Modelling nuclear power in energy system models

Winter 2025 ETSAP MEETING

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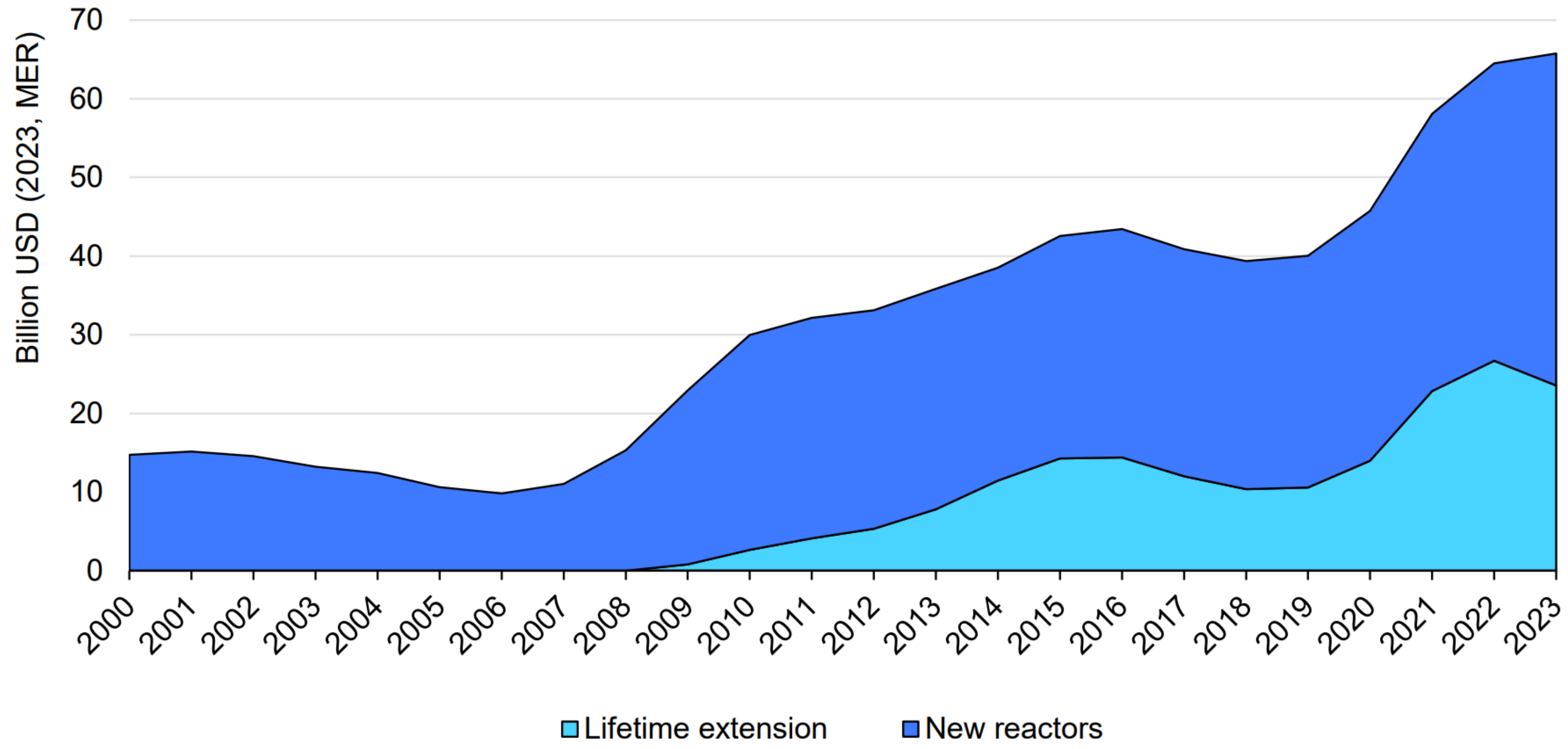
New era for nuclear power

