Advancing Underground Hydrogen Storage (UHS): A Data-Driven Approach to Site Selection and Performance Optimisation

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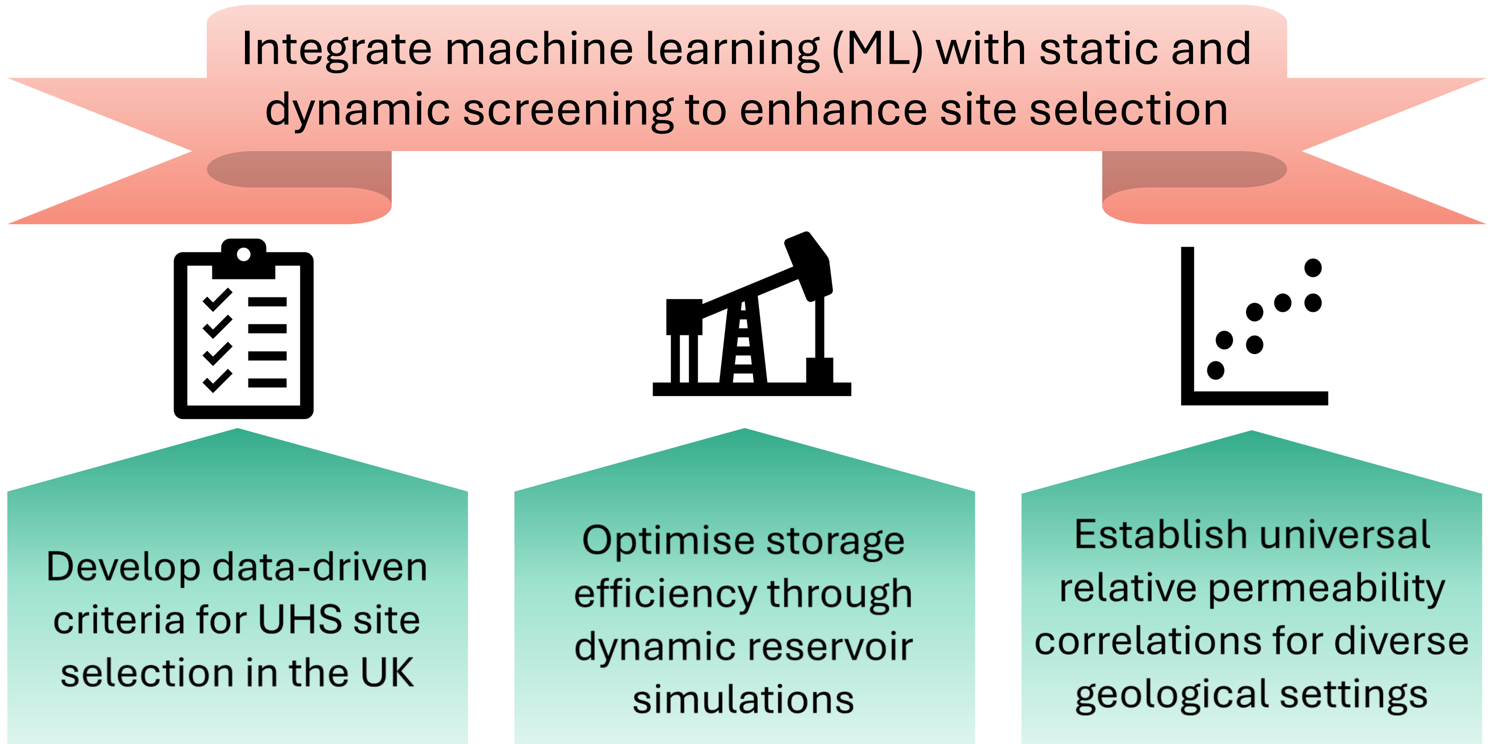
1. INTRODUCTION

