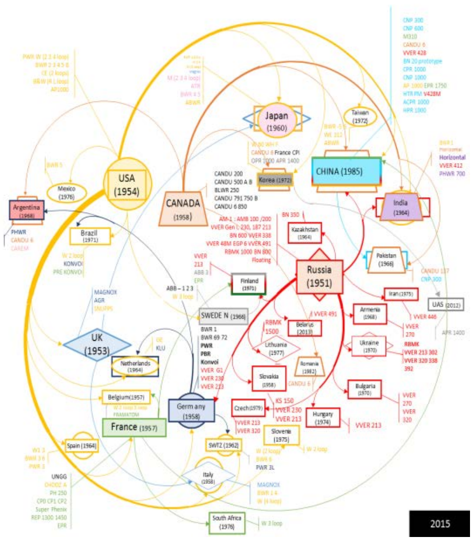
22nd REFORM Group Meeting,
August 26-31, Salzburg

Nuclear weapons and nuclear strategies: “Economies of scope”, country case studies (US, China and Russia), and the “nuclear resource curse” hypothesis



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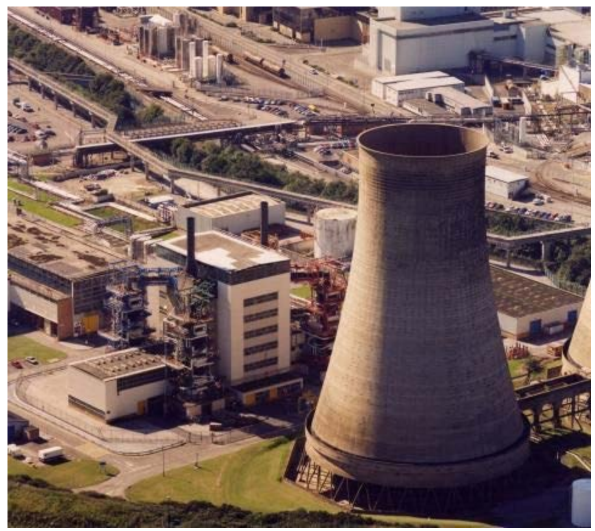

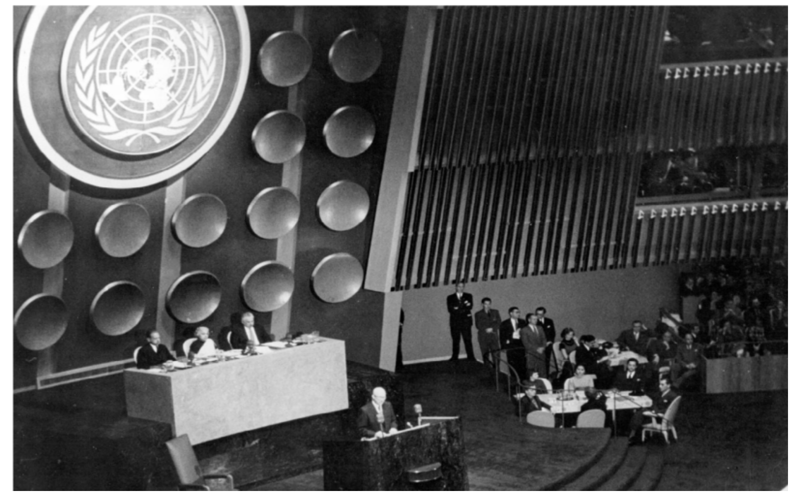

Ben Wealer, Simon Bauer, and Christian von Hirschhausen

Agenda

1) **Introduction**
2) The nuclear power paradox(es)
3) "Economies of scope" in nuclear technologies
4) Nuclear diplomacy and the nuclear resource curse
    1) Russia
    2) China
    3) United States of America
5) Conclusion

Research Program “Nuclear Power“ (TUB & DIW Berlin)


DIW BERLIN

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Data Documentation

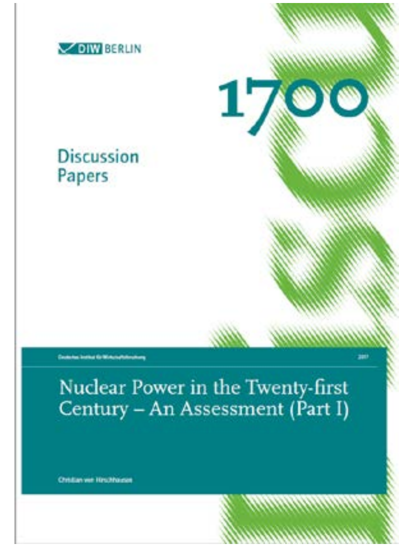
Deutsches Institut für Wirtschaftsforschung 2018

Nuclear Power Reactors Worldwide – Technology Developments, Diffusion Patterns, and Country-by-Country Analysis of Implementation (1951-2017)

Ben Wealer, Simon Bauer, Nicolas Landry, Hannah Seiß and Christian von Hirschhausen


IAEE Energy Forum Second Quarter 2017

Nuclear Energy Policy in the United States: Between Rocks and Hard Places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1700

Discussion Papers

Nuclear Power in the Twenty-first Century – An Assessment (Part I)


DIW Wochenbericht 22

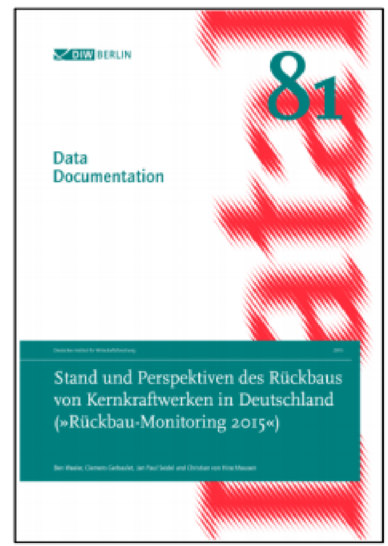
Abschaltung der Atomkraftwerke: Wie geht es weiter?

DIW BERLIN

Atomausstieg geht in die nächste Phase: Stromversorgung bleibt sicher – große Herausforderungen und hohe Kosten bei Rückbau und Endlagerung 523

»Öffentlich-rechtlicher Fonds könnte Zugriff auf Rückstellungen der Atomkraftwerksbetreiber sicherstellen« 532

Konkurrenz belebt, Tarifeinheit kann einschläfern 536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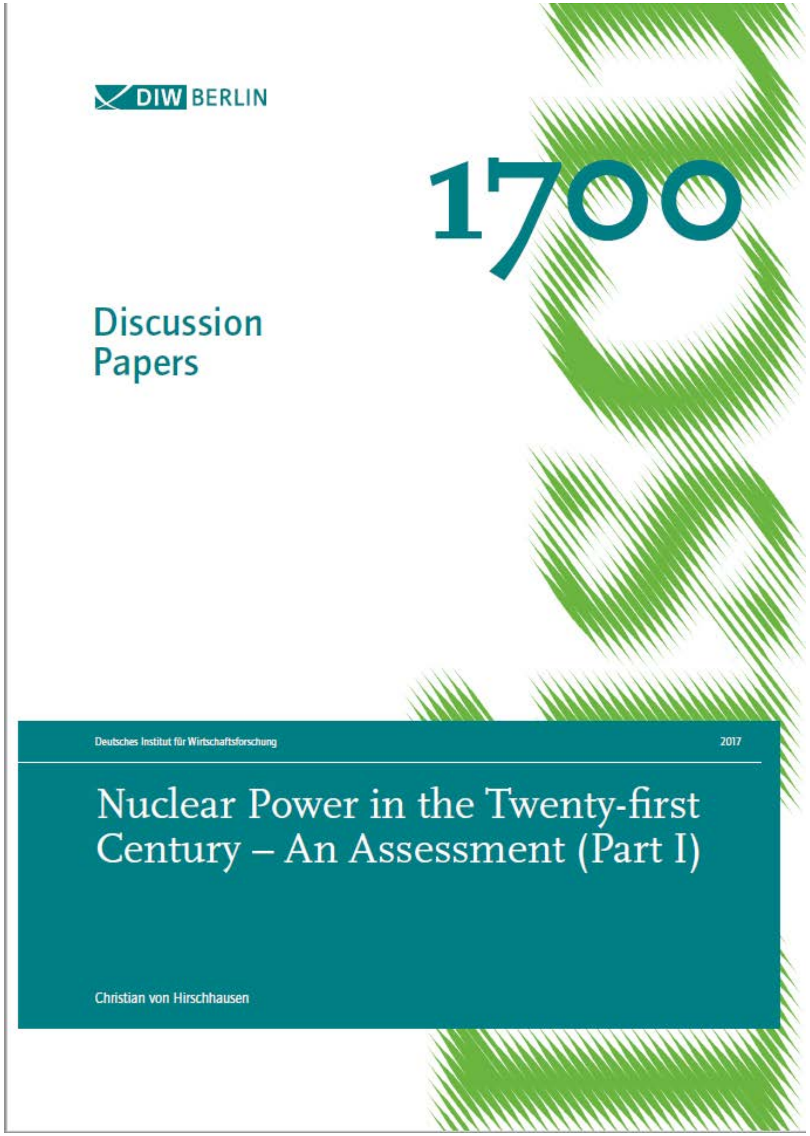
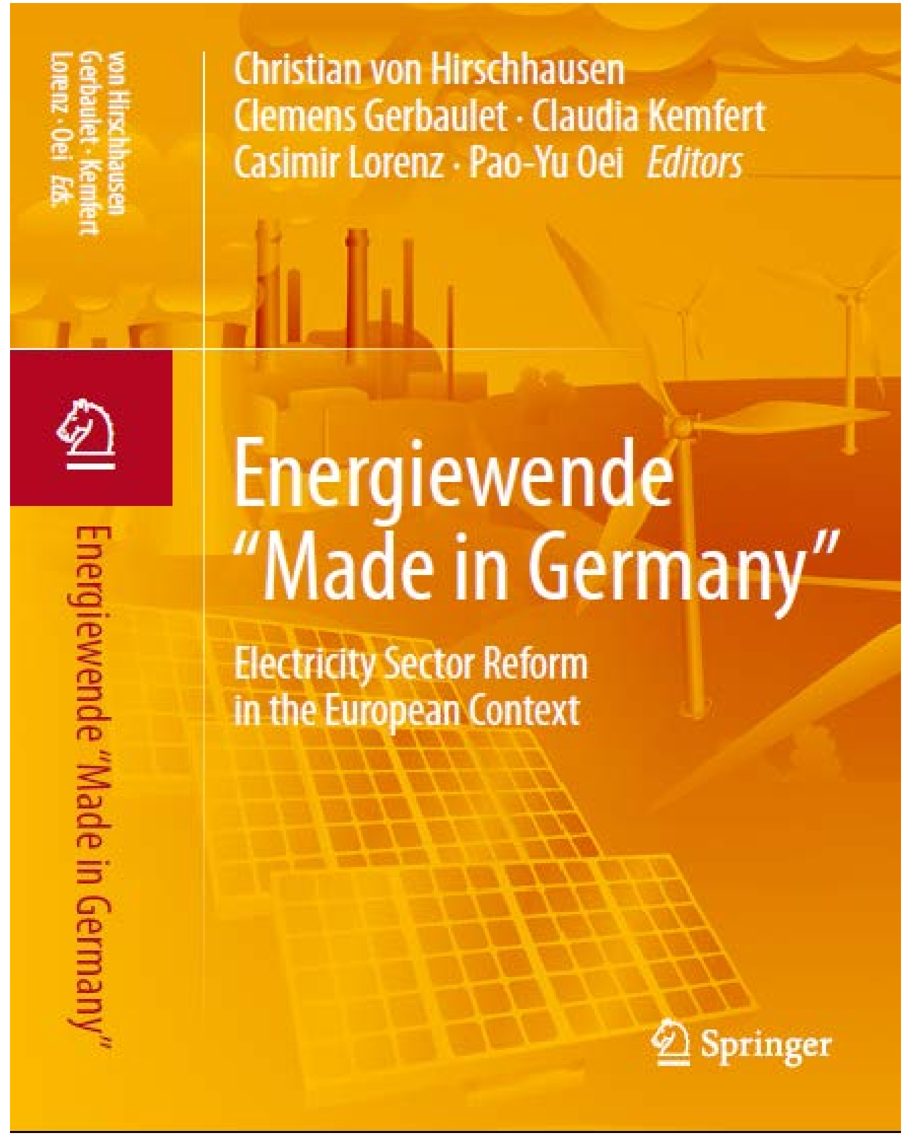
Data Documentation

Stand und Perspektiven des Rückbaus von Kernkraftwerken in Deutschland (»Rückbau-Monitoring 2015«)

Discussion Paper: Nuclear Power in the 21st Century, and reflection about “low-carbon energy transformation





Main Findings

1) Nuclear electricity has never been "economic"

2) "Economies of scope" can explain the nuclear paradox, i.e. high number of (uneconomic) projects

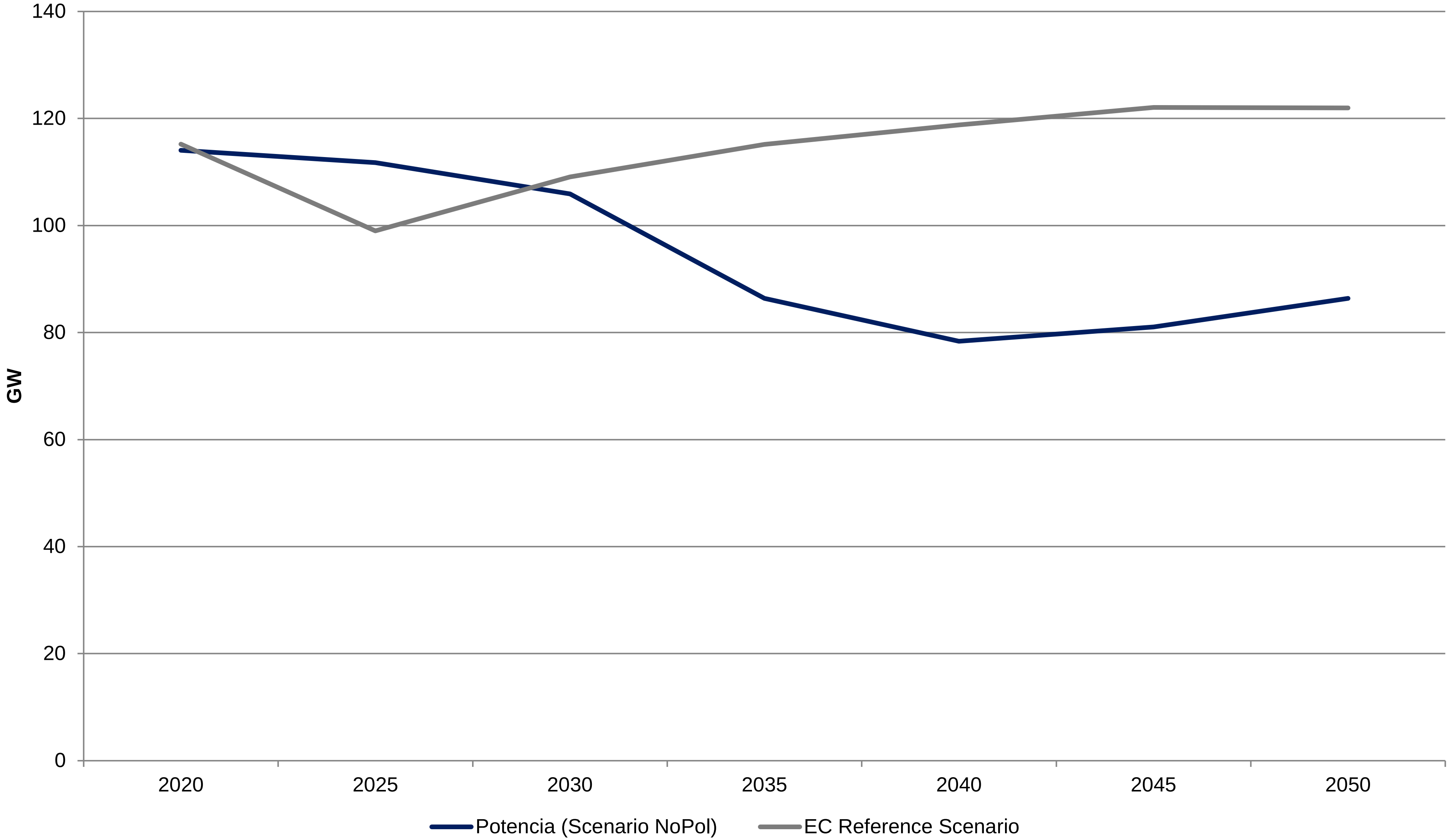
3) Nuclear power "resource curse" hypothesis: Positive relation between nuclear "newbies" and low level of civil and political liberties

