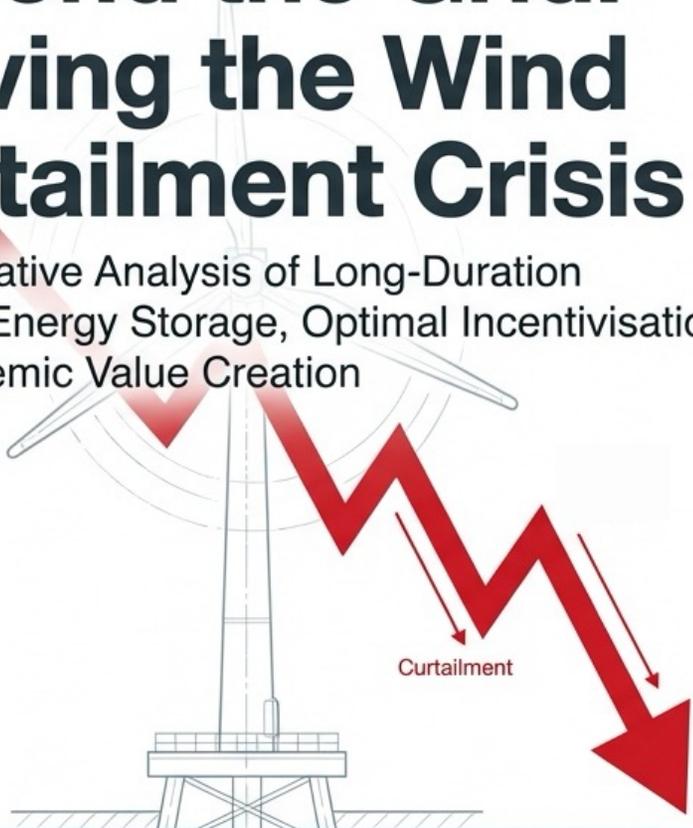
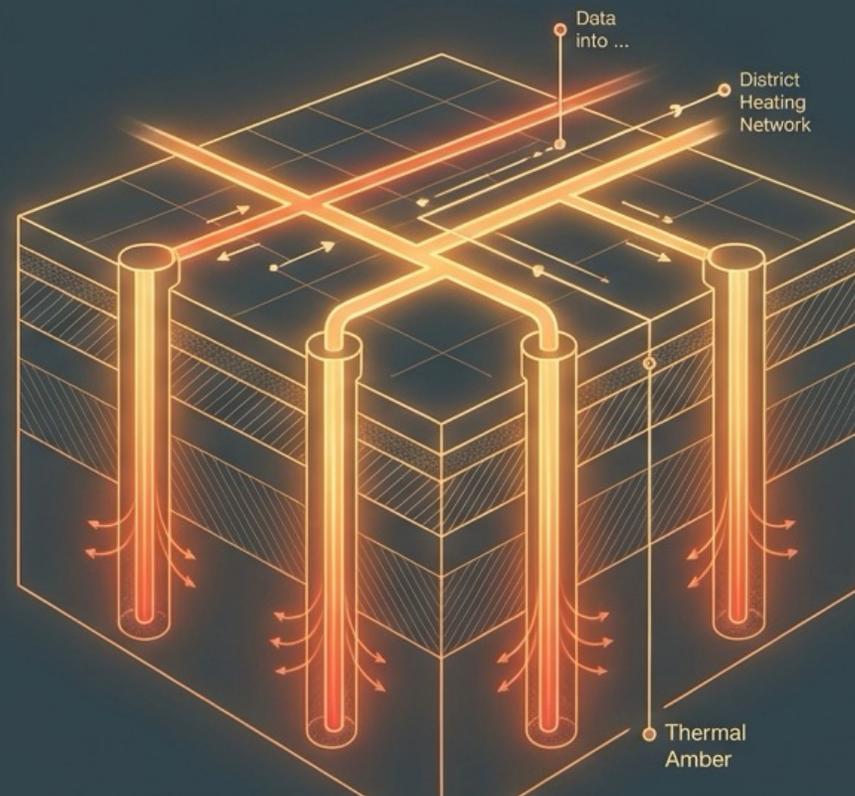


# Beyond the Grid: Solving the Wind Curtailment Crisis

A Quantitative Analysis of Long-Duration  
Thermal Energy Storage, Optimal Incentivisation,  
and Systemic Value Creation

