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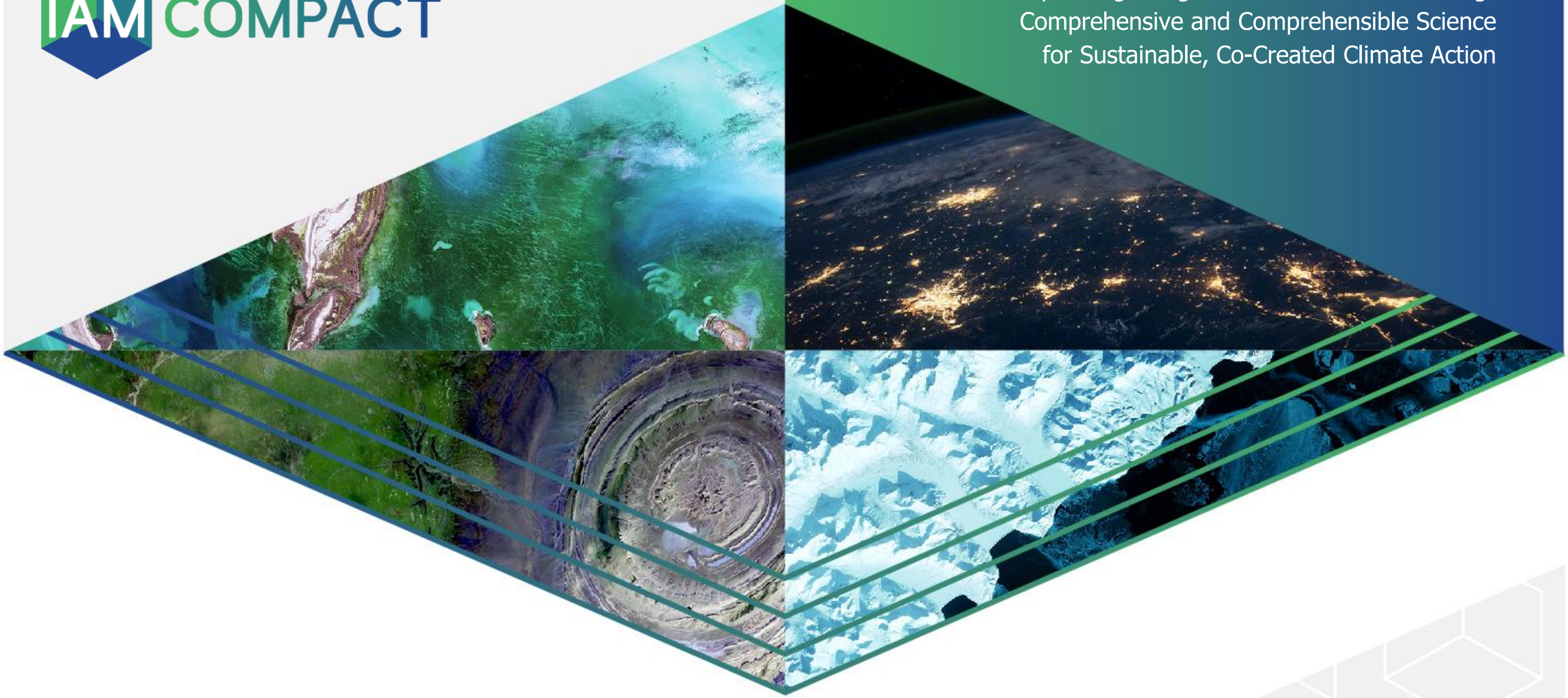
Expanding Integrated Assessment Modelling:
Comprehensive and Comprehensible Science
for Sustainable, Co-Created Climate Action



Responsive science in support of climate policymaking
IAM COMPACT Final Conference, Athens, 29 August 2025

The impact of disruptive events in climate planning

Alaa Al Khourdajie, Imperial College London

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Al Khourdajie, A., Gambhir, A., Keppo, I., Frilingou, N., Mittal, S., Van de Ven, D-J., Fragkos, P., Wells, C., Schoenberg, W. A., McJeon, H., Byers, E., Peters, G.P., McCollum, D.L., Zisarou, E., Smith, C., Westphal, M., Hawkes, A., Nikas, A.

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Climate change mitigation scenarios largely assume *predictable transitions*, yet face inevitable disruptions

Disruptive events: Incidents that fundamentally alter expected trajectories

- Climate disruptions: Compound stresses (e.g., heatwaves, and droughts)
- Societal disruptions: Cascading failures (e.g., financial crises → mitigation funding collapse…)

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Development of Emissions Reduction Scenarios

Qualitative Design	Quantitative Specifications	Modelling
Narratives & Storyline	Socio-economic Assumptions (SSPs)	PB Integrated Assessment Models
Scenario Protocol	Detailed Technical and Scenario Assumptions: e.g., NDCs, SPAs, Technology Parameters	Emissions & Removals Pathways
		Techno- & Socio-economic Scenario

The gap: Long-term mitigation scenarios lack systematic frameworks to assess resilience to disruptive events

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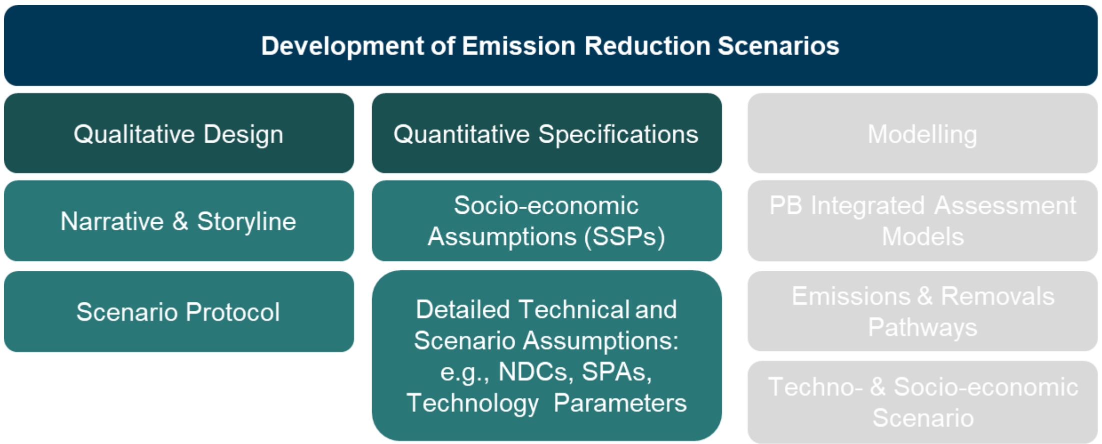
The Disruptive Events-Resilient Pathways (DERP) Framework

Narrative-based methodology to systematically translate disruptions into quantitative parameter adjustments

Demonstration with two stylised disruptions:

Heatwaves/droughts: Energy supply constraints + demand surges

Rapid DACCS: Cost-driven technological acceleration



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The Disruptive Events-Resilient Pathways (DERP) Framework

