ENERGETICS

Ammin/CRT/DENERG - Mitigating the risks of the energy transition: a multi-methodological energy planning approach

Funded By	Dipartimento DENERG Politecnico di TORINO [P.iva/CF:00518460019] FONDAZIONE CRT CASSA DI RISPARMIO DI TORINO [P.iva/CF:06655250014]

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Context of the research activity	This research addresses the need for integrated energy planning approaches that combine long-term and short-term risk assessments. It focuses on supply chain vulnerabilities and operational uncertainties in future renewable energy systems, leveraging advanced modeling and optimization techniques to support robust, flexible, and secure energy transitions.

	The European energy transition, driven by the objectives of the European Green Deal, envisions a system powered predominantly by renewable energy sources such as wind, solar, hydro, and biomass. This transformation promises enhanced sustainability, economic opportunities, and energy independence. However, it also introduces a complex set of risks and uncertainties that threaten the resilience and stability of future energy systems. Key long-term risks are linked to supply chain vulnerabilities, particularly concerning critical raw materials (CRMs) essential for the deployment of clean energy technologies and storage solutions. These disruptions may be driven by geopolitical instability, resource scarcity, and technological dependencies, ultimately impacting the affordability and scalability of the energy transition. Critical knowledge gaps persist in understanding how the future energy systems can remain robust under long-term systemic stresses and short-term operational disturbances. Existing modeling approaches often fail to adequately capture these multifaceted dynamics. Energy System Optimization Models (ESOMs) typically focus on long-term capacity expansion and investment planning, while Power System Operational Models (PSOMs) offer detailed representations of short-term dynamics, such as balancing and dispatch. However, these approaches tend to operate in silos, limiting their capacity to inform comprehensive resilience strategies. This PhD project proposes to develop an integrated modeling framework that overcomes the limitations of current methodologies by combining long-term and short-term perspectives. The research will proceed along four main lines:

Objectives	1) Long-Term Supply Chain Risk Assessment: The project will evaluate the impact of Critical Raw Materials availability on the deployment of renewables, storage systems, and electric vehicles. It will model scenarios at the European level that incorporate geopolitical uncertainties, resource limitations, and price volatility. Attention will be given to identifying potential technological lock-ins and their implications for long-term energy security. 2) Short-Term Operational Risk Modeling. By integrating ESOMs and PSOMs, the project aims to capture the full temporal spectrum of energy system dynamics. It will assess how operational flexibility — particularly through smart charging and vehicle-to-grid — can mitigate variability and enhance short-term resilience. This integration will help identify planning strategies that are not only optimal in the long term but also feasible and robust in real-time operation. The project will develop and apply a suite of advanced modeling techniques to generate diverse, policy-relevant scenarios. While Multi-objective optimization will support the trade-off analysis between cost, security, and flexibility, Stochastic optimization will address uncertainties in input parameters such as supply chains and technology costs. Finally, Modeling to Generate Alternatives (MGA) will be used to explore the solution space beyond strict optima, offering insight into near-optimal and structurally diverse configurations. Monte Carlo simulations will help quantify parametric uncertainties and assess systemic risks. Key output of the research will be a multi-model risk assessment framework that integrates findings across the long- and short-term dimensions. The framework will include quantitative indicators to measure resilience, adaptability, and vulnerability. These metrics will be designed to support strategic decision-making by policymakers, investors, and energy planners. The overarching goal is to provide a new generation of tools and methodologies for energy planning that explicitly account for risk, uncertainty, and interdependencies. By bridging the divide between strategic planning and operational feasibility, the project will offer actionable insights to build resilient energy systems capable of enduring the multifaceted challenges of Europe's decarbonization journey.

Skills and competencies for the development of the activity	The candidate should be skilled with energy planning tools (possibly with the TEMOA modeling framework), energy system optimization modeling and energy scenario analysis. The candidate should have a background in Energy and Nuclear Engineering.