Disaster Risk Management of Energy Infrastructures, a Need for Energy Security

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V INTERNATIONAL CONFERENCE

RISK MANAGEMENT IN ENERGY -- 2022

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Challenges in Energy Infrastructures Safety

- ✓ High exposures of hazard, vulnerability and risk in existing energy infrastructure/system (Grids, Power plants, Substations, Pipelines, ..);
- ✓ Stress on energy infrastructures are critical in most of the developing cities;
- ✓ With a redundancy of know-how (science, technology, standards, guidelines, etc.), strategies, policies, and resources, one would expect that energy of infrastructure would be at low risk, with acceptable of resiliency to disasters;
- ✓ Lack of systematic approach to DRR and resiliency (prevention, preparedness, response and recovery process and actions) in energy infrastructures system,
- ✓ Insufficient cooperation and integration of stakeholders and beneficiaries,
- ✓ Lack of integrated look at Nexus of Energy, Water, Climate, Food, etc.
- ✓ Presence of a gap between know-how, and policy and Implementation;

System Model for Energy Disaster Resilience

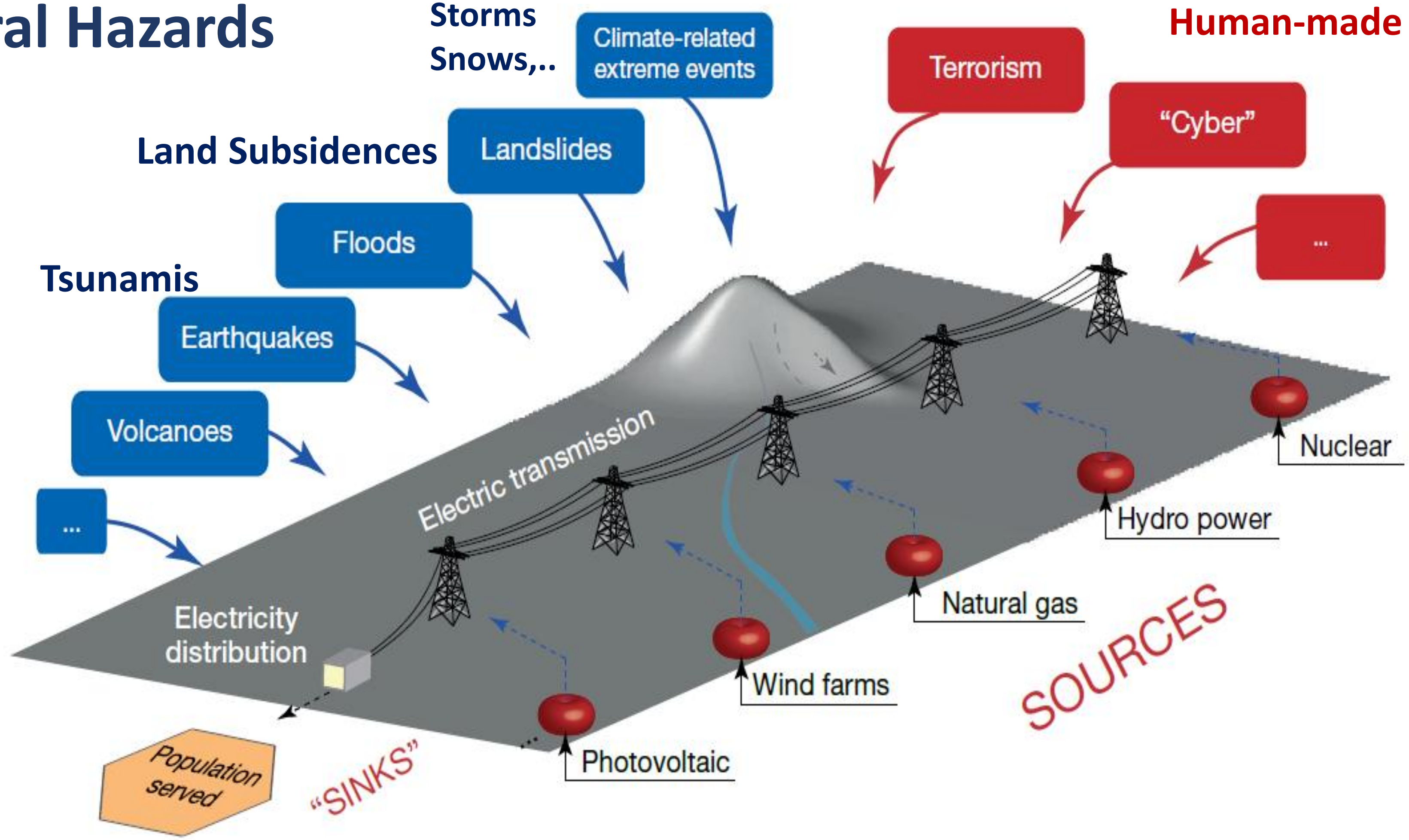
Natural Hazards

Extreme heat/cold
Strong winds
Lightening
Storms
Snows,..