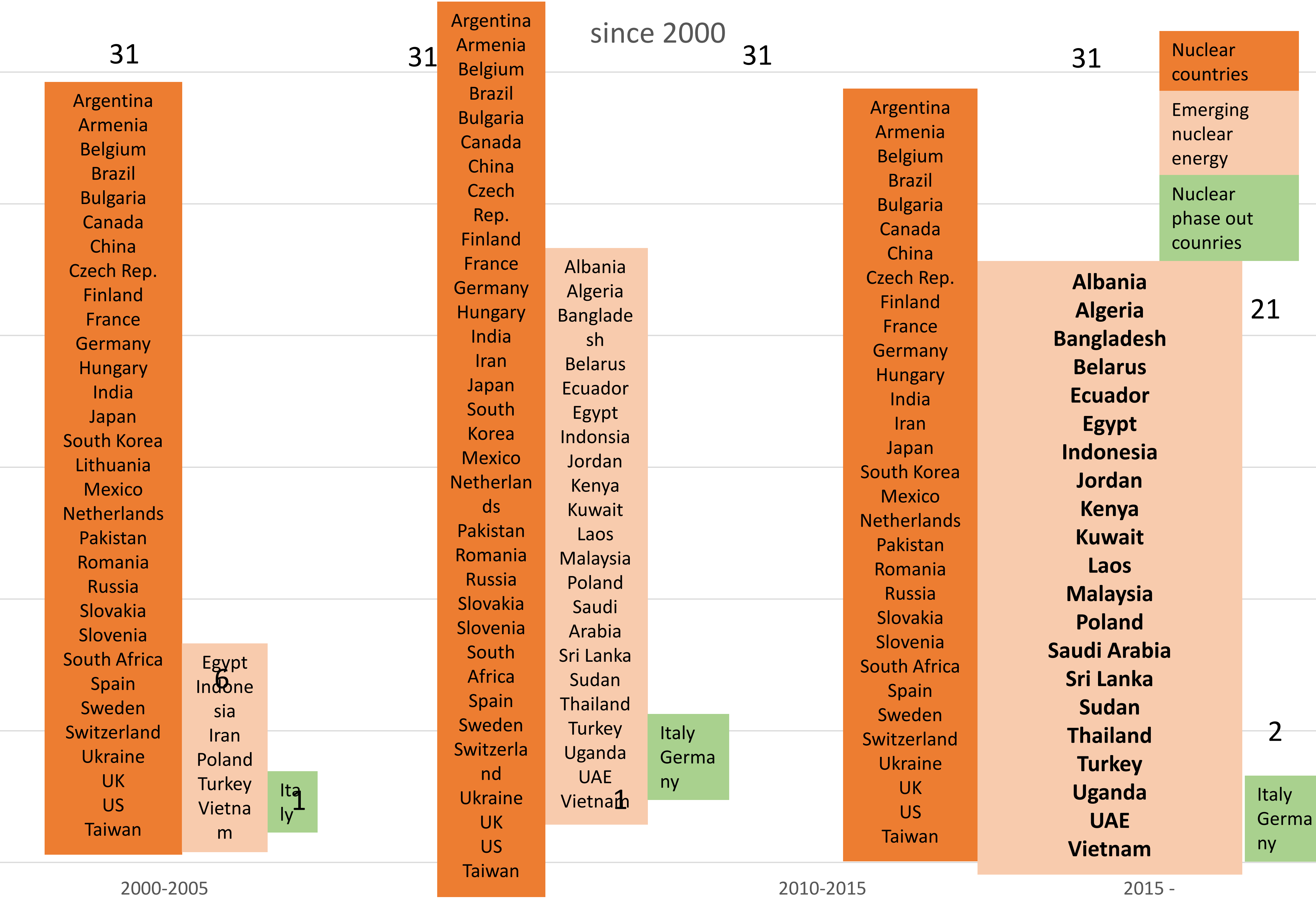
Agenda

1) Motivation
2) **The nuclear power paradox(es)**
3) "Economies of scope" in nuclear technologies
4) Nuclear diplomacy and the nuclear resource curse and
   1) Russia
   2) China
   3) United States of America
5) Conclusion

The European nuclear power paradox:

Nuclear Capacity Development in the EU Reference Scenario and the Potencia model calculations





since 2000
Nuclear countries
Emerging nuclear energy
Nuclear phase out counries
31
Argentina Armenia Belgium Brazil Bulgaria Canada China Czech Rep. Finland France Germany Hungary India Japan South Korea Lithuania Mexico Netherlands Pakistan Romania Russia Slovakia Slovenia South Africa Spain Sweden Switzerland Ukraine UK US Taiwan
6
Egypt Indonesia Iran Poland Turkey Vietnam
1
Italy
31
Argentina Armenia Belgium Brazil Bulgaria Canada China Czech Rep. Finland France Germany Hungary India Iran Japan South Korea Mexico Netherlands Pakistan Romania Russia Slovakia Slovenia South Africa Spain Sweden Switzerland Ukraine UK US Taiwan
Albania Algeria Bangladesh Belarus Ecuador Egypt Indonsia Jordan Kenya Kuwait Laos Malaysia Poland Saudi Arabia Sri Lanka Sudan Thailand Turkey Uganda UAE Vietnam
1
Italy Germany
31
Argentina Armenia Belgium Brazil Bulgaria Canada China Czech Rep. Finland France Germany Hungary India Iran Japan South Korea Mexico Netherlands Pakistan Romania Russia Slovakia Slovenia South Africa Spain Sweden Switzerland Ukraine UK US Taiwan
31
21
Albania Algeria Bangladesh Belarus Ecuador Egypt Indonesia Jordan Kenya Kuwait Laos Malaysia Poland Saudi Arabia Sri Lanka Sudan Thailand Turkey Uganda UAE Vietnam
2
Italy Germany
2000-2005
2010-2015
2015 -

Looking back …
…no-one ever pretended nuclear was „economic“ …

MIT (2003): The Future of Nuclear Power

> **“In deregulated markets, nuclear power is not now cost competitive with coal and natural gas.” (p. 3)**

University of Chicago (2004):

> **“A case can be made that the nuclear industry will start near the bottom of its learning rate when new nuclear construction occurs. (p. 4-1) … “The nuclear LCOE for the most favorable case, $47 per MWh, is close but still above the highest coal cost of $41 per MWh and gas cost of $45 per MWh.” (p. 5-1)**

Parsons/Joskow (EEEP 2012)

> **“may be one day …”**

D’haeseleer (2013): Synthesis on the Economics of Nuclear Energy

> **“Nuclear new build is highly capital intensive and currently not cheap, … it is up to the nuclear sector itself to demonstrate on the ground that cost-effective construction is possible.” (p. 3)**

Davis, L.W. (2012): Prospects for Nuclear Power. Journal of Economic Perspectives (26, 49–66))

> **“These external costs are in addition to substantial private costs. In 1942, with a shoestring budget in an abandoned squash court at the University of Chicago, Enrico Fermi demonstrated that electricity could be generated using a self-sustaining nuclear reaction. <u>Seventy years later the industry is still trying to demonstrate how this can be scaled up cheaply enough to compete with coal and natural gas.“ (p. 63)</u>**

Davis (2012; JEP, p. 11): „70 years later …“ current update for Europe (own calc.)

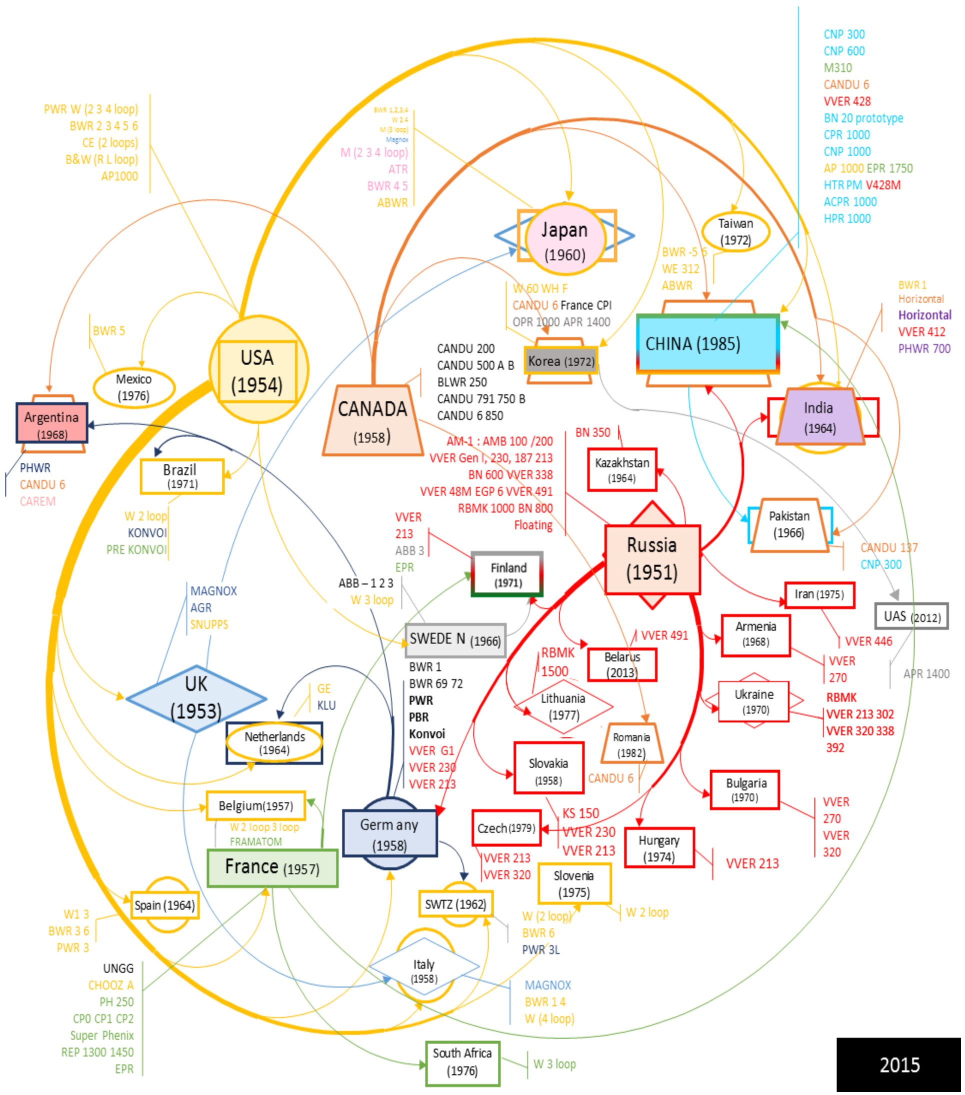
Table 3

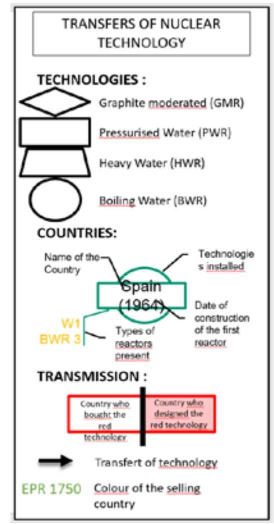
Levelized Cost Comparison for Electricity Generation

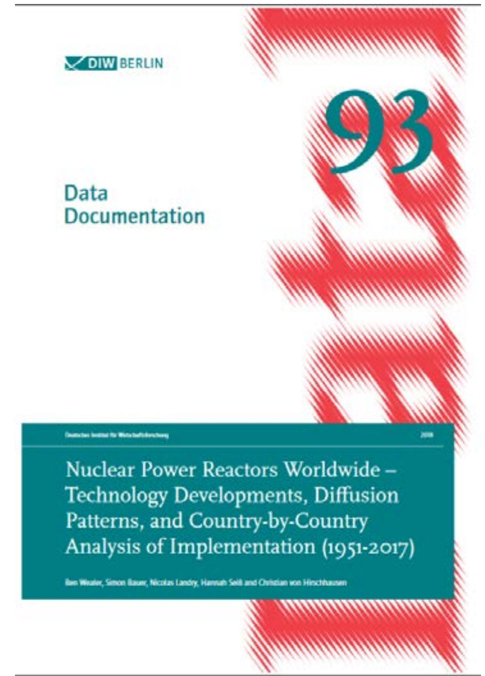
Source	*Levelized cost in cents per kWh*		
	Nuclear	*Coal*	*Natural gas*
MIT (2009) baseline	8.7	6.5	6.7
Updated construction costs	10.4	7.0	6.9
Updated construction costs and fuel prices	10.5	7.4	5.2
With carbon tax of $25 per ton CO_2	10.5	9.6	6.2

	Levelized costs in €cents/kWh		
	Nuclear	Coal	Natural Gas
Baseline (2016)	11	5,1	5,0
CO_2-price: 25 €/t	11	6,3	5,7
CO_2-price: 100 €/t	11	10,0	7,9

Empirical "proof" of non-economic emergence of nuclear power plants (Wealer, et al., 2018)

