⚡ Nuclear Fleet Retirement Analysis & Energy Security Implications

Project Summary:
This project models nuclear power capacity trajectories globally through 2050 under different build-out scenarios. Using reactor-level data from the IAEA, we forecast how plant retirements, absent new investments, lead to sharp declines in baseload capacity—raising critical concerns for grid reliability.

🔍 Scenario-wise analysis:

🔻 1. Global Decline Without Action

- In both the USA and RoW, nuclear capacity peaks around 2025.
- Without new builds, a steep decline begins post-2030, particularly in RoW.
- This drop reflects the retirement of aging nuclear plants, typically modelled at a 60-year operational lifespan.

By 2050, global nuclear capacity falls below 1990 levels in a no-intervention scenario—a critical concern for baseload supply.

🏗 2. "Required New Builds" Scenario Stabilizes the Decline

- If countries invest enough to maintain 2025 capacity levels, nuclear output stabilizes through 2050.
- This approach essentially compensates for plant retirements one-to-one—but does not increase capacity beyond today's baseline.

This scenario buys time for renewables to scale but does not resolve longer-term grid adequacy under electrification growth.

🚀 3. USA 300% Growth Scenario Shows Major Strategic Shift

- Under the "Linear 300% USA Growth" scenario, capacity triples between 2030–2050.
- This makes the USA the only group in the model with a rising nuclear trajectory.
- It creates energy resilience by building dispatchable, non-intermittent power alongside renewables.

This illustrates how long-term nuclear investments can reverse decline trends and offset fossil retirements.

🔍 Key Findings

1. Nuclear Capacity is Declining Rapidly Without New Builds

Our simulation assumes nuclear plants retire after 60 years of operation, with no new plants built. Under this “no-intervention” baseline:

- Global nuclear capacity **declines sharply after 2030**, as legacy reactors retire.
- The **USA is especially impacted**, with nearly half of capacity retired by 2050.
- Without action, this leads to a severe reduction in dispatchable baseload electricity.

2. Renewables Alone May Not Be Enough

While renewables are expanding, their **intermittency limits their ability to replace nuclear baseload**, especially during:

- **Evening peaks** (when solar drops but demand remains high)
- **Low-wind seasons or cold winters**
- **Industrial ramp-up periods** with sustained demand

These gaps will require **dispatchable or firm generation** capacity.

3. Coal Plants are Also Retiring

Most OECD and several developing countries are retiring coal due to emissions targets and aging infrastructure. This double loss—**coal + nuclear**—puts extreme pressure on the grid unless:

- Significant **energy storage** is added
- Or, **new firm generation** is commissioned

📈 Scenario Modelled: No New Nuclear Builds

We modelled global nuclear fleet capacity under the assumption that **no new plants are added after 2025**. Our simulation accounts for:

- Plant-level age and retirement dates
- Shutdown assumptions at 60 years
- Annual net capacity aggregation by country group

Result: Without reinvestment, global capacity falls well below 2025 levels by 2040, leaving a **gap of over 100 GW** in baseload capacity.

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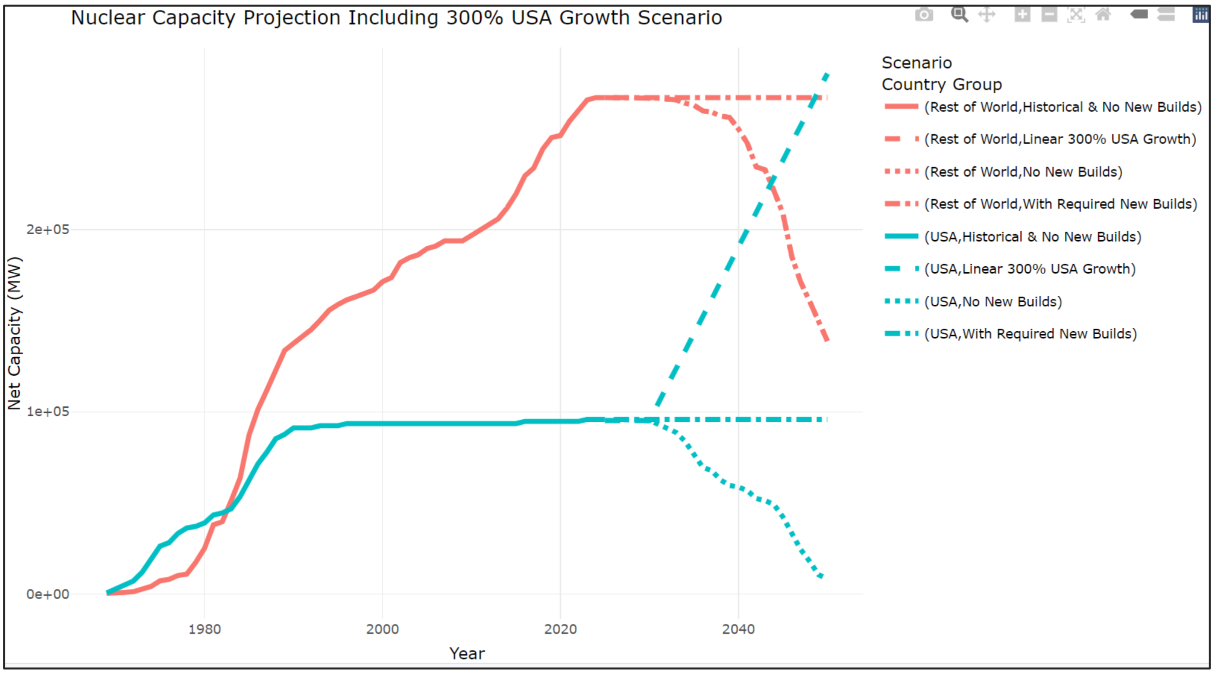

⚠ Energy Security Implications

- **Grid instability** becomes more likely as renewable share rises without firm backup.
- **Import dependency** increases in countries without local gas or hydro reserves.
- **Energy prices may spike** due to peak-hour shortages, as seen in several recent global power crises.

🧭 Strategic Recommendation

Nuclear should be evaluated not just for decarbonization, but as a **ramp-up buffer** for grids transitioning away from fossil fuels.

Governments and utilities need to factor in new nuclear development—especially small modular reactors (SMRs)—as a **non-intermittent complement to renewables**.

🛠 Tools & Techniques Used

- **Data**: IAEA reactor-level database
- **Modeling**: Plant life simulation, scenario analysis
- **Tools**: R (tidyverse, ggplot2, plotly), Excel
- **Output**: Interactive dashboards and PNG visual summaries

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🎯 Use This Work If You Are...

- A **clean energy startup** modelling long-term supply adequacy
- A **policy advisor** needing data-driven nuclear planning insights
- A **grid planner** needing tools to simulate capacity loss over time
- A **consulting firm** building energy scenarios for government clients

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👩‍💻 About the Analyst

This analysis was performed by a data scientist with experience in **energy markets**, **net zero modelling**, and **forecasting tools** for emissions and capacity planning. I specialize in translating raw data into **strategic insights and stakeholder-ready visuals**.