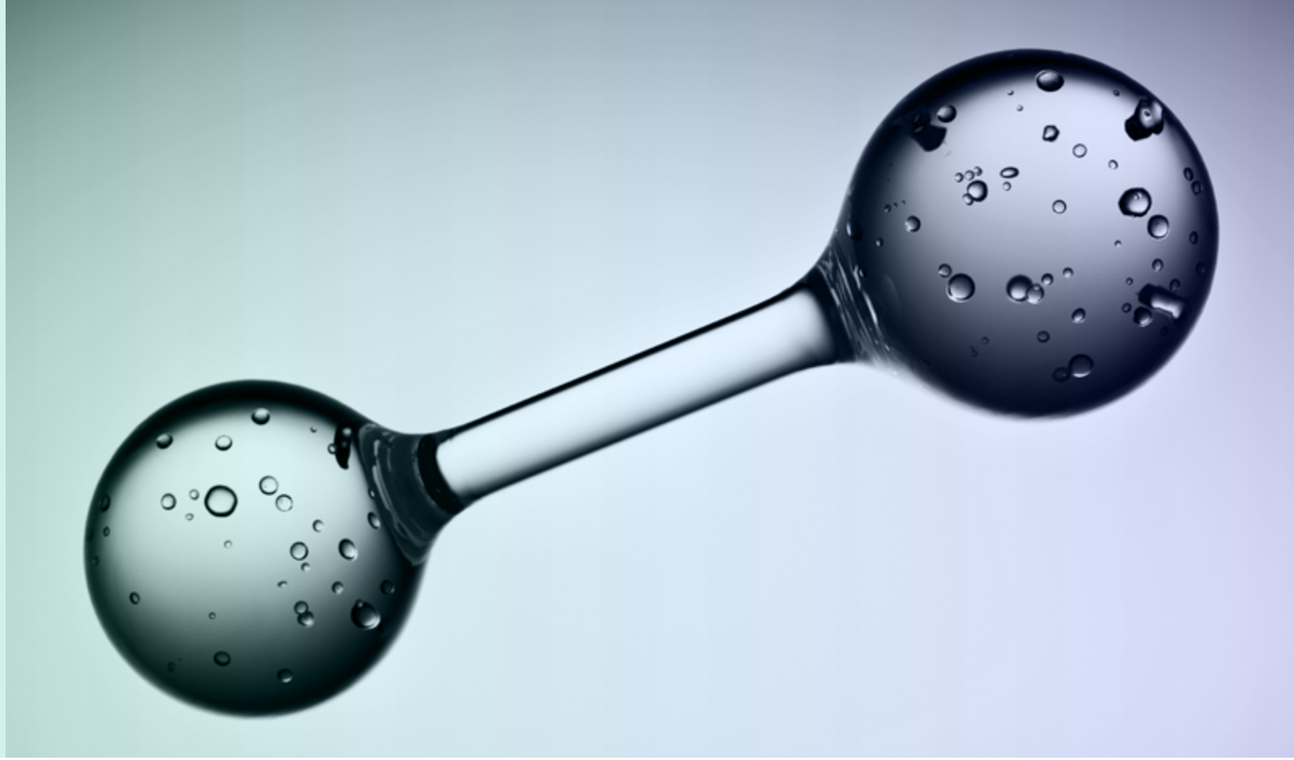
Towards a Resilience Evaluation Framework for Hydrogen Supply Chains

Project team:
University of Sheffield: Prof. Lenny Koh, Prof. Vania Sena, Prof. Darren Robinson, Dr Matthew Wood, Liang Kong



Challenge Statement

The case study responds to urgent challenges exposed by current geopolitical tensions, such as instability in the Middle East and the Russia-Ukraine war, where global disruptions have highlighted the limits of traditional resilience practices such as contingency planning. These reactive approaches have proved inadequate for the scale and complexity of modern supply chain shocks[1]. In today's volatile environment, organisations require proactive mechanisms that enable not only recovery but also adaptation and evolution. This is particularly vital for hydrogen supply chains (HSCs), which face raw material dependencies, weather risks, integration challenges, and sensitivity to stakeholder perceptions. Yet no framework currently guides firms in progressively building resilience, leaving a clear gap this study seeks to address. Current evidence supports this view[2]. Existing maturity models remain fragmented and function-specific, with few pathways, limited empirical evidence, and especially scarce hydrogen-specific insights despite the sector's importance to net-zero.

For South Yorkshire, these challenges are immediate. Hydrogen is central to the UK's industrial strategy, but its success depends on supply chains that are robust, adaptable, and sustainable. Funded by Research England, this research develops a conceptual maturity model for hydrogen resilience, providing a tool to strengthen supply chains and support a competitive, fair, and sustainable hydrogen economy.