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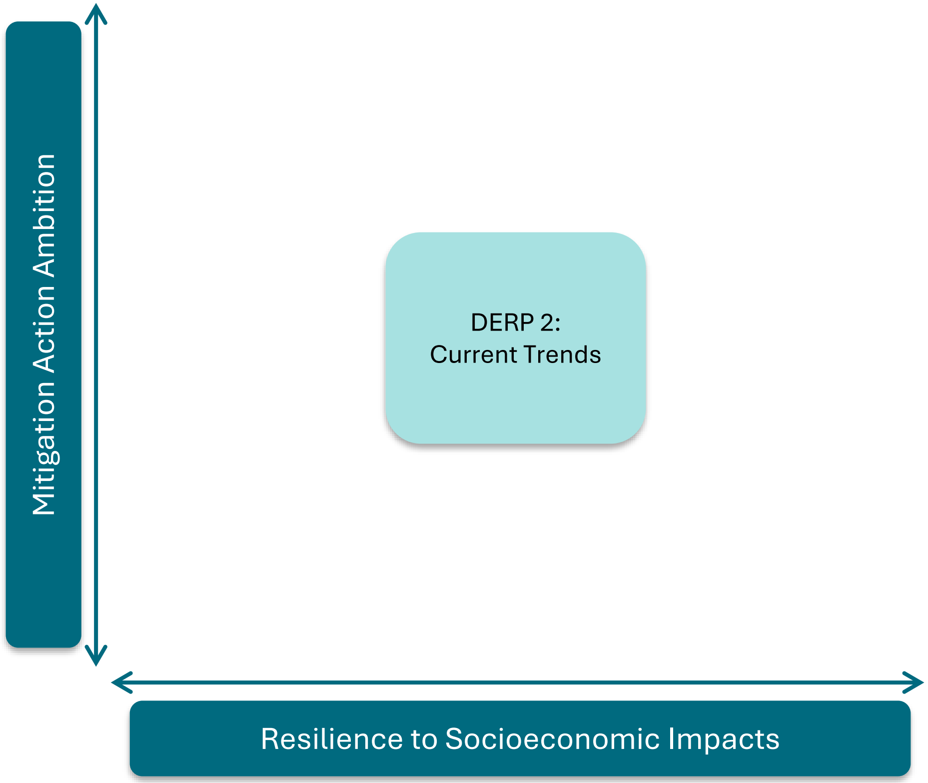

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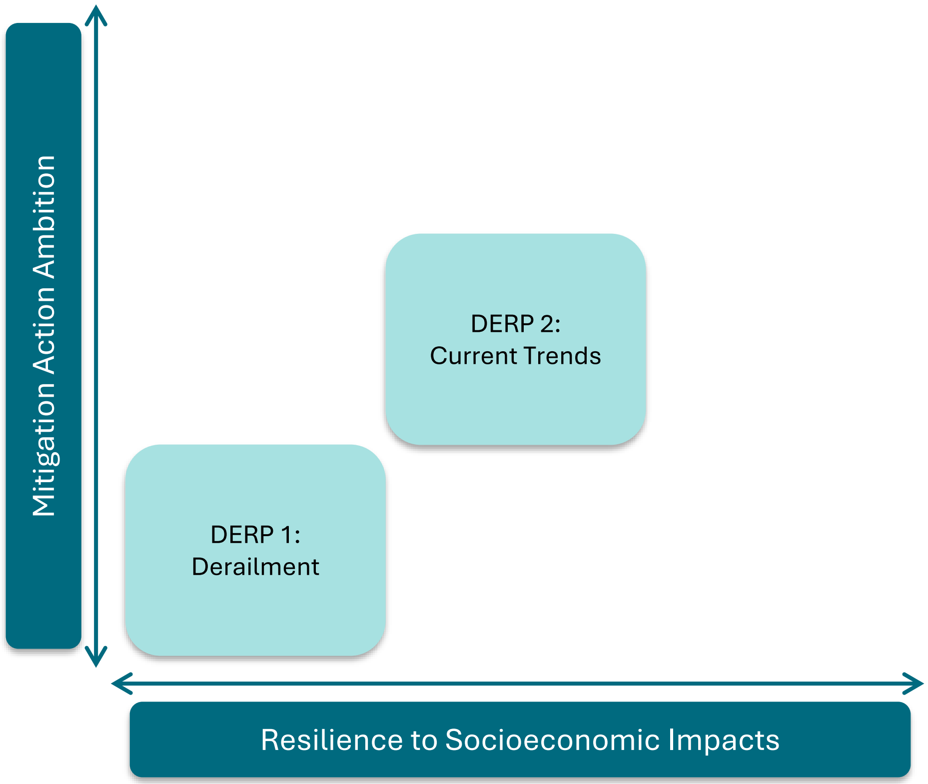

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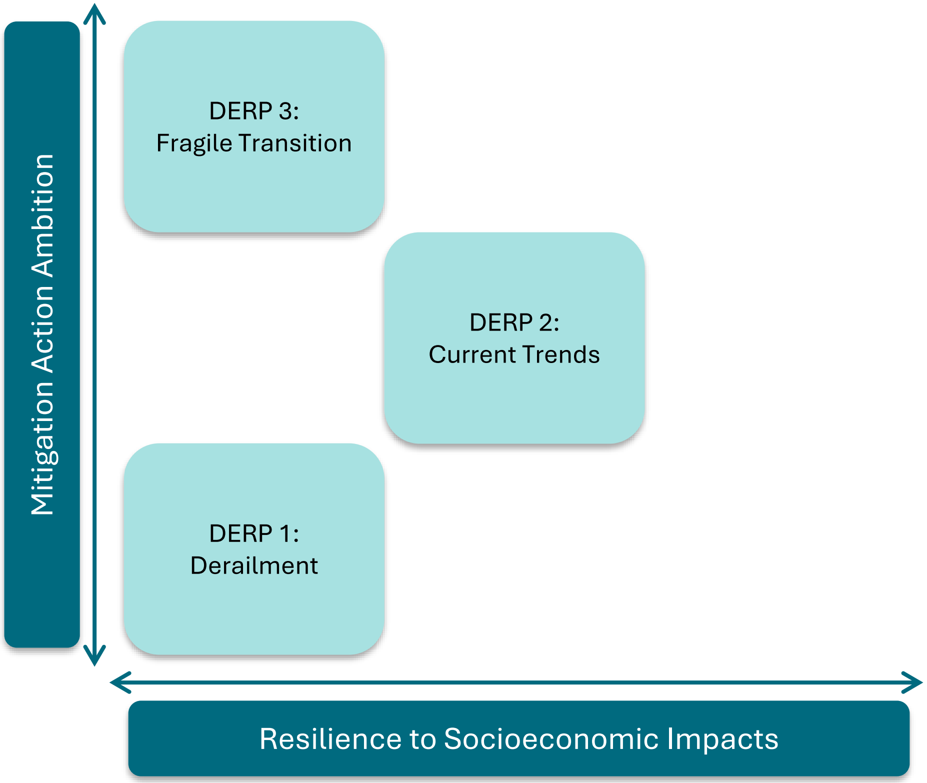