Land Subsidences

Tsunamis

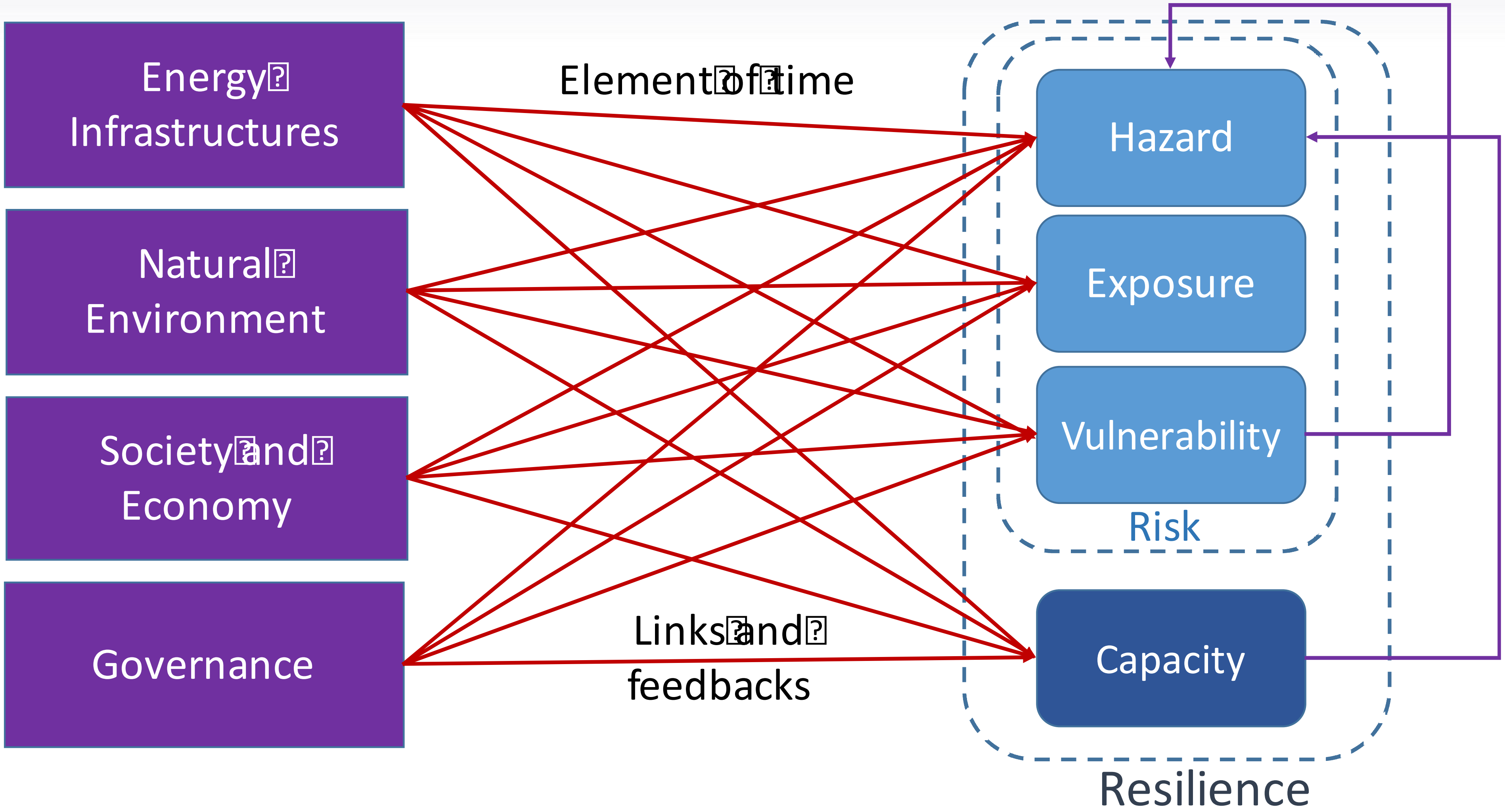
Human-made Hazards



Ref: Garcia-Aristizabal 2016, available in Komendantova et al. 2016

Vulnerability of Energy Grid to Earthquake

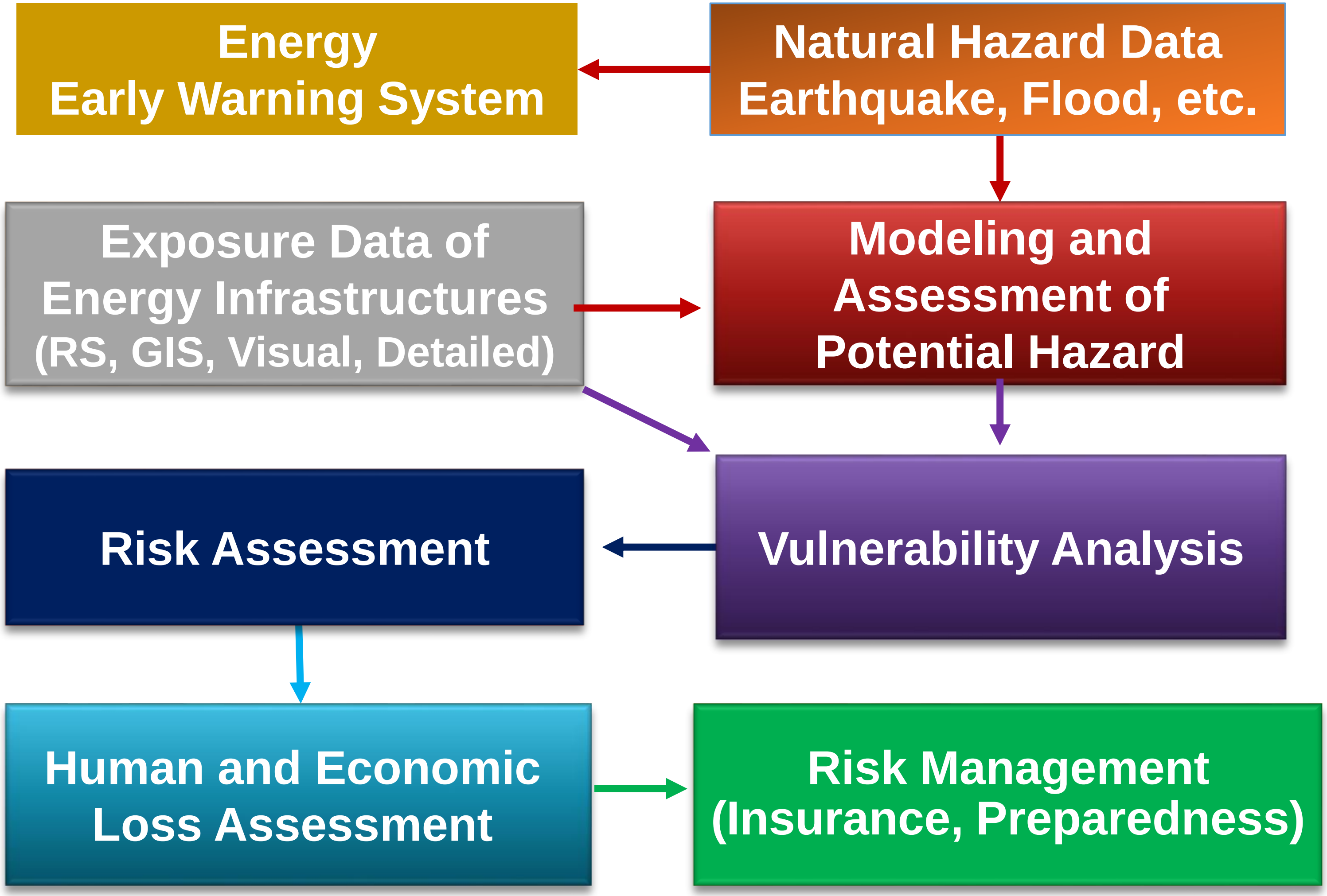
System Model for Energy Disaster Resilience



- Interconnectedness and dynamism (cities are extremely complex systems!)
- Modelling suggestion: each urban sub-system resilience could be defined by a bundle of Risk (Hazard, Exposure, and Vulnerability) + Capacity

Ref.: Dr. Hooman Motamed

Integrated Disaster Risk Information System For Energy Infrastructure Risk Assessment



