

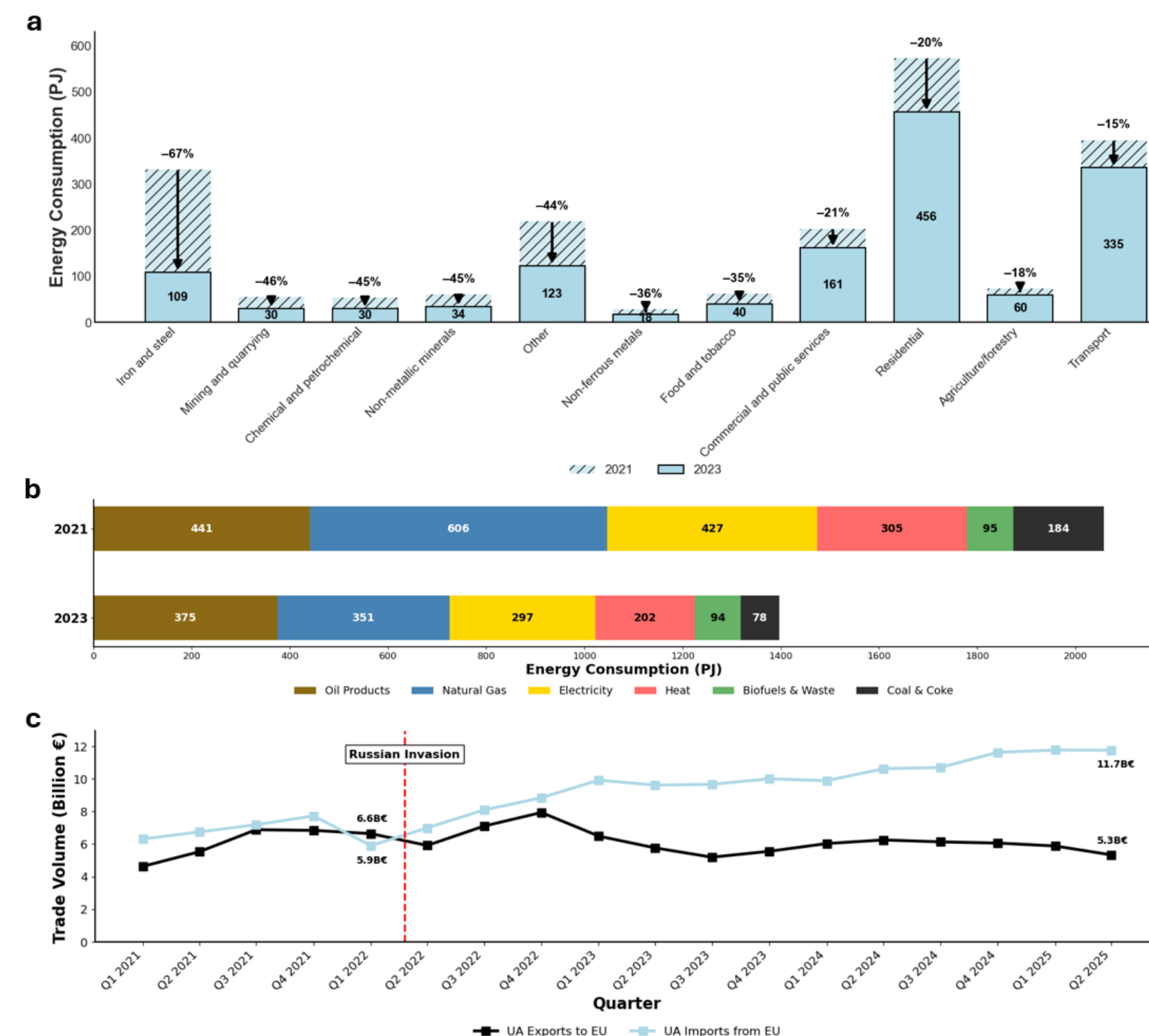
## Reconstructing Ukraine's Energy System for Net-Zero: Short-Term Recovery, Long-Term Decarbonisation Pathways, and Green Export Opportunities

Lukas Schirren, Borys Dodonov, Stephanie Hirmer, Ebbe Kyhl Gøtske, Jim Watson, Yaroslav Melekh, Miguel Sanchez Lopez, Adam Hawkes