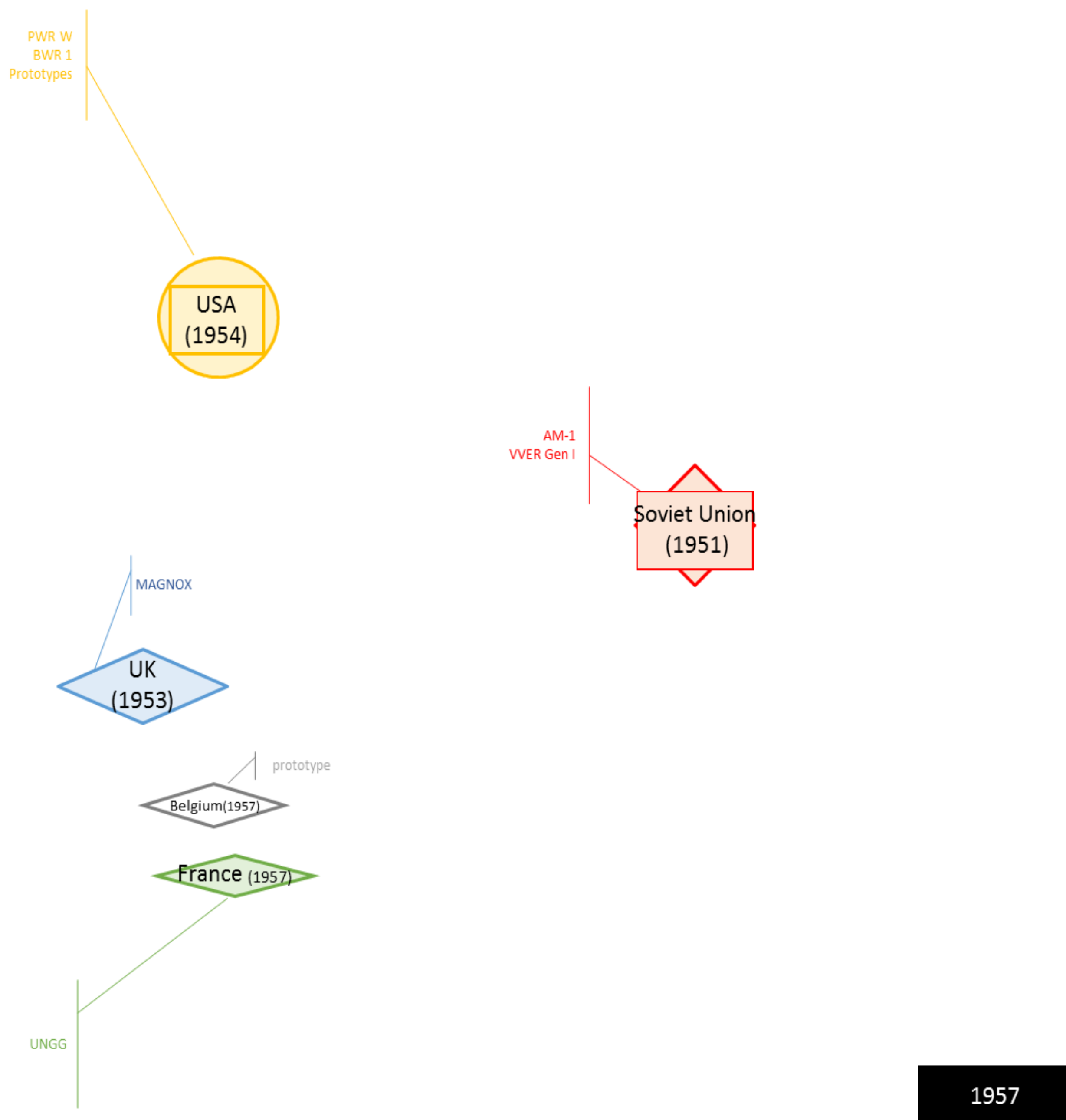


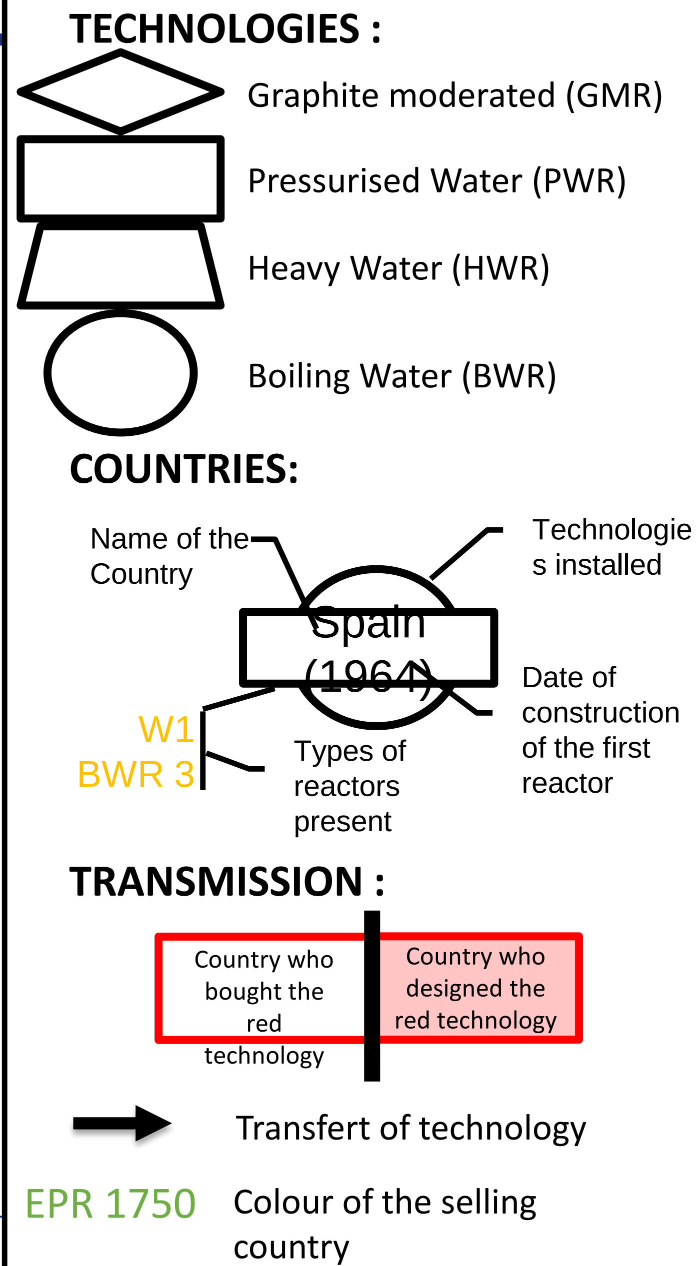




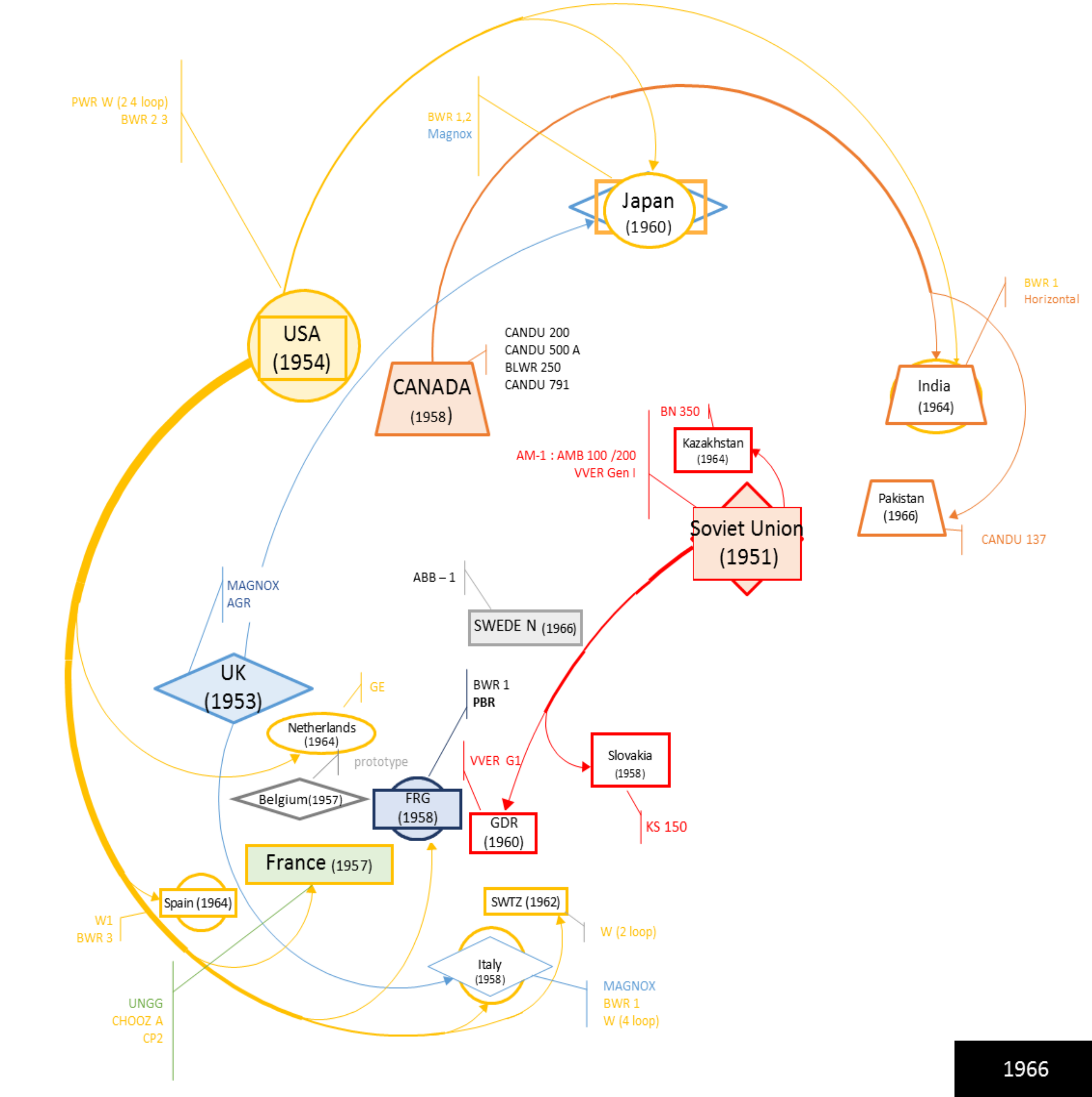
<u>None</u> of the 674 or so reactors analysed in the text and documented in the appendix, has been <u>developed based on what is generally considered "economic" grounds</u>, i.e. the decision of private investors in the context of a market-based, competitive economic system. Given current technical and economic trends in the global energy industry, there is no reason to believe that <u>this rule will be broken in the near- or longer-term future</u>.

