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Cross-country survey on the decommissioning of commercial nuclear reactors: status, insights, and knowledge gaps

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TECHNISCHE UNIVERSITÄT BERLIN

Cross-Country Survey on the Decommissioning of Commercial Nuclear Reactors: Status, Insights and Knowledge Gaps

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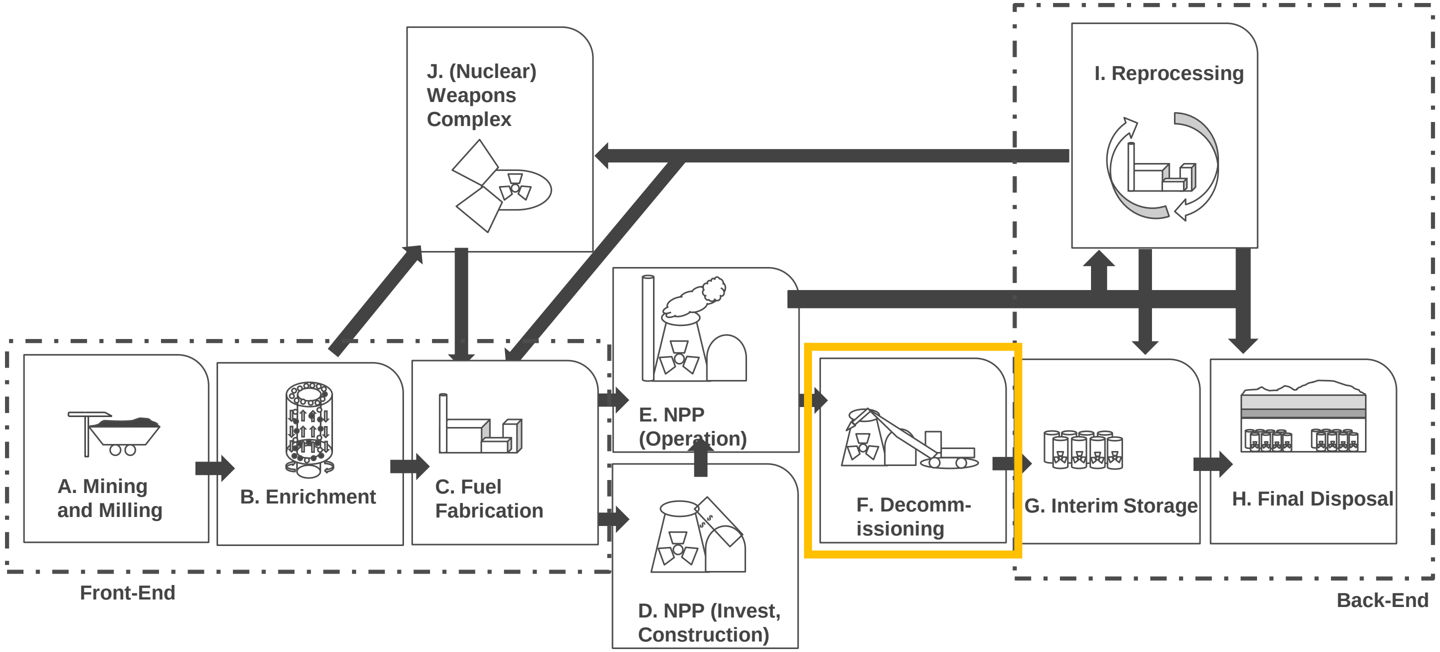
Agenda