Electric Power Grid Structure

System → **Subsystems** → **Components**

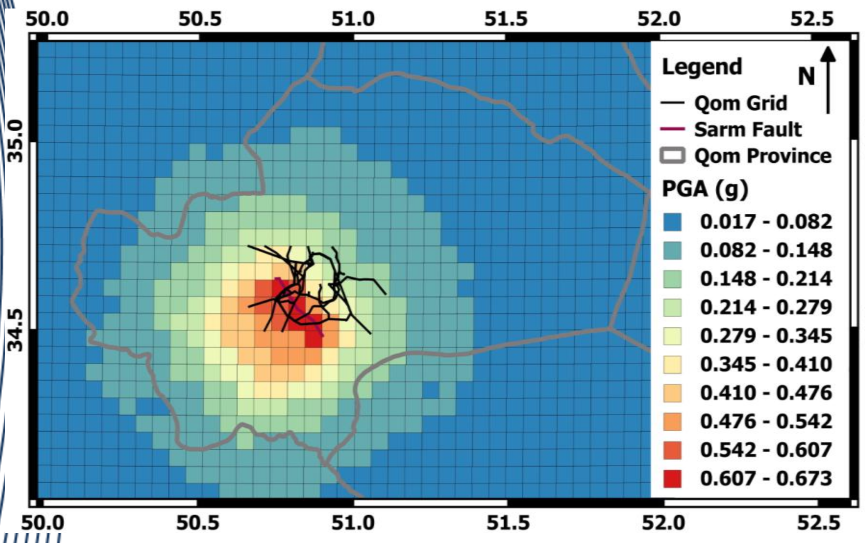
Generation, Transmission, Distribution

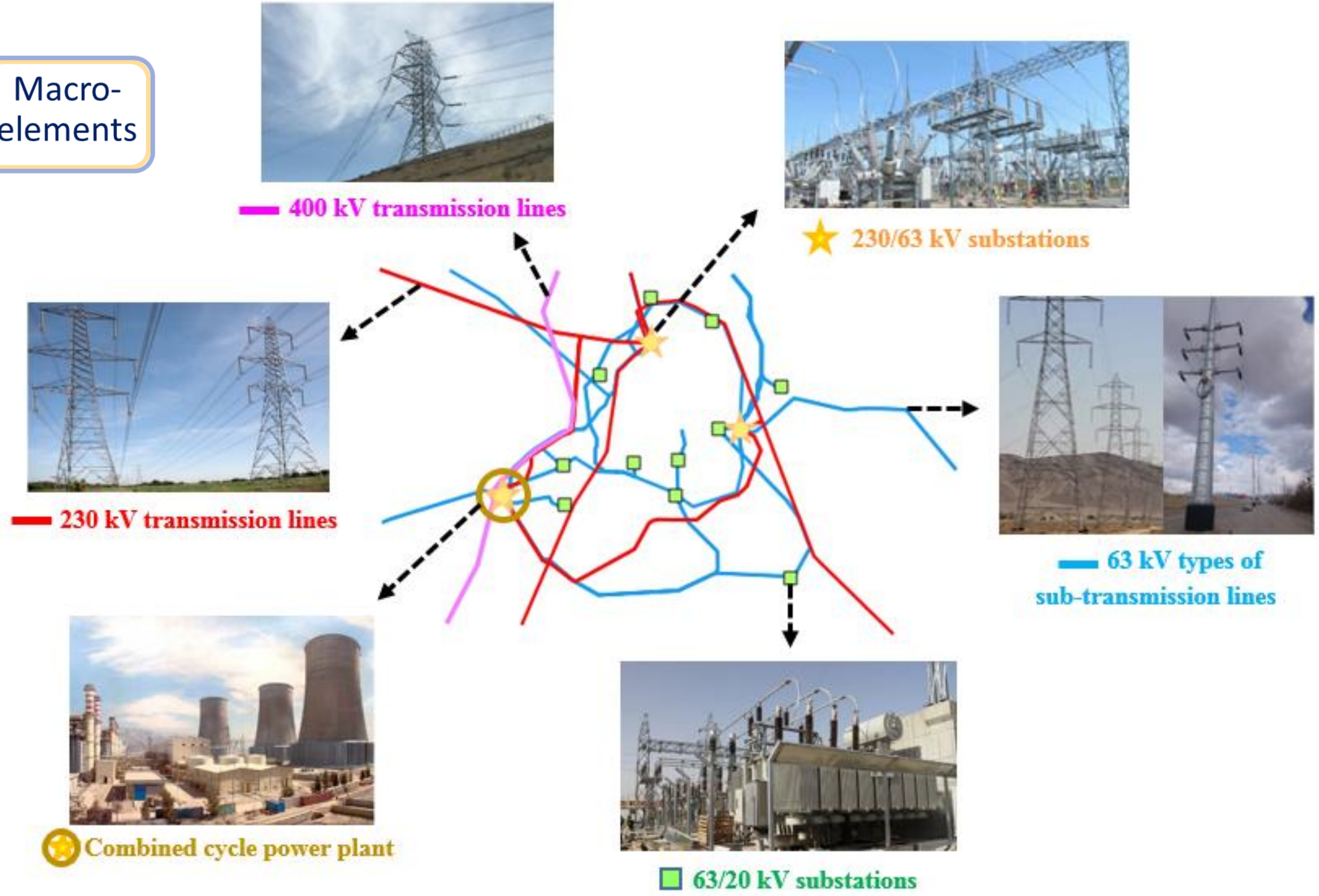
Power Grid

- Nodal (Power plants, Substations)
- Linear (transmission and sub-transmission circuits)

Macro-elements

- Powered Parts
- Indirect Outage Parts
- Direct Outage Parts

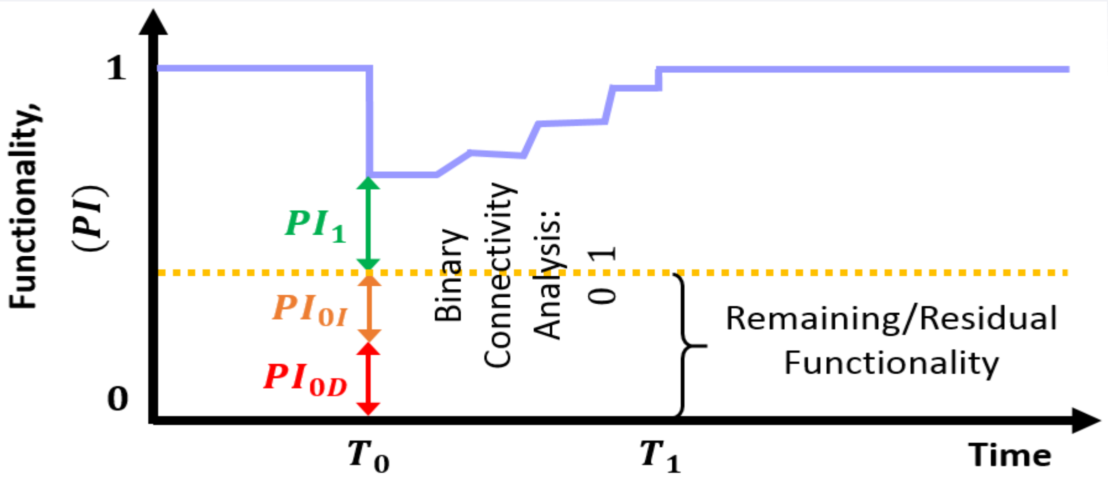




Electric Power Grid Seismic Resilience

Resilience

- Performance
- Recovery time



$$PI = PI_1 + PI_0; \qquad PI_0 = PI_{0I} + PI_{0D};$$

$$PI = PI_1 + PI_{0I} + PI_{0D}$$

No physical interruption	Physical outage	Physical blackout
All parts of the network are under power service	Some parts of the network are suffering power failures, while other parts are under power service	All parts of the network are out of power service
$PI = PI_1$ $PI_0 = 0$	$PI = PI_1 + PI_0$ $PI_1 \neq 0$ $PI_0 \neq 0$	$PI = PI_0$ $PI_1 = 0$

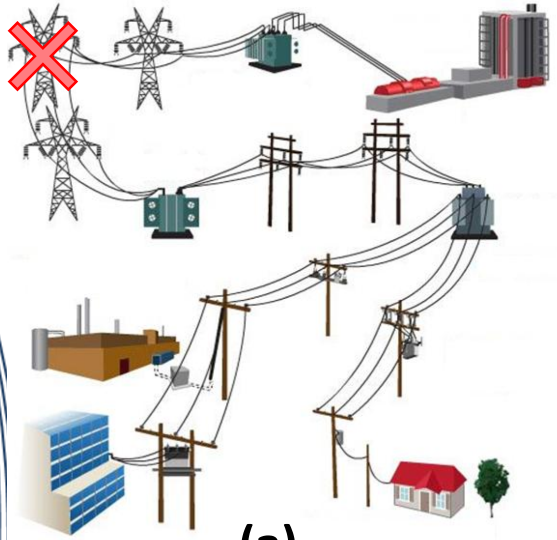
Connectivity Analysis

Power grid after the earthquake, PI

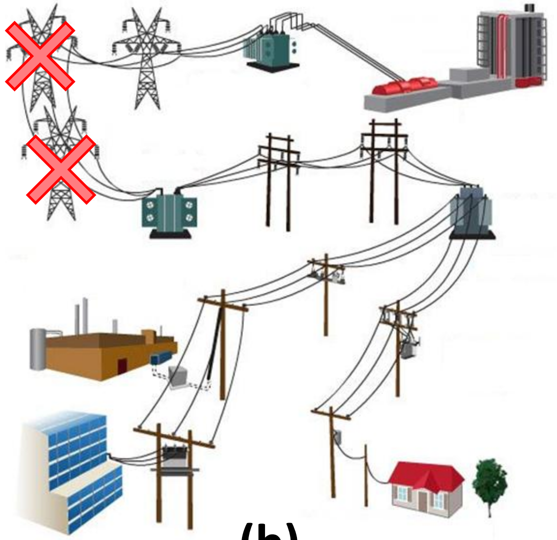
- Powered components, PI_1: $0.5 < F_i \leq 1$
- Outage components, PI_0: $0 \leq F_i \leq 1$
  - Direct outage components, PI_{0D}: $0 \leq F_i \leq 0.5$
  - Indirect outage components, PI_{0I}: $0.5 < F_i \leq 1$