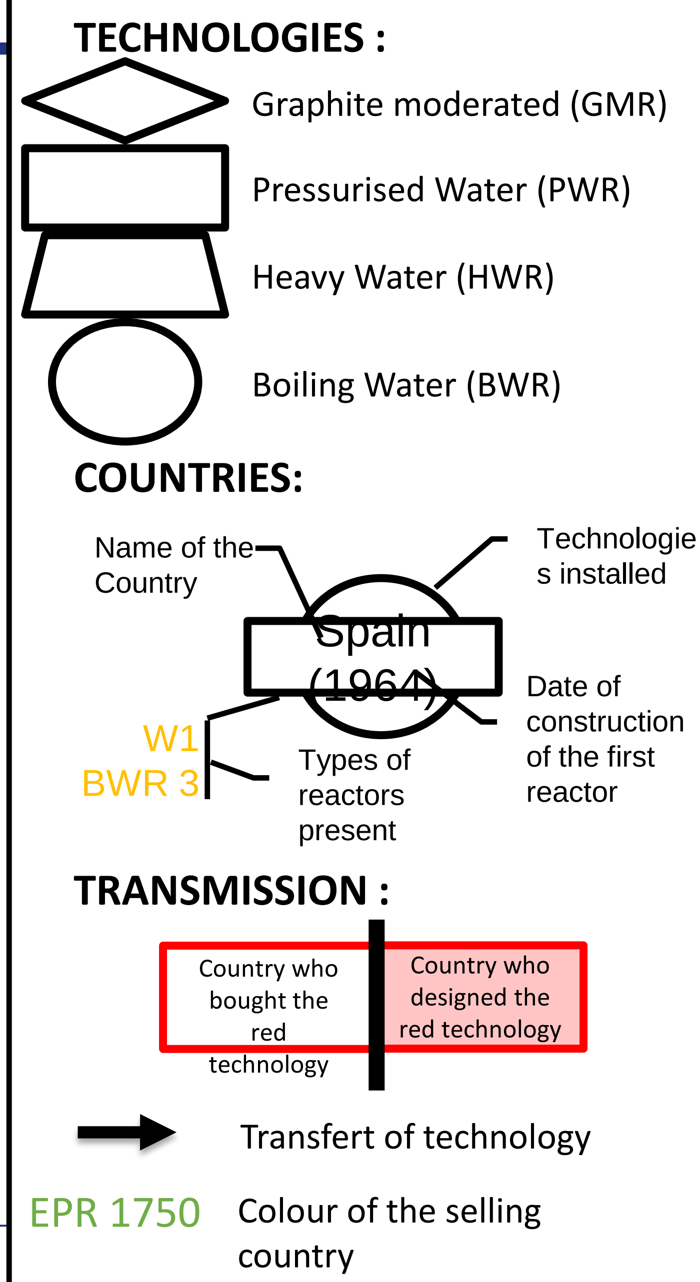
TRANSFERS OF NUCLEAR TECHNOLOGY

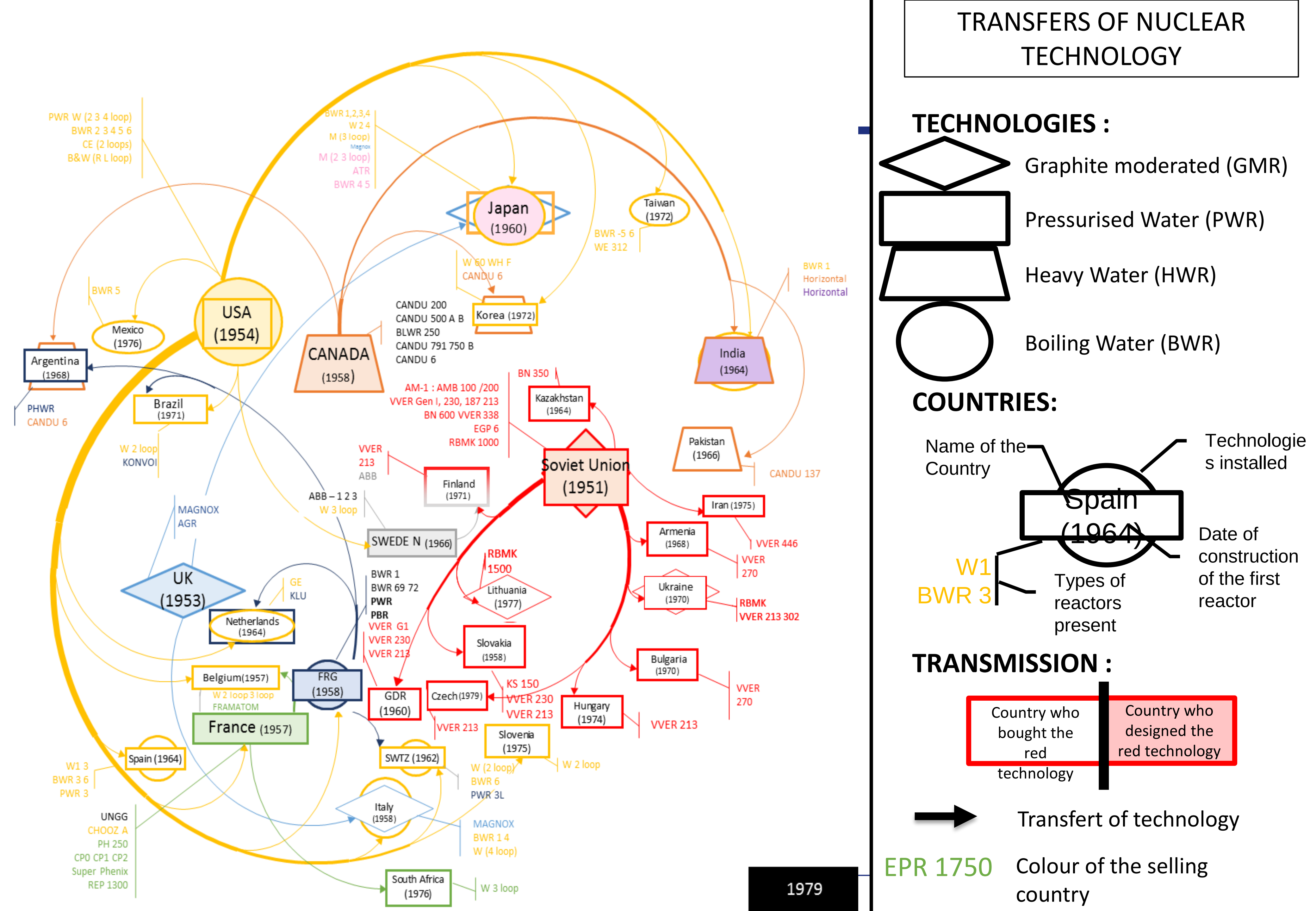




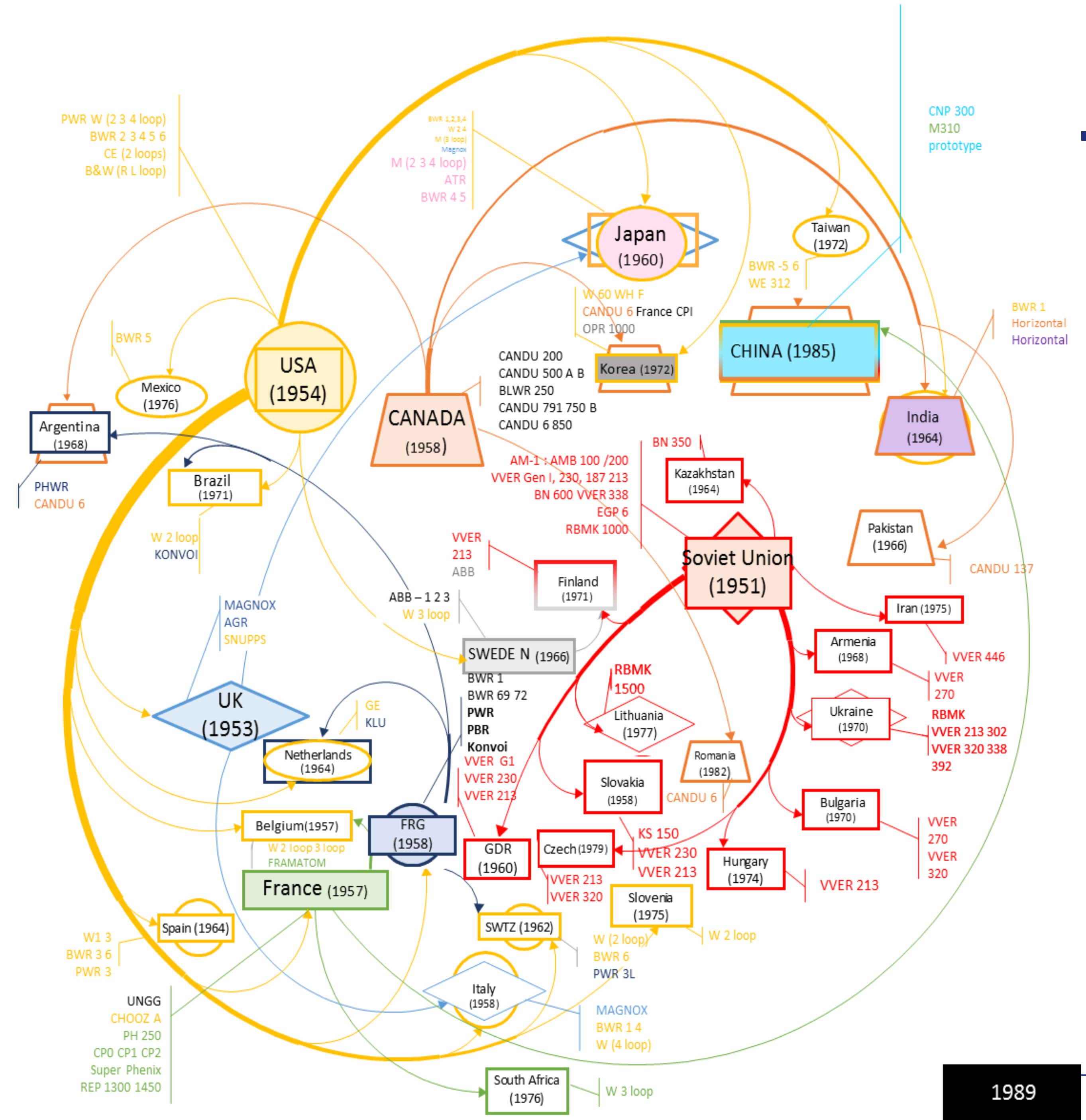
TRANSFERS OF NUCLEAR TECHNOLOGY

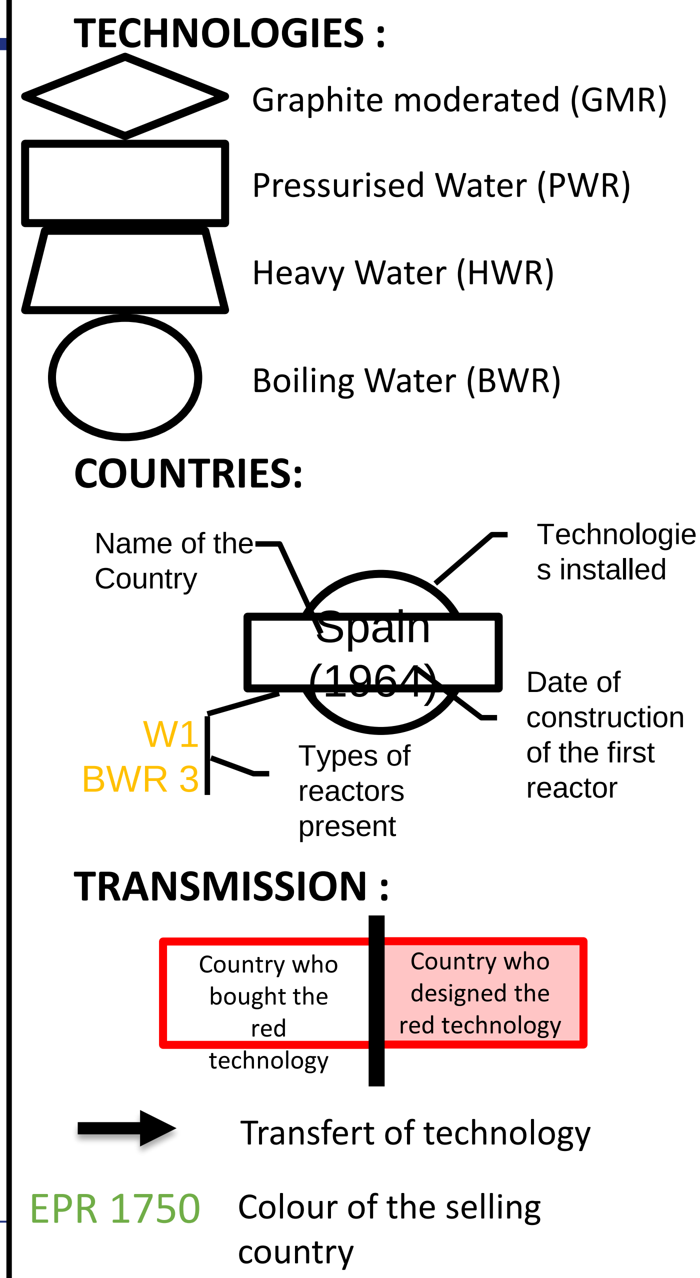





TRANSFERS OF NUCLEAR TECHNOLOGY
TECHNOLOGIES :
Graphite moderated (GMR)
Pressurised Water (PWR)
Heavy Water (HWR)
Boiling Water (BWR)
COUNTRIES:
Name of the Country
Technologies installed
Spain (1964)
W1
BWR 3
Types of reactors present
Date of construction of the first reactor
TRANSMISSION :
Country who bought the red technology
Country who designed the red technology
Transfert of technology
EPR 1750
Colour of the selling country
USA (1954)
CANADA (1958)
Japan (1960)
Taiwan (1972)
Korea (1972)
India (1964)
Pakistan (1966)
Soviet Union (1951)
Kazakhstan (1964)
Iran (1975)
Armenia (1968)
Ukraine (1970)
Bulgaria (1970)
Hungary (1974)
Czech (1979)
Slovakia (1958)
Lithuania (1977)
Finland (1971)
SWEDE N (1966)
UK (1953)
Netherlands (1964)
Belgium(1957)
FRG (1958)
GDR (1960)
France (1957)
Spain (1964)
SWTZ (1962)
Slovenia (1975)
Italy (1958)
South Africa (1976)
Mexico (1976)
Argentina (1968)
Brazil (1971)
PWR W (2 3 4 loop)
BWR 2 3 4 5 6
CE (2 loops)
B&W (R L loop)
BWR 1,2,3,4
W 2 4
M (3 loop)
Magnox
M (2 3 loop)
ATR
BWR 4 5
BWR -5 6
WE 312
W 60 WH F
CANDU 6
BWR 1
Horizontal
Horizontal
CANDU 200
CANDU 500 A B
BLWR 250
CANDU 791 750 B
CANDU 6
BN 350
AM-1 : AMB 100 /200
VVER Gen I, 230, 187 213
BN 600 VVER 338
EGP 6
RBMK 1000
CANDU 137
VVER 446
VVER 270
RBMK
VVER 213 302
VVER 270
VVER 213
KS 150
VVER 230
VVER 213
VVER 213
RBMK 1500
VVER 213
ABB
BWR 5
PHWR
CANDU 6
W 2 loop
KONVOI
MAGNOX
AGR
ABB – 1 2 3
W 3 loop
BWR 1
BWR 69 72
PWR
PBR
VVER G1
VVER 230
VVER 213
GE
KLU
W 2 loop 3 loop
FRAMATOM
W1 3
BWR 3 6
PWR 3
W (2 loop)
BWR 6
PWR 3L
W 2 loop
UNGG
CHOOZ A
PH 250
CP0 CP1 CP2
Super Phenix
REP 1300
MAGNOX
BWR 1 4
W (4 loop)
W 3 loop
1979

TRANSFERS OF NUCLEAR TECHNOLOGY





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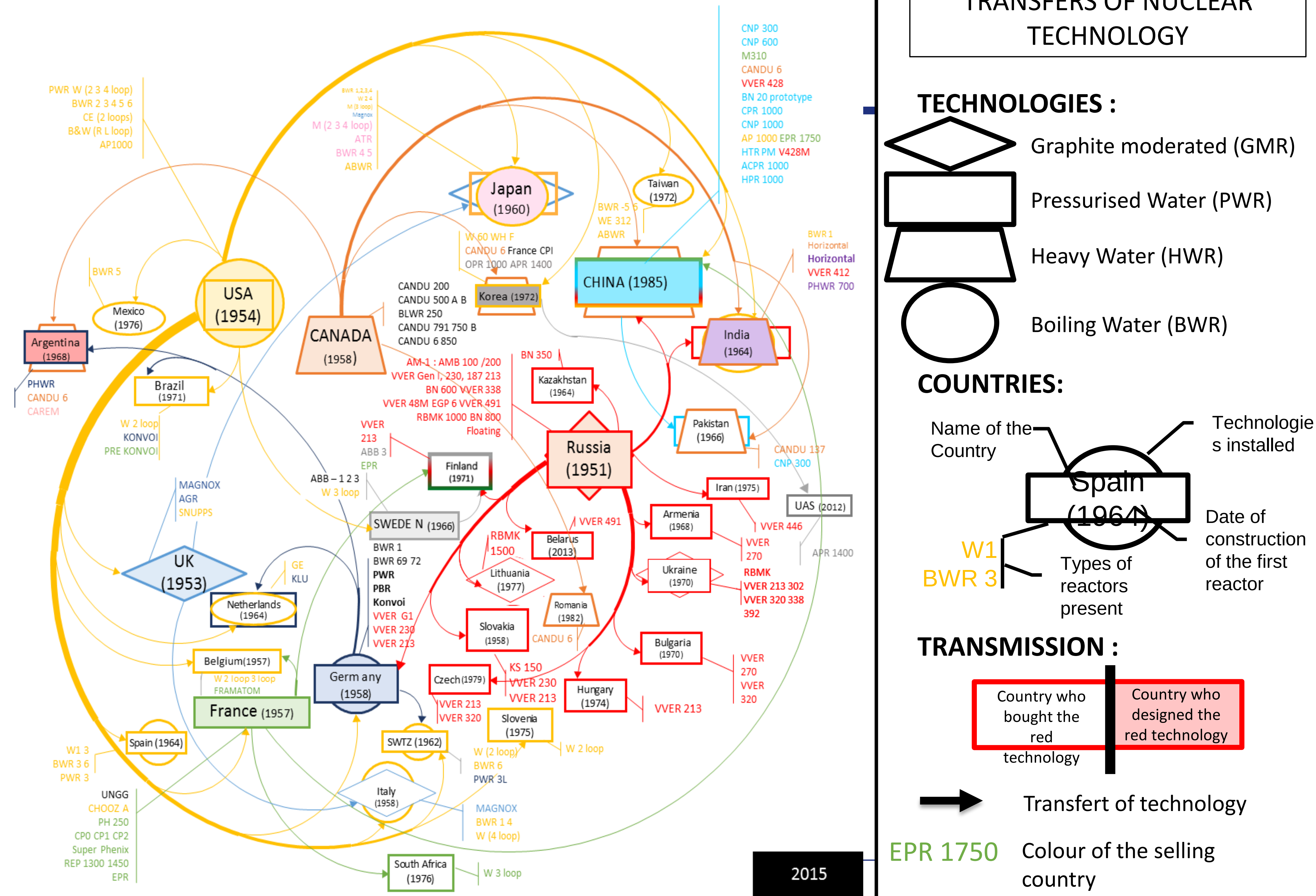
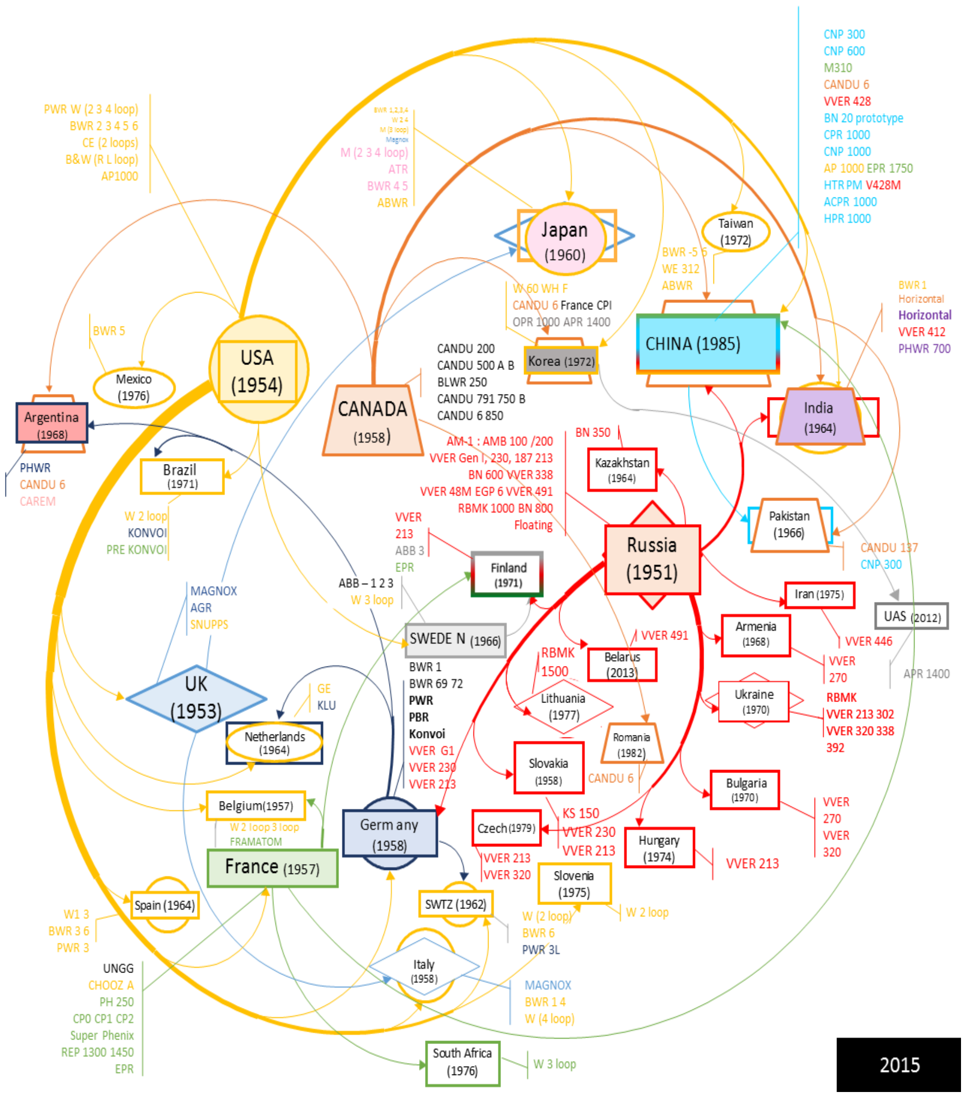
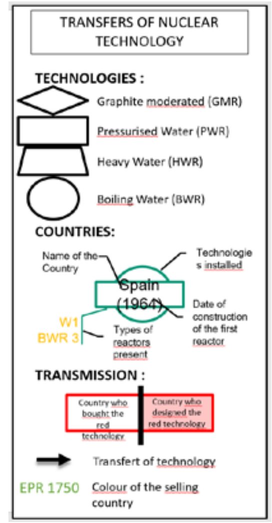
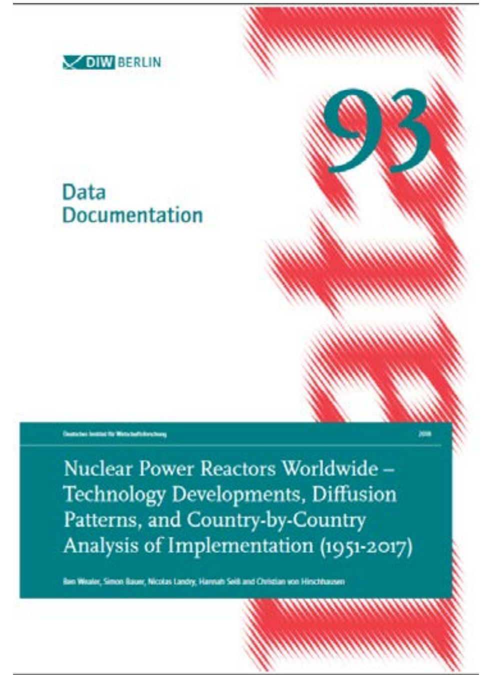