### Background

Ukraine's energy system has become both a battlefield target and a cornerstone of its long-term economic future. Russian attacks have destroyed or severely damaged large shares of thermal power capacity and critical grid infrastructure, forcing the country to manage rolling blackouts while planning for reconstruction under persistent security risks. The iron, steel, and chemical industries have been hit hardest. Rebuilding the energy sector cannot simply mean replacing lost capacity. It must simultaneously restore reliability, enable deep decarbonisation, and position Ukraine within emerging European green value chains. Near-term reconstruction choices will lock in infrastructure and emissions trajectories for decades. Long-term fuel prices, technology costs, capital availability, and EU climate policy will in turn shape the competitiveness of Ukrainian exports such as green steel, ammonia, and hydrogen.

This destruction creates an unusual opportunity. Ukraine's zero-carbon electricity mix, vast renewable potential, and large high-grade iron ore reserves make it well-placed to develop low-carbon industrial exports. Understanding how short-term reconstruction choices interact with long-term decarbonisation pathways and green export opportunities is therefore central to designing a resilient, EU-aligned recovery strategy.

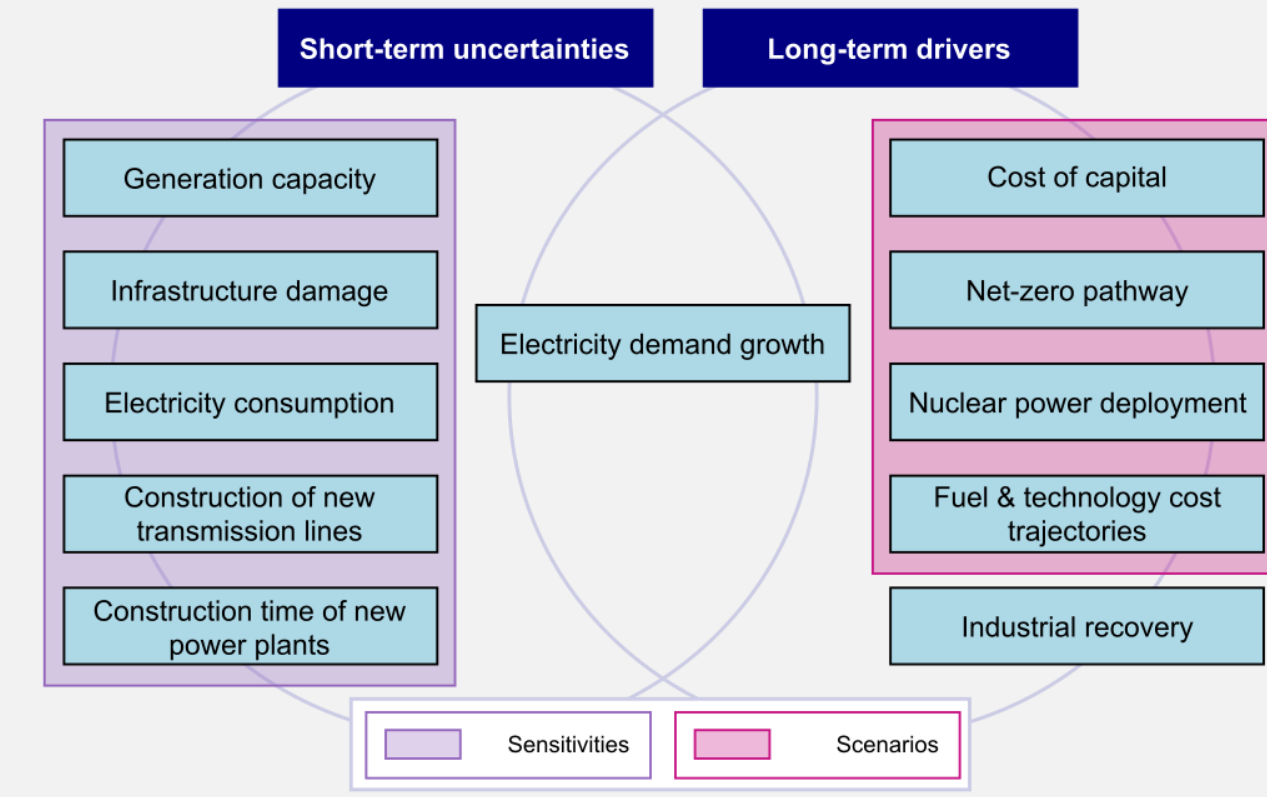


**Fig. 1 | Impact of the Russian invasion on Ukraine's trade with the EU and its energy sector.** a, Percentage reduction in energy consumption by sector before (2021) and during (2023) the war. b, Reduction by energy carrier. c, Change in Ukraine's exports to and imports from the EU. (a and b are based on the IEA energy balance for Ukraine from 2023. c is based on trade data from the European Commission.)

