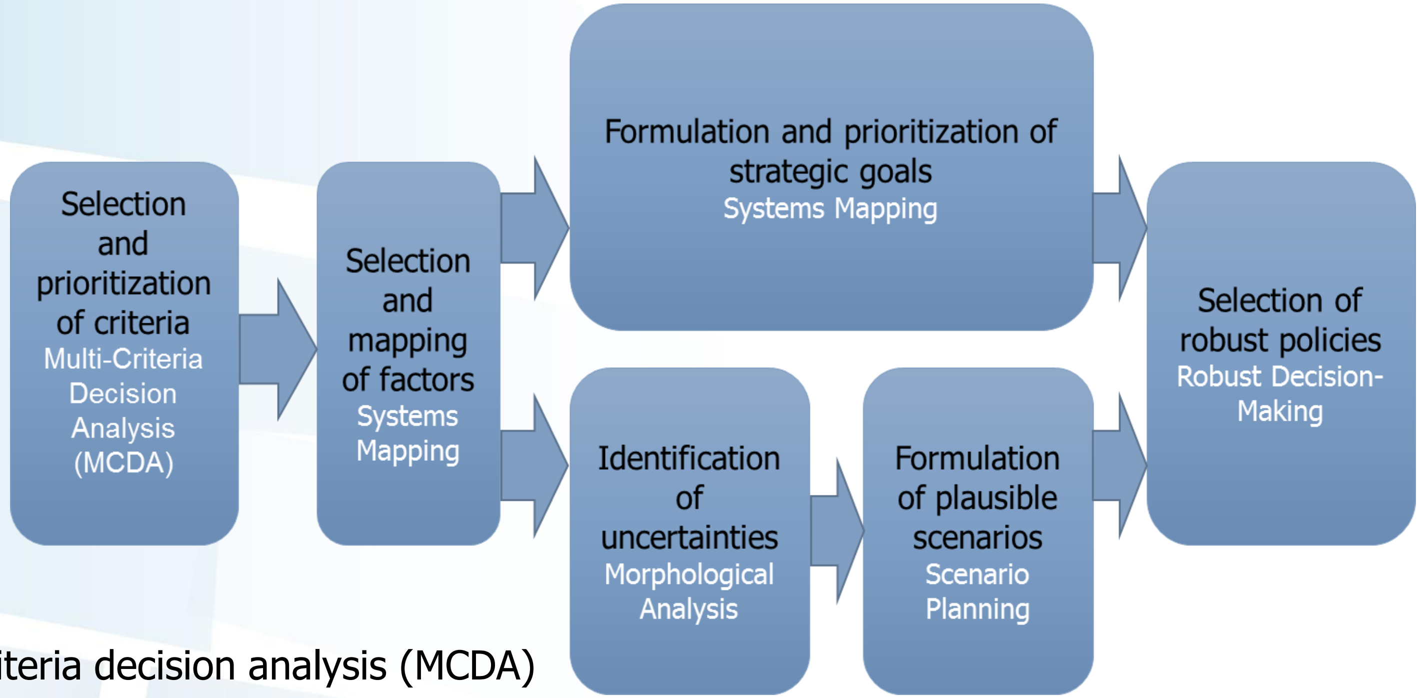
Methods of Systems Analysis Toolkit (SAT) developed by IIASA can help