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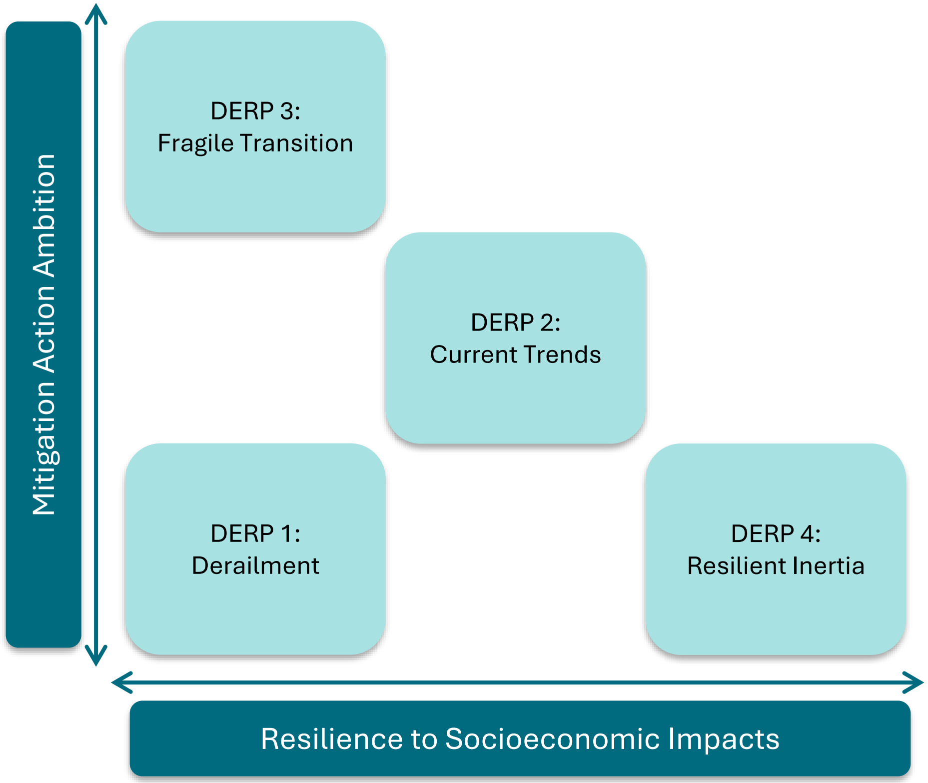

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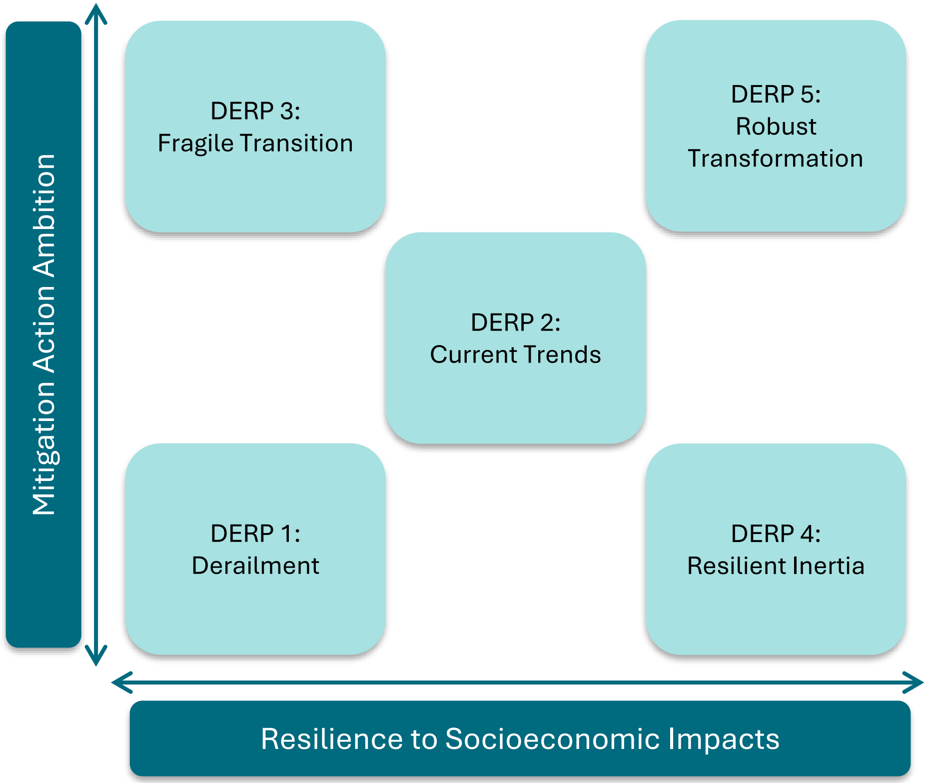

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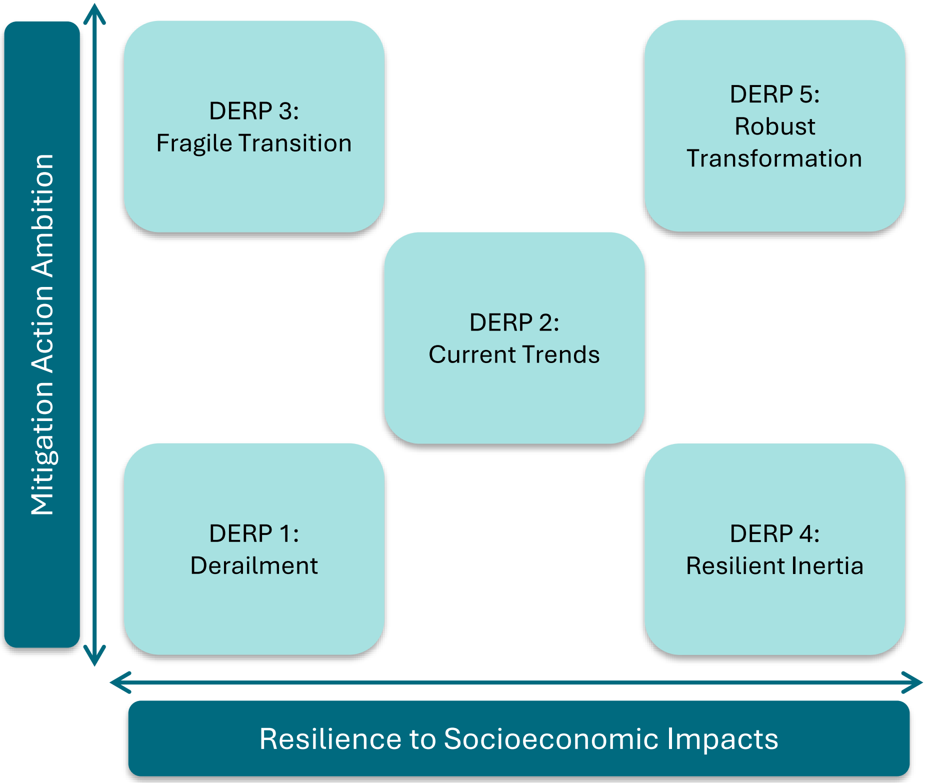