### Methods

This study employs a complementary short-term and long-term energy system analysis, reflecting the distinct uncertainties and drivers shaping post-war recovery versus net-zero transition. The short-term centres on the speed of building new electricity generation, while the long-term centres on export opportunities.

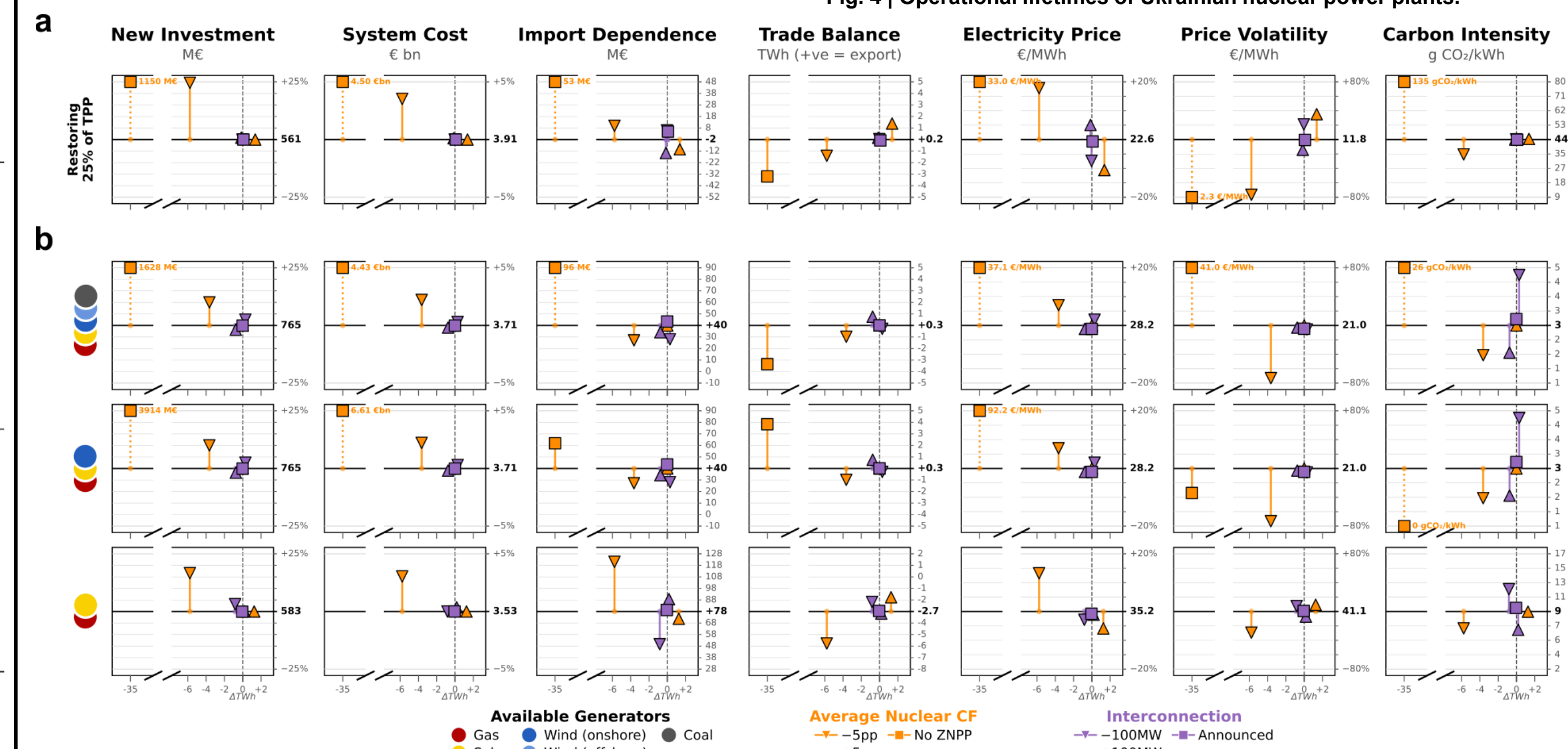
The analysis uses PyPSA-Eur, an open-source, sector-coupled European energy system model covering 33 countries at 50 nodes, with 3-hourly temporal resolution. The model was extended to represent Ukraine across 8 regions with energy sectors using the 2023 energy balance.