Structure the problem
and
assist in sense-making

Find compromise
among stakeholders

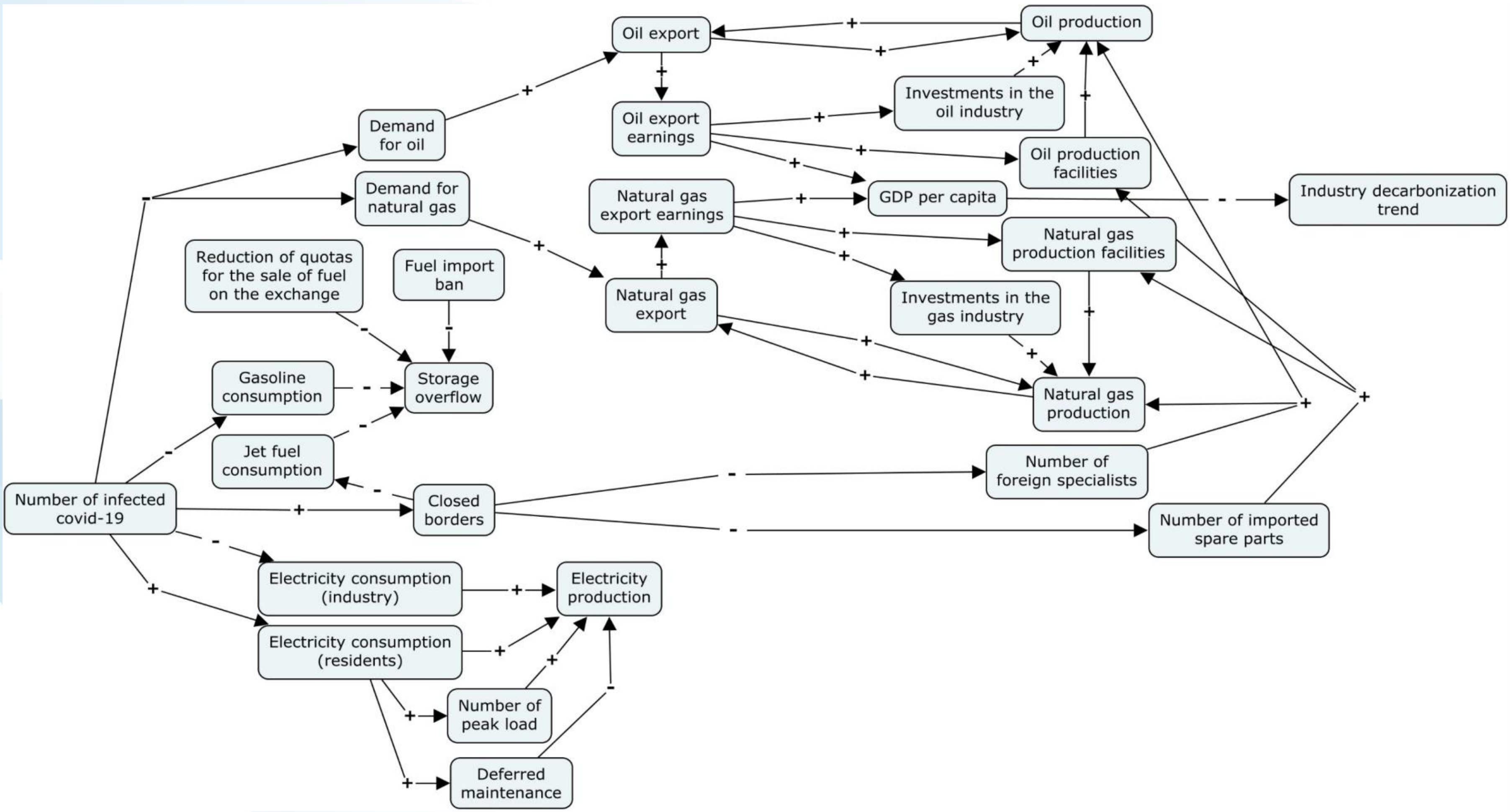
Provide social
learning and
exchange of
best practices

Source: Strelkovskii, Rovenskaya, Komendantova and Sizov, 2020



- Multi-criteria decision analysis (MCDA)
    - Elicitating and prioritizing **multiple stakeholder preferences** over competing goals
- Systems mapping
    - Creating a representation of the considered **system**, articulating its **boundaries**, components and **links** between them
- Morphological analysis
    - Revealing **uncertain factors** and their possible manifestations
- Scenario planning
    - Sketching **plausible futures** of the system’s development
- Robust decision making
    - Creating a **portfolio of actions** to achieve the preferred goals under **all** scenarios

Cognitive risk map shows impacts of various factors on activities of energy companies during Covid pandemic