DERP1 – Derailment: Limited mitigation action ambition with low resilience to socioeconomic impacts

In this narrative, society is characterised by two distinct, detrimental trends. Mitigation action ambition is scaled back as societies retreat from proactive mitigation efforts in favour of short-term economic priorities and continued fossil-fuel development. Simultaneously, socioeconomic resilience erodes through diminishing institutional ability to respond to disruptions, entering a state of 'derailment risk' (Laybourn et al., 2023), whereby a safe operating space is increasingly undermined by interacting biophysical and resulting socioecological pressures. These dual weaknesses compound each other: weak climate action increases exposure to future climate hazards, whilst low resilience means any disruption – climate, geopolitical, or economic – can trigger cascading failures. As such, systems face increasingly impactful and frequent disruptions, and feedback loops emerge that rapidly destabilise societies and further constrain their capacity to recover.

DERP2 – Current Trends: Moderately ambitious mitigation action with moderate resilience to socioeconomic impacts

At the centre of the DERP framework space lies DERP2, representing a continuation of current trajectories. In this narrative, societies implement moderate mitigation efforts, which exist independently from, but parallel to, moderate resilience capacity. This capacity is primarily built on responses to familiar disruptions from experience (e.g., the COVID-19 pandemic), enabling societies to manage their socioeconomic impacts but leaving them vulnerable to novel or more severe disruptions outside historical precedence. The two dimensions remain distinct but interact: moderate mitigation action reduces some future climate hazards and thus avoids associated socioeconomic impacts, while moderate resilience provides some capacity to deal with socioeconomic challenges arising from familiar disruptions.

DERP3 – Fragile Transition: Strong but narrowly focused mitigation action, with low resilience to socioeconomic impacts

This narrative involves ambitious but narrowly focused mitigation actions concentrated on specific sectors or approaches. Societies implement climate policies strongly supporting favoured solutions that are generally considered consistent with ambitious climate goals. The high-ambition drive, however, is confined to a limited technological and/or sectoral portfolio. Broader system considerations, such as supply-chain shocks, geopolitical volatility, feasibility limits, or public-acceptance limits, receive little attention. Institutional ability to face disruptions is limited. The interaction of the two dimensions finds narrow mitigation pathways lacking diversity and redundancy; separately, low resilience leaves systems with limited capacity to adapt when favoured solutions encounter unexpected disruptions, rendering the pathways vulnerable to unforeseen challenges.

DERP4 – Resilient Inertia: Limited mitigation action ambition with high resilience to socioeconomic impacts

This narrative features minimal proactive climate change mitigation, with societies prioritising maintenance of existing systems alongside developing strong reactive resilience capabilities focused on rapid crisis response and strategic resource allocation. These distinct approaches interact pragmatically: low mitigation action preserves resources for immediate response, whilst high resilience enables management of near-term disruptions. This creates a paradoxical situation where short-term stability is enhanced at the expense of long-term sustainability, as climate impacts intensify and response costs escalate, potentially eroding future resilience capacity.

DERP5 – Robust Transformation: High mitigation action ambition with high resilience to socioeconomic impacts

This narrative features comprehensive mitigation achieved through a diversified portfolio of low-carbon technologies and an economy-wide shift toward energy-efficient and low-emission production and consumption. Simultaneously, societies develop robust resilience capabilities through flexible infrastructure and redundant capacities. These distinct strengths interact synergistically: ambitious mitigation action reduces future disruption risks, whilst high resilience enables societies to manage both transition challenges and inevitable climate impacts through enhanced adaptive capacity and redundant systems.

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DERP Framework – From Narratives to parameters

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1. Define DE parameters: Same DE applied across narrative (Constrained by evidence and model capabilities)

2. Define resilience characteristics (RCs) parameters: Vary by narrative to reflect societal capacities (Determine how societies absorb and respond)

Parameter category	Indicative parameters	DERP1 - Eroded Resilience	DERP2 - Current Trends	DERP3 - Myopic Transition	DERP4 - Incremental Resilience	DERP5 - Systemic Resilience	Rationale
DIMENSION 1: Mitigation action effectiveness							
Climate policy	Carbon pricing	- -	0	+	-	+ +	Reflects variation in climate ambition and scope of climate policy instruments
	Emissions constraints	- -	0	+	-	+ +	Captures the strength and breadth of climate targets
	Energy efficiency standards	- -	0	+	0	+ +	Represents regulatory approaches to climate action
Technology	Low-carbon technology learning rates	- -	0	+ + (favoured techs) WITH - - OR 0 (for others)	-	++ (diverse portfolio)	Captures differential investment patterns and innovation focus
	Technology deployment rates (e.g., renewables share)	- -	0	+ + (favoured tech) WITH - - OR 0 (for others)	-	++ (diverse portfolio)	Indicates speed of technology adoption

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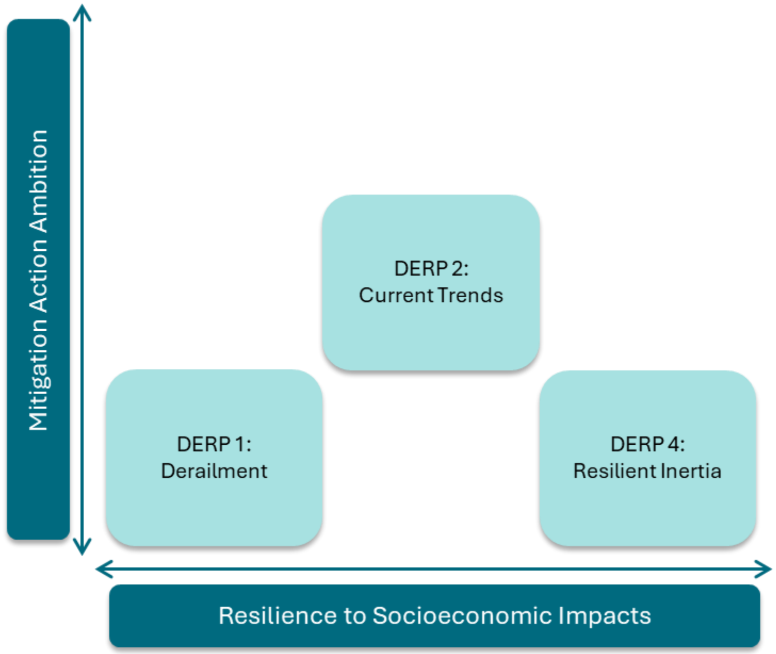
Intensifying heatwaves and droughts