Research Response

Research contributes to tackling resilience challenges in HSCs by offering structured approaches that reflect the sector's unique vulnerabilities. This study develops a resilience capability maturity model (RCMM) that provides a phased framework for assessing resilience across maturity levels, tailored to hydrogen's regulatory, market, and technological contexts. Drawing on complex adaptive systems (CAS) theory, the model explains how firms adapt and self-organise under disruption. Unlike existing maturity models, which are either sector-specific or largely conceptual, this framework addresses hydrogen's challenges such as hazard management, sustainability demands, and market volatility. It enables benchmarking, identifies capability gaps, and provides actionable insights, while laying the groundwork for broader empirical validation.

Where hydrogen is central to energy and net-zero strategies, the challenge lies not only in scaling technologies but in ensuring the value chains remain resilient and adaptable. Heavy reliance on subsidies risks dependency and reduced adaptability. The RCMM helps address this by equipping firms with tools to benchmark resilience, identify weaknesses, and pursue continuous improvement. Emphasising technical independence, organisational learnability, and ecological resilience, the model supports firms in anticipating risks, building adaptive capacity, and sustaining competitiveness in volatile markets.

The project's goal was to create a sector-specific model for HSCs, operationalising resilience management through defined maturity levels, from reactive recovery to ecological resilience. Tested through exploratory case studies, it offers a roadmap for organisational progression, supports benchmarking, and provides a basis for validation across sectors and regions.

Evidence and Outputs

Existing maturity models in supply chain management are either sector-specific or largely conceptual, making them insufficient for addressing the resilience needs of HSCs. To address this gap, a conceptual RCMM tailored to hydrogen was developed. The model demonstrates a progressive pathway: early stages focus on manufacturing resilience through reactive responses and recovery capabilities, while higher stages emphasise ecological resilience, characterised by proactive adaptation, external network integration, and long-term sustainability. Exploratory case studies of seven companies across three continents showed that the RCMM can identify capability levels, highlight gaps, and provide companies with a roadmap for advancing resilience maturity. The research indicated that firm size and age matter, with larger and older firms generally better positioned to recover and adapt due to accumulated resources and experience. The research also highlights trade-offs. Hydrogen technologies are resource-intensive, with high energy and leakage risks. At the same time, policy dependency, particularly on subsidies, was found to risk undermining long-

1 Koh, S. C. L., Suresh, K., Ralph, P., & Saccone, M. (2024) Quantifying organisational resilience: An integrated resource efficiency view. International Journal of Production Research, 62(16), 5737–5756.

2 Kong, L., Koh, S. C. L., Sena, V., Robinson, D., & Wood, M. (2025) Towards a resilience evaluation framework for hydrogen supply chains: A systematic literature review and future research agenda. International Journal of Hydrogen Energy, 99, 589-606.

Resilience Capability Maturity Model

	Manufacturing Perspectives		Ecosystem Perspectives		
Maturation Path	Level 1: Initial	Level 2: Commercialisation	Level 3: Scale-up	Level 4: Industrialisation	Level 5: Business Ecosystem
		Improved technical ability	Declining costs	Developed supply network	Affordable and new technologies emerge
Themes	Focus on technical infrastructure readiness, organisational structure, resource accumulation for operations and reactive response capabilities	Focus on integrating internal capabilities, developing key supply chain structures and extending proactive resilience capabilities	Adopt a proactive attitude, strengthen internal resilience practices and collaborate with supply chain partners on risk management	A comprehensive and systematic approach to implementing resilience practices, internally and across the supply chain, requires collaboration with partners and stakeholders to build a robust business ecosystem	Resilience practices are embedded across corporate and supply network processes, with strong partner synchronisation driving value creation, business model innovation and a sustainable ecosystem
Stakeholders	Departments of the focal enterprises, the focal enterprises, key component and infrastructure suppliers, power supply companies, governments, academic institutions	Departments of the focal enterprises, the focal enterprises, key component and infrastructure suppliers, power supply companies, customers	Key component and infrastructure suppliers, power supply companies, the focal enterprises, customers	Renewable energy enterprises, the focal enterprises, customers, regional and national governments, international industry associations, academic institutions	Renewable energy enterprises, the focal enterprises, customers, regional and national governments, international organisations, academic institutions

Technical Resilience: considering from manufacturing technique, process, equipment and R&D perspectives

Sub Levels	Level 1: Technical Readiness	Level 2: Commercialisation	Level 3: Scale-up	Level 4: Industrialisation	Level 5: Business Ecosystem
	Objective: Ensure the technical readiness of the system	Objective: Supply and demand coordination	Objective: Improve the scale, stability and efficiency of the manufacturing process	Objective: Regional risk control	Objective: Ensure the technical readiness of the system