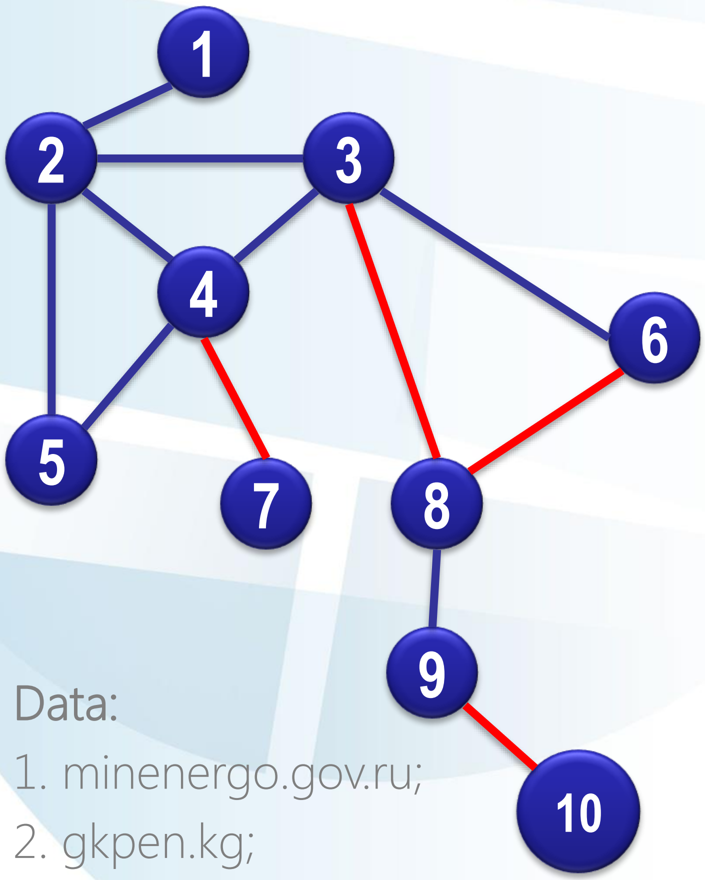


Source: Alexey and Ludmila Massel, Department of Artificial Intelligence Systems in Energy
Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences

Impacts

- Main impact: reduction of demand for energy resources
- Closure of borders: reduced mobility (reduced consumption of fuels) and reduced flow of foreign specialists
- Electricity: reduced consumption by industrial and commercial facilities but increased consumption by private households combined changes in consumption schedule

Example of optimization modeling



#	Country	Load (MW)	Gen. (MW)
1	Russia	153 164	236 343,63
2	Kazakhstan	13 279	22 055,5
3	Kyrgyzstan	3 248	3 746

#	Country	UPS	Load (MW)	Gen. (MW)
1	Russia	Nordwest	15 436	23 572,13
2	Russia	Center	35 208	52 878,57
3	Russia	Ural	37 101	51 131,73
4	Russia	middle Volga	17 158	27 003,22
5	Russia	South	14 738	20 601,65
6	Russia	Siberia	28 688	51 969,83
7	Kazakhstan	West	1 659,3	2 667,6
8	Kazakhstan	North	8 884,73	16 638,68
9	Kazakhstan	South	2 735,1	2 749,23
10	Kyrgyzstan	-	3 248	3 746

Data:

1. minenergo.gov.ru;
2. gkpen.kg;
3. energo.gov.kz

Reference: Iakubovskii, D., Komendantova, N., Rovenskaya, E., Krupenev, D., & Boyarkin, D. *Geosciences*

- **- - Data - -**

1) Searching for **maps of seismic zones** for Russia, Kazakhstan and Kyrgyzstan;

2) Looking for information about **each power plant** in regions (full Kazakhstan, full Kyrgyzstan, UPS Siberia of Russia) **and each interconnection** (btw nodes);

3) Set up the **seismic resistance parameter** for each element by catalog;

4) **Combine** the seismic zones and EPS **maps**, **find the probabilities** for power plants and interconnections;

- **- - Software - -**

5) Apply this data to model minimization of capacity deficits;