Climate stress on energy systems:

- Capacity factor reductions for hydro and thermal power plants
- 10-20% higher capital costs, depending on the technology
- increased cooling demand

Three scenarios tested: Current Trends (DERP2), Derailment (DERP1), and Resilient Inertia (DERP4) under high climate sensitivity

Resilience: Different institutional responses determine severity of system degradation and ability to maintain functioning



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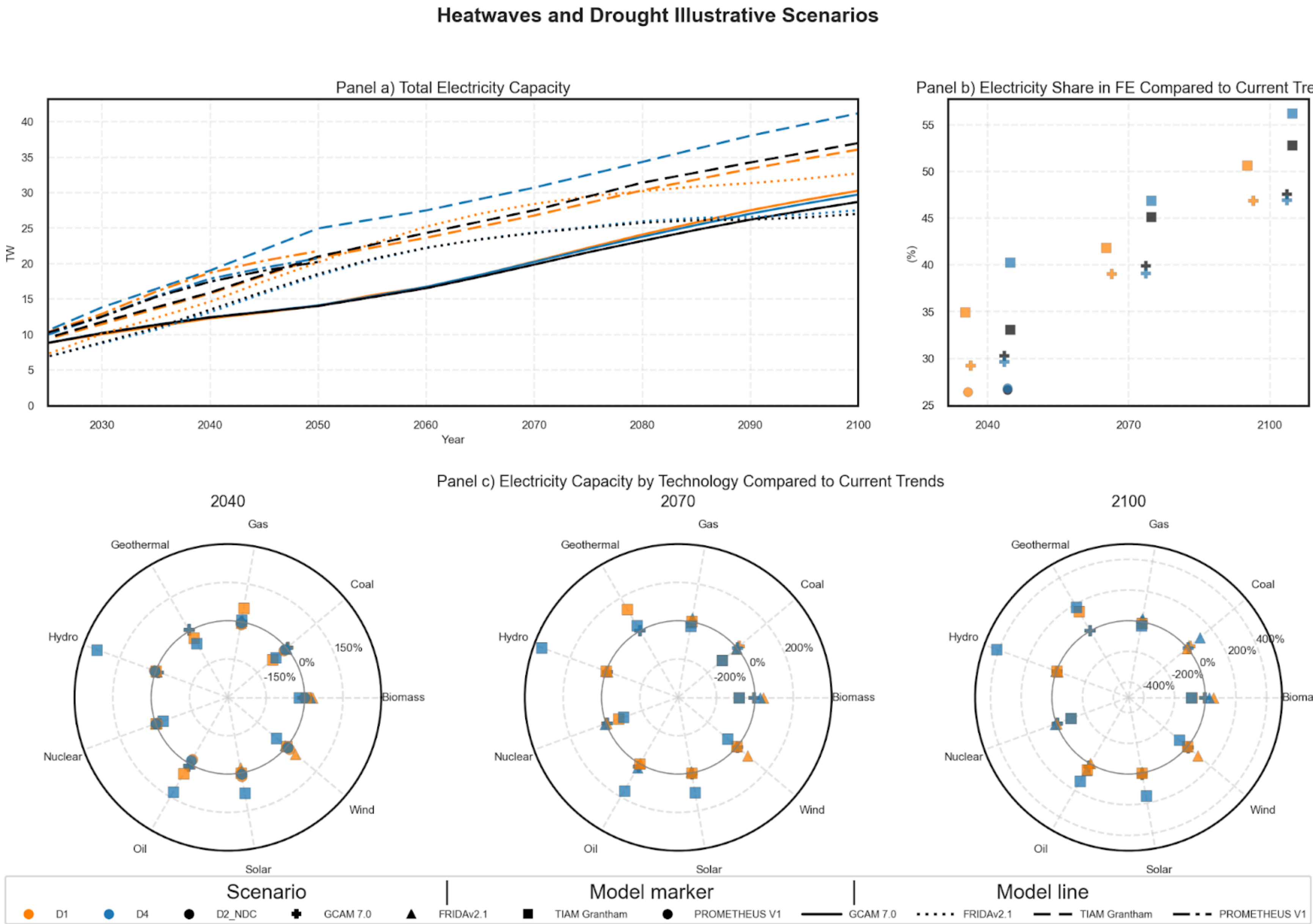
Intensifying heatwaves and droughts



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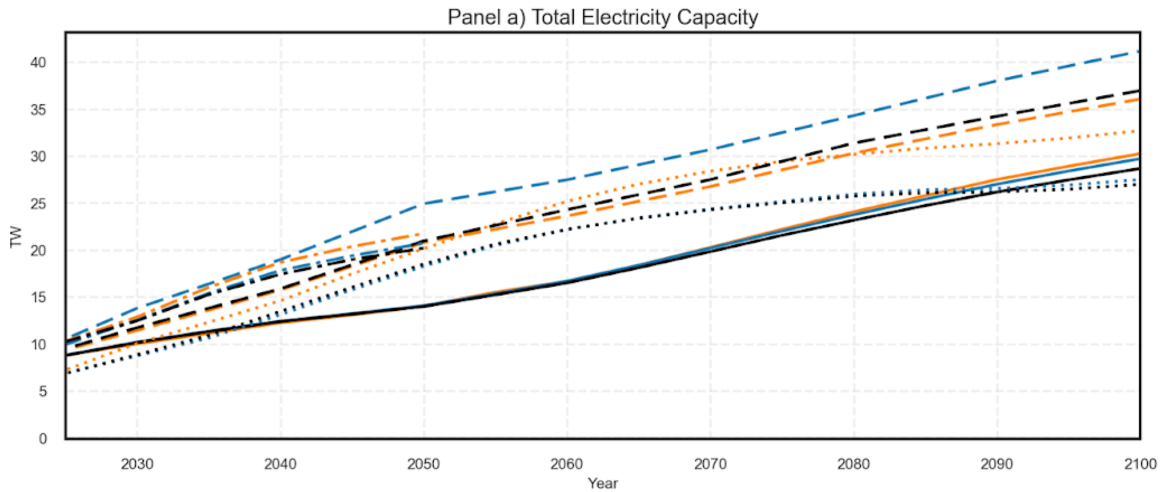
Heatwaves and Drought Illustrative Scenarios



Low-resilience pathways can be far more resource-intensive, with DERP1 (Derailment Narrative) projecting higher total electricity capacity than resilient scenarios

This suggests over-investment in gross physical capacity to compensate for poor operational effectiveness and inability to manage demand flexibly