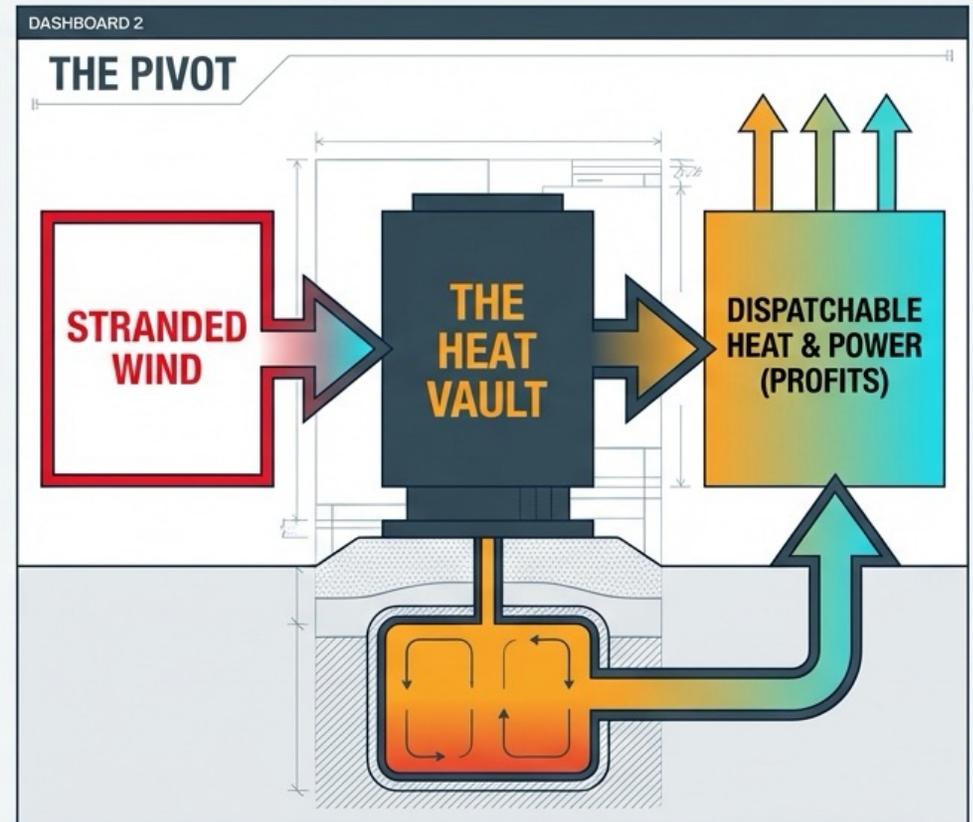
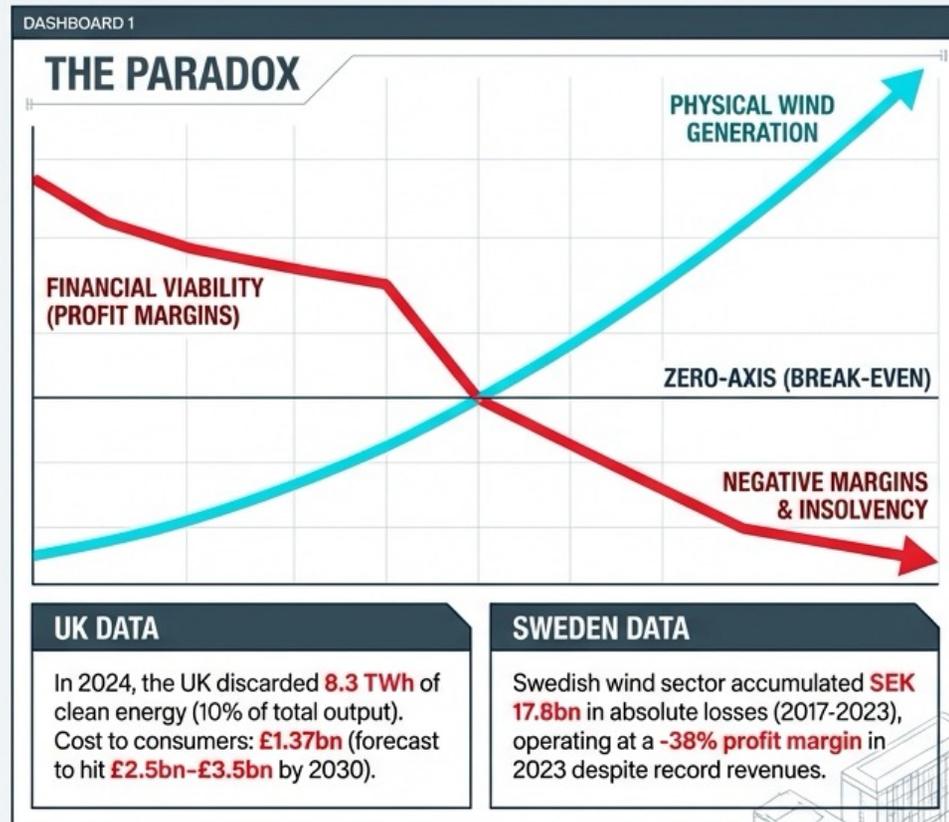


Transforming multi-billion-pound grid liabilities into profitable national assets.

