CASE STUDY

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The Challenge

The UK's transition to Net Zero depends not only on achieving decarbonisation but also on ensuring that energy systems can withstand, absorb, and recover from disruptions. However, most existing resilience assessment methods rely on detailed operational or historical data, resources that do not exist for emerging technologies such as hydrogen, smart grids, and large-scale renewables. This makes it extremely difficult to assess resilience at the design stage, when decisions have the greatest long-term impact.

Additionally, resilience lacks a consistent definition or measurement approach. Current methods are fragmented across disciplines, leading to inconsistency, complexity, and poor applicability for industry. Without a clear and practical framework, decision-makers risk building low-carbon systems that are efficient but fragile under real-world conditions.

The core challenge addressed by this project was therefore: 'How can resilience be embedded into the design of Net Zero energy systems when operational data is scarce and existing methods are inconsistent?'

This question lay at the heart of the collaboration between the University of Sheffield and the Energy Systems Catapult. The project sought to develop a structured, qualitative framework that defines, prioritises, and models resilience characteristics for Net Zero energy systems, enabling designers, policymakers, and industry partners to evaluate system robustness early in the planning process and ensure that resilience becomes a cornerstone of the UK's secure energy transition.

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Innovation

This project introduced a novel methodology for assessing resilience in Net Zero Energy Systems (NZES), a first of its kind at the design stage. Rather than depending on unavailable operational data, it used structured expert judgement to identify, prioritise, and model resilience characteristics.

The research combined three innovative elements:

- Resilience framework development – over 100 studies were reviewed to define two dimensions (survivability and recoverability), four planes (anticipation, absorption, adaptation, restoration), 14 metrics and 50 indicators.
- Fuzzy Analytical Hierarchy Process (FAHP) – applied to prioritise indicators based on expert input, providing a transparent way to weight qualitative factors under uncertainty.
- Dynamic Bayesian Network (DBN) – integrated expert scores and probabilistic reasoning to simulate how system resilience evolves under disruption.

This integration of qualitative indicators with probabilistic modelling breaks new ground in resilience research, offering a credible and flexible method where traditional quantitative approaches are infeasible.

Crucially, the work was co-designed with the Energy Systems Catapult, ensuring practical alignment with industry and policy needs. The outcome is a scalable, transparent, and user-friendly tool that allows resilience to be systematically evaluated across diverse energy technologies, from hydrogen production to offshore renewables, supporting evidence-based decision-making before systems are deployed at scale.

Result

The project successfully developed a comprehensive resilience framework for Net Zero Energy Systems, providing the first structured and scalable way to assess resilience at the early design stage.

Key results include:

- A hierarchy of two resilience dimensions, four planes, 14 metrics, and 50 indicators, validated through expert engagement.
- A set of prioritised indicators, identifying which attributes most strongly influence survivability and recoverability in NZES.
- A Dynamic Bayesian Network model demonstrating how resilience can be assessed probabilistically even in the absence of historical data.

The findings confirm that resilience can be systematically evaluated using qualitative information, transforming it from a vague concept into an actionable design criterion.

This approach not only provides clarity but also bridges the gap between academic theory and industrial practice. For the Energy Systems Catapult, it offers a credible framework to identify vulnerabilities, guide investment priorities, and integrate resilience into whole-system energy modelling.

The methodology's flexibility means it can evolve with new data and technologies. The research team and ESC have agreed to continue refining the framework as further expert responses are collected, ensuring it remains relevant and data-informed.

