Multilayer Network Analysis of Energy Networks

Muhammad Kazim, Harun Pirim

Department of Industrial & Manufacturing Engineering, North Dakota State University, Fargo ND

Introduction

For the first time, we use network science to study energy networks in a unique dual approach:

1. Multi-layer perspective focusing on Electricity and Gas layers connected via hubs.

2. Multiplex analysis to understand node failure effects and layer interdependencies.

This research unveils critical insights into network dynamics and the consequences of disruptions, setting the direction for future infrastructure planning.

Research Objective

1. **Dual Network Analysis:** Investigate energy networks from both a multi- layer and multiplex perspective.
2. **Network Dynamics:** Explore interconnections, node prominence, and robustness in energy networks.
3. **Impact Assessment:** Understand cascading effects of node failures and evaluate resilience against disruptions.
4. **Guide Future Planning:** Offer insights to inform future infrastructure and energy management strategies.

Methodology

In our analysis, we utilize two main metrics: **Centrality and Robustness**.

1. Centrality is universally applied to both Multilayer and Multiplex analyses.

2. Robustness:

- Both Multilayer and Multiplex utilize the Coverage Evolution metric.
- Exclusively within the Multiplex framework, we further explore:
  - **Random** and **Targeted** Attacks.
  - Structure Stability Index(**SSI**), which integrates both Molley Read Criteria and Minimum Threshold.
  - Interlayer Comparative Analysis and Community Detection as unique considerations for Multiplex.