The origins of nuclear power: science and warfare (Lévêque 2014)







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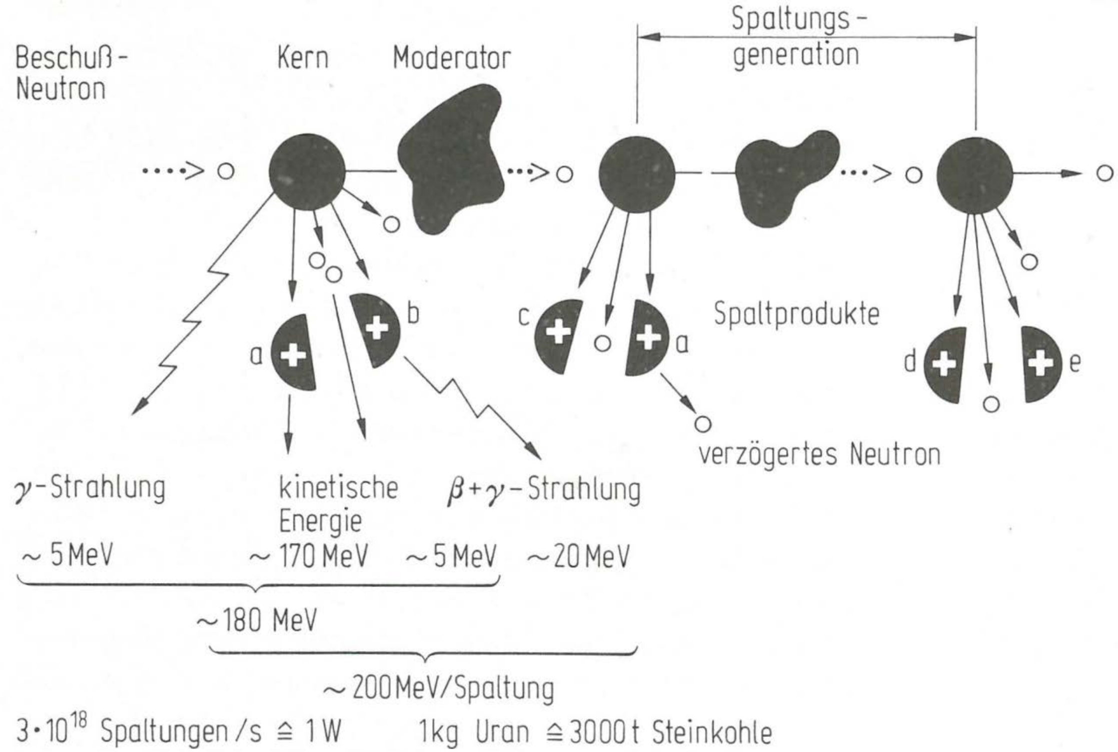
Francois Lévêque (2014, p. 212):
„The nuclear industry is the child of science and warfare“



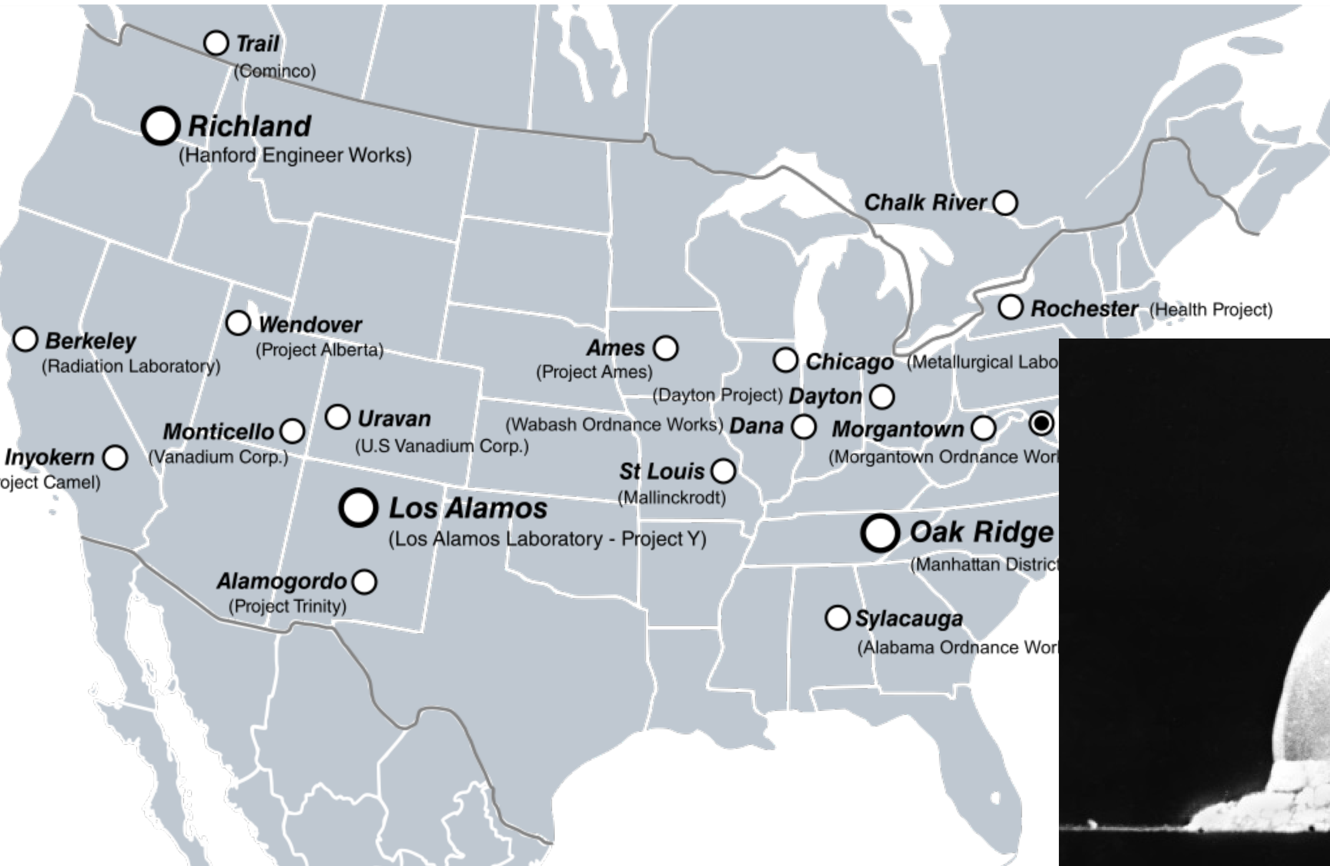
Durchschnittliche *Energieverteilung* für die Spaltung des U^{235}-Kerns in MeV:

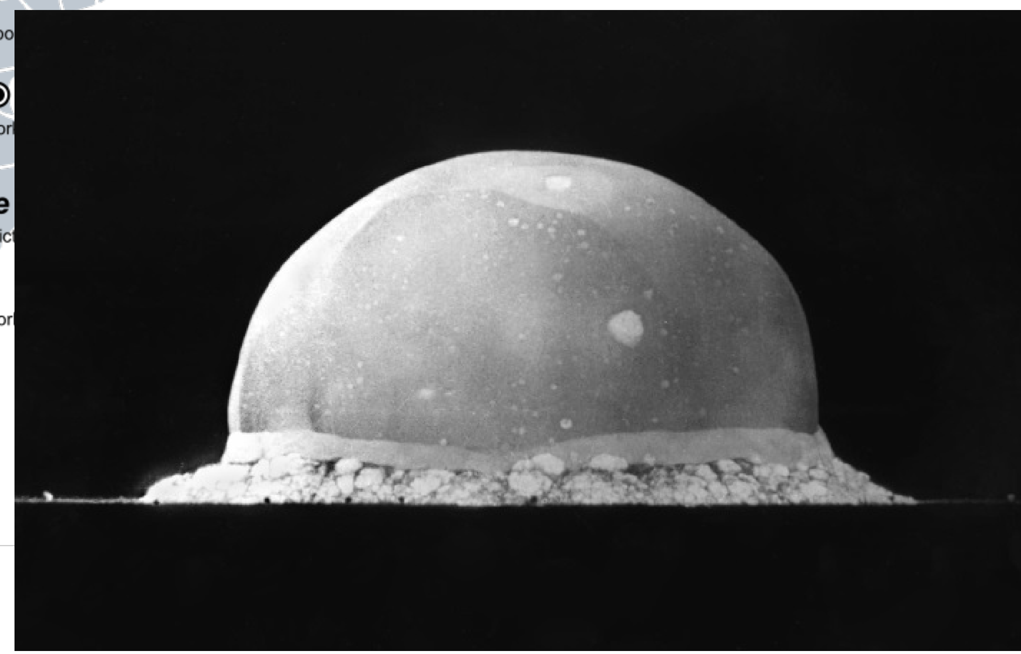
$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{89}_{36}Kr + {}^{144}_{56}Ba + 3\,{}^{1}_{0}n$$

Ausgangskern (Spaltstoff)	thermisches Neutron 2000 m/s	kurzlebiges Zwischenprodukt	hier Krypton	hier Barium	3 Neutronen
			(als Beispiel häufiger Spaltprodukte)		

Manhattan Project (1942 – 1946): Science … and military warfare

Manhattan Project: 1942-1946: General Groves + Professor Oppenheimer (Jaensch and Herrmann, 2015)





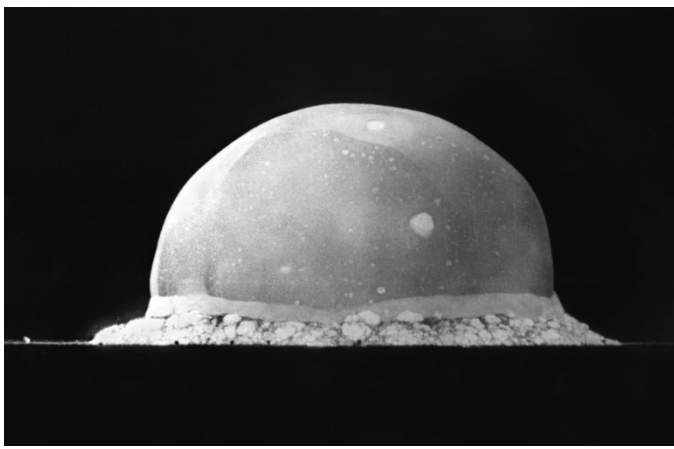
First nuclear bomb: Trinity-Test, July 16, 1945

„Nuclear energy is the daugther of science and the military“ (FL, 2014)

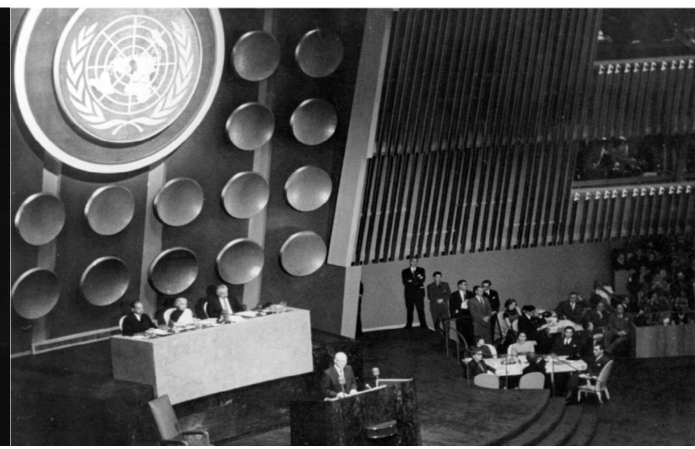
No „economic“, but military incentives at the outset

Joint production emerging in the 1950s

No nuclear power plant built within a competitive, market-based system



Erste Atombombe: Trinity-Test , 1945
(Quelle: Wikipedia)



US-Präsident Eisenhower: Atoms for Peace, 1953
(Quelle: germanhistorydocs.ghi-dc.org)

Unterzeichnung des EURATOM-Vertrags, 1957 (Quelle: germanhistorydocs.ghi-dc.org)

The inseparable nexus: nuclear power and nuclear weapons

Acheson-Lilienthal Report (1946, p.10): "*The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course interchangeable and interdependent.*"

Lovins et al. (1980, p. 1144): "*The propagation of nuclear power thus turns out to have embodied the illusion that we can split the atom into two roles as easily and irrevocably as into two parts—forgetting that atomic energy is a-tomic, indivisible.*"

Other work in this sense by many (REFORM and other) researchers

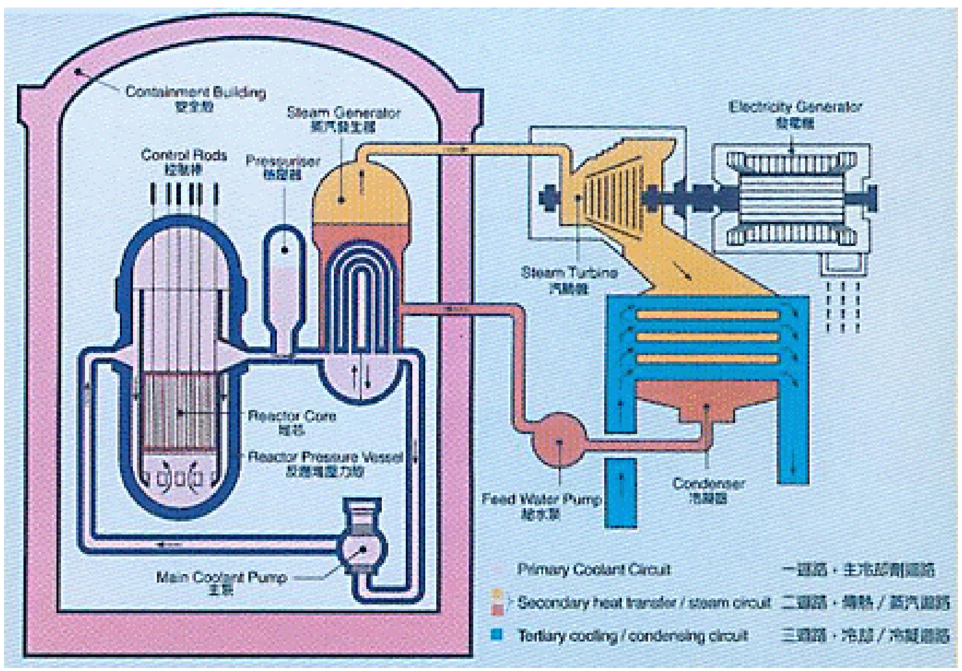
Hirschhausen (2017): interpretation of the nuclear industry in terms of "economies of scope", where strategies, costs, and benefits must be assessed in the multiproduct context of military and civilian uses of nuclear power.