Nuclear Power as a System Good

Stylized Description

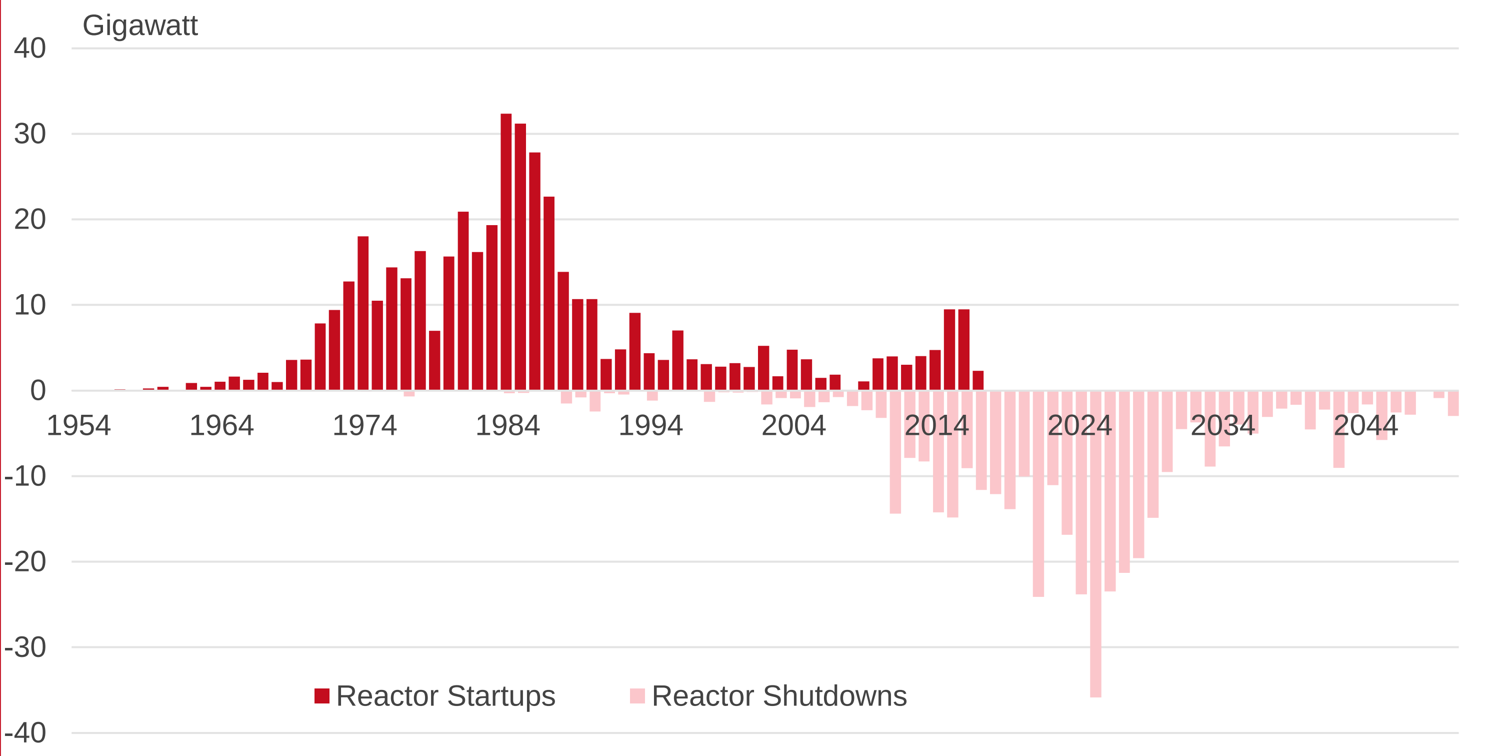


- Nuclear decommissioning is conducted once a nuclear reactor is shut down
- This includes activities from the shutdown itself, the removal of nuclear material and, depending on the target, the environmental restoration of the site
- The process is lengthy and expensive
- From a safety and security view, it is imperative that nuclear reactors are decom. to minimize risk
- Historically, decom. has been neglected as a distant obligation
- In some cases, the combination of inexperience and insufficient planning led to undesired outcomes

Taken from Wealer & von Hirschhausen (2020) Nuclear power as a system good: Organizational models for production along the value-added chain. DIW Discussion Paper 1883. URL: http://hdl.handle.net/10419/222865.