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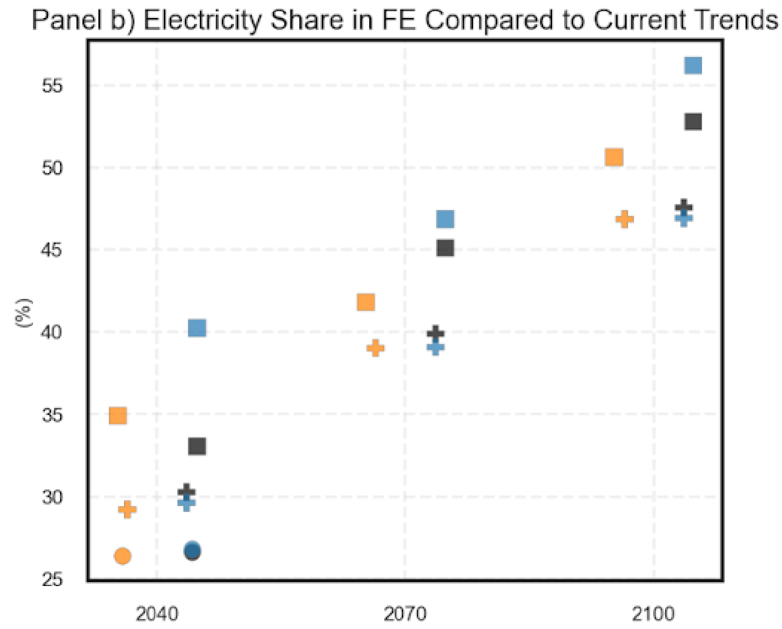

Socioeconomic resilience enables higher electrification rates

Resilience emerges as a precondition for effective mitigation action, not merely a parallel goal, directly enabling key decarbonisation strategies

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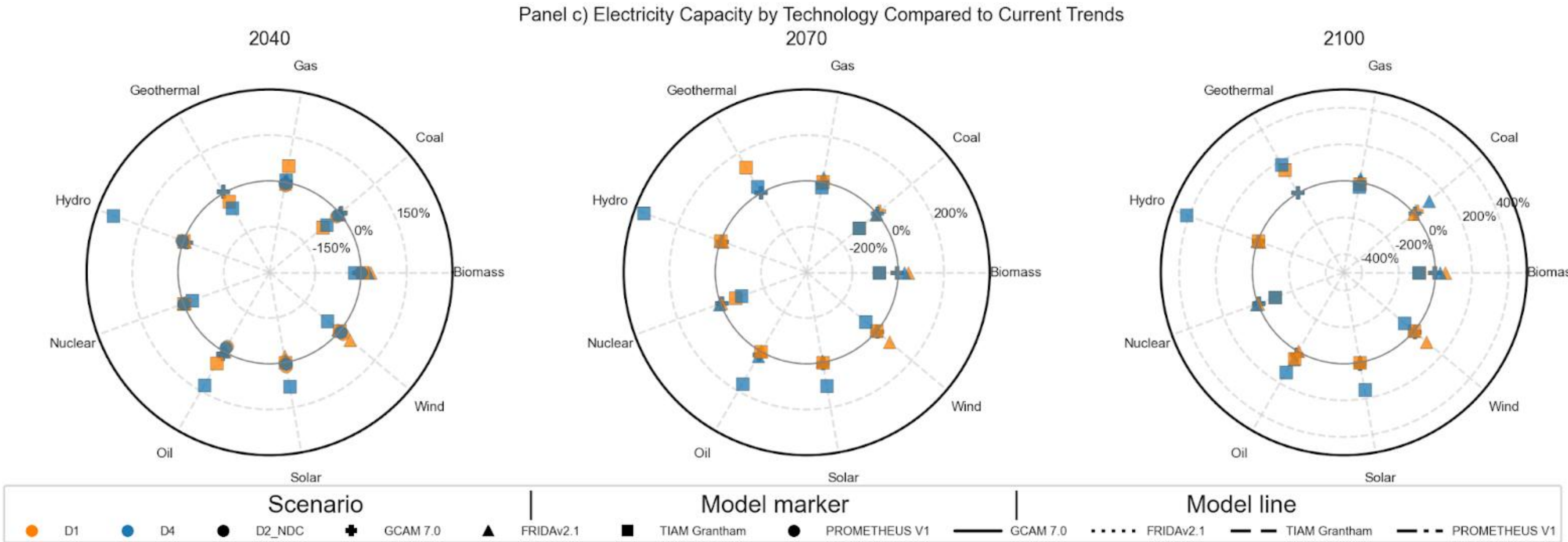
Perfect-foresight optimisation can perversely recommend heavy investment in climate-vulnerable technologies

Diversified technology portfolios enhance systemic robustness, even when appearing suboptimal from a purely deterministic, least-cost perspective



Rapid uptake of DACCS technology

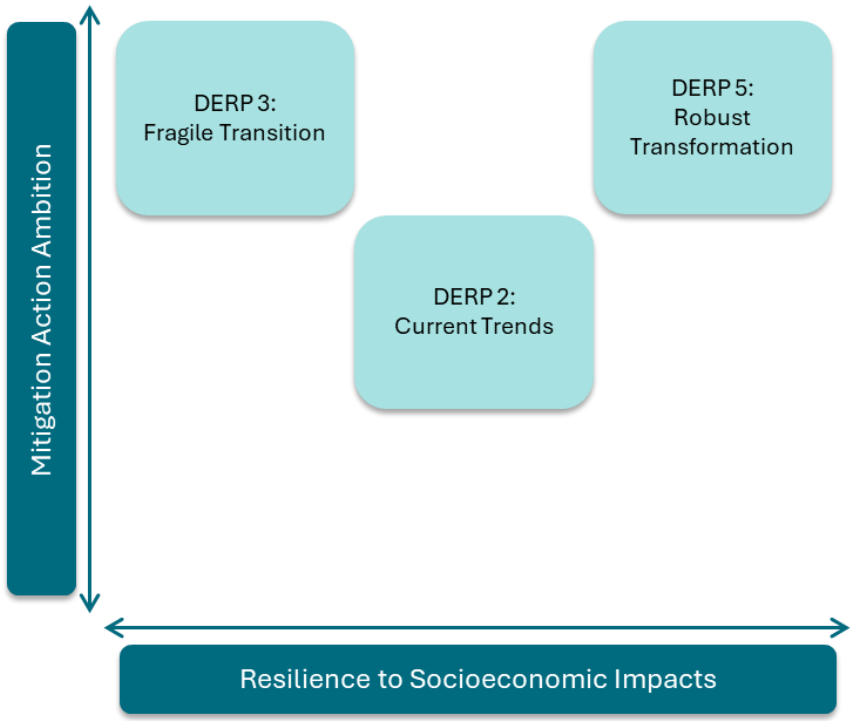
DACCS disruption on energy systems:

- Rapid cost reduction in Direct Air Carbon Capture and Storage technology
- 50% energy price shock (2040-2050) to test vulnerability of DACCS-dependent pathways
- Tests both beneficial disruption potential and moral hazard of over-reliance

Four scenarios tested:

- Current Trends with limited DACCS (DERP2),
- two Fragile Transition variants with single technology focus - gas-powered (DERP3-NG) or electric (DERP3-HP),
- and Robust Transformation with diversified deployment (DERP5)