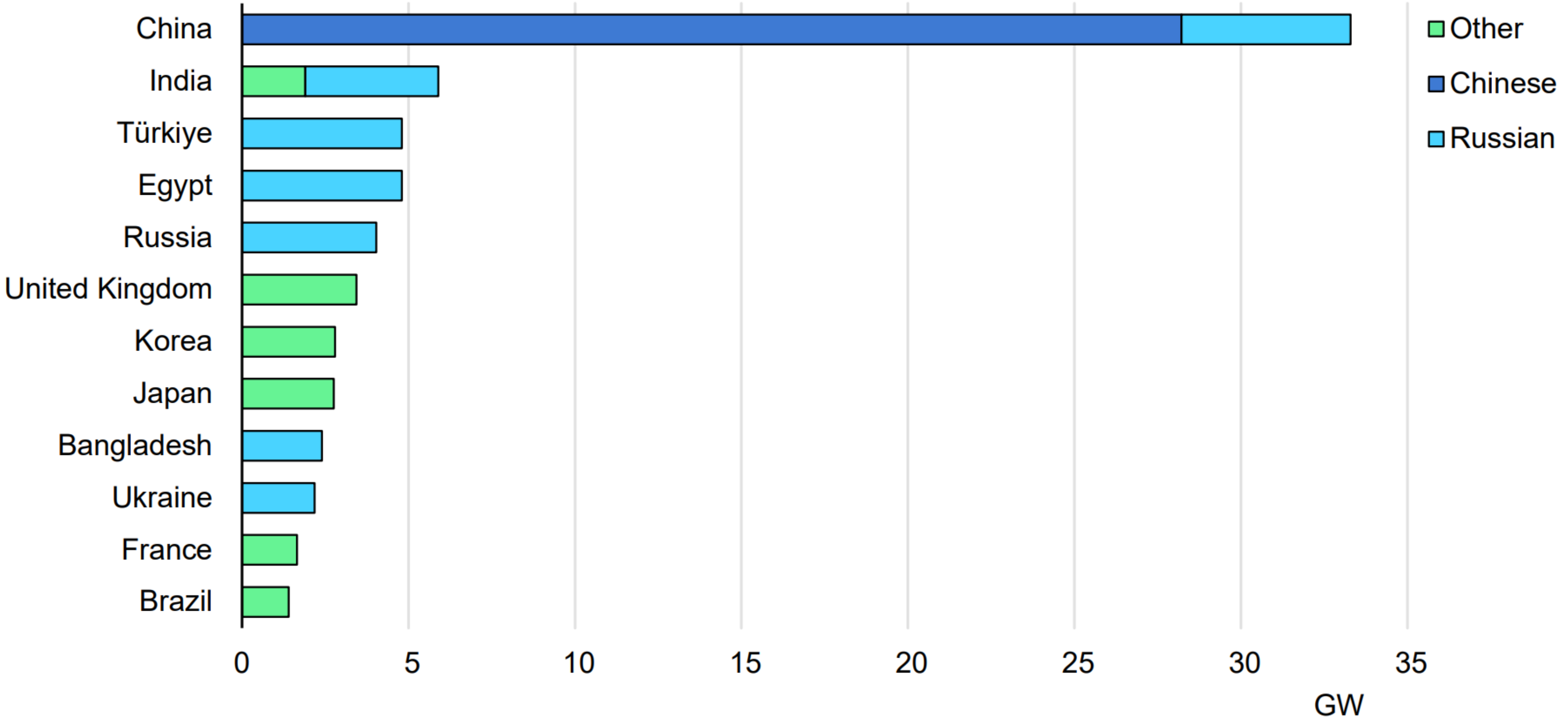
Figure 1.8 Global nuclear energy investment by type, 2000-2023



From: IEA (2025) - The Path to a New Era for Nuclear Energy

New era for nuclear power

Figure 1.5 Nuclear power capacity under construction by region and national origin of technology, as of December 2024



From: IEA (2025) - The Path to a New Era for Nuclear Energy

New era for nuclear power

Small Modular Reactors (SMR)

- Typically, up to 300 MW
- over 80 different concept under development
- Advantages
  - Small & Modular
  - Grid integration
  - Excess heat utilization
- Exposed to great uncertainty
  - Maturity, costs & policy

From: Ontario Power Generation (OPG)

- BWRX-300 SMR at Darlington site in Canada
- Planned commercial operation by the end of 2029

New era for nuclear power

60 municipalities interested in SMR

Fra NRK Vestland

Norwegian authorities DSA/NVE/DSB

• "International best practice requires developing national criteria for selecting nuclear power plant sites"

• "Process should start by identifying suitable locations based on these criteria"

TIMES energy system models can:

- analyse nuclear power
- identify suitable locations

ETSAP-project
Modelling nuclear power in energy system models

- Accepted at Winter 2023 ExCo-meeting
- Coordinated by IFE, Norway
- Aim:
  - Foster collaboration among ETSAP members
  - Map current methodology, identify main challenges & best modelling practices
- Deliverables
  - A two-day workshop + survey (May 2025)
  - A technology brief (in review) – Dr. James Glynn
  - Report on best modelling practices (in review)
  - A workshop on project findings

Workshop

- Brussels, Belgium
- 23 participants
  - 13 different institutes/ universities
  - 11 nationalities
  - Belgium nuclear center
  - IAEA
- Day 1: Modelling methodology
- Day 2: Key challenges & solutions

Current modelling practices

- **Model specifications;** regional scope, temporal resolution, and discount rate.
- **Methodology for nuclear technologies;** endogenous investments, lifetime extensions, ramping capabilities, waste heat integration, flexibility options, and fuel cycle considerations.
- **Assumptions for 2035 and 2050;** including investment and operational costs, lifetime, fuel costs, hurdle rates, waste management, decommissioning, and ramp rates for both conventional and SMR technologies.
- **Relevant literature used to support model assumptions.**

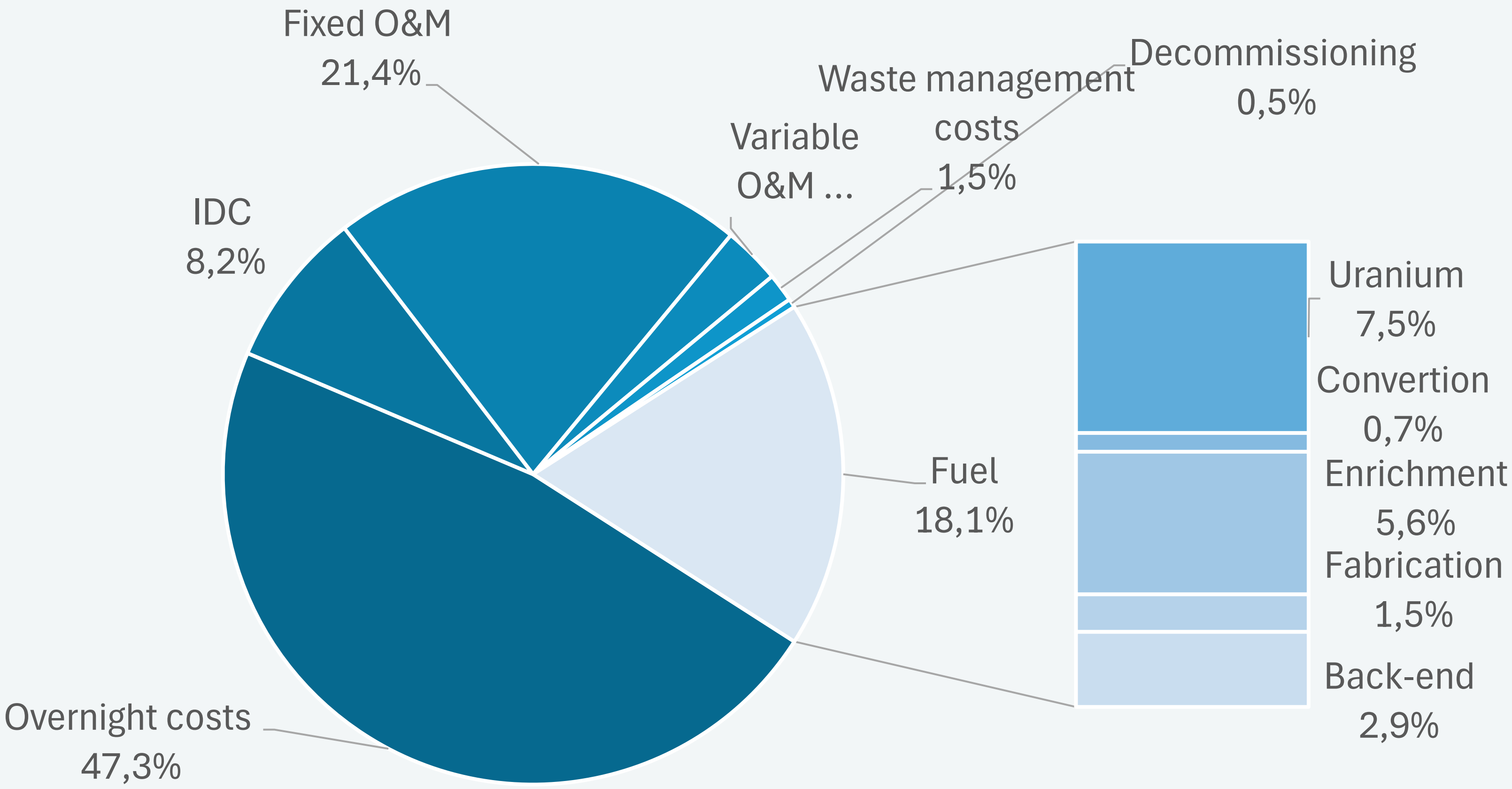
- **Conventional nuclear in 9 of 11 models.**
  - Varying detail level
  - PSI - Generation II pressurized water reactors (PWRs) and Generation I boiling water reactor (BWR)
  - EML - Third-generation pressurized water reactor.
  - Several modelling teams, including VITO, include investment options for lifetime extension