Nuclear Decommissioning
Relevance of Nuclear Decommissioning

Distribution of Global Nuclear Reactor Startups and Shutdowns



- Assuming a 40-year lifetime, many reactors built in the 1980s will begin shutting down in the coming years
- All of these reactors will have to be decom. at some point
- Lifetime extensions (50, 60 or 80 years) can only push this inevitability into the future
- The global decom. industry is still developing and remains largely untested as only around a dozen commercial reactors have been fully decommissioned

Taken from Wealer et al. (2018) Nuclear Power Reactors Worldwide – Technology Developments, Diffusion Patterns, and Country-by-Country Analysis of Implementation (1951–2017). DIW Data Documentation 104. URL: http://hdl.handle.net/10419/179000

Nuclear Decommissioning
Strategies and Technical Approach

STRATEGIES

Direct Dismantling	Deferred Dismantling	Entombment
• Decom. is conducted directly after shutdown of the NPP • Institutional knowledge of on-site personnel can be utilized • Faster release of site for other use • Most often used strategy	• After shutdown, the NPP is placed into “longterm enclosure” for years to decades • This reduces hazards through radiation as radioisotopes decay	• Remaining radioactive material is permanently encapsulated on site • Typically, this strategy is an appropriate strategy after an accident

TECHNICAL APPROACH

Warm-Up Stage	Hot-Zone Stage	Ease-Off Stage
• Includes post-operational phase and preparatory tasks • Reactor core is defueled and first components are removed	• Highly contaminated parts (e.g., reactor pressure vessel) are removed • It is the most dangerous, complex and costly part of the process	• Buildings and remaining components are decontaminated and demolished • Depending on the target (greenfield vs. brownfield), the landscape may be remediated

Our Research

- We explore the current situation in **six countries**: France, Germany, USA, UK, Switzerland and Sweden
- We want to understand what the existing **institutional**, **regulatory** and legal, **financial**, and **technical regimes** for decommissioning in these countries are
- We identify **insights** from comparing the countries’ approaches in order to **identify research gaps**
- In our ongoing project, we subsequentially aim at answering some of these gaps
- Others can be picked up by future research

Agenda

Case Study Overview
General Information

France
- 56 (somewhat) homogeneous NPPs operational that account for 2/3 of electricity generation
- New build ongoing at Flammanville
- Single utility responsible (EDF)

Germany
- Since April 2023, end of commercial operation of nuclear power reactors
- Parallel decommissioning ongoing at over 30 reactors
- Diverse ownership structure, special case for GDR legacy fleet

Sweden
- 30% of Swedish electricity generated by 13 nuclear reactors
- Legal pathway for new reactor construction paved in 2022

Switzerland
- 4 operational NPPs generate 1/3 of Swiss electricity
- End of commercial operation planned for 2040s
- Prohibition on nuclear new builds by law since 2017

United Kingdom
- 10 reactors account for 15% of British electricity generation
- Fleet consists of mainly gas-cooled reactors, so-called “legacy” fleet of Magnox reactors challenging
- New build ongoing (Hinkley Point C)

United States
- Largest commercial power reactor fleet worldwide (92 operating)
- Significant support schemes for nuclear power in place
- New build at Voglte Station delayed and expensive

Case Study Overview
Decommissioning progress as of June 2022

Country	Closed reactors (total)	Warm-Up	Hot-Zone	Ease-Off	LTE	Radiologically Decommissioned (of which are Greenfield)
France	14	4	2	0	8	0 (0)
Germany	30	9	8	9	1	4 (3)
Sweden	7	3	4	0	0	0 (0)
Switzerland	1	1	0	0	0	0 (0)
UK	34	13	9	0	8	0 (0)
USA	41	7	3	1	13	17 (6)

Of our case study countries, only Germany and the USA have completed decommissioning at some reactors.
Most projects have been ongoing for years (or work has not yet begun).