Sub Criteria: Foundation of a system coordinated development (Vulnerability Control), reliability, maintainability, independence of critical infrastructures, resources to build up resilience and to response (Monitoring and Landscape)

Operational Resilience: considering from cash, information, material flow and relationship management perspectives

Sub Levels	Level 1: Responsiveness	Level 2: Commercialisation	Level 3: Integration	Level 4: Collaboration	Level 5: Sustainability
	Objective: Develop operations management capabilities	Objective: Production efficiency	Objective: Supply network extension	Objective: A mutually cooperative win-win approach	Objective: Sustainable development capability achieved

Sub Criteria: Operational management capabilities (Cost-down Abilities, Efficient Manufacturing/Optimality), Information sharing (Visibility and Transparency), Adaptability (Flexibility, Optimisation and Recovery Capabilities)

Organisational Resilience: considering from organisational structure, culture and administration process perspectives

Sub Levels	Level 1: Structure Constuction	Level 2: Functional Integration	Level 3: Organisational Process Integration	Level 4: External Stakeholder Integration	Level 5: Dynamic Alliance
	Objective: Appointment of resilience management specialists and establishment of cross-department teams	Objective: Optimisation of organisational structure and establishment of a resilience management system	Objective: Foresight	Objective: Ecosystem building	Objective: Possess high resilience and flexibility, be manageable and continuously improved

Sub Criteria: Organisational structure (Robustness and Agility), Objectives, values and culture (Clarity of Vision and Mission and Learnability)

term resilience, indicating the need for strategies that balance short-term support with sustainable independence.

The main output is a conceptual maturity model (the RCMM) that functions as both a descriptive and comparative tool, enabling firms to assess their resilience maturity, benchmark against peers, and develop strategies for improvement. Incorporating five levels across technical, organisational, and operational dimensions, and grounded in CAS theory, the model offers guidance for companies and policymakers. While designed for HSCs, it has potential transferability to other sustainability-focused industries, though further empirical testing to confirm its generalisability.

Interim access to the framework can be provided upon request through the research team. Please email liang.kong@sheffield.ac.uk for access.

This research has also been published and the research paper can be viewed here.

What does this mean for the region?

For South Yorkshire, where energy affordability is a regional concern, resilience planning should be integrated with environmental regulation, energy market design, and community engagement. Supporting renewable energy communities and decentralised production would enhance both technical resilience and social equity, requiring cross-disciplinary collaboration. The RCMM identifies supply network integration as another driver of resilience. Building partnerships across transport, manufacturing, logistics, and heavy industry can foster collective resilience, reduce vulnerabilities, and create high-value jobs, supporting a just transition.

South Yorkshire can apply the RCMM in regional clusters such as hydrogen transport hubs and decarbonised steel, while also positioning itself as a national and international leader in resilience-focused hydrogen development. By exporting governance frameworks alongside technologies, the region can attract investment and strengthen its reputation.

For the UK and globally, this research informs and highlights the critical need to evaluate maturity and resilience of HSCs, as part of the hydrogen, energy and net-zero policies to maximise sustainability and security.

Next Steps

To maximise the impact of this work, the next step is to apply the maturity model more widely across different firms, sectors, and regions. The model could be embedded into hydrogen clusters such as transport hubs, industrial decarbonisation projects, and renewable energy communities. Doing so would provide benchmarking data, guide targeted interventions, and demonstrate the model's value as a regional policy tool. Embedding the framework into industrial strategies and net-zero roadmaps would also ensure that resilience is systematically assessed alongside growth and sustainability goals.

The research also highlights new questions that warrant further exploration. One important area is how firm characteristics, such as size, age, and resources, shape progression through resilience maturity levels. Another concerns the balance between policy support and long-term independence, particularly the extent to which subsidies enable growth but may reduce adaptability and innovation (Kong et al., 2025). There is also scope to adapt the model to environmental challenges such as energy demand, water use, and hydrogen leakage, linking resilience more closely with environmental governance.

Collaboration is key to advancing this agenda. Partnerships between academia, industry, and regional policymakers could establish pilot projects where firms apply the model and share data to build comparative insights. Cross-regional and international collaborations could further position South Yorkshire as a leader in both hydrogen technology and resilience governance. By pursuing these opportunities, the region can strengthen its evidence base, attract investment, and accelerate progress toward a just and sustainable hydrogen economy.

Figure 1 (left): Proposed RCMM Abstract, credited by Liang Kong, Prof. Lenny Koh, Prof. Vania Sena, Prof. Darren Robinson, Dr Matthew Wood