F_i: Component functionality; PI: System/Subsystem performance indicator;

Separating out-of-service elements from each other by assigning different functionality values, $\mathbf{0 \leq F \leq 0.5}$



(a)



(b)

- ✓ Two different power transmission lines suffering cable rupture at only one and several points, respectively;
- ✓ Different cost and repair time for these two lines

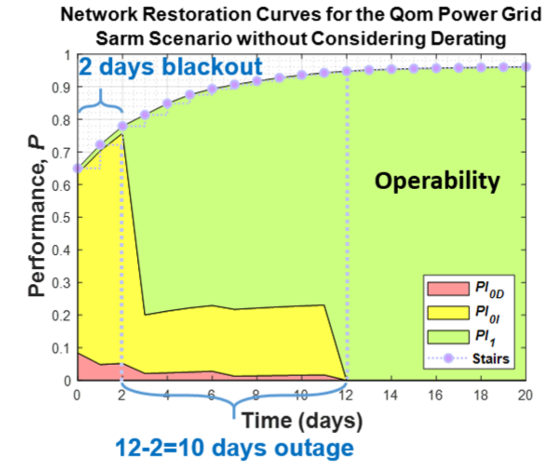
Distinguishing under-service elements from each other by assigning different performance values, $\mathbf{0.5 < F \leq 1}$

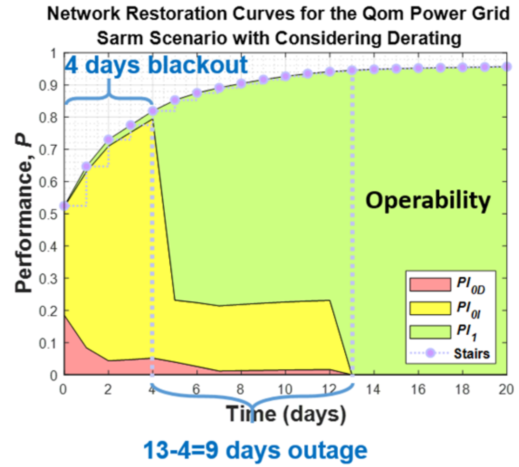
Leaning tower

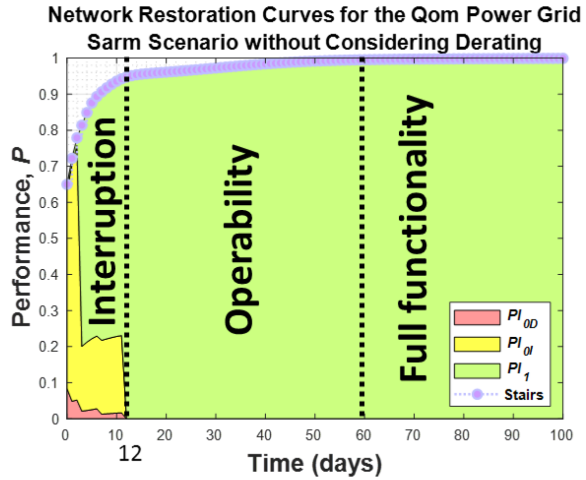
Electric Power Grid Seismic Resilience Functions

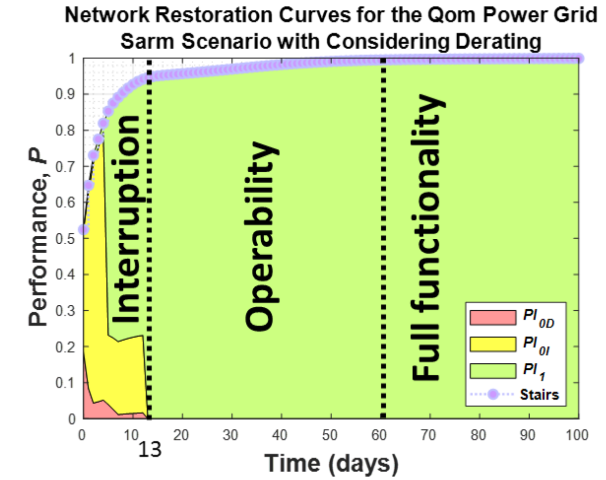
Earthquake of Sarm fault scenario, 20 days

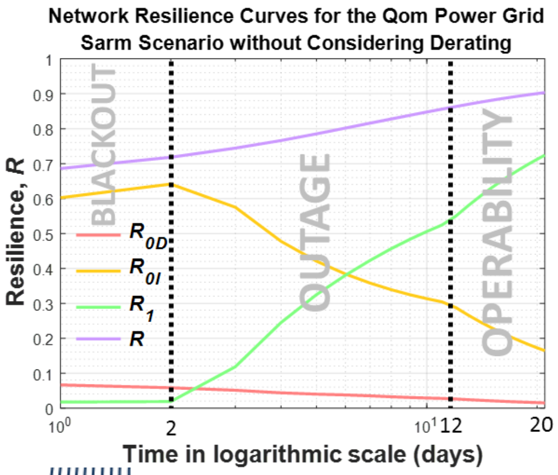
Earthquake of Sarm fault scenario, 100 days