6) Programming on C++ 11

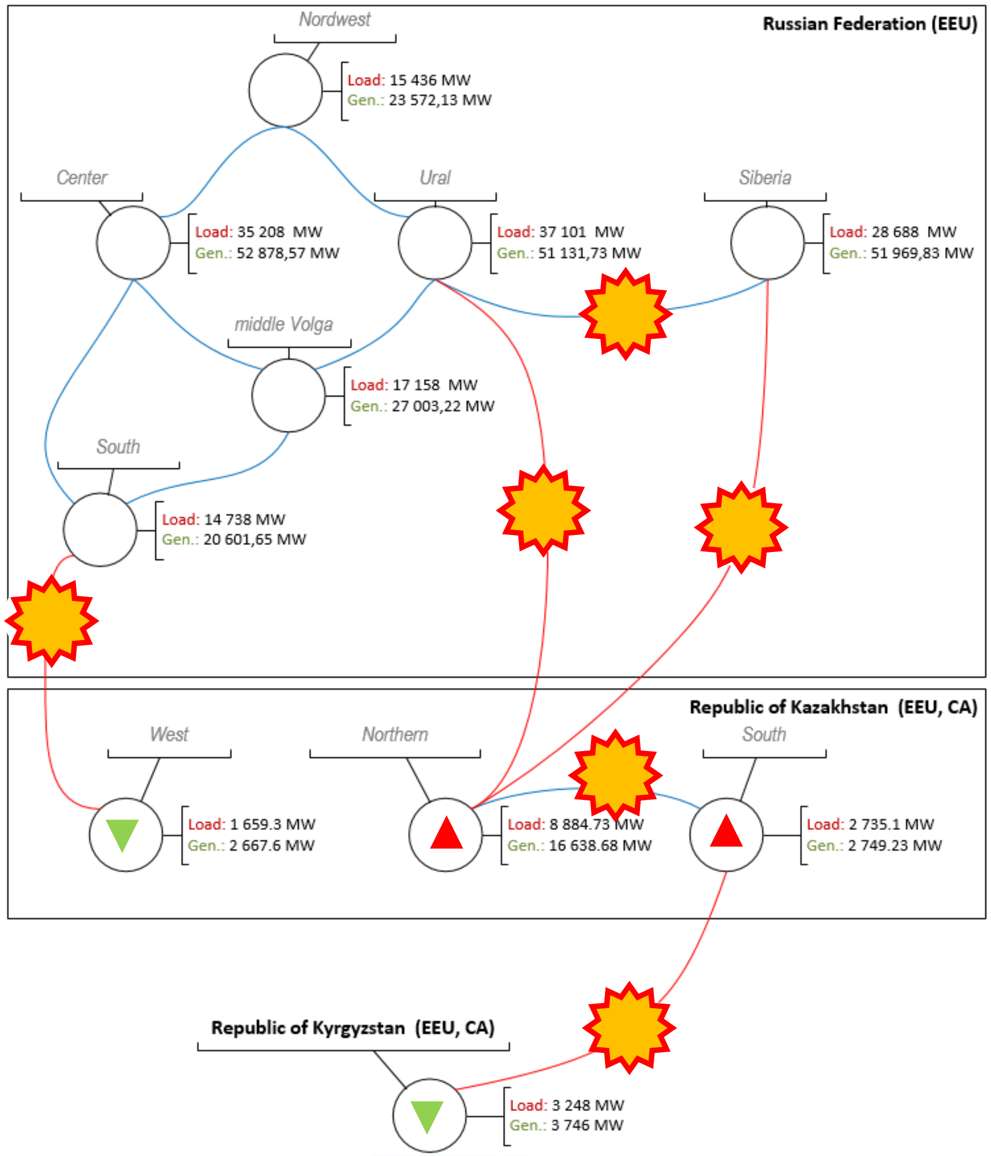
7) Generate **states** for this model with **dependence** only for elements **with no null probability** (by criteria: n-1; n-2; n-3)**;**

8) **Optimize** this model for each state (Gradient method);

- **- - Results - -**

9) Make two distributions for each working and not working lines (deficit and probability of event);

10) Use the T-Test for find important lines.



#	Criteria	Description
1	N-3	**RU** (U)-(N) **KZ** failure **RU** (Si)-(U) failure **KZ** (N){Load} Increase
2	N-2	**KZ** (S)-(**KG**) failure + **KG** {Gen} Decrease
3	N-2	**RU** (So)-(W) **KZ** failure + **KZ** {Gen} Decrease
4	N-2	**KZ** (N)-(S) failure **KG** (S){Load} Increase
5	N-1	RU (Si)-(N) **KZ** failure
…	…	…

Legend:

- Earthquake
- Generation decrease
- Loading increase
- Node (UPS)

- - Software - - (Model optimization)