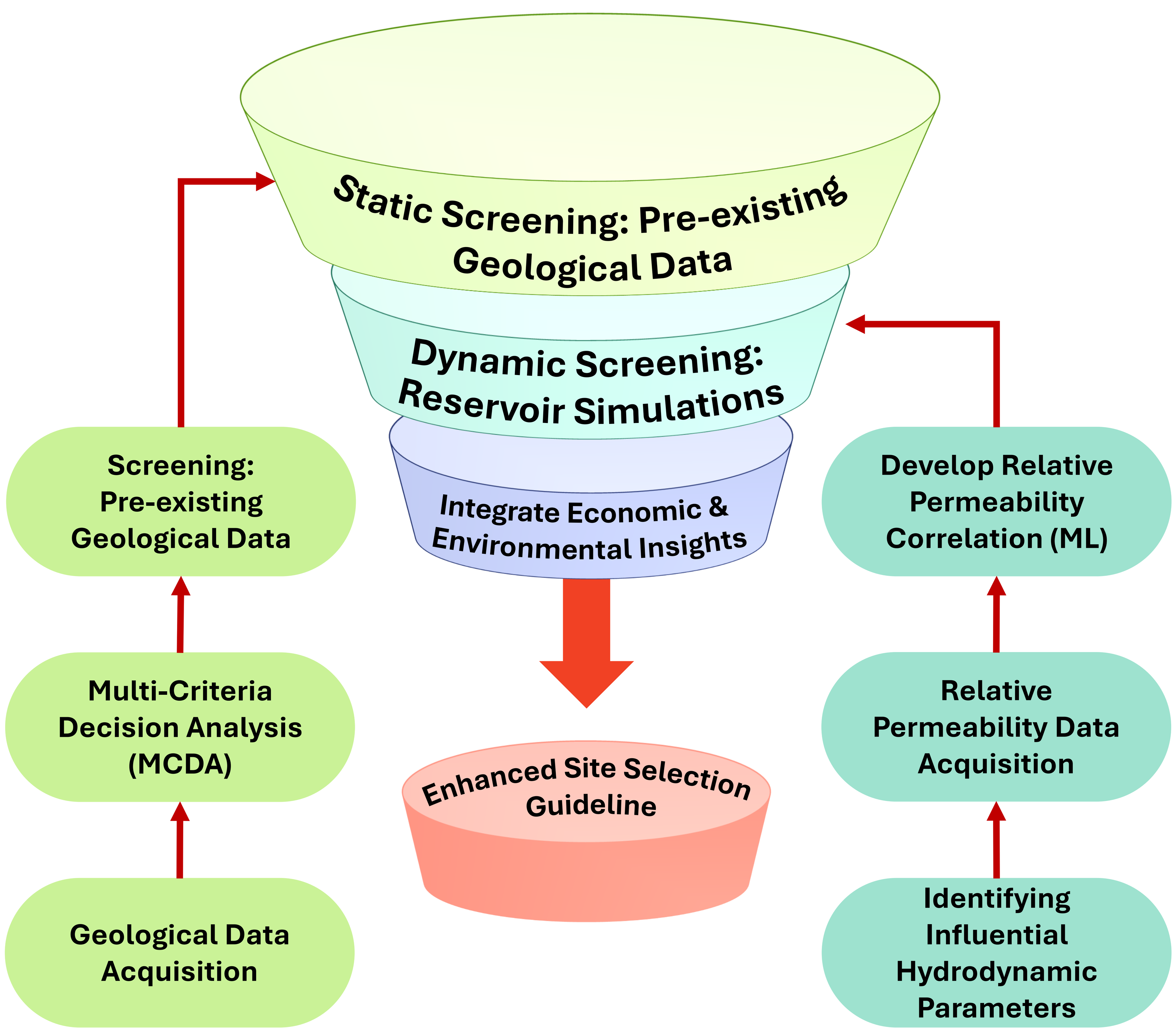
Hydrogen is poised to play a pivotal role in global decarbonisation and the UK's journey to net zero. Underground geological formations offer a promising solution to the challenges of finding a reliable storage site.

- Selecting suitable storage sites poses significant challenges due to **geological variability** and **operational uncertainties**.
- Most studies have focused on the **static properties** of geological formations, including rock porosity, permeability, and risk factors such as seismic activity.
- **Hydrodynamic parameters**—including hydrogen trapping, reservoir heterogeneity, and hysteresis in flow functions—also play a key role in determining more realistic storage capacity and efficiency.

2. PROJECT AIMS



3. METHODOLOGY



4. RESULTS

4.1 Impact of Hydrogen Trapping

Gas bubbles are expelled or "snapped off" from a liquid-filled pore throat in porous media when the wetting liquid phase builds up and meets at the throat, leading to an unstable interface that breaks the gas bubble apart (Figure 1).