Resilience: Diversified technology strategies reduce vulnerability to energy price shocks compared to concentrated technological lock-in approaches



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Intensifying heatwaves and droughts

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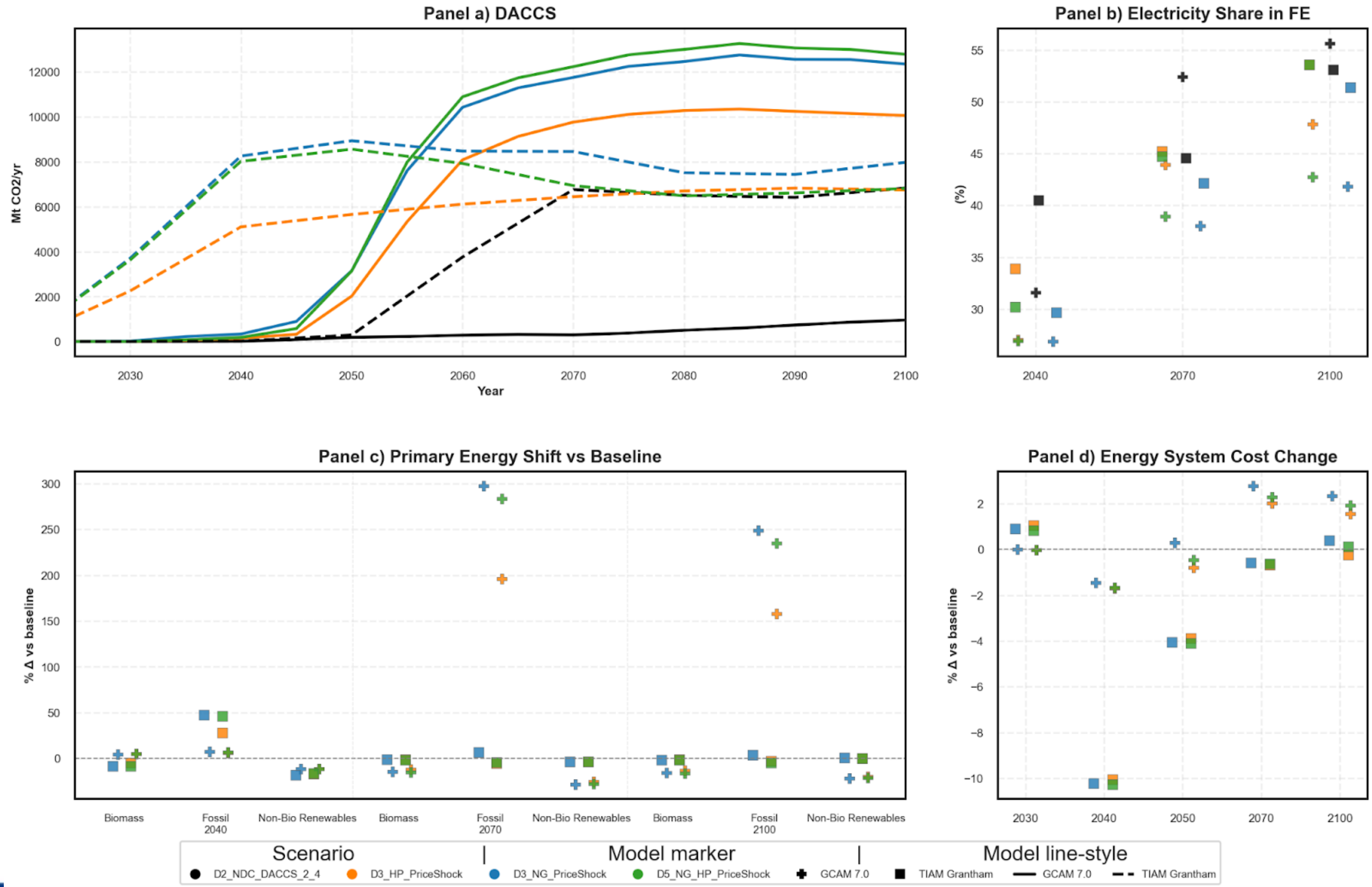
DACCS Illustrative Scenarios



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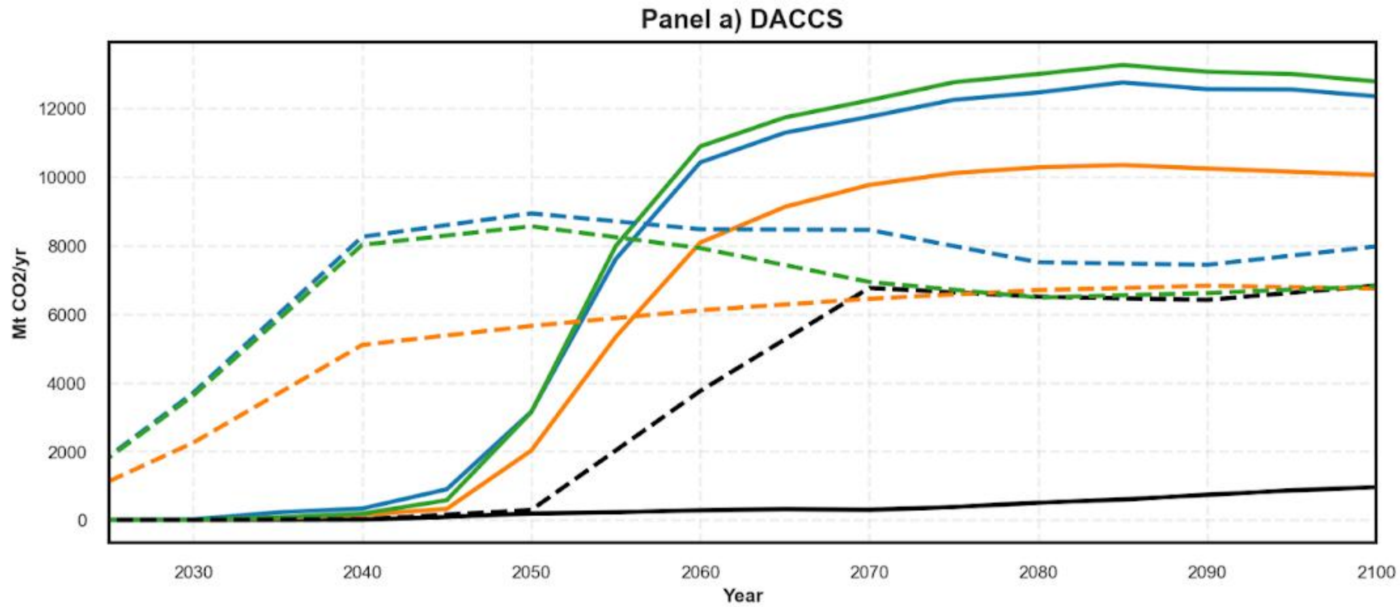
DACCS Illustrative Scenarios