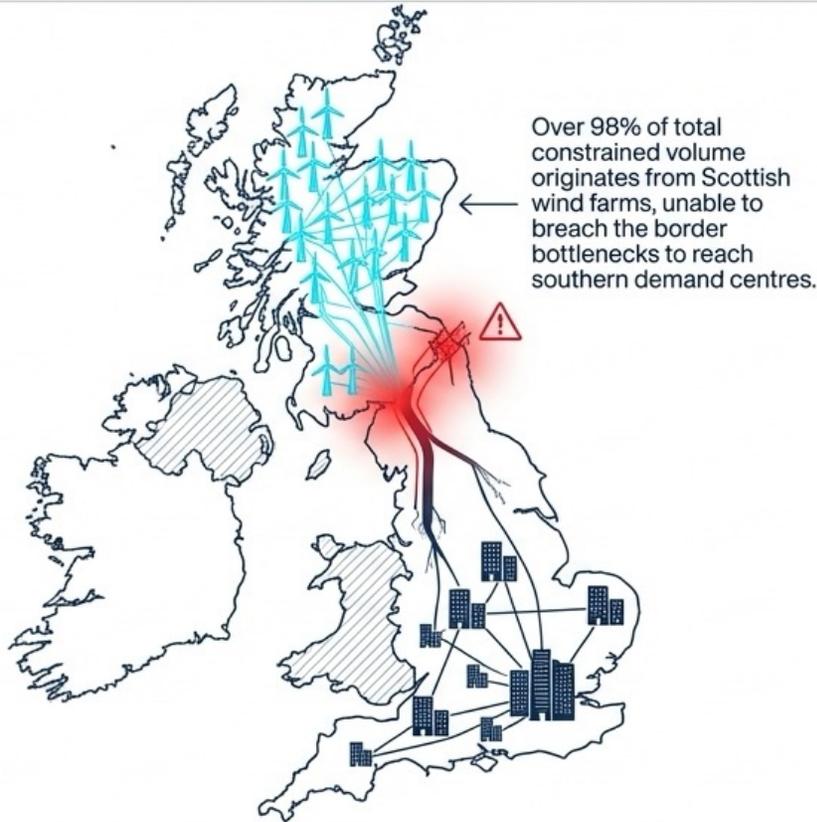


# The Wind Power Paradox: Record Expansion, Systemic Insolvency

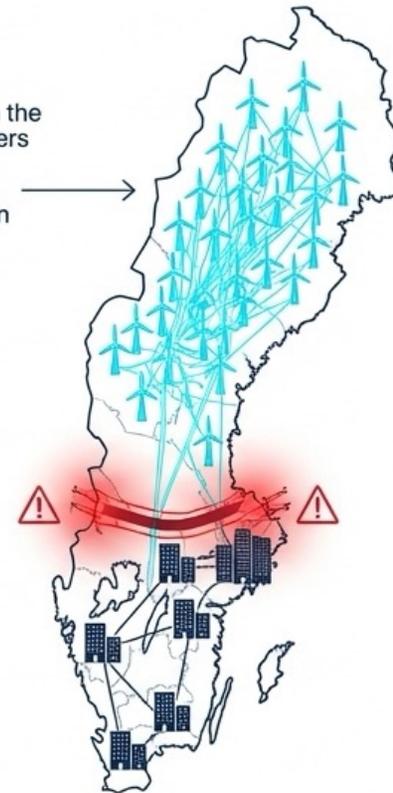
**Core Insight:** Record physical expansion has decoupled from financial viability. Every new turbine added worsens the economics for all via price cannibalisation.



# The Root Cause: A Fundamental Geographic Mismatch



Massive generation in the North (SE1/SE2) triggers negative pricing. SE2 experienced 794 negative price hours in 2024 alone.

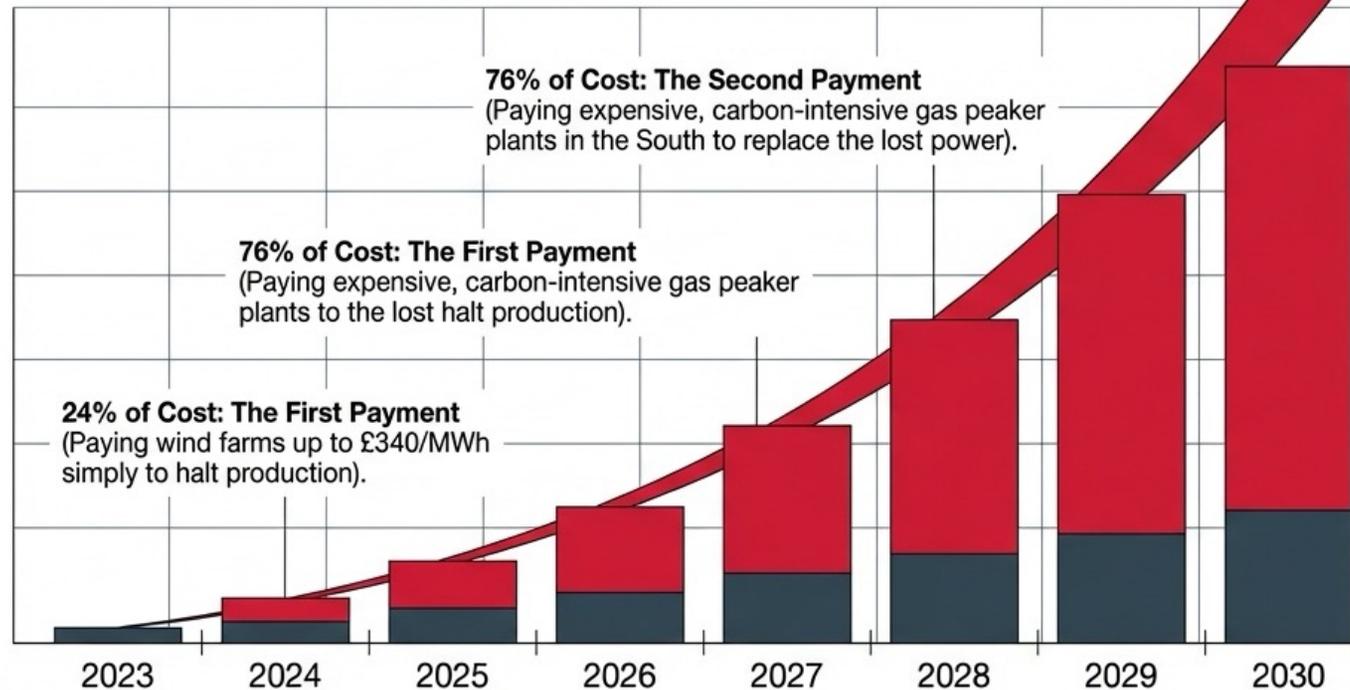


The legacy transmission network acts as a physical barrier, forcing system operators to deliberately discard clean power to prevent catastrophic blackouts.