- Objective function :

$$\sum_{i=1}^{n} (\bar{y}_i - y_i) \to \min$$

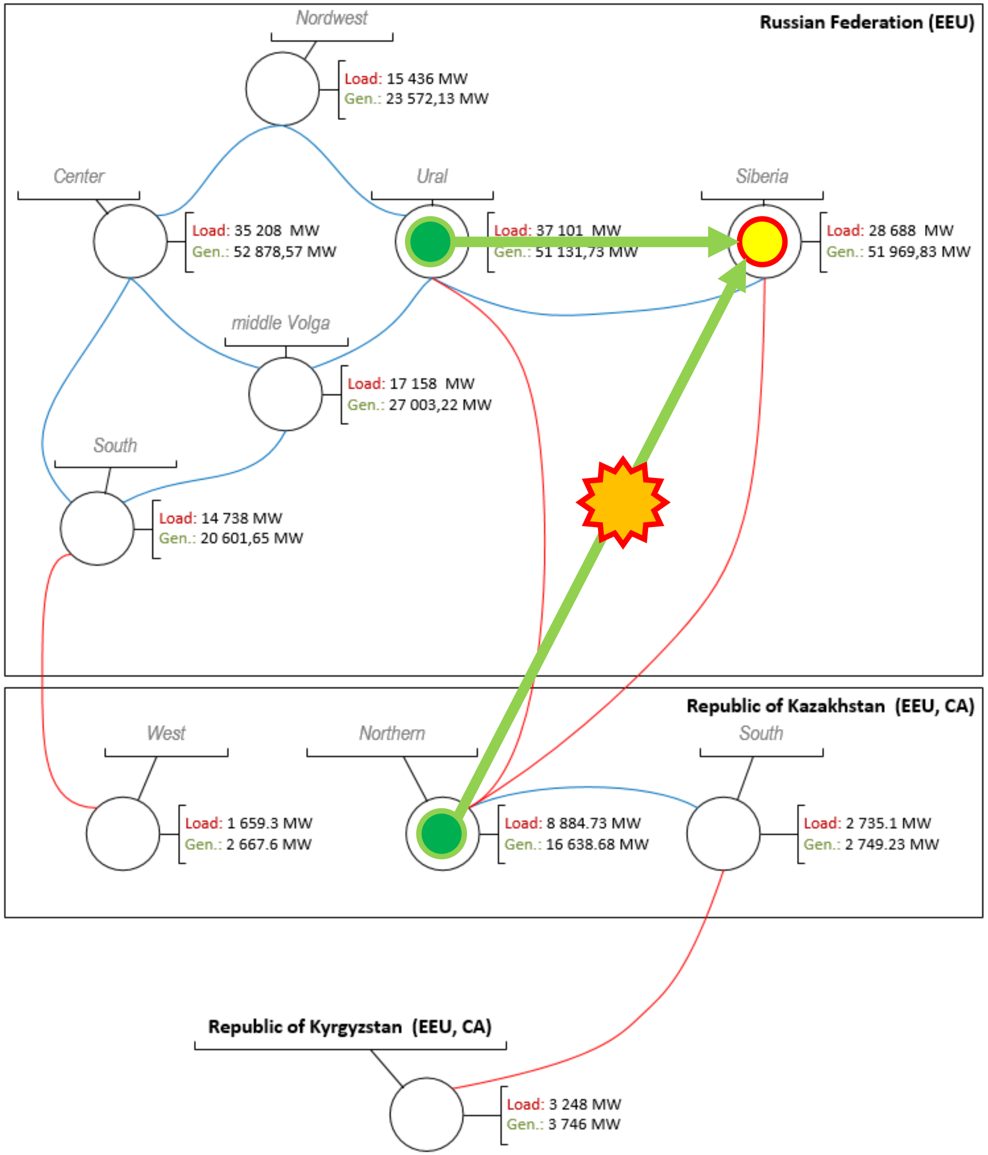
- Balance constrains :

$$x_i - y_i + \sum_{j=1}^{n} (1 - a_{ji} z_{ji}) z_{ji} - \sum_{j=1}^{n} z_{ij} \geq 0,$$

$$i = 1, \dots, n,\ j \neq i,$$

- Other constrains :

$$z_{ij} * z_{ji} = 0$$
$$0 \leq y_i \leq \bar{y}_i,$$
$$0 \leq x_i \leq \bar{x}_i,$$
$$0 \leq z_{ij} \leq \bar{z}_{ij},$$
$$i = 1, \dots, n,$$
$$j = 1, \dots, n,$$
$$j \neq i.$$



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