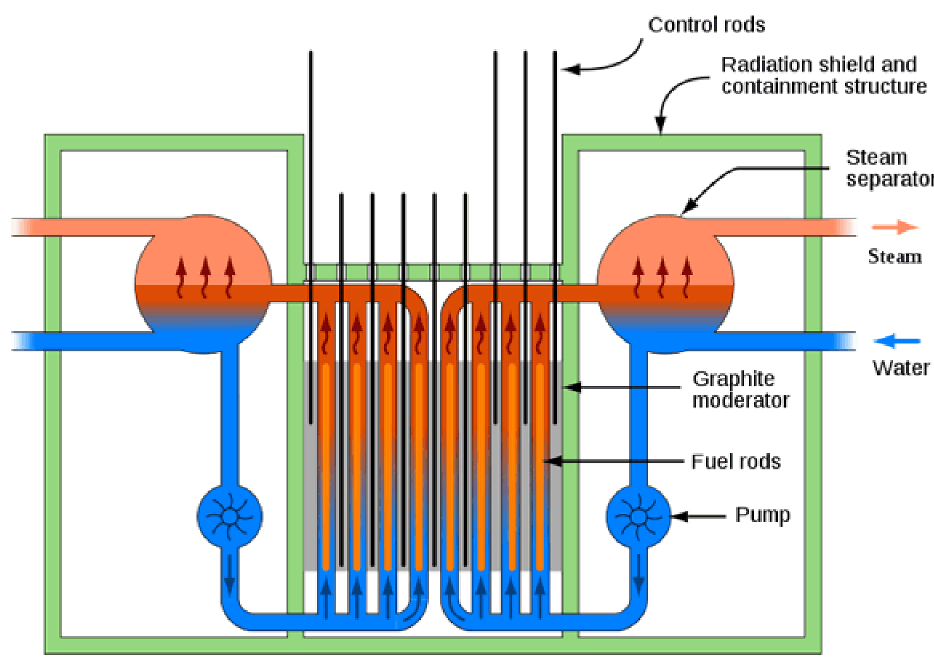
Historical-empirical support for the “economies-of-scope“ hypothesis (“dual use“): C(x, y) < C(x, 0) + C(0, y)

Country	“military use“	“civil use“
USA	~ Nuclear power as cornerstone of military strategy: Project Manhattan, post-war build up ~ nuclear weapon upgrade program (2014 – 2023): US-$ 350 bn.	~ first co-production of electricity in Hanford ~ Nautilus submarine: first use of PWR
Soviet Union	~ nuclear power as cornerstone of “Cold War“	~ direct synergies through the dual use of graphite-reactors to facilitate the extraction of plutonium + electricity
UK / France	~ indpendent military strategies post WW II	~ + some electricity
India	~ converted the spent fuel to produce weapongrade plutonium (1974)	~ purchase of CANDU-heavy water reactor for civil purposes (l960s)
South Africa, North Korea, Sudan, etc.	…	…

Stylized comparison between graphite- and light-water (pressurized) reactors

Reactor types compared	
LWR/PWR: ~ under pressure ~ focus on electricity ~ plutonium extraction possible, but complex	Graphite-moderated (e.g. RBMK „reactor bolshoy moshchnosty kanalny") ~ no pressure, rods flexible ~ continuous, flexible plutonium extraction





Are graphite-moderated NPPs („plutonium factories“) different from “normal“ light-water reactors? Total outage data

2014 Operating Experience

DE-23 GRAFENRHEINFELD

6. Full Outages, Analysis by Cause

Outage Cause	2014 Hours Lost			1983 to 2014 Average Hours Lost Per Year		
	Planned	Unplanned	External	Planned	Unplanned	External
A. Plant equipment problem/failure		242			187	
C. Inspection, maintenance or repair combined with refuelling	437			762	3	
L. Human factor related					25	
Z. Other					4	
Subtotal	437	242	0	762	219	0
Total	679			981		

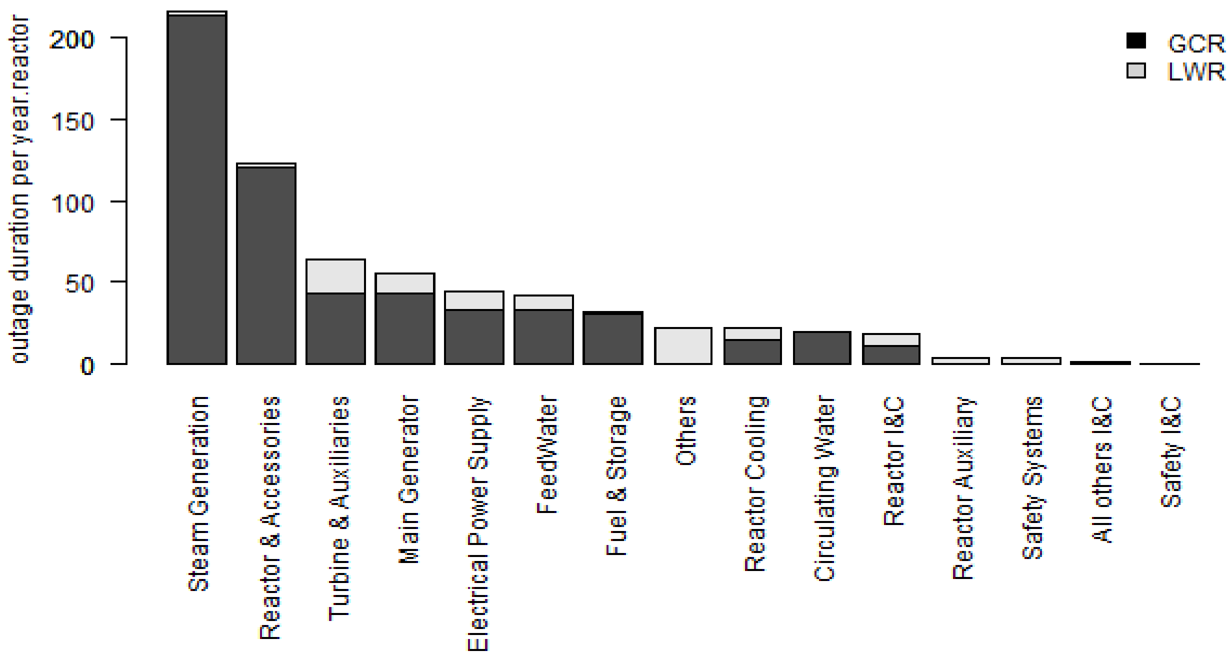
7. Equipment Related Full Outages, Analysis by System

System	2014 Hours Lost	1983 to 2014 Average Hours Lost Per Year
11. Reactor and Accessories		22
14. Safety Systems		0
15. Reactor Cooling Systems		34
16. Steam generation systems		18
31. Turbine and auxiliaries	119	22
32. Feedwater and Main Steam System		13
35. All other I&C Systems		24
41. Main Generator Systems		47
42. Electrical Power Supply Systems	123	3
Total	242	183

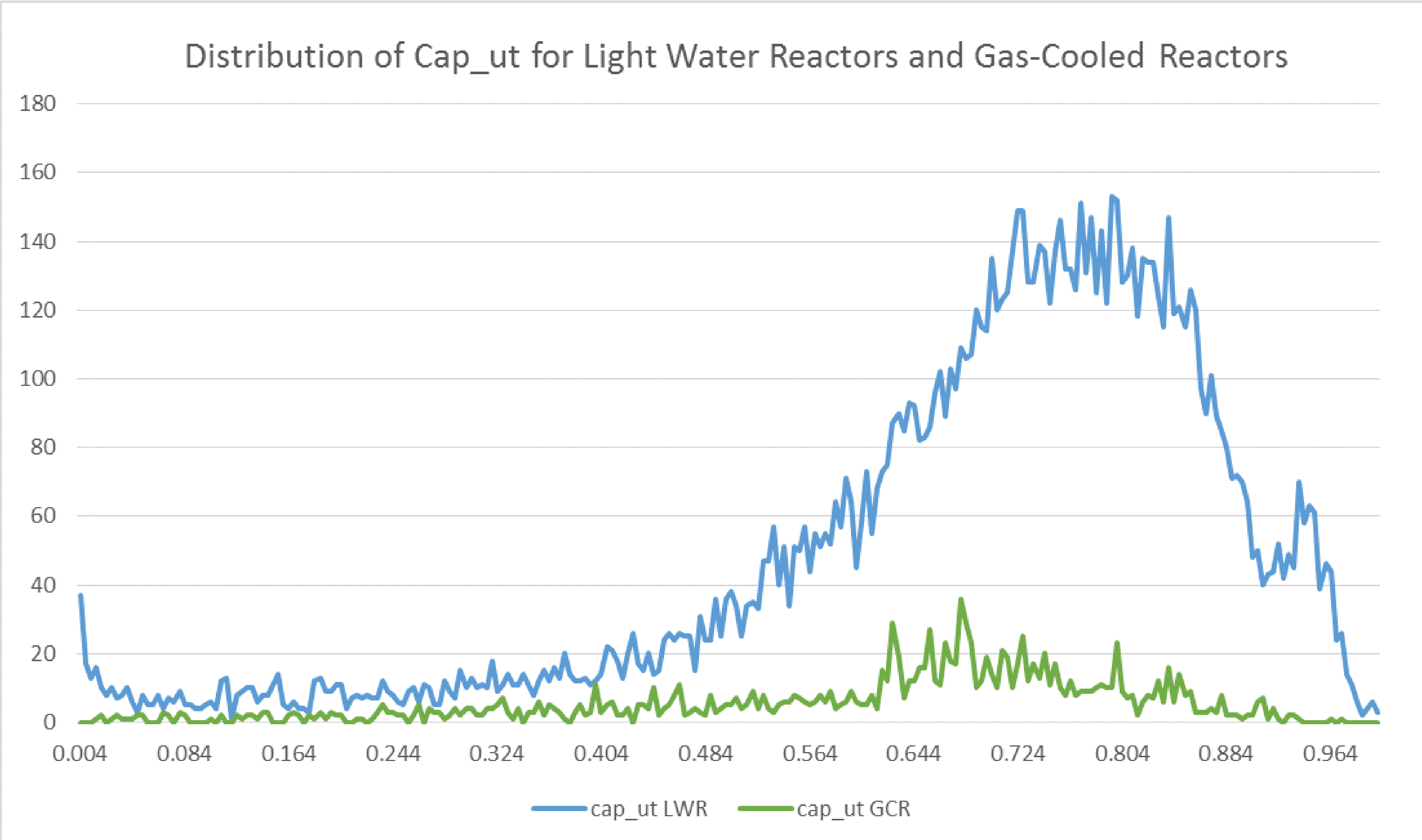
Data on unexpected outages

Extended data to 2006-2015

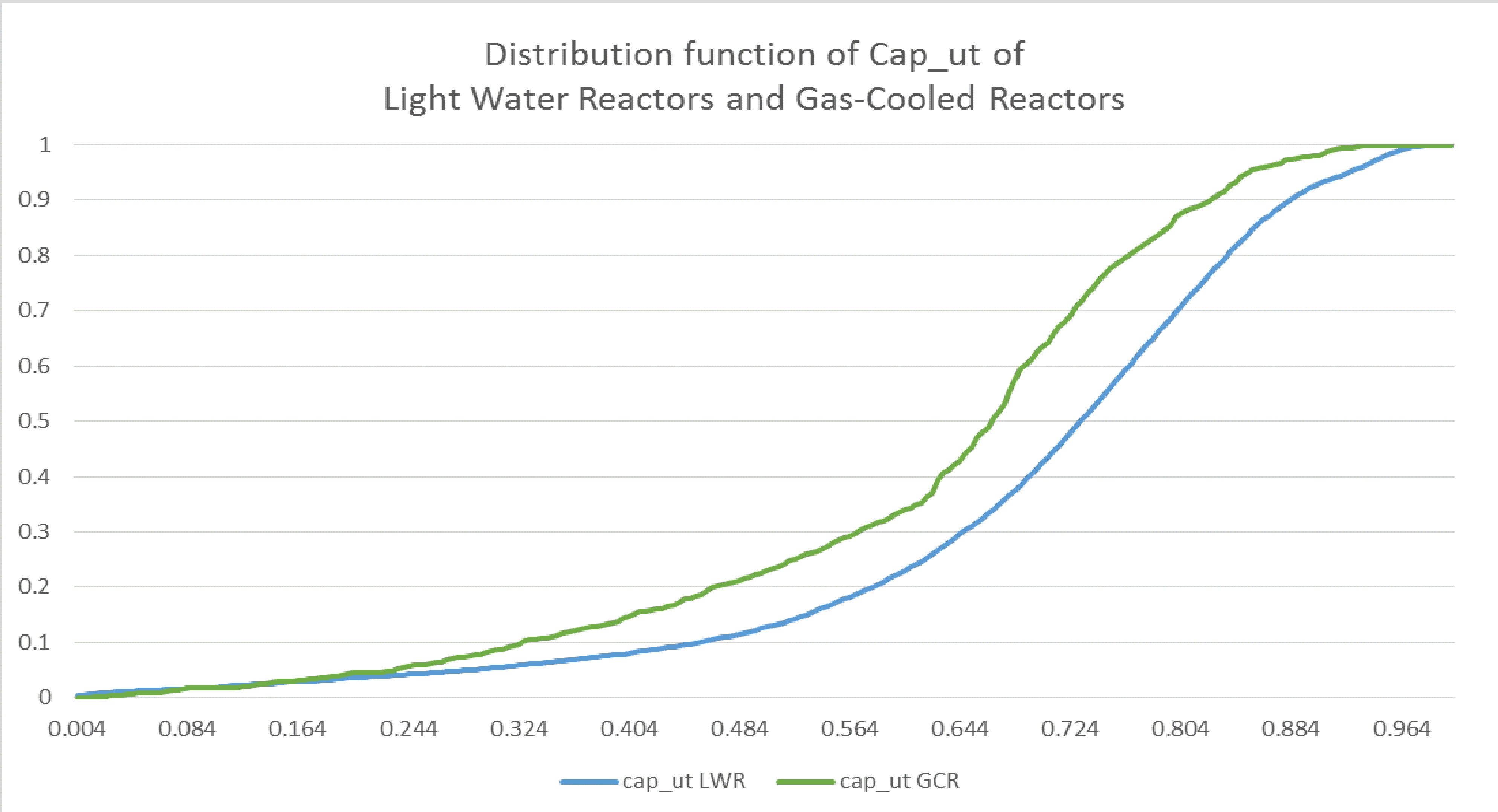
	CAN	FRA	JPN	ESP	CHE	GBR	USA
GCRs in year.reactor	0	0	0	0	0	173	0
LWRs in year.reactor	0	580	525	80	50	10	1031
mean capacity (MWe)	704	1.080	866	942	667	548	995
mean availability	79%	77%	38%	86%	88%	68%	90%



Graphite-moderated (0.49) and light-water reactors (0.67): different mean (t-value: 10.054, p-value: 2.2e-16) …



… and different distribution of capacity utilization values (Kolmogovor-Smirnov, p-value of 0.02566)



Data Analytics: The hypothesis seems to be correct… (Seifert, et al., 2018)

			Upsampling		Downsampling	
			GCR	LWR	GCR	LWR
CART	Prediction	GCR	76.87% (8.65 %)	24.90% (4.80 %)	75.42% (9.99 %)	25.91% (5.05 %)
		LWR	23.13% (8.65 %)	75.10% (4.80 %)	24.58% (9.99 %)	74.09% (5.05 %)
RF	Prediction	GCR	75.69% (1.27 %)	24.13% (1.88 %)	68.80% (5.87 %)	27.56% (9.01 %)
		LWR	24.31% (1.27 %)	75.87% (1.88 %)	31.20% (5.87 %)	72.44% (9.01 %)
BO	Prediction	GCR	NA (0.00 %)	NA (0.00 %)	83.33% (27.33 %)	16.99% (2.03 %)
		LWR	NA (0.00 %)	NA (0.00 %)	16.67% (27.33 %)	83.01% (2.03 %)

Table 4: Best predictions

The atomic-industrial complex today

- Mills (1956) and Eisenhower (1961)