Agenda

Insights and Research Gaps
Overview

Organization / Regulation

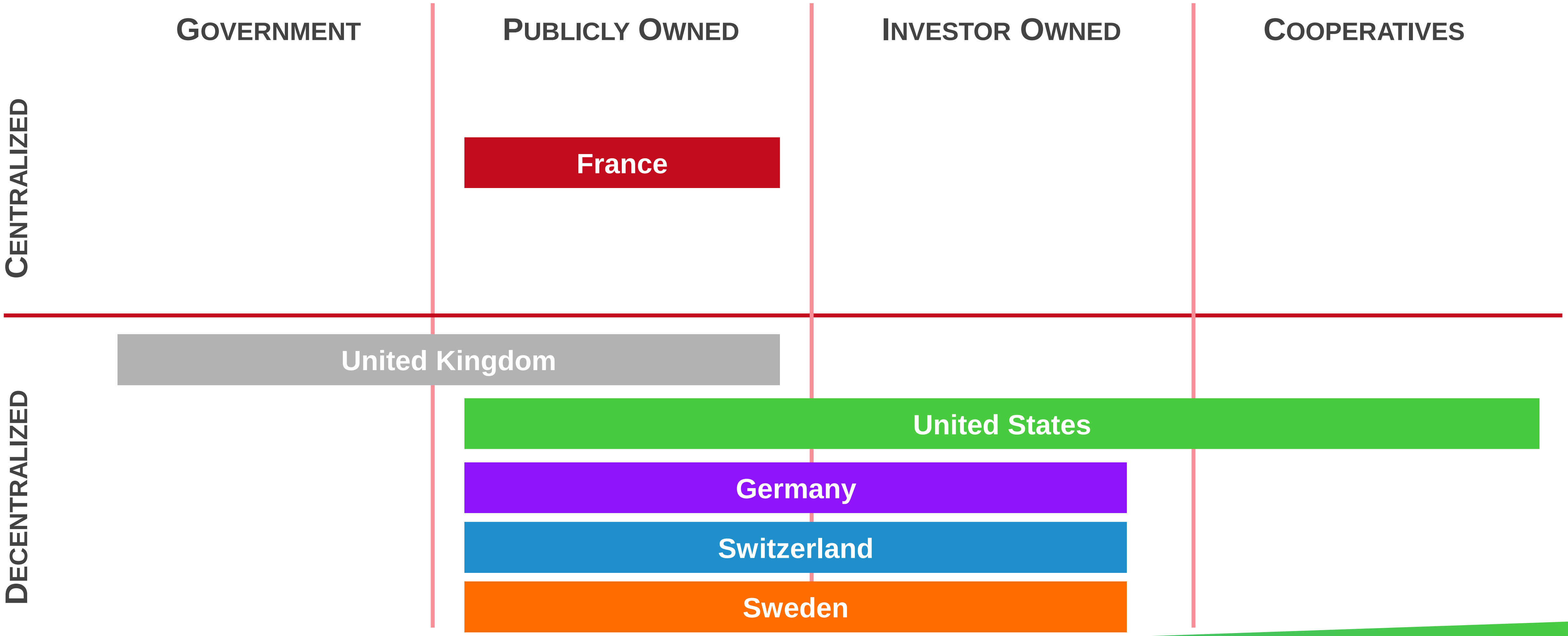
Financing

Production

Waste Management

Insights and Research Gaps

Organization of Ownership as of October 2022



Insights and Research Gaps
Organization and Regulation

Organization / Regulation | Financing
Production | Waste Management

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Organization / Regulation

Interlinkage between ownership and nuclear decom.	Influence of regulatory framework on nuclear decom.
• **Direct influence of ownership** on decommissioning via financing, scheduling, production of decom. work and liability for unfunded work • Possible **differences of incentivation** for swift, safe and cost-efficient decommissioning for private owners vs. government owners	• Decommissioning process **highly dependent on country-specific laws and regulations** • These differ amongst countries, e.g., in terms of responsible agencies (several vs. a single agency) • Key challenge for “newcomer” countries is to harmonize domestic with foreign regulations

Insights and Research Gaps
Financing of Nuclear Decommissioning

	Public Budget	Internal Segregated	Internal Non-Segregated	External Segregated	Guarantees
State Funded	United Kingdom Germany				
Polluter Pays		France	Germany	United Kingdom United States Switzerland Sweden	United States

Bärenbold, Bah, Lordan-Perret, Weigt (University of Basel) and Steigerwald, von Hirschhausen, Wealer, Wimmers (TU Berlin)

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Insights and Research Gaps
Financing

Financing

Improving of cost and contingency estimations

- Cost estimations vary significantly; historically **costs** have been **underestimated**
- **Accurate estimations** might help reduce liability risks and understand incentivation of actors

Decommissioning fund adequacy and transparency

- Decommissioning fund volumes are not always publicly accessible and it often remains unclear for what money is used
- **Transparency and increased fund scrutiny** might reduce liability risks

