ARISTOTELES: ARtificial **I**ntelligence and **STO**chas**T**ic simulation for the r**E**si**L**ience of critical infrastructur**ES**

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INTRODUCTION

Critical Energy Infrastructures (CEIs), such as electrical grids, gas networks, communication systems, and transportation systems, are essential for societal functioning. Recently, CEIs have been exposed to natural hazards (i.e., earthquakes, tsunamis, hurricanes, and floods) of increased frequency and intensity, possibly due to climate change. Thus, resilience — the ability to withstand disruptive events and swiftly recover — must be considered in the design and operation of CEIs.

Such events and their consequences have a track record. For example, the Fukushima disaster was triggered by an earthquake-induced tsunami, which led to a nuclear plant accident that resulted in recovery costs of 180 billion USD and mass evacuations. More recently, the California wildfires of January 2025 destroyed over 18,000 homes, forced the evacuation of almost 200,000 people, and led to the incineration of over 57,000 acres of land.

ARISTOTELES is a scientific project that aims to develop a framework to assess the resilience of CEIs by integrating natural hazard and climate change modeling with the stochastic modeling of the cascading process of failures induced by natural events. By integrating artificial intelligence and stochastic simulation, ARISTOTELES provides a scalable approach to quantify, simulate, and optimize the performance of CEIs during such events, to evaluate infrastructure vulnerability and operational performance under uncertainty.

RESEARCH OBJECTIVES

To demonstrate the applicability of the ARISTOTELES framework, a case study is conducted on an integrated power and natural gas system located in Sicily (Italy), exposed to seismic, tsunami, and flood hazards. The CEI is modeled by coupling a physics-based AC Optimal Power Flow (AC-OPF) for the power network with the physical Weymouth equations for the natural gas network. Methodologically, ARISTOTELES has five research objectives:

RO1: Modelling Natural Hazards: Natural hazards are modelled by leveraging knowledge gained from probabilistic hazard analysis for earthquakes and tsunamis, including their interdependencies.

RO2: Modeling Climate Change: Climate change is modelled to assess its influence on the manifestation of undesirable operational conditions and to account for the increased intensity of natural hazards.

RO3: Modelling Vulnerability: The vulnerability of CEIs is assessed by identifying scenarios that can lead to significant performance loss through the coupling of hazard impact and fragility studies.

RO4: AI and stochastic simulation for modelling resilience: CEI response to disruptive scenarios is characterized and uncertainty is propagated using advanced stochastic simulation methods (i.e., affine-invariant, subset simulation) to capture the complex dependences involved and to identify rare system configurations. AI methods (i.e., Kriging surrogate models) are employed to reduce the computational burden of such a task.

RO5: Resilience Optimization: Strategic actions that fully integrate performance objectives across the entire disruption cycle are proposed and simulated to enable the proactive incorporation and enhancement of resilience in the design and operation of future CEIs.

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- Politecnico di Torino
- Istituto Nazionale di Geofisica e Vulcanologia (INGV)

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