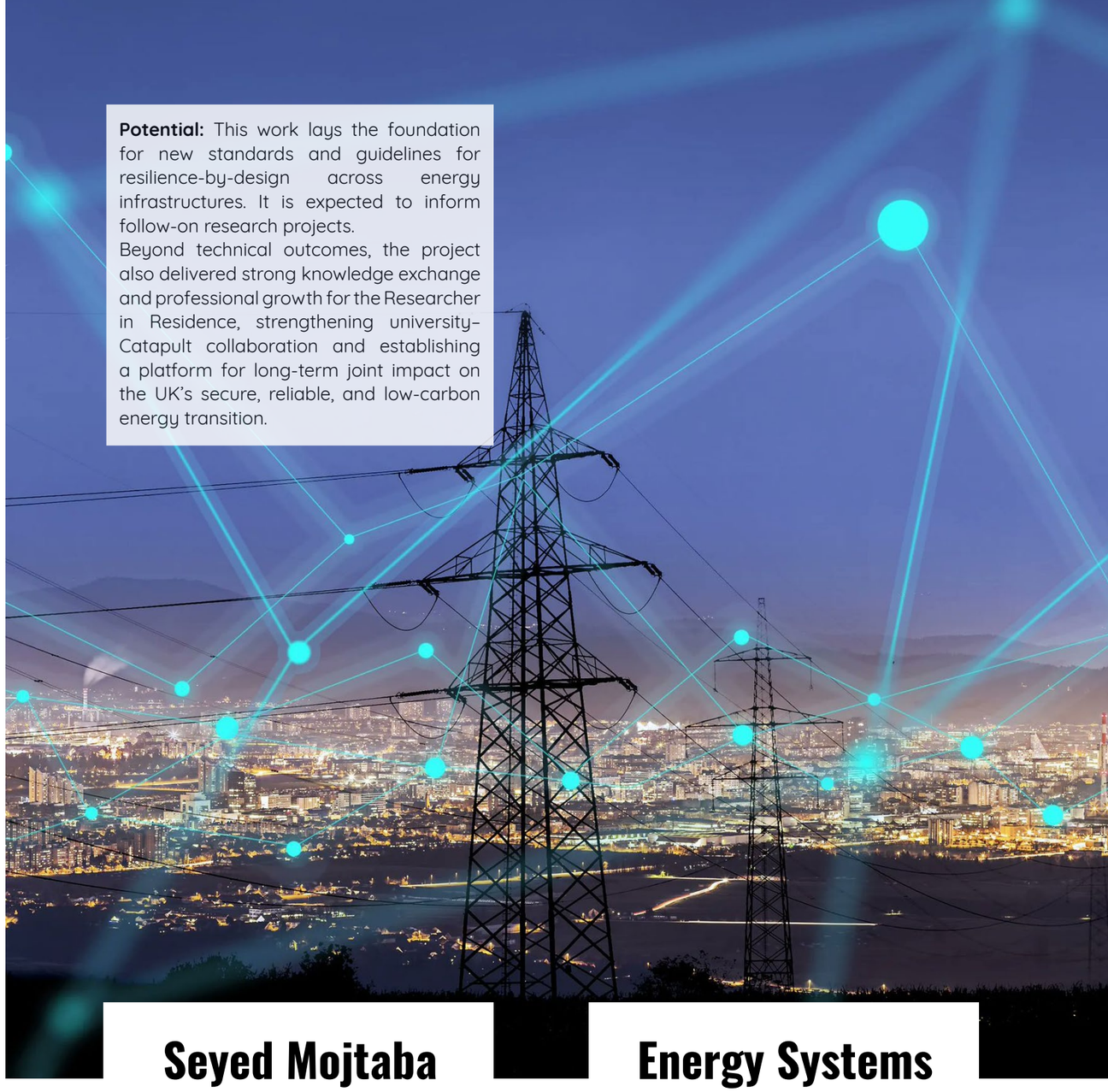
Ultimately, the project demonstrated that embedding resilience early can reduce long-term costs and improve system reliability, supporting a smoother, more secure pathway to the UK's net zero future.

Impact

This project has created a step-change in how resilience is assessed and designed within the UK's Net Zero transition. By developing a practical framework usable in data-scarce contexts, it has made resilience assessment accessible to policymakers, engineers, and system designers.

The "so what": Resilience is now measurable and actionable — no longer an abstract aspiration. Decision-makers can use the framework to evaluate vulnerabilities, prioritise interventions, and design systems that are robust to shocks such as equipment failure, cyberattacks, or extreme weather.

Sectoral change: The methodology directly supports whole-system energy planning, helping organisations like the Energy Systems Catapult, Ofgem, and DESNZ to embed resilience thinking into early-stage design and national modelling exercises. It also provides a pathway for industry adoption, enabling developers and utilities to integrate resilience criteria into investment and regulatory decisions.



Potential: This work lays the foundation for new standards and guidelines for resilience-by-design across energy infrastructures. It is expected to inform follow-on research projects.

Beyond technical outcomes, the project also delivered strong knowledge exchange and professional growth for the Researcher in Residence, strengthening university–Catapult collaboration and establishing a platform for long-term joint impact on the UK's secure, reliable, and low-carbon energy transition.

Seyed Mojtaba Hoseyni

Energy Systems Catapult

"Working with the Energy Systems Catapult allowed me to translate academic resilience theory into a practical tool that policymakers and industry can use. This collaboration showed how structured expert judgement can unlock resilience assessment even when data is scarce."

"Net Zero energy systems pose new and evolving resilience challenges. Mojtaba's work has provided a strong framework and a promising approach to tackle the real-world challenges we face to ensure that the system we develop meets our expectations of resilience." - Alex Buckman, Innovative Solutions Architect

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