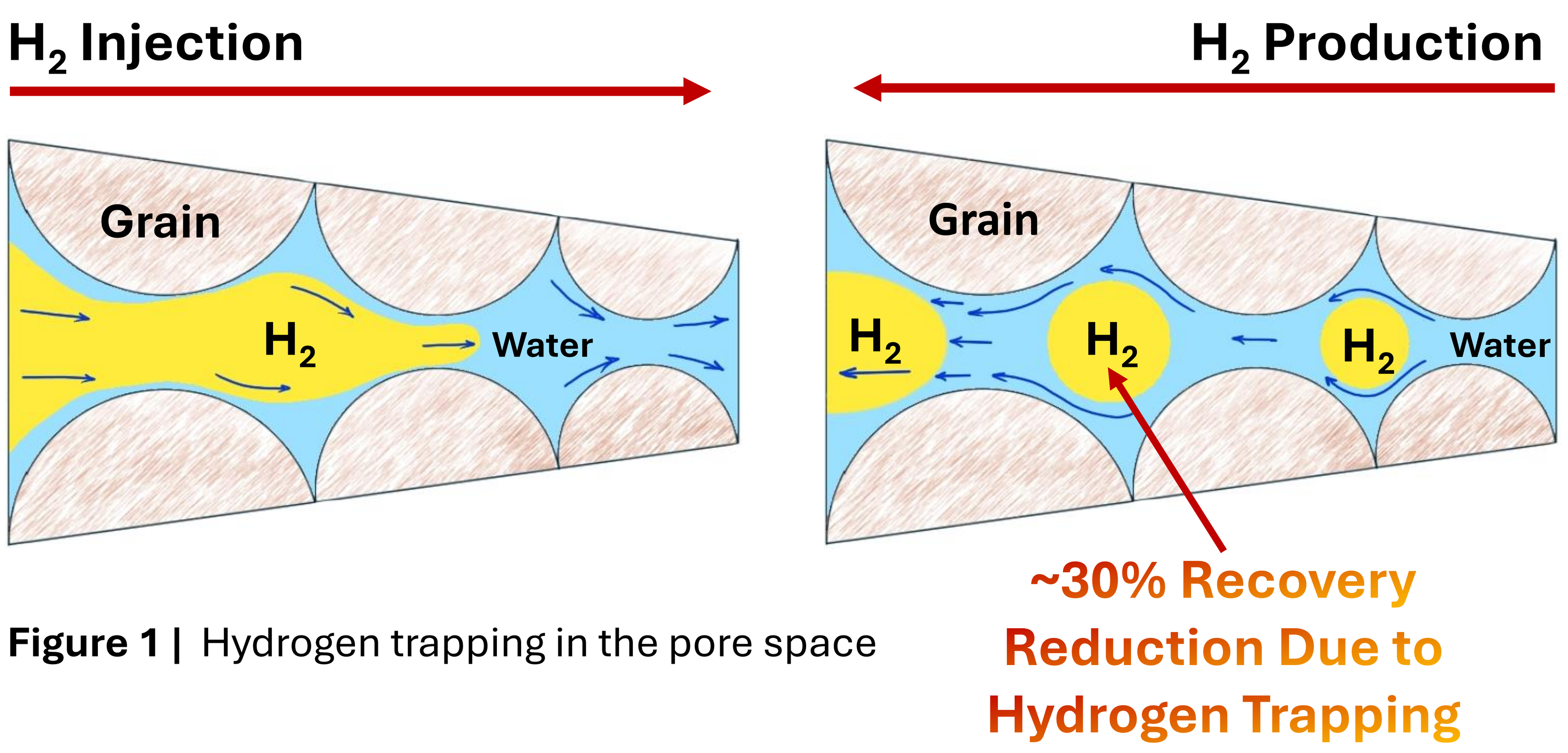


Figure 1 | Hydrogen trapping in the pore space

4.2 Various Porous Media

Permeability heterogeneity and spatial continuity significantly impact hydrogen storage (Figure 2). Flow-aligned anisotropy (0°) results in low recovery and high water-cuts, while perpendicular anisotropy (90°) improves recovery but risks pressure-related damage. In contrast, omni-directional and 45° models offer balanced outcomes.