**Fig. 2 | Short-term uncertainties and long-term drivers with overlapping categories.** Illustrates the key short-term uncertainties, and the long-term drivers embedded in the scenarios.

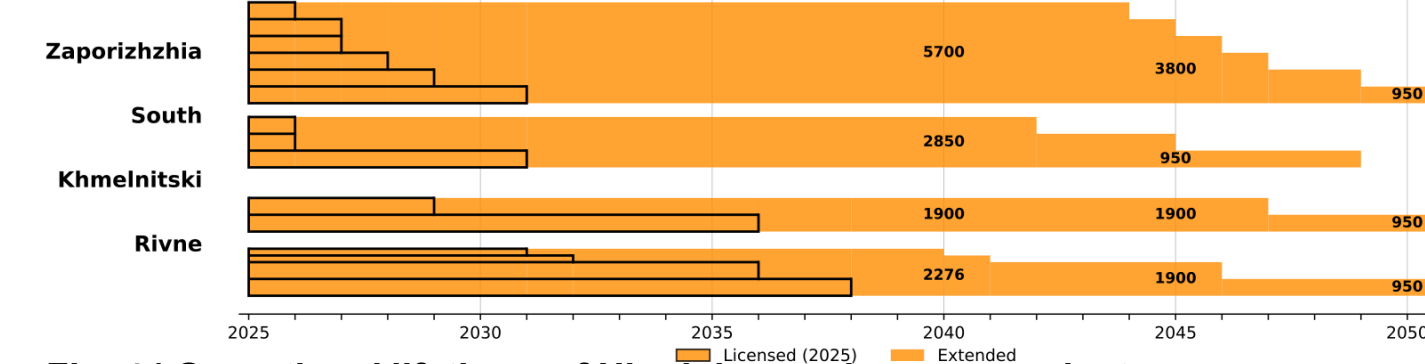
### Short-Term

Construction times are simulated by adding technologies over time: solar can be deployed within a year, while wind take longer, etc. Deep uncertainty over fossil fuel asset status motivates two bounding cases: restoring 25% of pre-war thermal capacity and a system retaining only hydro, nuclear, and newly built capacity. Ukraine has two main levers in the short-term: increasing nuclear generation and cross-border interconnection capacity.



**Fig. 3 | Sensitivity of power system indicators to key post-war levers.** Seven system-level indicators (columns) are evaluated under two infrastructure assumptions. a, Damaged thermal power plants (TPP) are partially restored to 25% of its pre-war capacity. b, No restoration of damaged thermal capacity; only nuclear, hydro, and newly built capacity. Sensitivities are computed with respect to two principal levers: increasing the average nuclear capacity factor and extending cross-border interconnection capacity. The horizontal position of each dumbbell indicates the change on production ( $\Delta TWh$ ) produced by the lever, while its vertical extent shows the resulting change relative to the baseline of that scenario. Coloured circles denote the generation technologies available in each recovery year.

**In the transition, while coal is economical in the short-term, it does not align with the long-term transition. Independently, the long-term is dominated by the decommissioning of nuclear powerplants.**