# The Escalating Cost of Systemic Failure

NESO constraint actions reveal a perverse market distortion. Consumers pay twice: once to discard clean energy, and a larger second time to generate expensive, carbon-intensive energy to replace it.

## NESO Constraint Cost Projection



**Projected  
£2.5bn–£3.5bn  
Projected  
£2.5bn–£3.5bn  
Annual Cost  
by 2030**

**Insight:** The current mechanism financially rewards developers building in constrained locations, worsening the bottleneck.

# The 'Distress Premium' & The Myth of the Bargain Asset

**Context:** Northern Swedish wind farms are selling for "absurd" valuations of €10/MW. This is not a bargain; it is a transfer of immense operational liability.

## The OPEX Dissection

	Modern Benchmark Asset	Distressed Northern Asset (High Scenario)
<b>Turbine Degradation &amp; Component Obsolescence</b>	€16,100/MW/year	€60,000/MW/year
<b>Cold Climate Risk</b>	Modern heated blades	Up to 15% AEP loss & extreme mechanical fatigue from atmospheric icing
<b>Grid Fees &amp; Taxes</b>	Standard locational tariffs	High locational grid tariffs penalising northern assets
<b>Total Estimated OPEX</b>	~€25,000/MW/year	<b>Up to €91,000/MW/year</b>

### The Repowering Fallacy

Municipal vetoes prevent upgrading to modern turbines, "locking in" the asset's obsolescence.

Assets are not cheap; they are liabilities.

# The Structural Failure of Conventional Contracts



## Merchant Model

Fully exposed to the spot market.

**Result:** Unsustainable losses due to the explosion of negative price hours during high-generation periods.



## Volume-Based PPAs

Example: Markbygden Ett.

**Result:** "Economic suicide."

Contractual obligations force the asset to buy expensive replacement power on the spot market when production falls short.



## Locational Marginal Pricing (LMP)

Internalising the cost of transmission constraints directly into local prices.

**Result:** Formally rejected in the UK's Summer 2025 REMA update due to extreme complexity and capital flight risk.

The electricity-only business model is fundamentally broken for grid-constrained assets. Viability demands a paradigm shift.

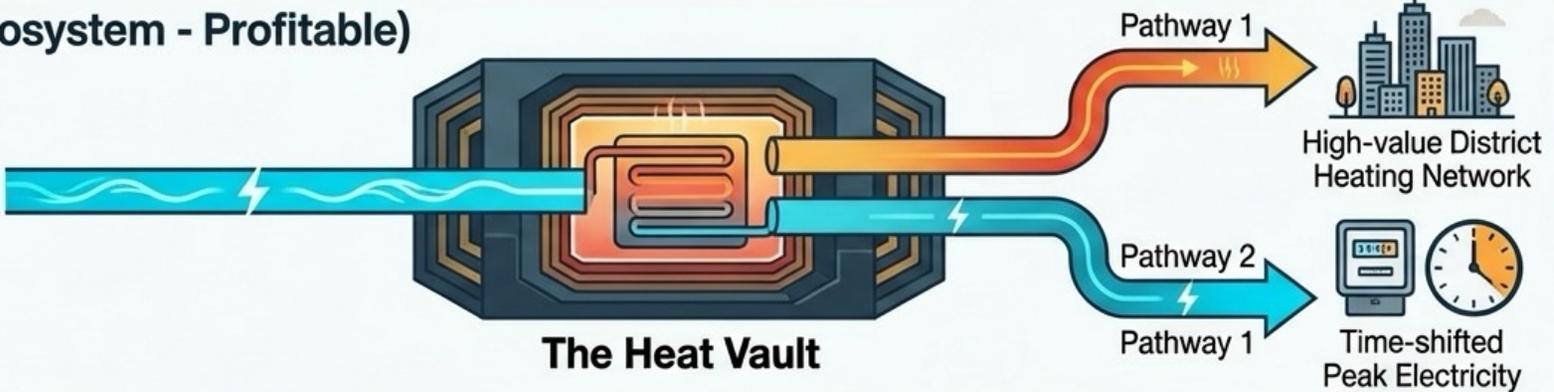
# The Paradigm Shift: Wind-to-Heat (Sector Coupling)

**Core Concept:** Decouple wind viability from the volatile power market. Convert low-value or negative-value electricity into a storable, high-value commodity (heat).