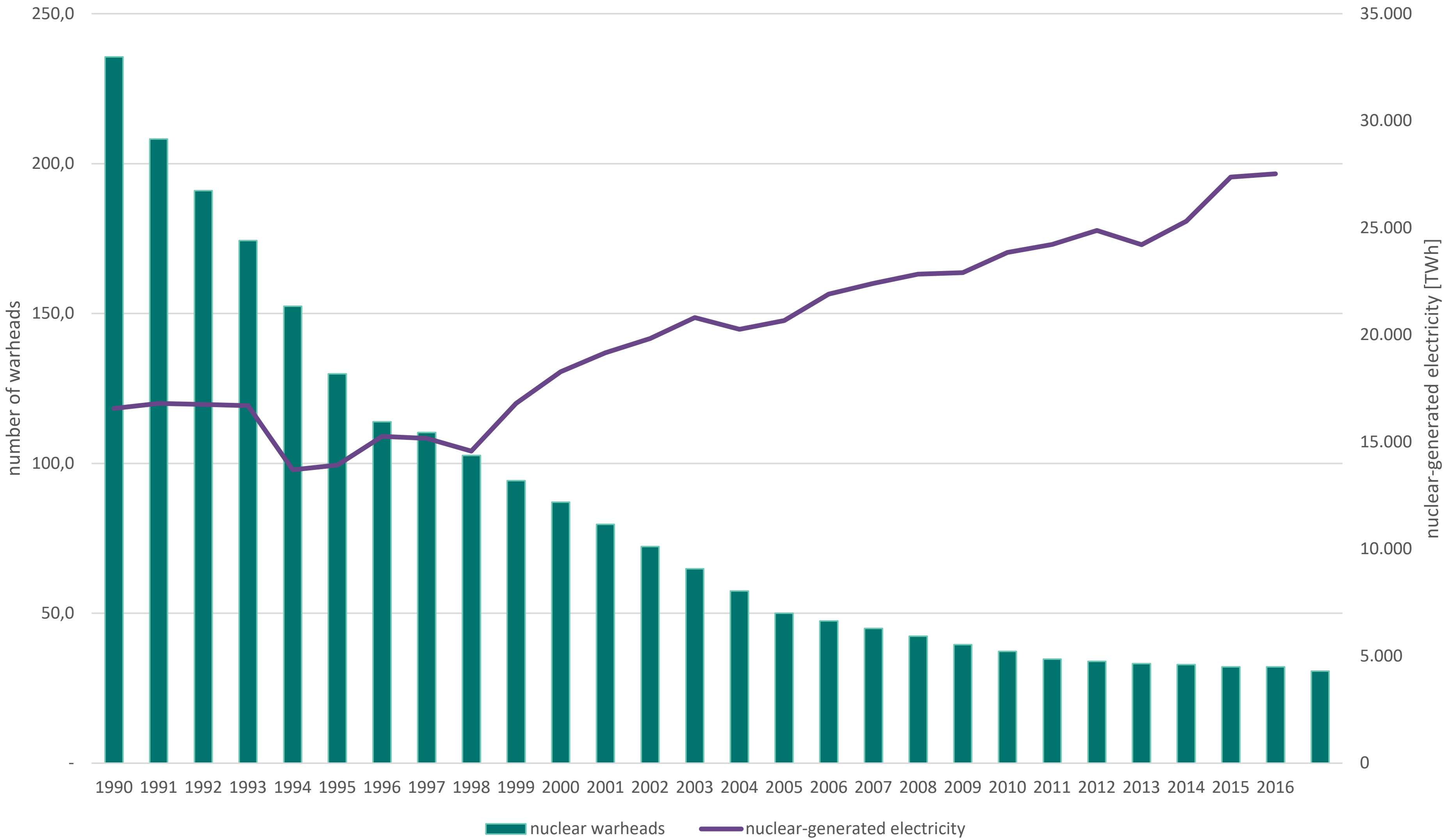
- Military and nuclear research apparatus are often the same e.g. CEA in France, CNNC in China, UKAE in the U.K., Pakistan

- Reactor vendors Areva (now-Framatome), KEPCO, Rosatom (Atomstroyexport) are state-owned companies in a centralized market environment

- Reactor vendors GE, Westinghouse are also military technology suppliers

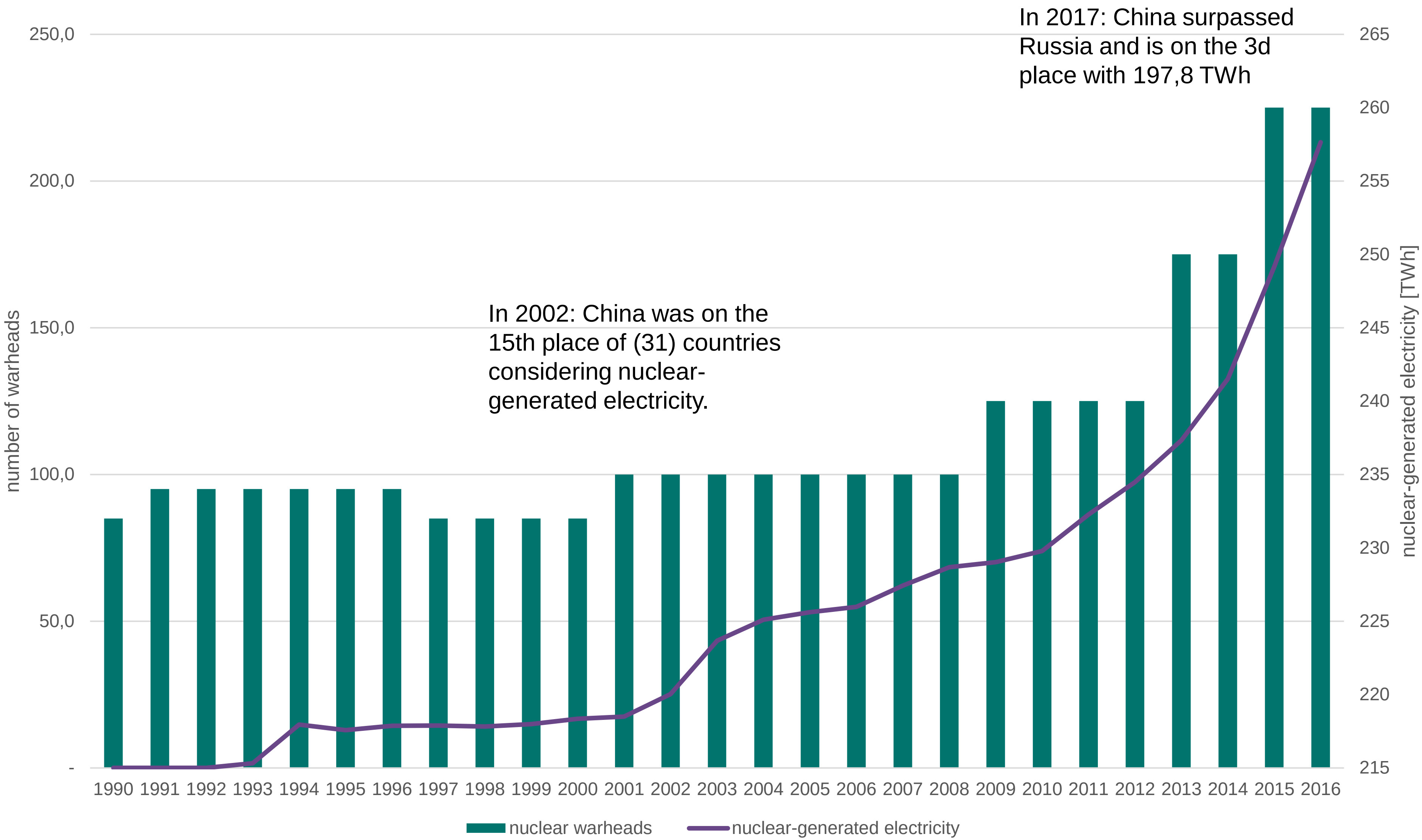
- Financial aspect: “nuclear diplomacy” in form of offering technology and low interest loans (e.g. Export Import Banks, state loans)

Russia: Nuclear share of electricity generation and nuclear weapons in Russia, 1990-2016



Source: Own depiction based on Bulletin of the Atomic Scientists (2017) and BP (2017).

China: Nuclear share of electicity generation and nuclear weapons in China, 1990-2016



Source: Own depiction based on Bulletin of the Atomic Scientists (2017) and BP (2017).

US– Key Apects of the Military Nuclear Strategy (Nuclear Posture Review 2018)

Deployed warheads	Other warheads	Total inventory
1,930	2,500	7,000

Rehabilitation and modernization of the nuclear triade.

More strategic (taktisch) nuclear weapons in the form of "mini nukes".

In the short term, "mini nukes" will be employed on submarines. Advantage: There is no need for a "host nation" (e.g. Germany, Italy, Turkey).

In Europe: increase the number of bombers and „dual capable aircraft"

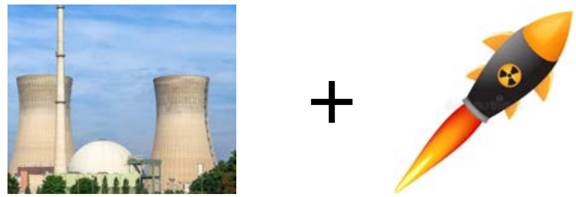
Budget for the modernization and expansion of the nuclear arsenal: +6,4% of DoD Budgets (+/- 33 bn USD, DoD Base Budgets 2018: 521,8 bn USD).

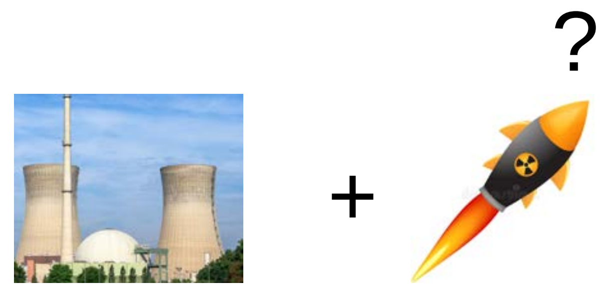
No ratification of the Comprehensive Nuclear Test Ban Treaty.

Main motivation: allegation, that Russia broke agreements (e.g. Intermediate-range Nuclear Forces Treaty). Russia denies this and accuses the US to have done the same (e.g. nuclear weapons systems in Romania and Poland)

Overall strong "antirussia" rhetoric in the report.

The perspectives of nuclear power



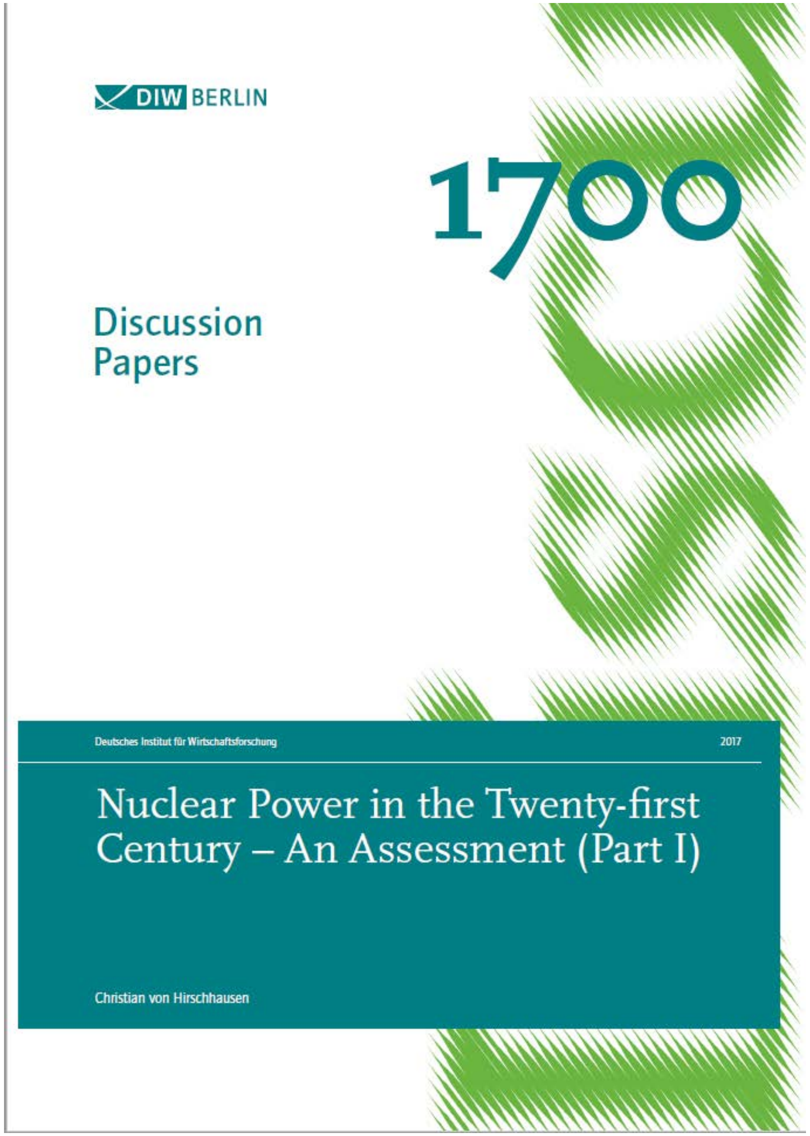


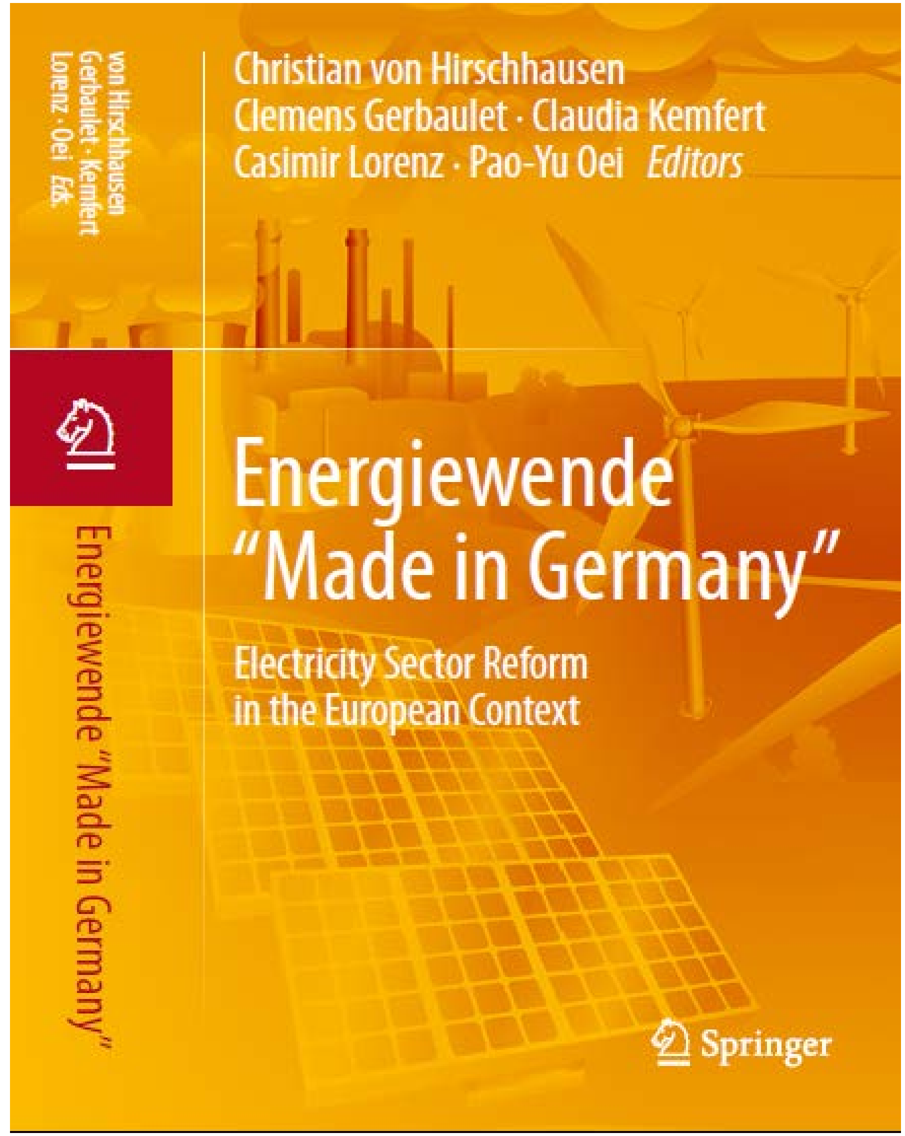
No Scope countries	Scope countries	Newcomer countries
Germany, Spain, Belgium, Italy, Switzerland, Sweden, South Korea ➔ Close down NPPs, currently no replacement foreseeable What about Japan, Eastern Europe?	USA, UK, India, Pakistan, France, North Korea, Russia, China ➔ Scope countries call for future nuclear deployment, heavy investments into the nuclear supply chain, and retrofitting of older nuclear plants.	Iran, UAE, Turkey, Saudi Arabia, Egypt, Jordan, Bangladesh, Sudan, Belarus ➔ High dynamics especially in the Middle East: if Iran wants reprocessing, Saudi Arabia will want it too