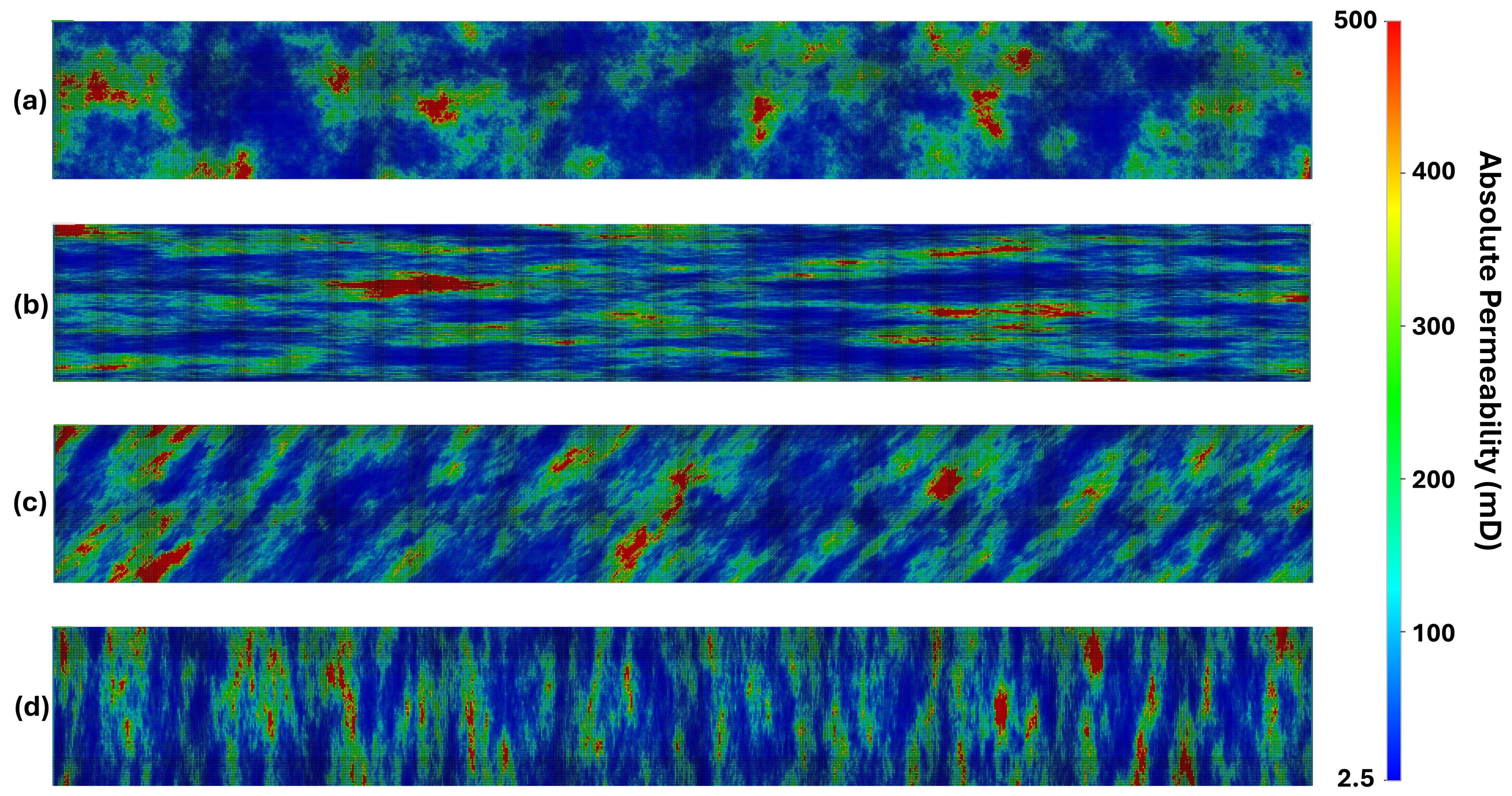


Figure 2 | Absolute permeability map generated by the SGS simulation method. a) Omni-Directional continuity, b) Bi-Directional continuity with an angle of 0 degrees, c) Bi-Directional continuity with an angle of 45 degrees, d) Bi-Directional continuity with an angle of 90 degrees.

4.3 Hydrogen Storage Performance Optimisation

Optimal rate of 4.15 m^3 /day for Omni-Directional, 5.55 m^3 /day for 0° Bi-Directional, 4.25 m^3 /day for 45 ° Bi-Directional, 3.29 m^3/day for 90 ° Bi-Directional (Figure 3).