## Before (1D Grid - Failing)

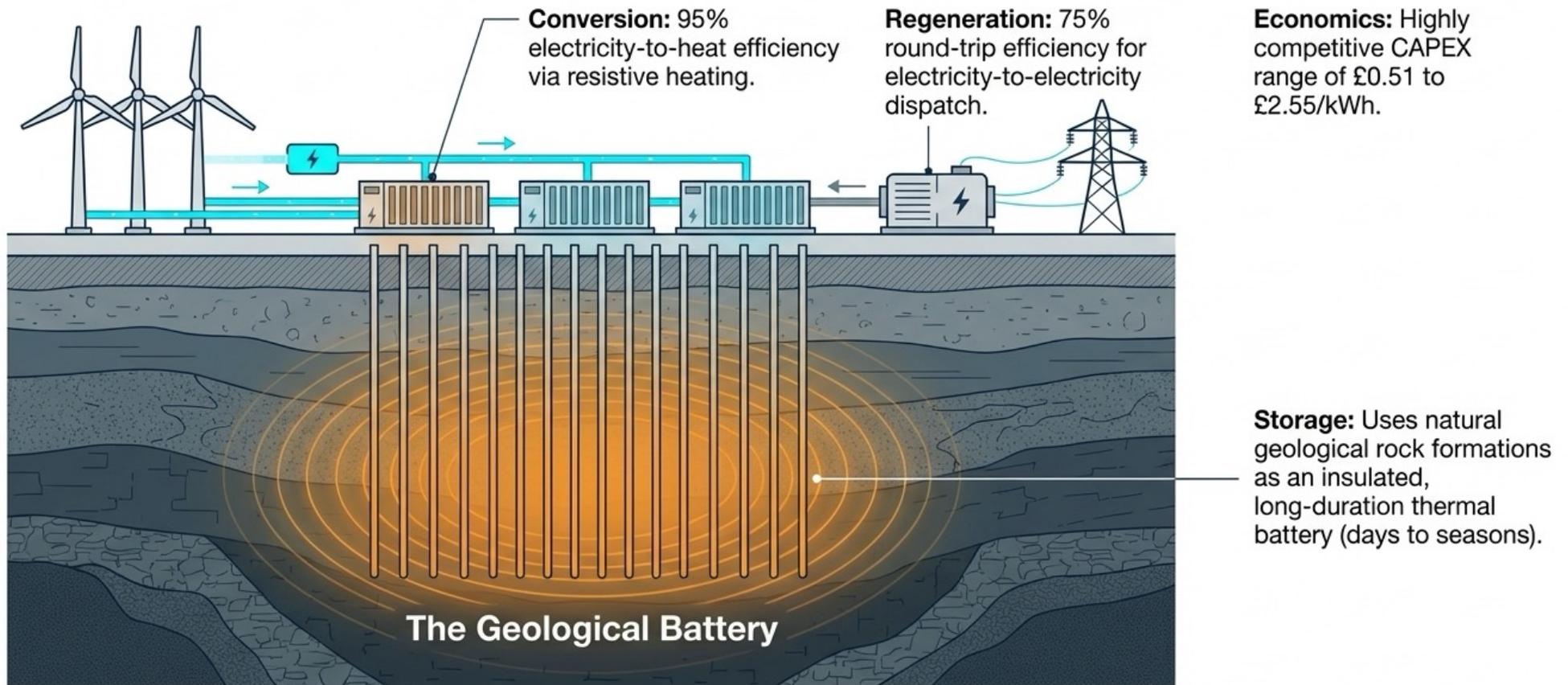


## After (2D Ecosystem - Profitable)



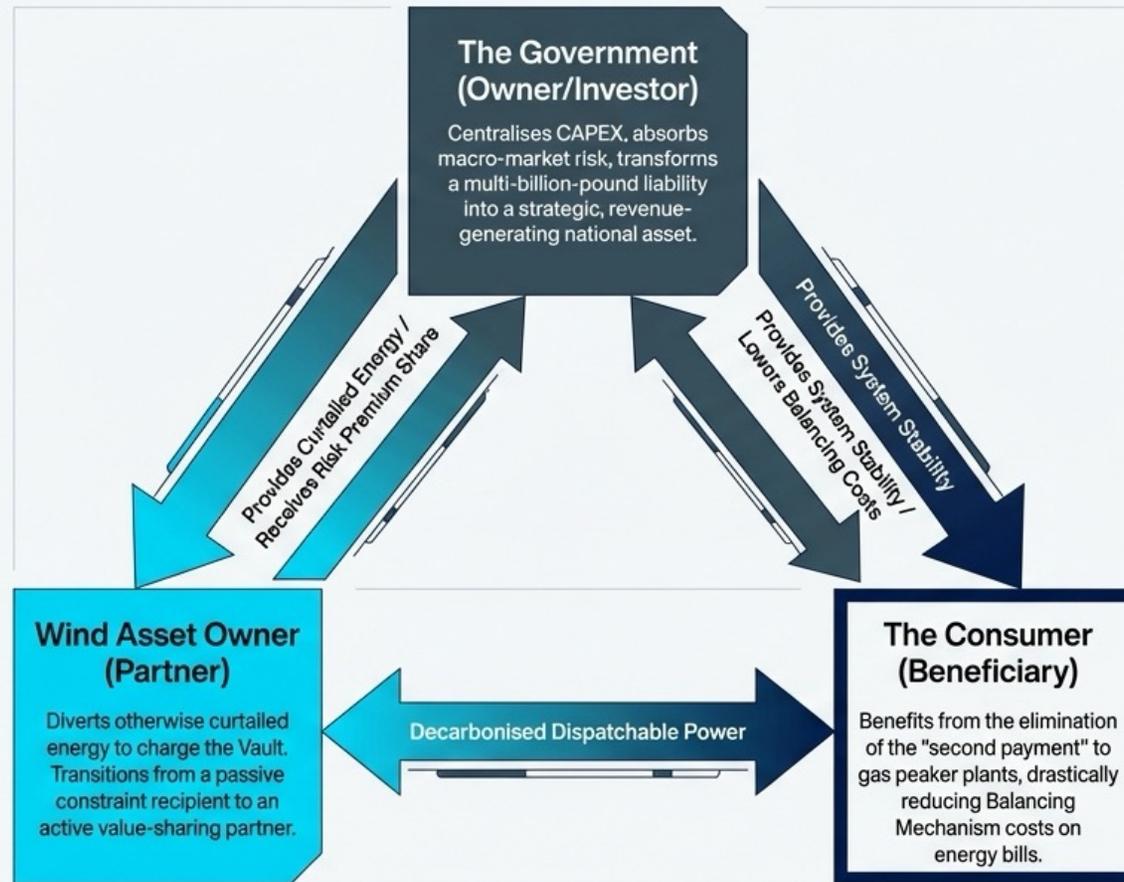
**Strategic Imperative:** Pivot from being a volatile electricity supplier suffering price cannibalisation to a reliable, baseload provider for municipal district heating and peak power markets.