Technological breakthrough triggers large-scale DACCS deployment, but models favour different strategies based on their decision-making logic

GCAM's myopic approach favours gas-dependent DACCS initially, whilst TIAM's perfect-foresight optimises for operational costs over diversification

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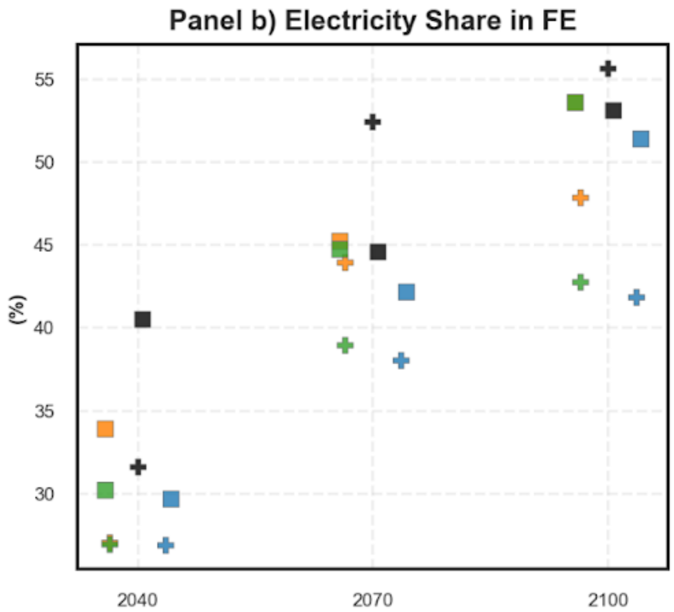
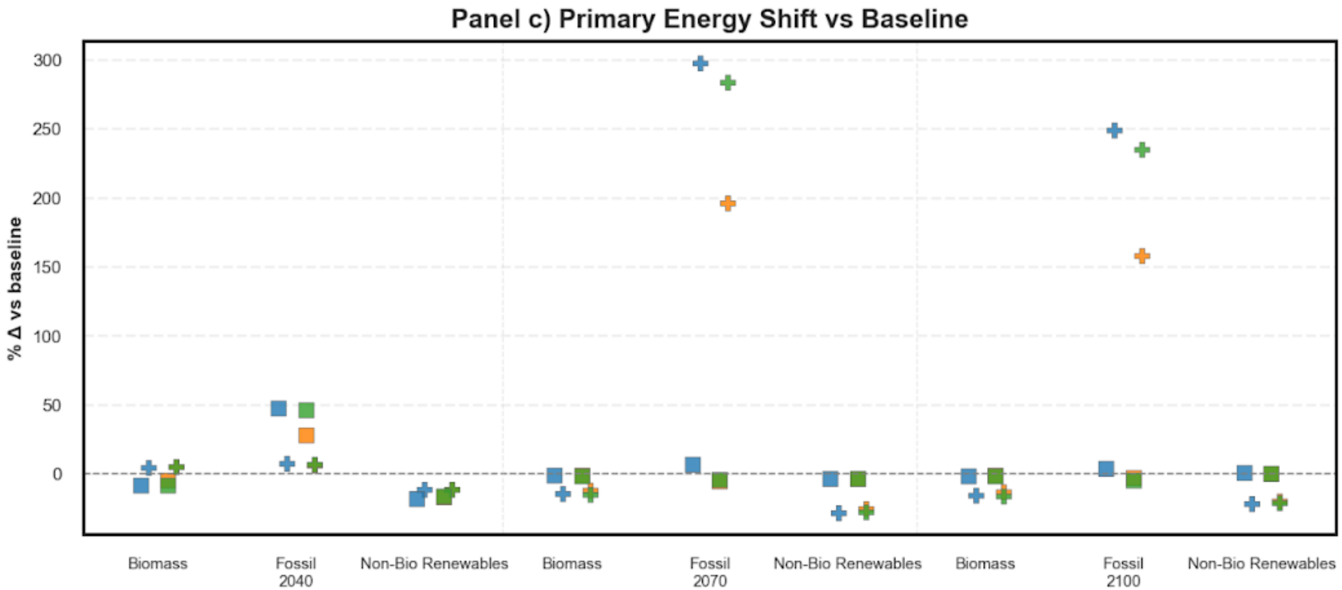
High DACCS deployment pathways reduce electrification rates compared to baseline scenarios

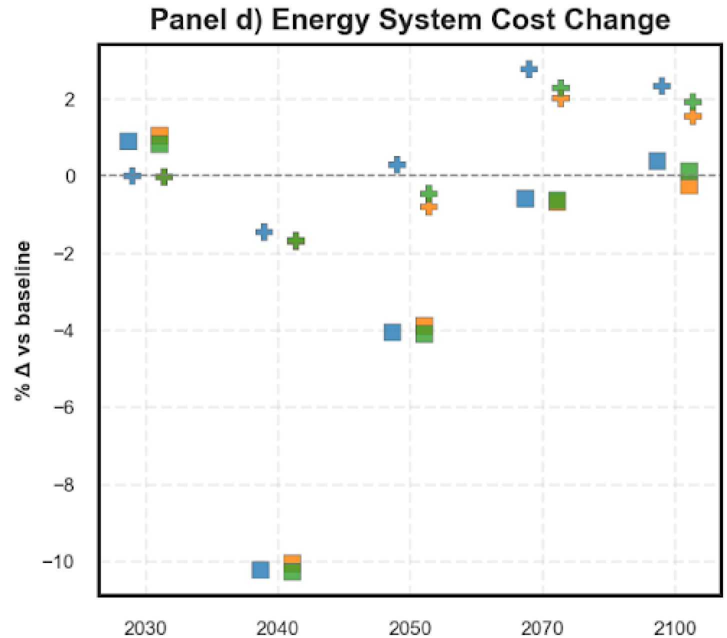
Single-technology DACCS strategies increase fossil fuel dependence relative to diversified approaches





Diversified DACCS strategies achieve systemic resilience at minimal additional cost compared to concentrated technological approaches

Diversification provides hedge against technology-specific risks for essentially no extra cost, making it the superior strategic choice



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Heatwave and Drought Scenario:

- Resilience enables capital efficiency: Low-resilience systems over-invest in gross physical capacity to compensate for poor operational effectiveness
- Resilience is a precondition for mitigation: not merely a parallel goal to effective mitigation action
- Diversified portfolios enhance systemic robustness even when appearing suboptimal from a purely deterministic, least-cost perspective

DACCS Scenario:

- Avoid technological lock-in: Myopic focus on a single technological solution can shift decarbonisation efforts away from necessary structural change
- Diversifying to achieve systemic resilience can come at little to no additional system cost
- Diversified strategies provide hedge against technology-specific risks

Overarching Finding: The most robust mitigation pathway is unlikely to be the one that appears cheapest or easiest under the assumption of a predictable future.

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Thank you!

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