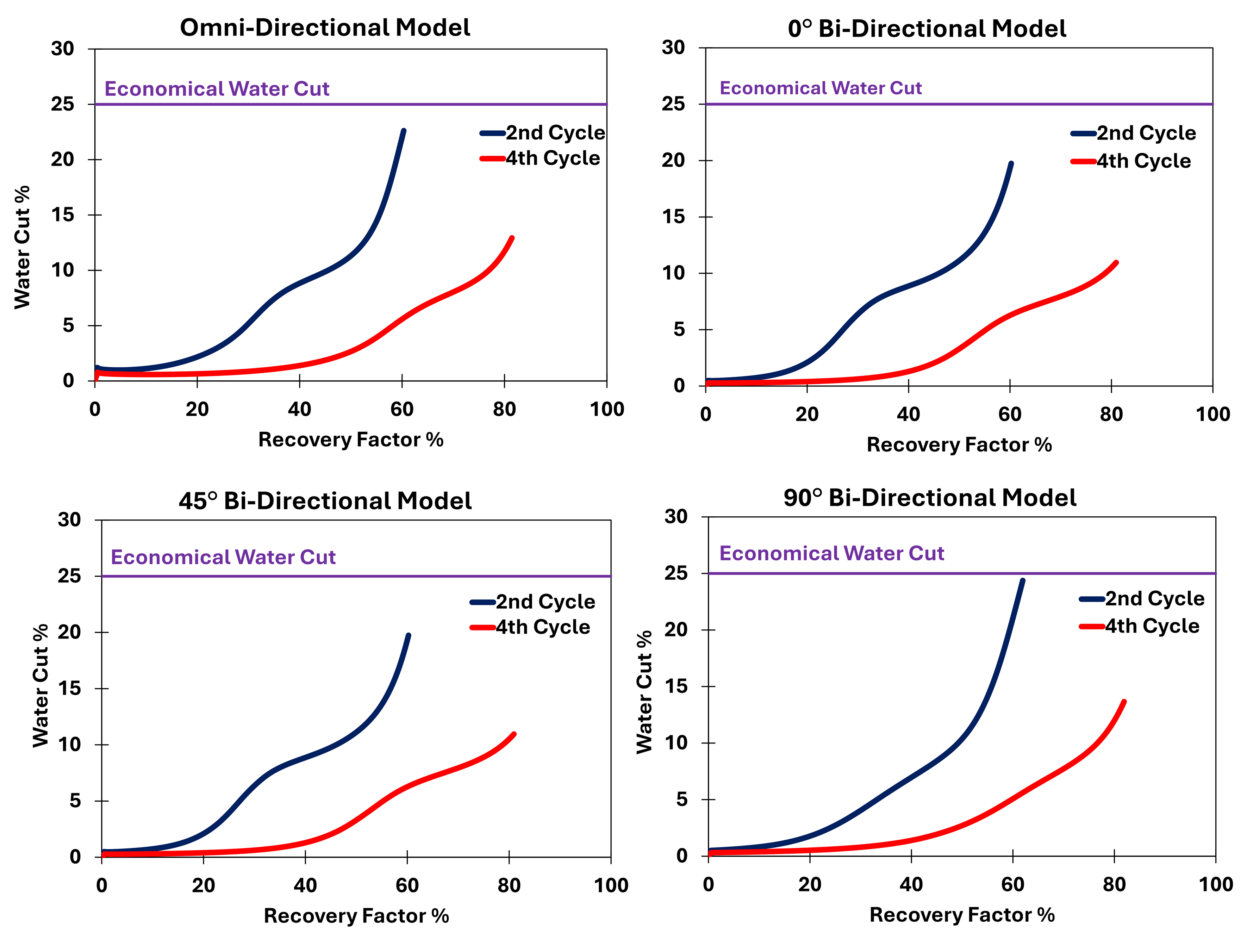


Figure 3 | Water cut (ratio of water to gas) vs recovery factor comparison in the heterogeneous systems under optimised gas flow rate during two stages of the production cycle (2nd and 4th)

5. CONCLUSIONS

- **Reservoir Characterisation is Critical:** A comprehensive analysis of hysteresis effects and permeability heterogeneity is essential. Permeability anisotropy (e.g., 0° vs. 90° flow alignment) demands customised strategies to harmonise recovery, pressure control, and reservoir integrity.
- **Tailored Operational Strategies:** Adjusting injection/production rates based on reservoir heterogeneity balances recovery efficiency (e.g., 25% water cut limits) with geomechanical stability (e.g., pressure thresholds < 20,000 kPa).
- **Mitigate Water Management Challenges:** Adaptive strategies are vital to minimise water influx and maximise economic viability in heterogeneous systems.

References

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