# The Technology: Borehole Thermal Energy Storage (BTES)



Grounded in proven international BTES deployments, offering verifiable, quantifiable performance metrics.

# The Commercial Framework: A Public-Private Partnership (PPP)



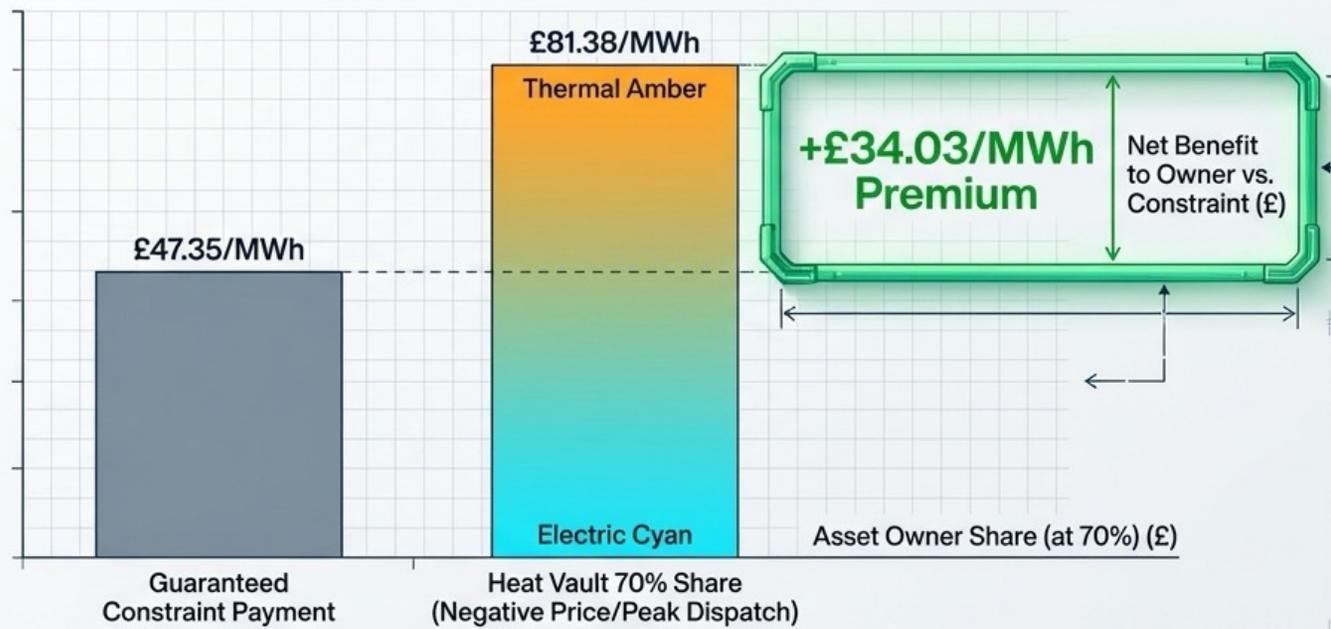
# The Economic Engine: Supercharging via Negative Pricing

## Equation

Price Condition	Input Cost/ (Gain) (£)	Dispatch Price (£)	Gross Revenue (£)	Result
<b>Normal Price</b>	Input Cost: +£85.00	+ Dispatch Price: £115.00 (Peak)	= Gross Revenue: £115.00	= Result: Modest positive spread.
<b>Zero Price</b>	Input Cost: £0.00	+ Dispatch Price: £115.00 (Peak)	= Gross Revenue: £115.00	= Result: Strong positive spread.
<b>Negative Price</b>	Input Cost (Gain): <b>(£40.00)</b> -> Asset is *paid* to charge.	→ Dispatch Price: £115.00 (Peak)	+ Gross Spread Equation: £115 (Sale) + £40 (Input Payment) = <b>£155</b> <b>Total Value Created.</b>	= Net Benefit (70% Owner Share): <b>+£34.03</b> premium over constraint.