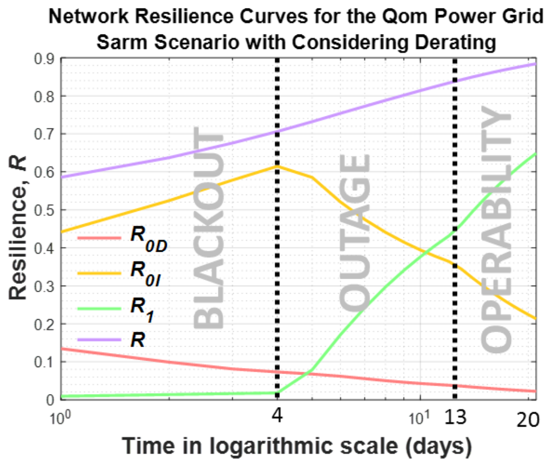


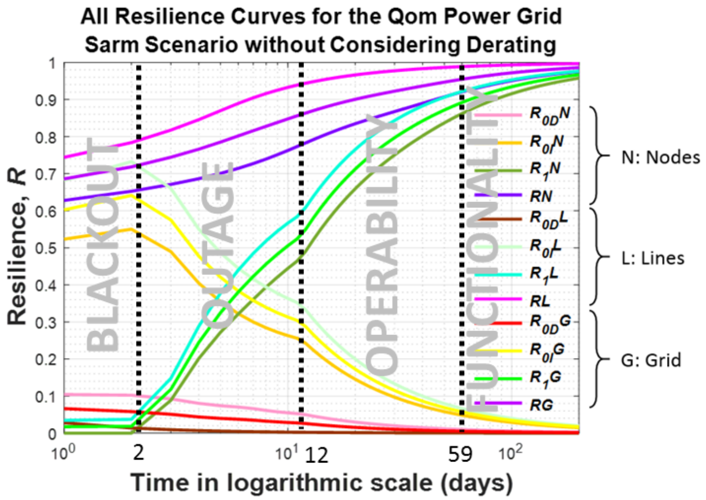


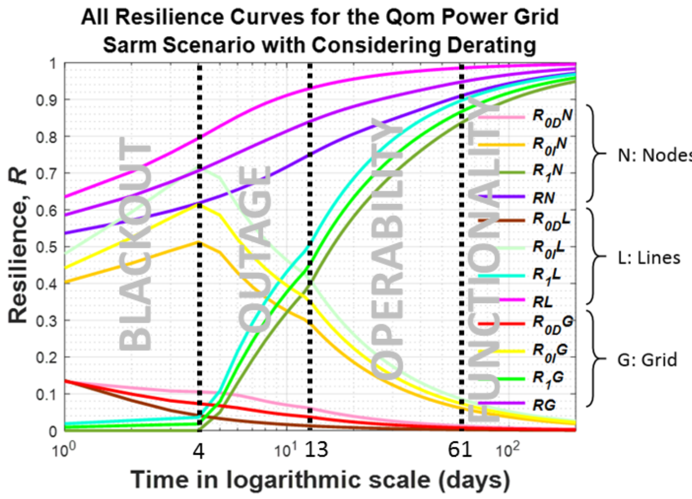




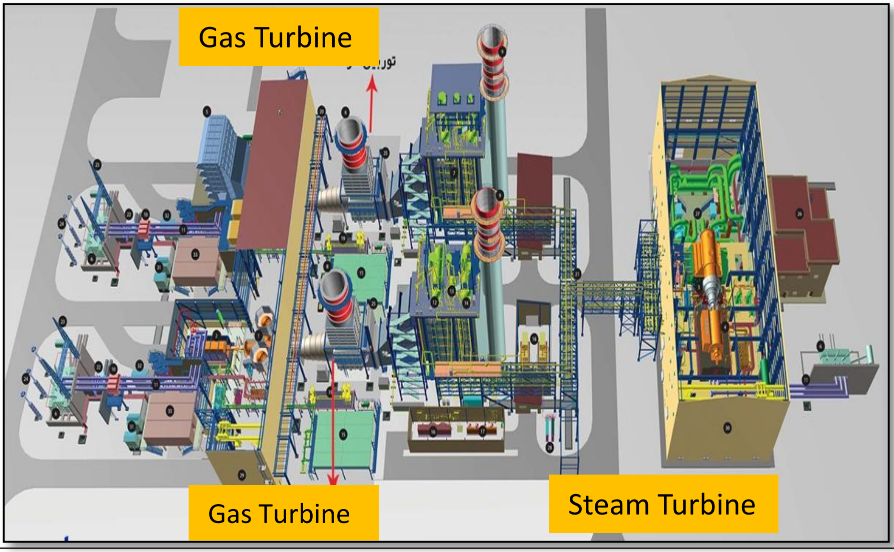


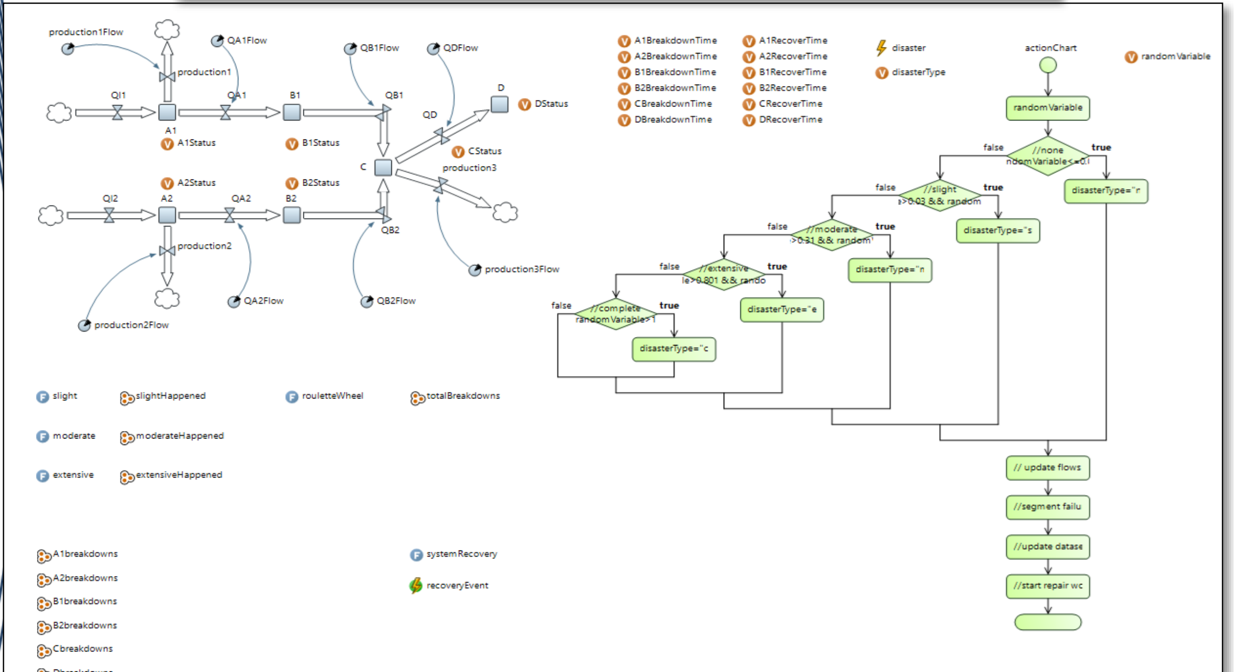


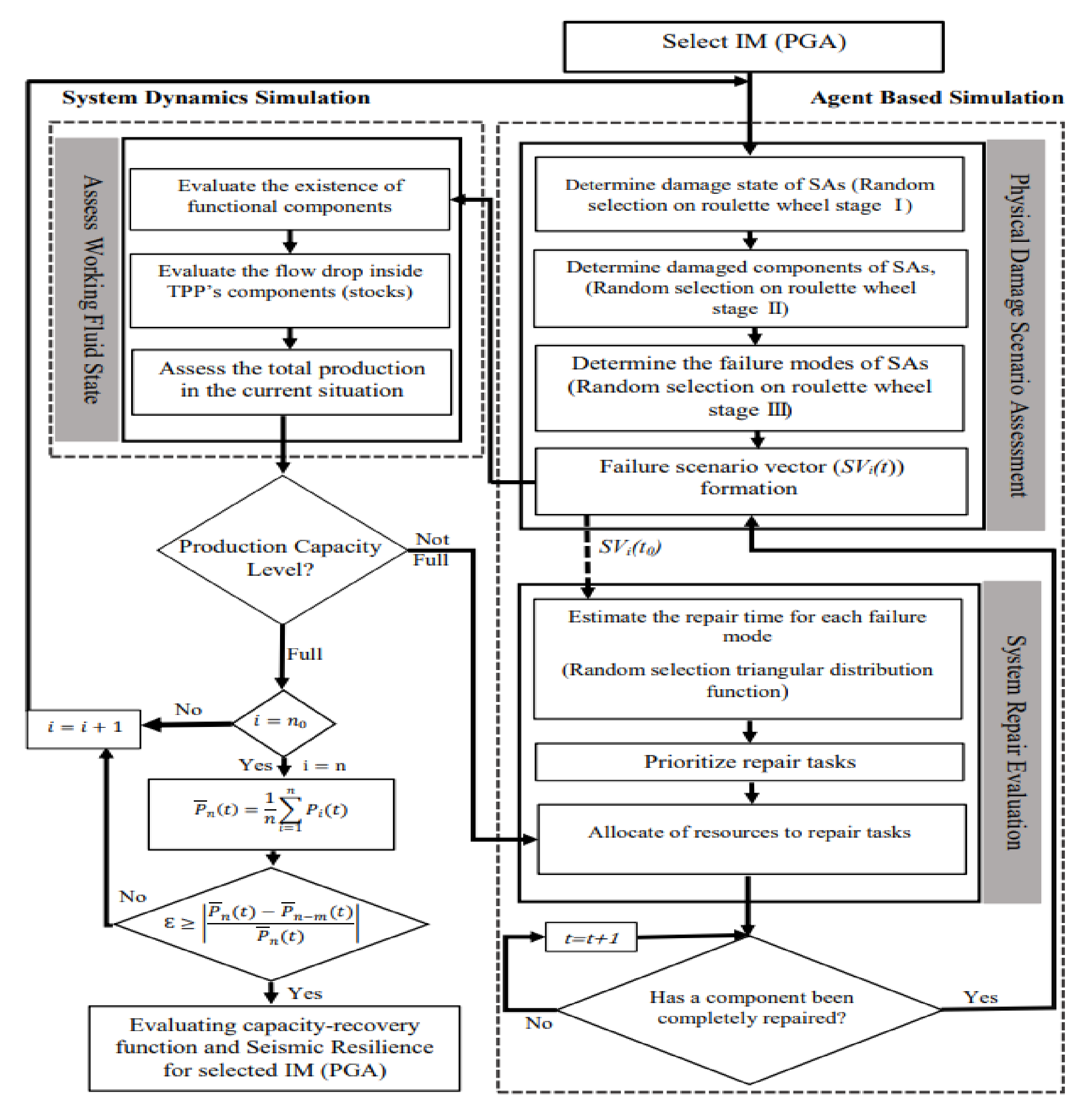




Toolbox for Gas-Combined-Cycle Powerplant Resilience

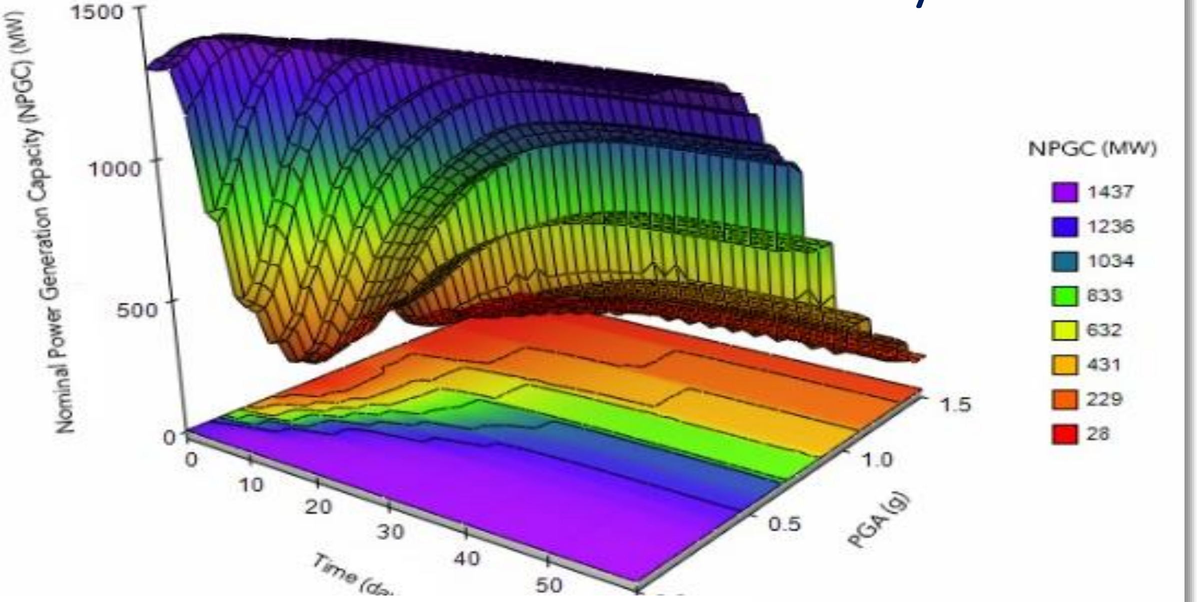