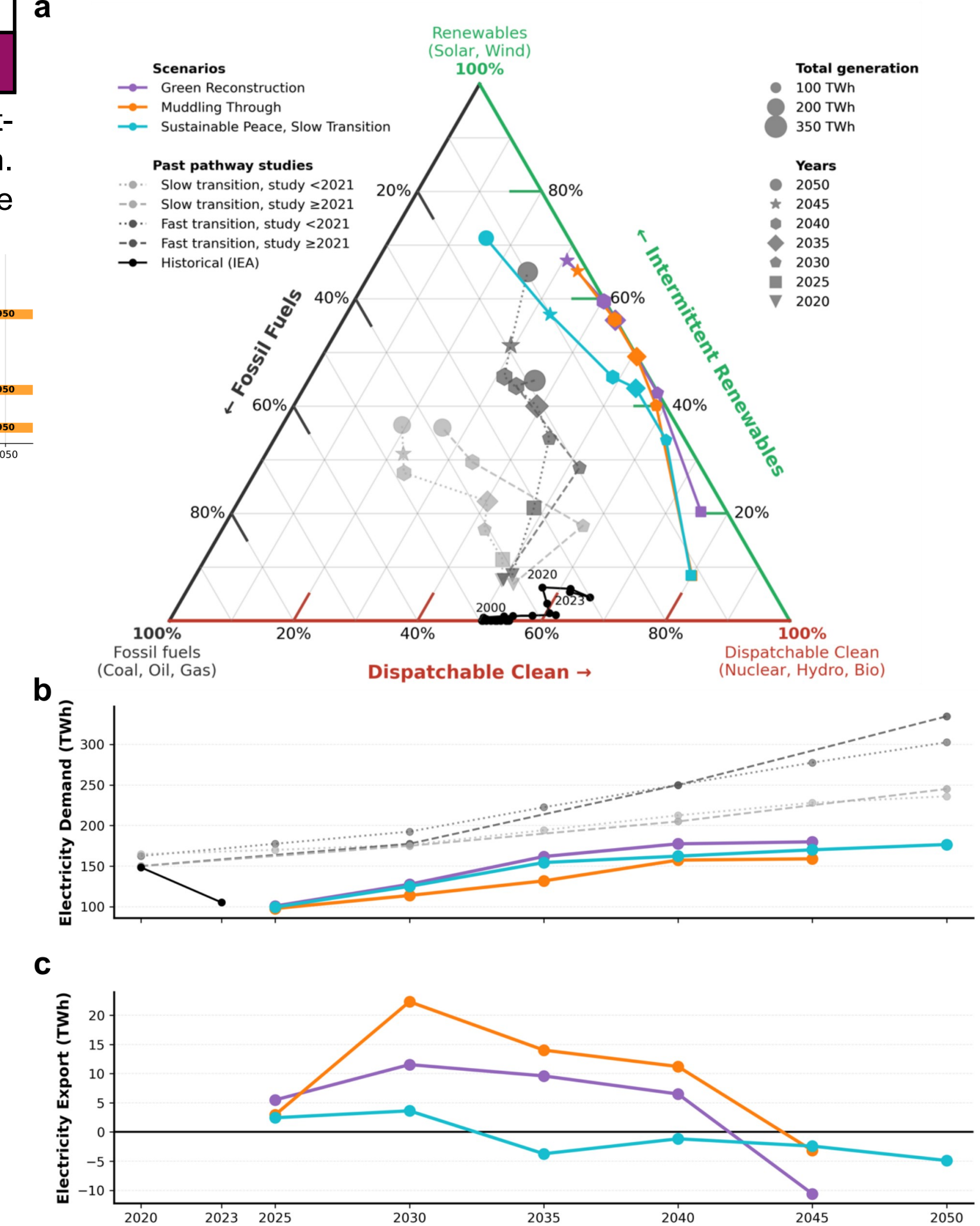
**Fig. 4 | Operational lifetimes of Ukrainian nuclear power plants.**

### Long-Term

Three scenarios spanning 2025–2050 capture alternative futures: **Green Reconstruction** envisions a durable peace with green-led recovery at its core. Ukraine integrates into the EU Single Market by 2030, unlocking export opportunities for low-carbon electricity, and steel. Cost of capital is lowest (8.9%).

**Sustainable Peace, Slow Transition** assumes lasting peace but a fossil-led rebuild, with nuclear as the backbone of the electricity sector and limited renewable deployment. Cost of capital is moderate (12.3%).

**Muddling Through** describes a fragile peace with persistent security risks. Despite difficult conditions, high fossil fuel prices make green hydrogen increasingly cost-competitive. Cost of capital is highest (16.8%).



**Fig. 5 | Modelled scenario pathways for Ukrainian electricity mix and demand to 2050.** a, Ternary diagram showing shares of total electricity generation among fossil fuels (bottom-left corner, left leg), variable renewables (top corner, right leg), and dispatchable clean firm sources (bottom-right corner, base); direction of ticks shows how to read each axis. Past pathway studies are averaged. b, Ukrainian electricity demand in TWh evolution to 2050. c, Net electricity export in TWh for Ukraine (negative values indicate import reliance).