Key Insight: In a negative pricing event, the arbitrage spread is the sum of the sale price and the payment received for charging. This dual revenue stream is the financial bedrock of the model.

# Validating the 70/30 Incentive Threshold

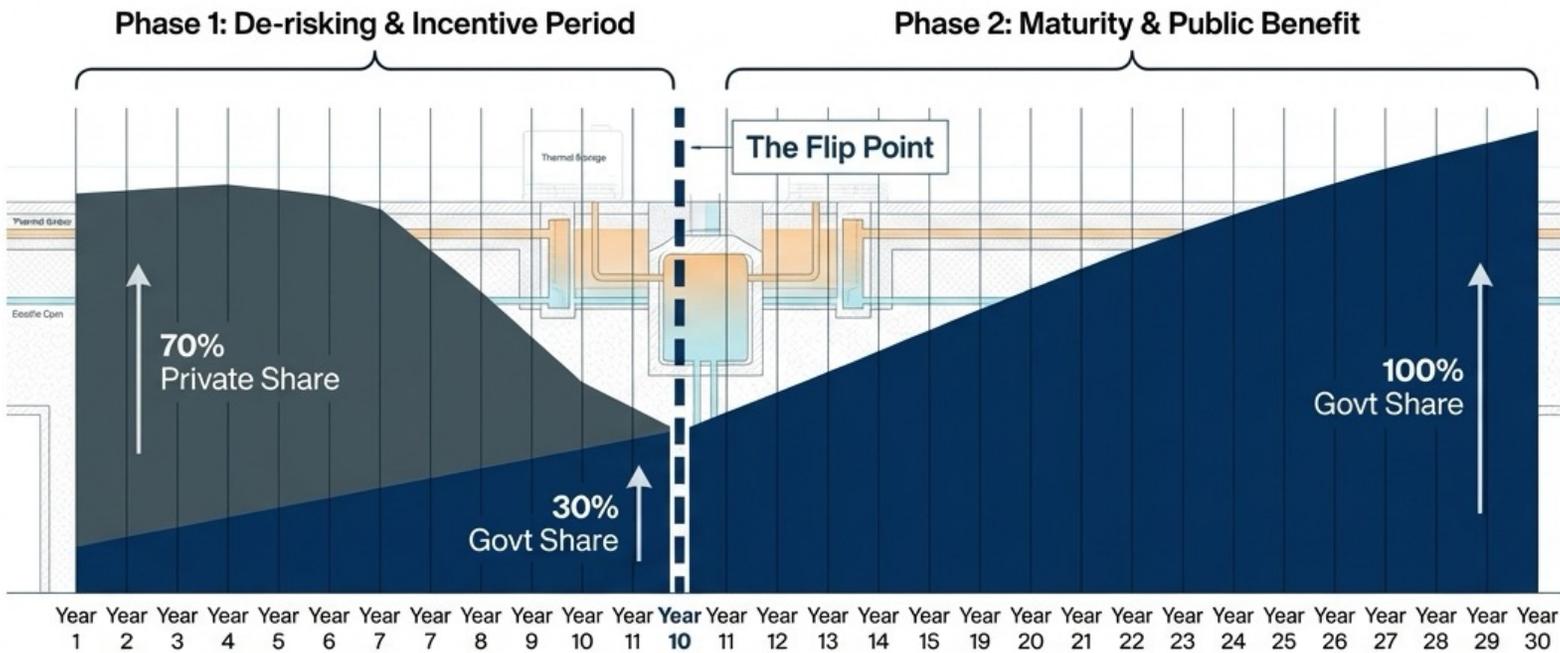


1. Data Breakdown: Under negative pricing events (dispatched at peak), the 70% net revenue share delivers a return versus the static £47.35 guaranteed constraint benchmark.

2. The Premium: This represents a compelling risk premium of +£34.03/MWh over the static £47.35 guaranteed constraint benchmark.

3. Conclusion: A 70% share is the necessary and sufficient financial incentive to drive wind asset owners to abandon passive constraint payments and accept market-dependent participation.

# The Tapered Revenue Model (The “Flip” Point)



**+150%**

This dynamic structure transforms the Vault into a permanent public asset, increasing total government revenue by +150% compared to a static 30% fixed split over the asset's lifespan.

The 30% public share services debt on CAPEX and covers the 4% annual OPEX. The 70% private share incentivises adoption.

The revenue share "flips." The government becomes the sole beneficiary.

# Synthesis: A Dual Strategic Role

## Transitional (The 2020s)

- Functions as a 'Non-Wires Alternative' (NWA).
- Hedges government infrastructure risk by mitigating the £2.5bn+ annual cost of delayed 'Great Grid Upgrades'.
- If grid upgrades are delayed, Vault profits soar as constraint values rise.