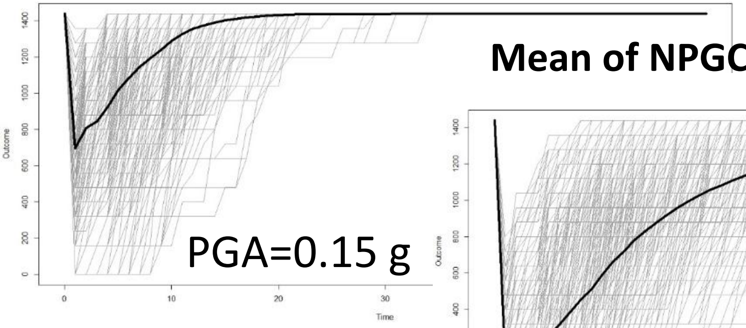


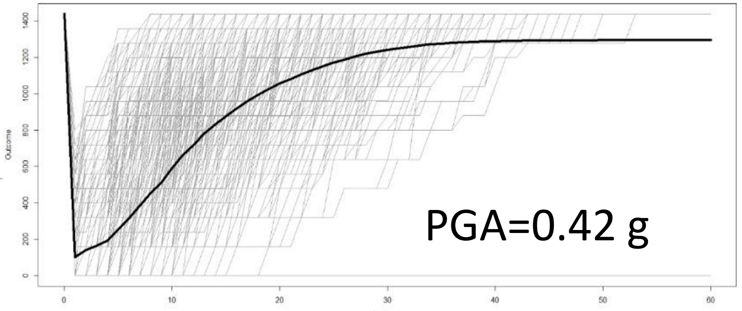


Toolbox for Gas-Combined-Cycle Power-plant Resilience

Multivariate non-linear regression model of GTCC-PP Seismic Resiliency



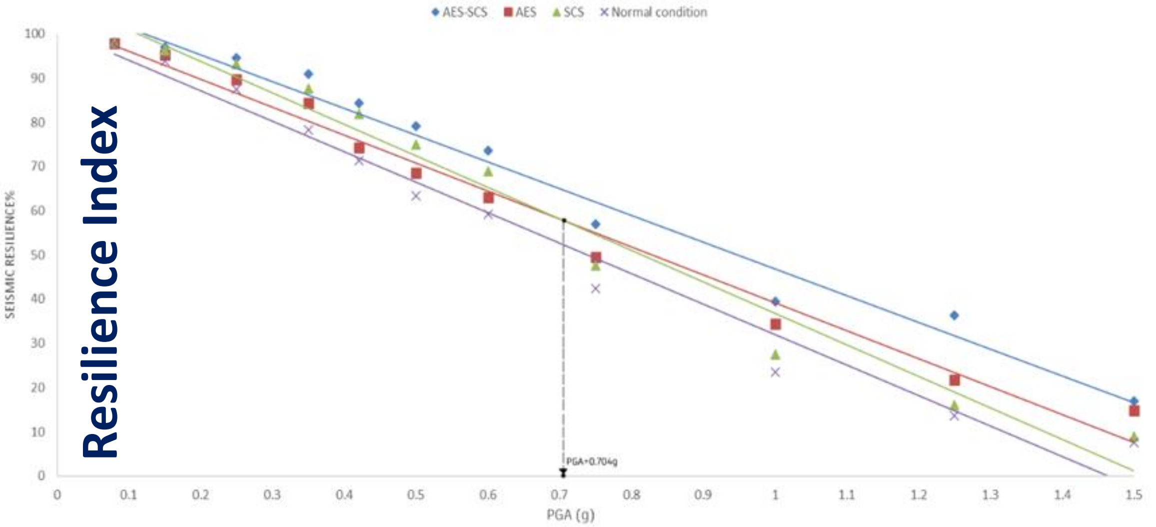




Seismic Resilience Curve of GTCC-PP

Seismic Resilience of GTCC-PP with various Resilience Enhancement Strategies:

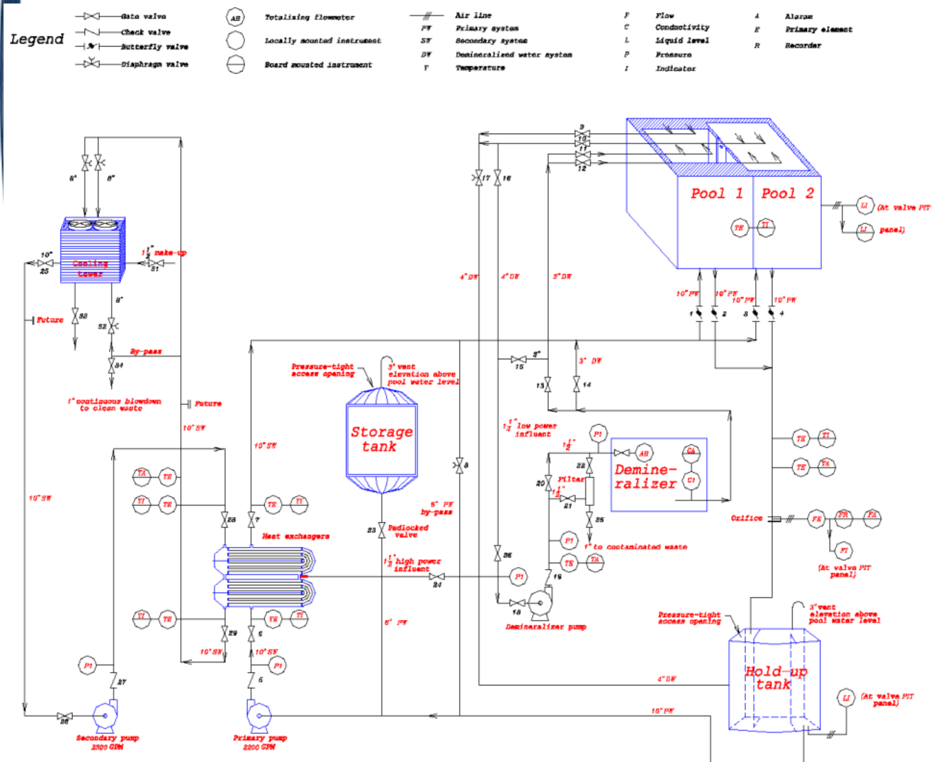
1) Anchoring Equipment Strategy (AES)
2) Sufficient Crews Strategy (SCS)
3) Both strategies (AES-SCS)

