

Exploring Energy System Vulnerabilities

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Overview

The recent natural gas crisis in Europe has highlighted the critical issue of strategic security of supply (SoS), once again bringing it to the forefront of the political and energy policy agenda. However, geopolitical tensions represent only one facet of our energy systems' numerous threats. To date, energy research programs and policy discussions have paid limited attention to the full range of potential threats, leaving key vulnerabilities insufficiently explored.

Vulnerabilities are understood in multiple ways and there exist various definitions, ranging from physical and systemic vulnerability definitions to measures. In this study, we understand vulnerabilities as being open to attack, damage, or disrupt the energy system in specific ways. Our focus is on vulnerabilities that, while unlikely or unforeseen today, could have catastrophic impacts. By systematically investigating and describing these vulnerabilities, we aim to provide an integrated overview of their potential risks and impacts.

To that end, this study has three key objectives: (1) to identify critical energy system vulnerabilities, (2) to examine their sources, potential impacts, and current mitigation measures, and (3) to structure this set into categories. By offering a comprehensive and interdisciplinary analysis, this research aims to unravel the complexities of energy systems vulnerabilities and guide better-targeted future research and decision-making. Ultimately, this work aims to support the transition to a secure and sustainable energy system by addressing vulnerabilities both now and in the long term future.

Methods

This study follows a three-step approach to identify and describe critical energy system vulnerabilities, better understand their sources and impacts, and categorize the set of vulnerabilities.

1. Literature Review and Expert Interviews

The first phase involves an extensive literature review of existing research and policy documents to identify known energy system vulnerabilities. This step provides a foundational understanding of both well-documented risks (e.g., geopolitical tensions) and emerging challenges (e.g., cyberattacks and damage to infrastructure). To complement this review, informal expert interviews are conducted with professionals from academia, industry, and policymaking to contextualize these vulnerabilities and provide insights into their sources, potential impacts, and the effectiveness of current mitigation measures.

2. Survey for Vulnerability Categories

In the second phase, a survey is conducted to assess and categorize the identified vulnerabilities. Participants include a diverse group of stakeholders, such as energy experts, researchers, policymakers, and industry practitioners. The survey focuses on evaluating the perceived threat level of each vulnerability, considering factors like likelihood, potential impact, and interdependencies within the energy system. This phase allows for a quantitative assessment of vulnerabilities, establishing a categorization based on their risk profiles.

3. Focus Group Validation and Scenario Development

The third phase involves focus group discussions with a panel of experts to validate and refine the findings from the previous steps. This phase emphasizes exploring the interconnections and cascading effects of vulnerabilities, as well as identifying overlooked risks. Experts are also asked to envision long-term scenarios for vulnerabilities, considering how evolving factors such as technological innovation, geopolitical shifts, climate change, and unknown factors might impact energy systems by 2050 or beyond.

By integrating these three phases, this approach ensures a comprehensive analysis of vulnerabilities. The results aim to provide insights into high-impact risks and foster more resilient and sustainable energy systems.

Results

This study is anticipated to yield a systematic overview of the critical vulnerabilities present in current and future energy systems. The literature review, supplemented by expert interviews, is expected to highlight a wide spectrum of vulnerabilities—ranging from physical and systemic threats to emergent and less understood ones. These vulnerabilities will likely include not only well-documented risks, such as physical attacks and geopolitical supply risks, but also less explored scenarios, such as vulnerabilities arising from societal movements.

The survey results are expected to categorize these vulnerabilities based on their perceived threat levels, with input from diverse stakeholders offering insights into which threats are deemed critical. This categorization will likely reveal a set of high-impact vulnerabilities that call for closer investigation. Furthermore, the focus group discussions are anticipated to refine this list by validating and discovering interconnections between vulnerabilities, exploring long-term scenarios, and identifying gaps in current mitigation strategies. Key deliverables from this study will include:

1. A comprehensive overview of vulnerabilities that integrates insights from existing literature, expert perspectives, and survey data.
2. A categorization of vulnerabilities.
3. Scenarios of future vulnerabilities that consider long-term energy system evolution and currently unknown factors.

The study is expected to emphasize the interconnected and interdisciplinary nature of energy system vulnerabilities, providing a robust foundation for future research and policymaking.

Conclusions

This research highlights the need for a holistic understanding of energy system vulnerabilities, focusing on their potential risks, impacts, and long-term implications. By systematically identifying and categorizing vulnerabilities, the study emphasizes the importance of addressing not only immediate and apparent threats but also those that are improbable or unforeseen today. The findings highlight the criticality of forward-looking perspectives, particularly as our energy system becomes more complex and interdependent.

The study's outcomes are expected to contribute to better-targeted research efforts and more informed decision-making processes, enabling policymakers, researchers, and industry stakeholders to better allocate resources toward mitigating high-impact vulnerabilities. Additionally, the interdisciplinary insights generated by this research may serve as a foundation for future studies exploring the resilience and sustainability of energy systems. Through a deeper understanding of vulnerabilities, this study supports the transition to a more resilient, secure, and sustainable energy landscape.