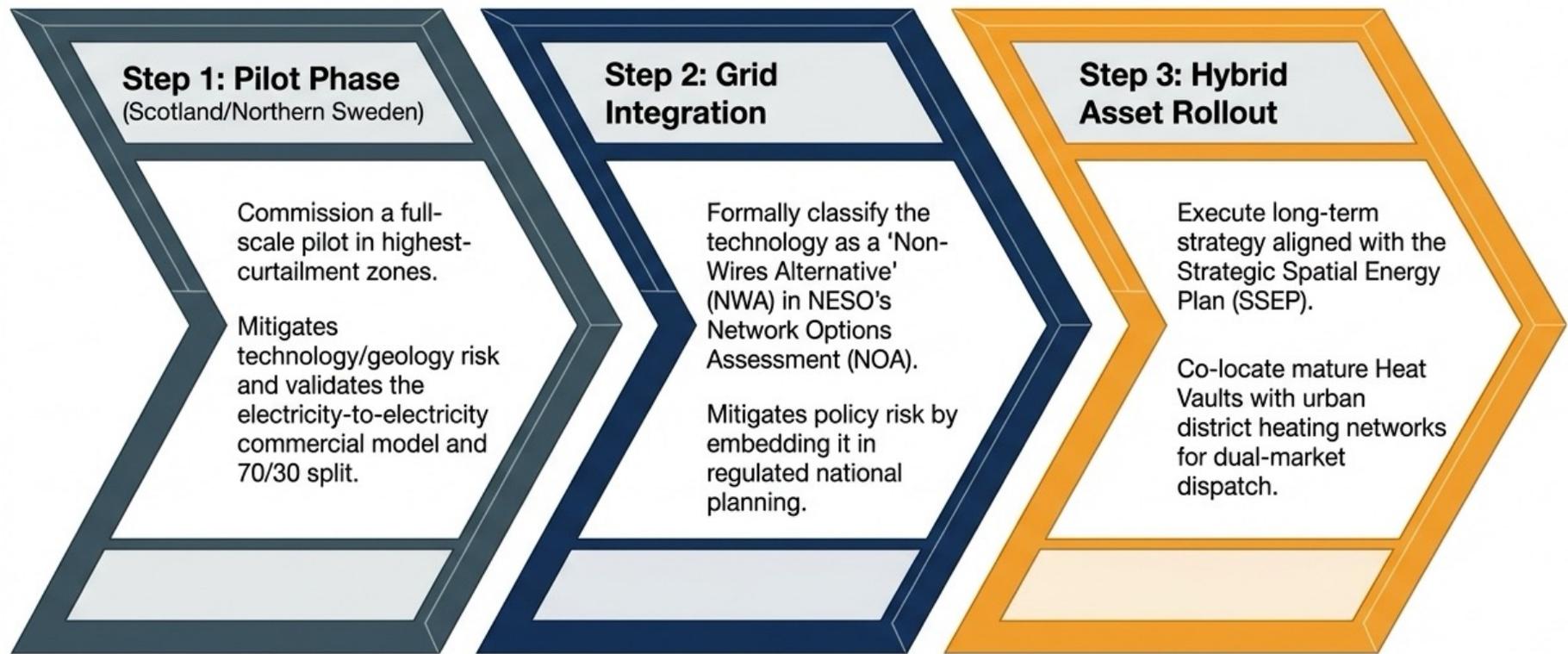


This Deep Slate is the exact same physical asset serving both sequential purposes without needing modification.

## Enduring (The 2030s+)

- Grid is upgraded; asset seamlessly transitions.
- Provides essential long-duration seasonal storage to manage intermittency.
- Acts as an anchor asset for the decarbonisation of urban district heating networks.

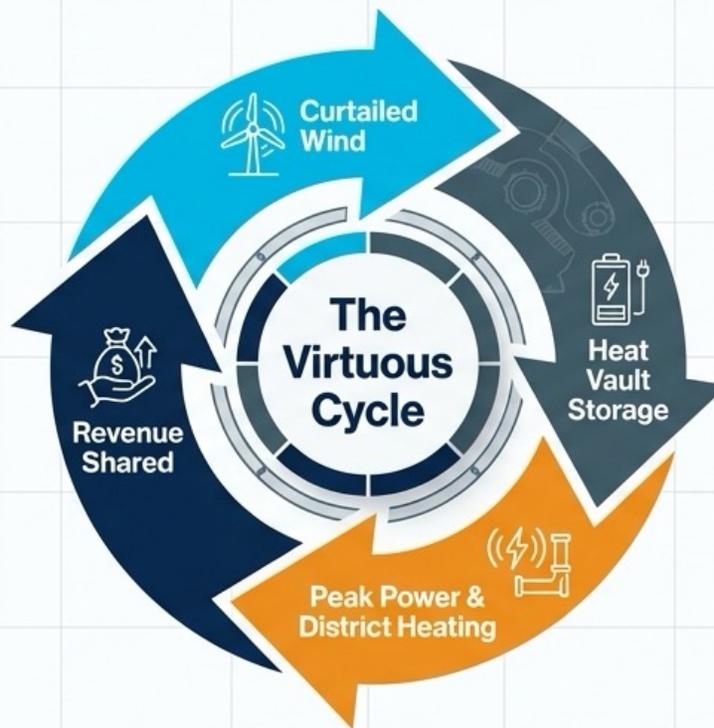
# Implementation Strategy & Risk Mitigation



# Conclusion: Redefining the Asset

## The Problem:

The electricity-only model is structurally failing under high variable renewable penetration, destroying capital and costing consumers billions.



## The Solution:

The Heat Vault PPP decouples viability from volatile power markets by converting wasted electricity into high-value, storable thermal energy.

**The Action Directive:** Commission a strategic pilot immediately in the SE1/SE2 or Scottish bottlenecks to validate the tapered commercial framework and unlock the stranded value of the grid.