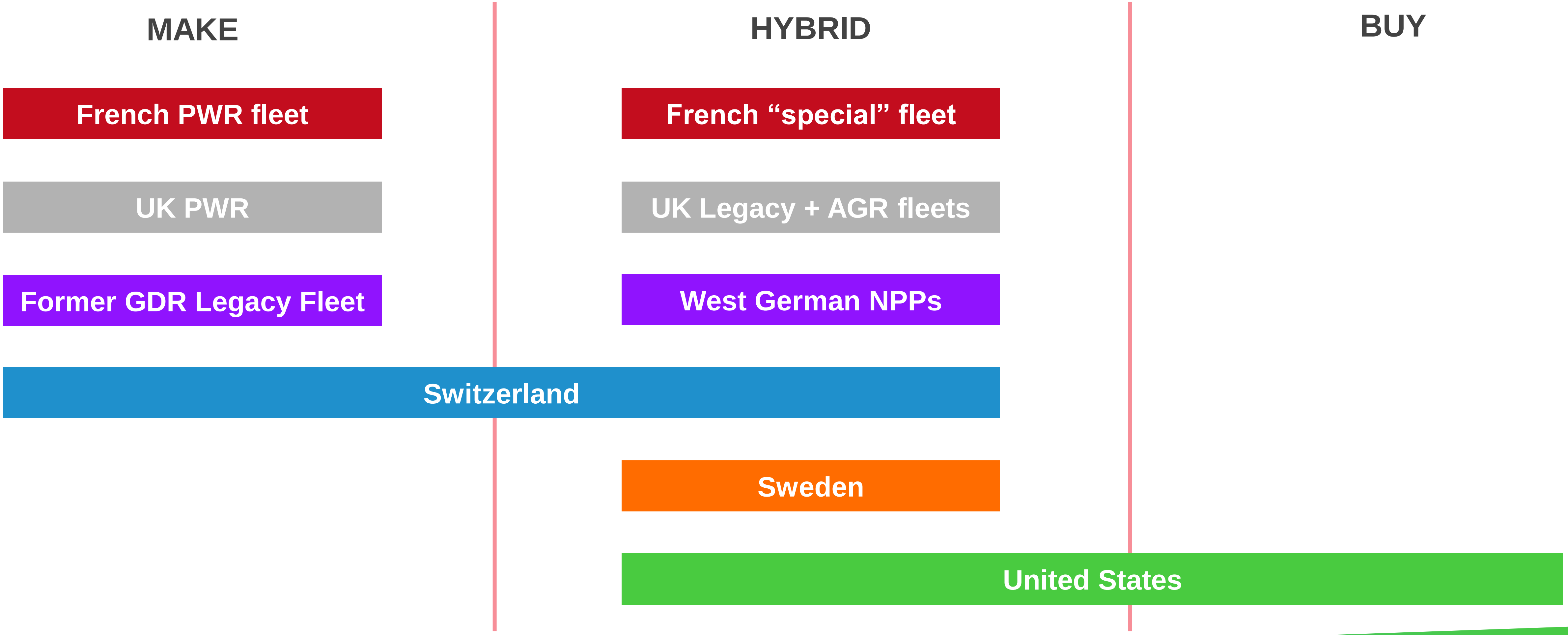
Determining financial liability

- In some countries (esp. US), final **financial liability is sometimes unclear**
- Understanding how other countries might account for fund shortfalls could increase responsibility for cost-efficient decom.

External influences on decommissioning funds

- Market development can influence decommissioning funds that are often accumulated over NPP lifetime
- **Identifying influences and potential risks** for these funds could increase **fund resilience**

Insights and Research Gaps
Production of Nuclear Decommissioning



Insights and Research Gaps
Production

Organization / Regulation | Financing | Production | Waste Management

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Production

The make or buy decom. production decision

- Nuclear reactors **are highly asset specific**, resulting in limited number of actors active in the market
- No country follows a single approach
- External or internal conditions must exist that influence decisions

The role and influence of specialized firms

- Highly **specialized actors** are emerging in the decom. market
- These specialists have begun to take over whole to-be-decommissioned plants or are responsible for full reactor fleets
- Possible **efficiency increases through specialization** might occur