- **SMRs in 9 of 11 models**
  - Varying detail level
  - Often modelled similar as conventional nuclear

What influences modelling results on nuclear power

- **Cost assumption**
  - Investment costs
  - Construction time
  - Hurdle rates
  - Difference between end and first of a kind
- **Energy system configuration**
  - Decisions on nuclear power is driven by the competition between other energy supply options and demand
- **Operational flexibility and co-generation**
- **Resources and material supply chains**
  - Water and material needs
- **Other constraint**
  - Energy dependence and land use

What influences modelling results on nuclear power



Example model assumptios on SMR

Current modelling challenges

- **Uncertainty**
  - cost assumptions
  - policy and regulation
  - supply chains and material needs
- **Characterization of SMR technologies**
  - various concepts with different TLD
- **Operational flexibility**
  - fuel cycles
  - ramping rates and minimum up-time
- **Waste management**
  - modelling
  - fuel re-use
- **Model biases**
  - spatial and temporal resolution
- **Techno-economic rationality does not always align with**
  - political decisions
  - investment behaviour
- **Using discount costs for decommissioning undervalues the well-being of future generations**

Best modelling practices (on going work)

1. Address uncertainty in cost assumptions
2. Account for policy and regulatory uncertainty
3. Represent the diversity of SMR technologies
4. Incorporate operational flexibility (when affecting results)
5. Avoid biases towards one technology (renewables)

Inputs on best modelling practices?

Technology brief

- Global Fleet Divergence: Global capacity (376 GW) is stable, but is characterized by a deep contrast: significant reactor retirements in advanced economies (OECD) are offset by programmatic new construction primarily in Asia (e.g., China has 33 reactors under construction).
- LTEs are the Most Cost-Effective Capacity: For OECD nations, Lifetime Extensions (LTEs) of the existing fleet ($500–$1,100/kW) are the most significant and cost-competitive source of nuclear capacity, yielding an LCOE "well below $40/MWh."
- Regionally-Differentiated Costs are Paramount: New Generation III+ large reactor costs diverge dramatically: OECD nations face a massive "restart premium" (e.g., Vogtle final cost over double original estimate), while Asian builds achieve much lower Nth-of-a-Kind (NOAK) costs.
- TIMES models must use regionally-differentiated cost parameters.

Technology brief

- SMRs Remain Pre-Commercial: Small Modular Reactors (SMRs) are unequivocally pre-commercial as of 2025. Their low-cost economic case is contingent on a large, committed order book (5-10 deployments of a single design) to catalyze factory-based learning-by-doing.
- HALEU is the Hardest Barrier: The single greatest technical and geopolitical barrier to most Gen IV and advanced SMR designs is the non-existence of a commercial High-Assay Low-Enriched Uranium (HALEU) fuel supply chain in Western nations, which forces reliance on geopolitical rivals (Russia, China).
- New Market Potential in Inflexible Demand:A major new market is providing 24/7 "clean-firm" power for inflexible demand sectors like Data Centers and AI, where nuclear's firmness and dispatchability create new value over simple LCOE-based competition with VRE.

Technology brief

- Methodological Updates for TIMES Modelling: A simple, unconstrained least-cost model will produce misleading results. Essential updates include:
  - Modelling Endogenous Learning (e.g., 5% learning rate) for BOAK-to-NOAK cost reduction.
  - Applying Regionally-Differentiated Capacity Constraints on annual build-out.
  - Linking Gen IV deployment to the HALEU enrichment process as a hard constraint.