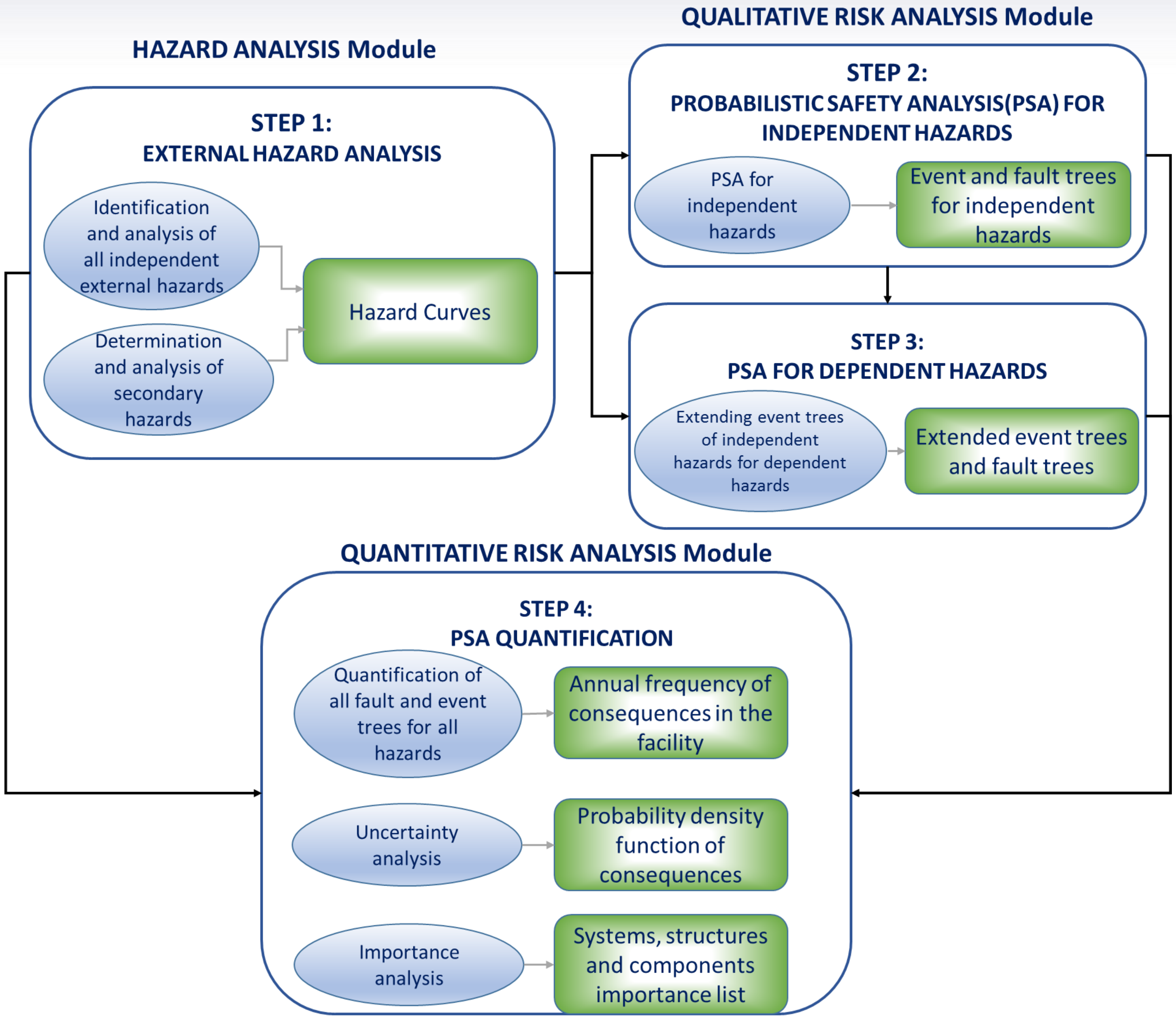


PGA=0.02-1.5 g

Multi-Hazard Probabilistic Safety Analysis of Power Plants

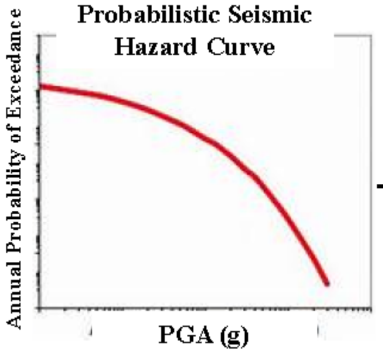
Section of a Power Plants

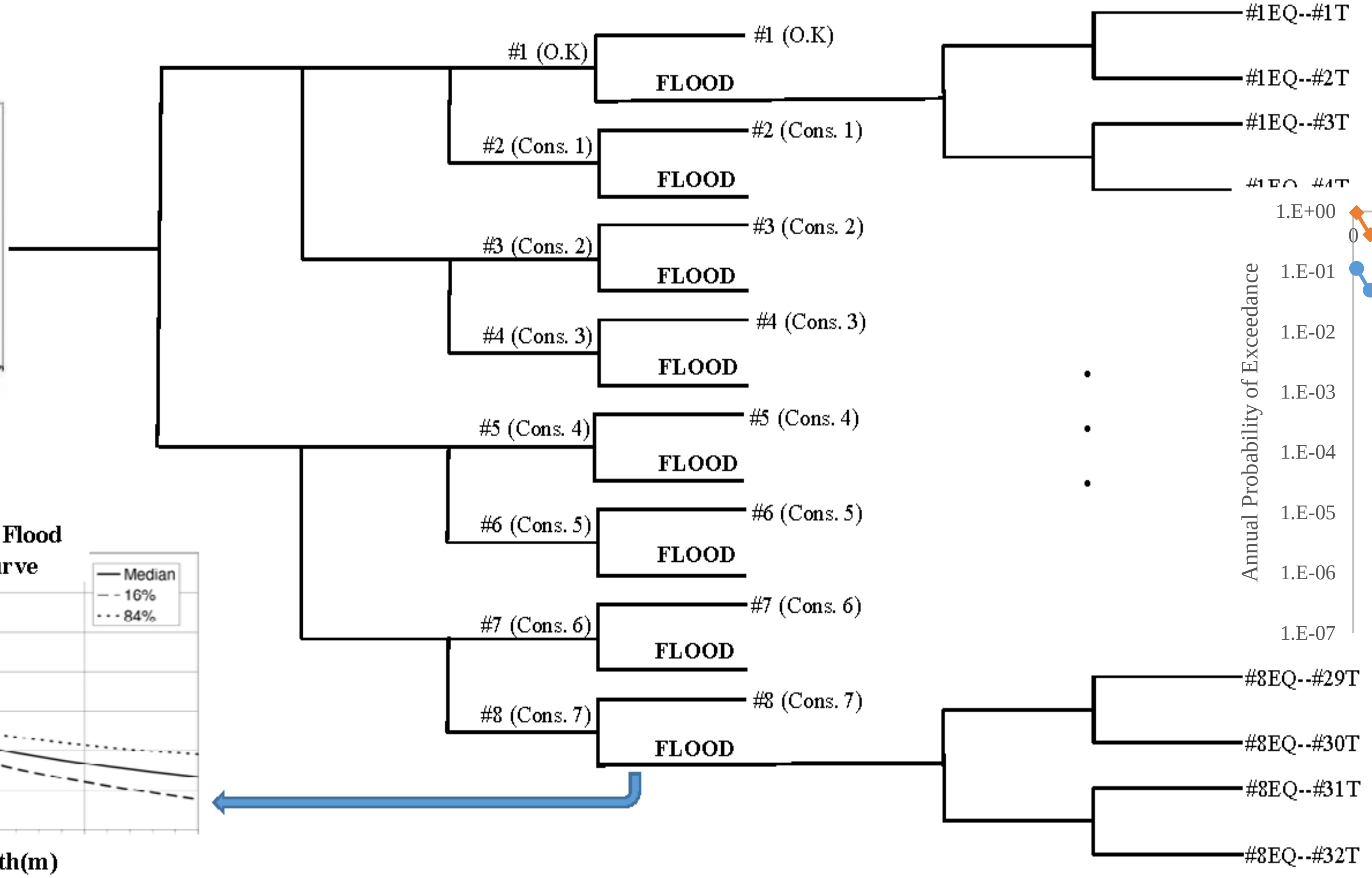


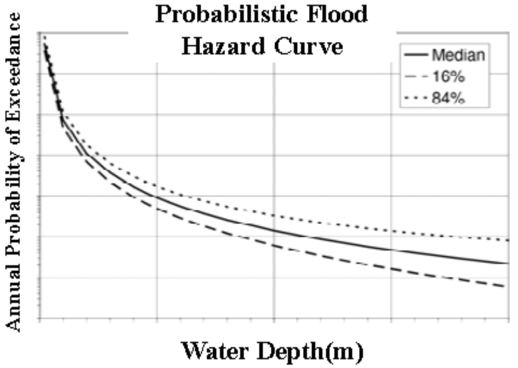


Multi-Hazard Probabilistic Safety Analysis of a PP section

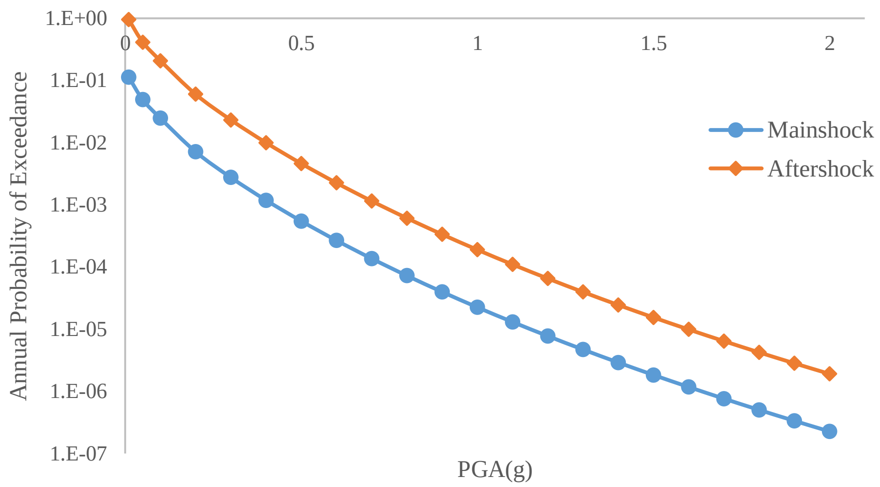
Initiating Event	Systems with functions required for strong ground motion in earthquakes			Earthquake Outcomes	Seawall Performance	Systems or functions required for flooding in facilities		Earthquake-Tsunami Outcomes
	System 1	System 2	System 3			System 4	System 5	







Earthquake-Tsunami Risk Curves



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Concluding Remarks:

- ✓ Past disasters have shown that Energy Infrastructures are at high risk which has been endangered energy security, and economic development considering its cascading impacts.
- ✓ To secure energy security, requires an integrated approach to energy infrastructure risk management.
- ✓ Systematic approach is required for DRR (prevention, preparedness, response and recovery process and actions) in energy infrastructures to ensure Resilience Infrastructures.
- ✓ Advising IIASA System Analysis Program, and Cooperation-Transformative Governance group to develop Energy Infrastructure Resilience project

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IIASA 50th Anniversary Event Seminar on Systems Analysis

Urban Resilience through Systems Approach

24-25 October 2022

IIEES, Tehran, Iran

International Institute for Applied Systems Analysis

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