Developing the decommissioning supply chain

- With many NPPs likely to be coming offline at similar times, concerns regarding **possible supply chain bottle necks** are emerging (human capital, specialized material & infrastructure)

Inspecting claims of efficiency

- **Parallel decommissioning** of (somewhat) homogeneous reactor fleets are proposed to go hand in hand with efficiency gains
- Past experience (esp. in nuclear construction) shows that such claims were historically unfounded

Insights and Research Gaps
Waste Management

- There are different types of radioactive waste which are disposed of in different types of facilities
- Almost all countries struggle with the management of High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)
- Switzerland, Sweden and France have chosen a site for a deep geological repository to store HLW/ SNF
- Five countries (all except for France) have currently an interim storage facility for HLW/ SNF available
- Low-Level Waste (LLW) is the majority of waste arising from nuclear decommissioning
- Thus, access to LLW facilities might become a critical chokepoint for decommissioning
- Our surveyed countries all have dedicated nuclear waste regulations
- Variation exists in the involvement of the government

Insights and Research Gaps
Waste Management

Organization / Regulation | Financing | Production | Waste Management

Waste Management

Access to waste disposal facilities

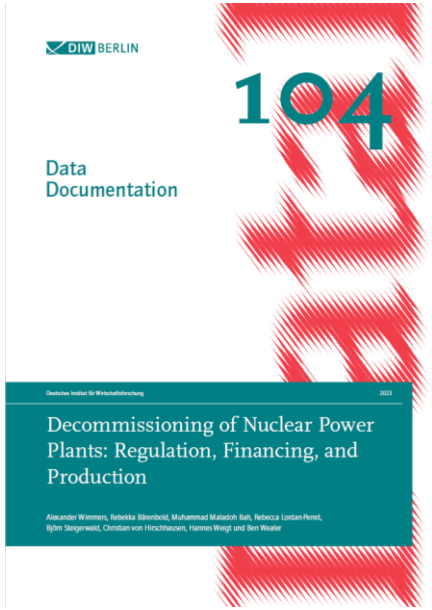
- Worldwide, **no final geological repository for highly radioactive waste is in operation**
- Three of our six countries have identified a location
- **Access to disposal routes** for low, medium and high-level waste is imperative for nuclear decommissioning to succeed
- Currently, most waste is stored **in interim facilities** that might be in operation for many decades
- **Lack of disposal routes probably increases decommissioning duration and cost**

Conclusion

- Our survey paper brings together insights from six country case studies on decommissioning commercial NPPs
- We focused on organization/ regulation, financing, production and waste management
- The results from our survey shows that there are many differences between the countries, yet similarities arise
- Ultimately, our overarching goal is to find and evaluate best practices in the nuclear decommissioning industry
- Our insights here will help us on this path

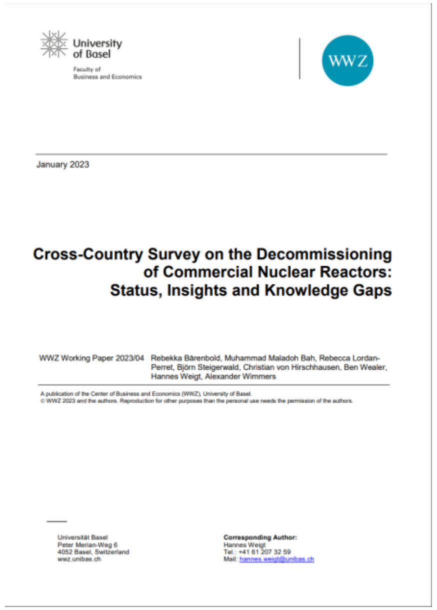
This research is freely accessible

DIW Data Documentation 104: Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production



https://dx.doi.org/10.18723/diw_ddc:2023-104

WWZ Working Paper 2023/04: Cross-Country Survey on the Decommissioning of Commercial Nuclear Reactors



https://edoc.unibas.ch/93620/1/20230213094735_63e9f9279b5a5.pdf

Thank you for your attention!

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BACK-UP | Insights and Research Gaps
Generalized Regulation