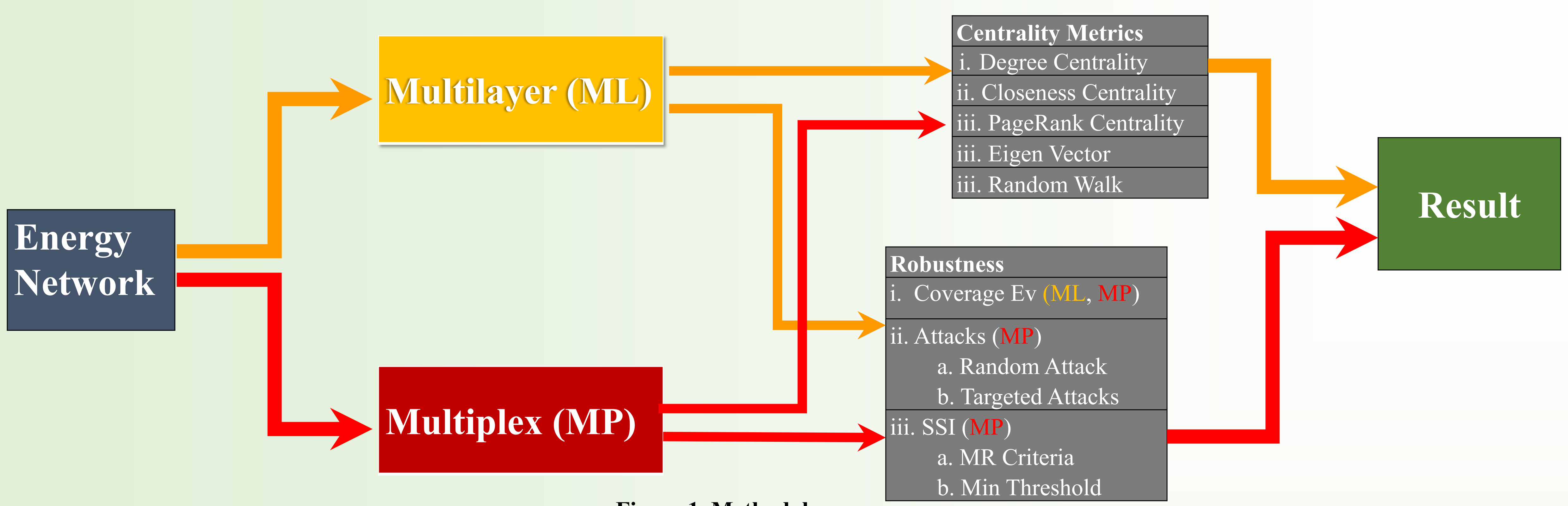


Figure 1. Methodology

Network Construction

1. The Multilayer Network comprises Electricity and Gas layers, with pivotal nodes in Electricity connecting to Gas.

2. The Multiplex Network has five layers: the first is a default load, while the next four are based on nodes

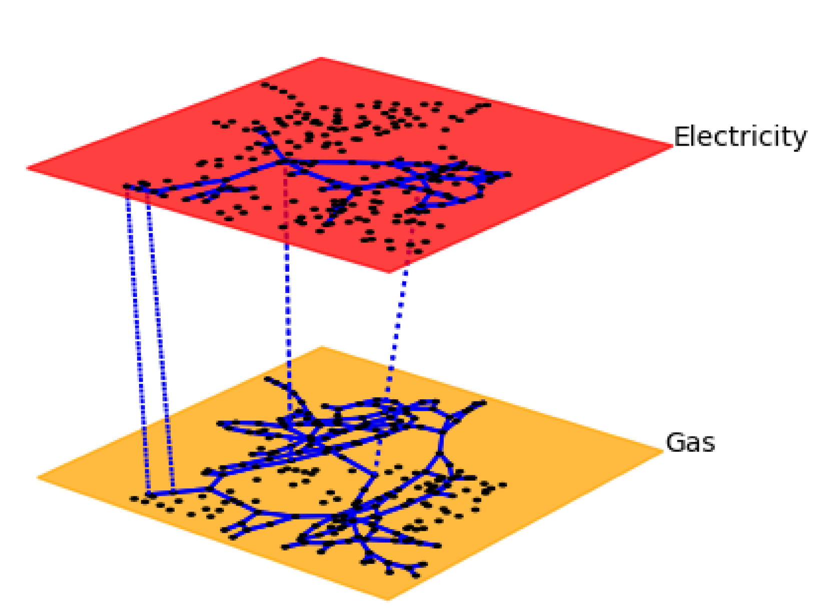


Figure 2. Multilayer Network

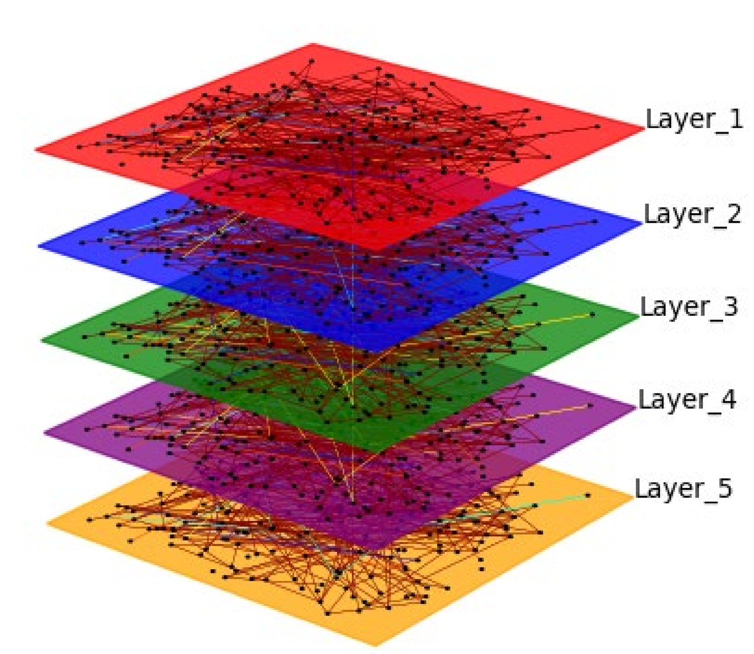
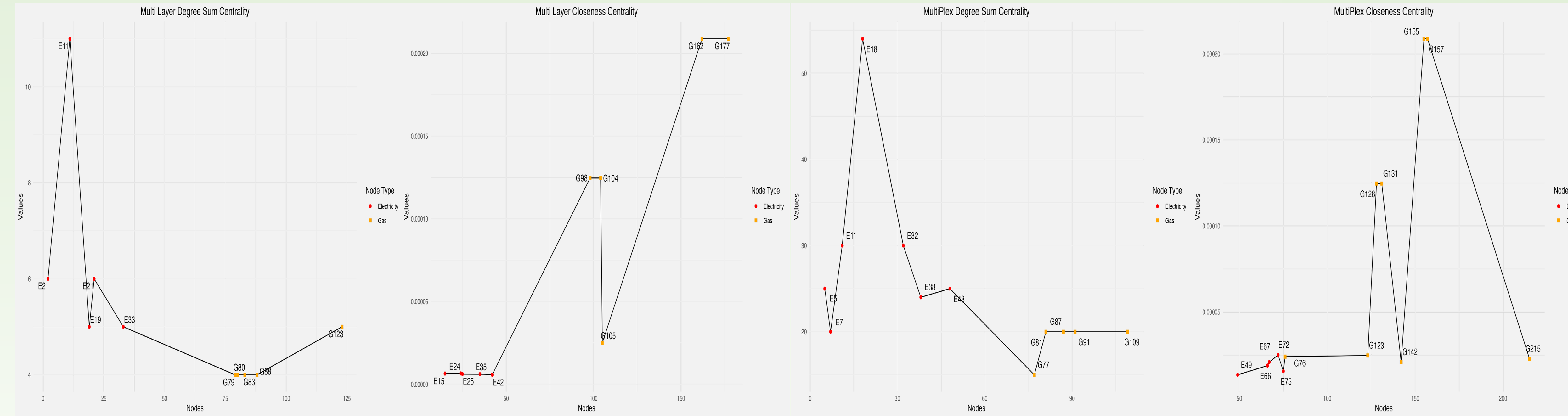


Figure 3. Multiplex Network

Centrality Results

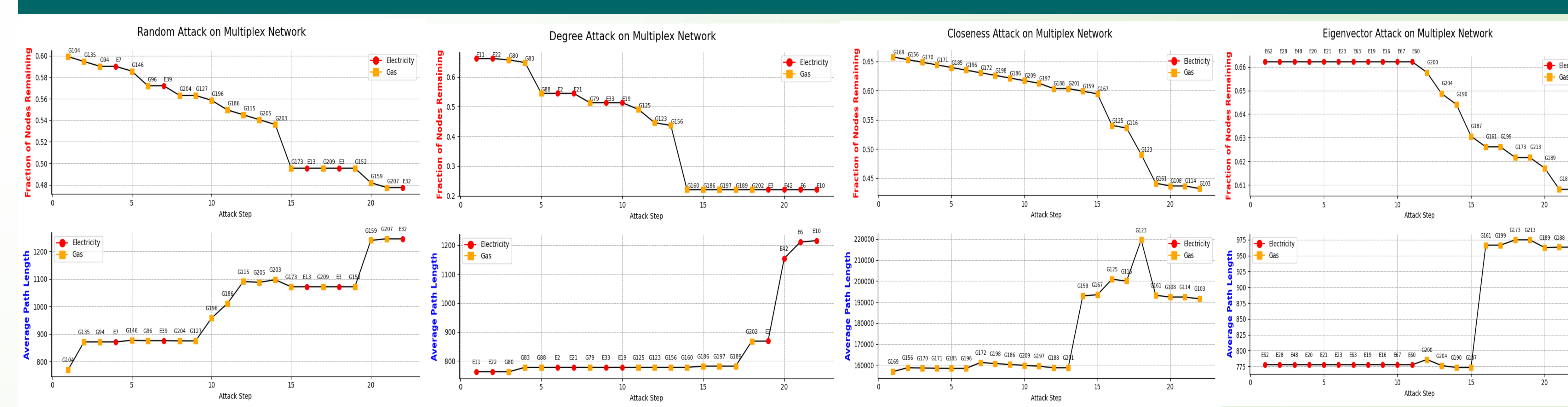


Robustness (Coverage Evolution) Results

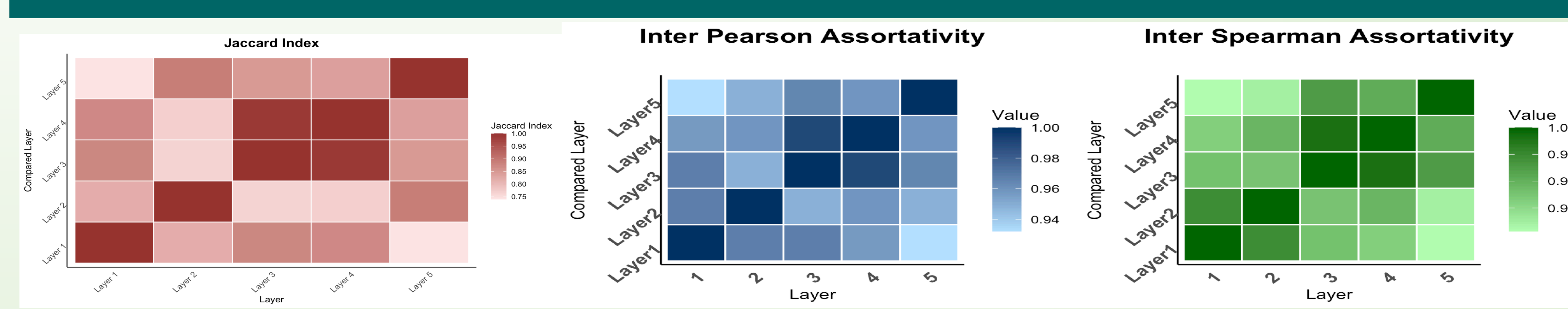
Multilayer Coverage		Multiplex Coverage	
Time Point	Values	Time Point	Values
01	0.0089	01	0.0087
02	0.0132	02	0.0129
03	0.0176	03	0.0171
04	0.0219	04	0.0214
05	0.0262	05	0.0257

Structure Stability Index (MP)	
Metric	Values
Molley Reed Criterion	03.50
Critical Threshold	00.66

Robustness (Attacks) Results



Comparative Analysis of Multiplex Network



Conclusion

By using the power of network science, we conducted a deep dive into the intricacies of energy networks, examining them through both multi-layered and multiplex lenses. Our in-depth analysis brought to light the complex dynamics inherent in these networks, with a special emphasis on understanding the cascading repercussions that arise from node disruptions. Furthermore, by employing methodologies like Centrality, Robustness, and layer-layer comparisons, we've unearthed findings that are indispensable. These insights not only enhance our understanding of current energy systems but also stand to play a crucial role in shaping strategies and decision-making for the development of future energy infrastructure.

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