Agenda

1) Motivation
2) The nuclear power paradox(es)
3) "Economies of scope" in nuclear technologies
4) **Nuclear diplomacy, the nuclear resource curse and low carbon transformation**
    1) Russia
    2) China
    3) United States of America
5) Conclusion

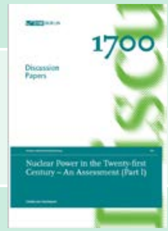
Discussion Paper: Nuclear Power in the 21st Century, and reflection about “low-carbon energy transformation

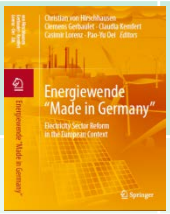




Bridging nuclear policies and “low-carbon transformation“ at the country level

		Sectors					
		CoalExit	Nuclear	Renewab les	Efficienc y	…	
Countries							
Germany							
Russia							
China							
India							
U.S.							
Mexico							
…							





The traditional “resource curse“

“One of the surprising features of modern economic growth is that economies with abundant natural resources have tended to grow less rapidly than natural-resource-scarce economies.“ (Sachs and Warner, 1995)

Recent examples:

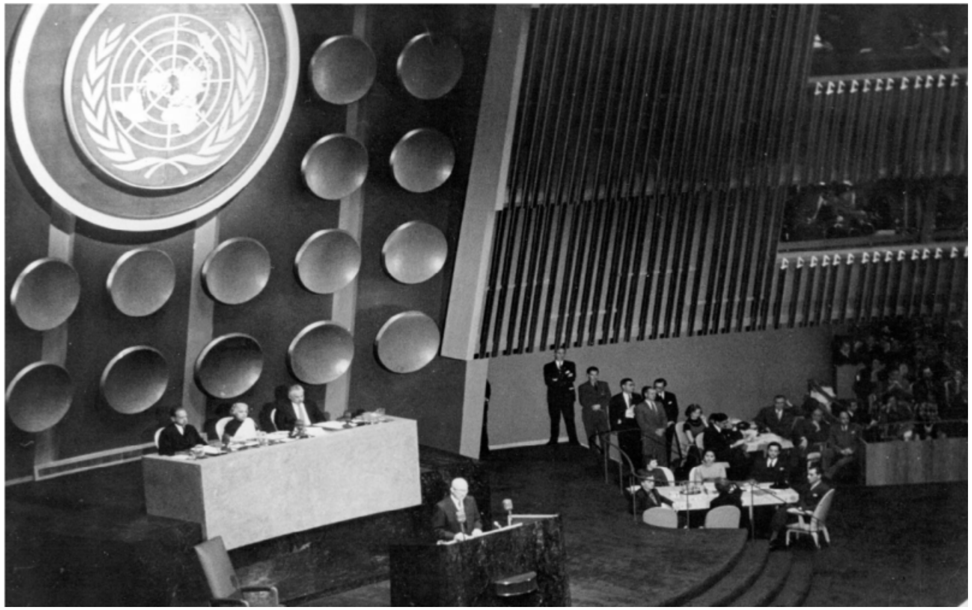
~ Venezuela (oil)

~ Democratic Republic of Congo (mineral resources)

[not to distinguish with: “Dutch disease“, not part of the resource curse analysis]

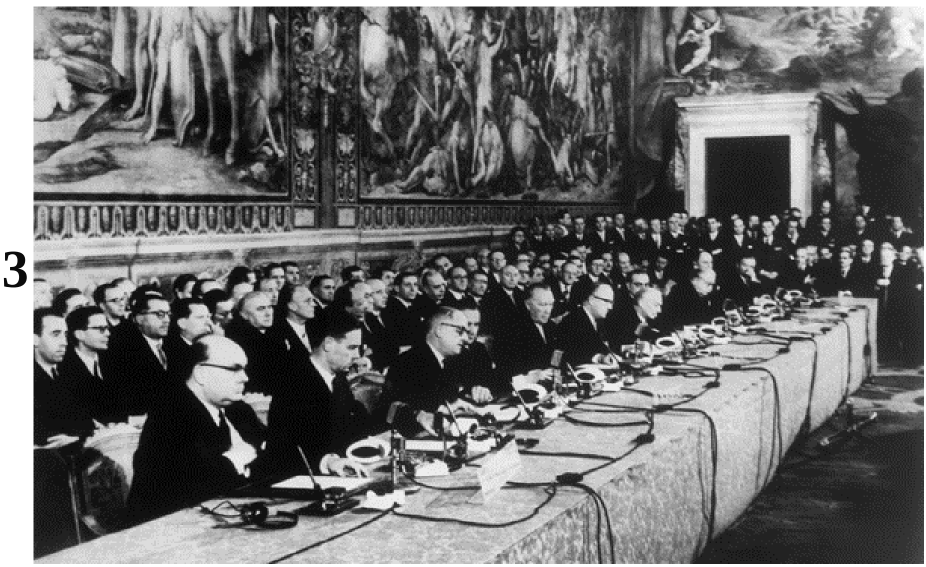
➔ Nuclear hypothesis: The availability of abundant and cheap nuclear power capacities, the “resource”, incites many emerging and poor countries to enter the sector (to “go nuclear”), but is likely to turn into a resource curse not only in economic, but also in longer-term development perspectives.

Imports “too cheap to meter“after World War II …



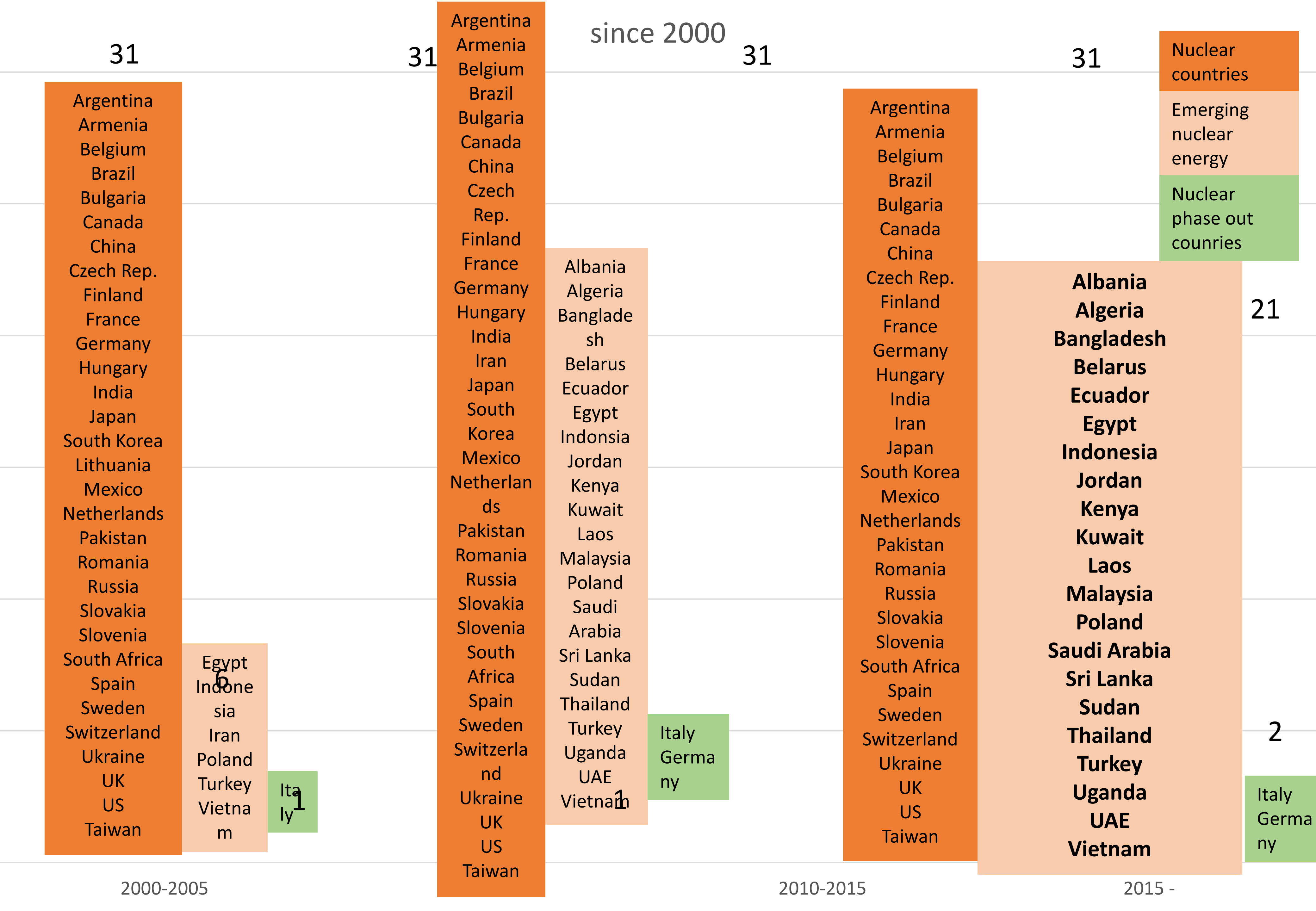
US-Präsident Eisenhower: Atoms for Peace, 1953

(Quelle: germanhistorydocs.ghi-dc.org)



EURATOM-Treaty, 1957

(Quelle: germanhistorydocs.ghi-dc.org)


since 2000
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Italy Germany
Nuclear countries
Emerging nuclear energy
Nuclear phase out counries
2000-2005
2010-2015
2015 -

Russia's nuclear diplomacy: the major seller of reactor technology

Rosatom claims 67 percent of the worldwide nuclear construction projects—35 units are signed as contracts and intergovernmental agreements.

Of the 54 construction projects in late 2017 17 or ~32 percent are built by Rosatom.

Russian „nuclear diplomacy" with reactor exports to India, Belarus, China and contracts with Turkey, Egypt, Saudi Arabia.

Russia not only delivers technology but also the financial capital (low interest loans), e.g. 11.35 bn for Bangladesh, 9bn for Belarus, 25bn for Egypt…

According to Rosatom, the ordering portfolio is worth over 133 billion USD.

A large part of the funding for these projects comes from Russia's Wealth Funds, which is also used for stabilizing the Russian economy.

Supplier Country	Number of NPP construction projects	Share [%]	HHI
Russia	17	31,48	991
China	12	22,22	494
Korea	9	16,67	278
USA	6	11,11	123
India	4	7,41	55
France	4	7,41	55
Japan	2	3,70	14
Total	54	100,00	2.010

China‘s nuclear diplomacy: …

China‘s unique Position as a seller and buyer of reactor technology.

China has established itself firmly among the three global nuclear superpowers, alongside or even leading the United States and Russia.

In 1993, China started exporting reactors: CNP 300 to Pakistan ...

… and has been successful in its nuclear diplomacy recently, providing the Hualong HPR to countries like Pakistan, probably Sudan, the U.K., and Argentina

The export of reactor technology is done by the Chinese companies in cooperation with the China Bank of Development and the Export and Import Bank of China in countries like UK, Pakistan, or Argentina.

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USA‘s nuclear diplomacy: … unclear

Currently only construction project outside of the US: China. Westinghouse expects China to build at least 20 AP1000s in the coming decade <u>but</u> due to the technology transfer, the company will not earn money on this.

Current discussions: India and Saudi Arabia

Westinghouse received strong support from US Energy Secretary Rick Perry for its plan to build six AP1000s in India.

Westinghouse is also confident that it will be shortlisted for the Saudi Arabian tender.

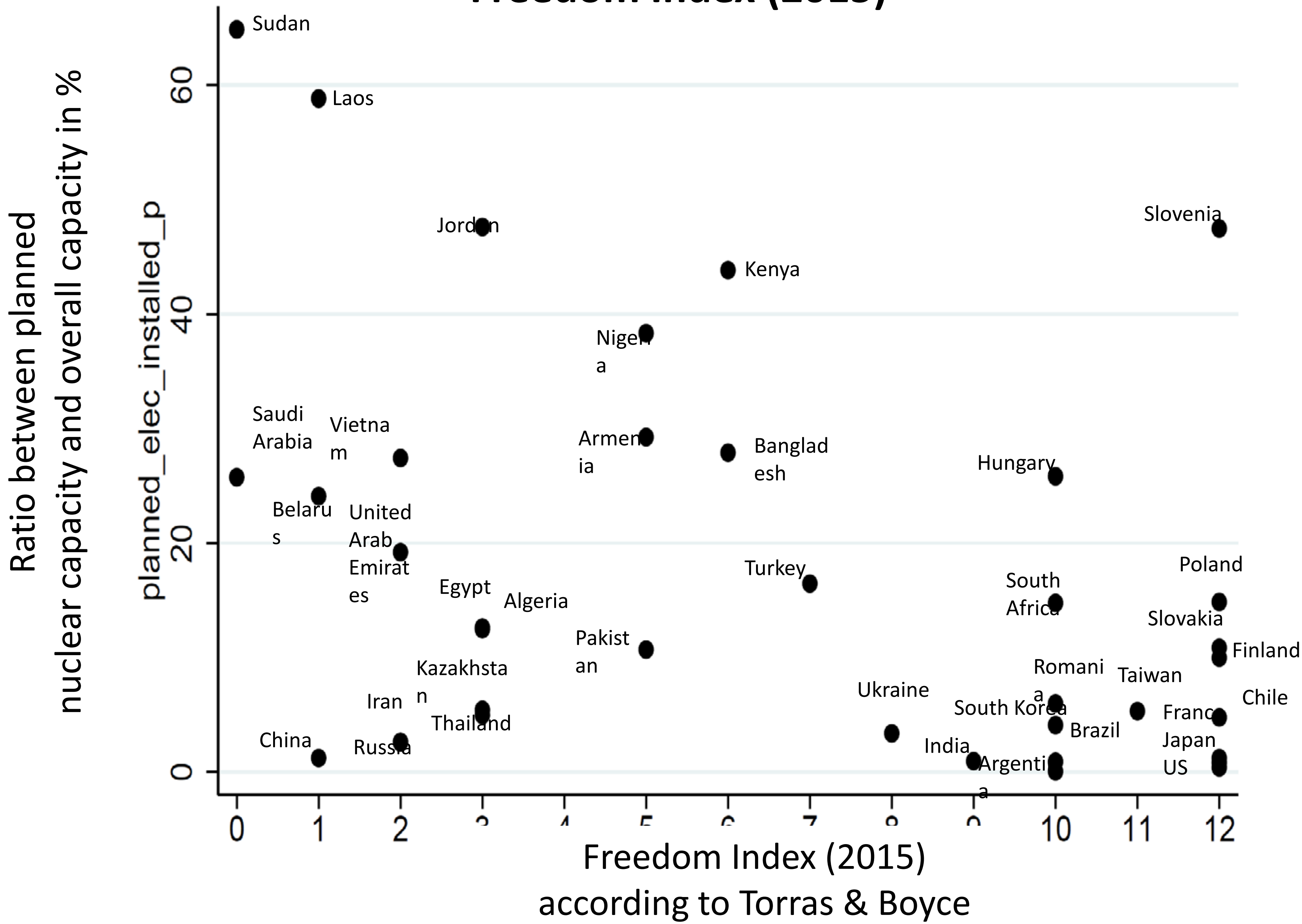
But Rosatom’s business model seems to be more promising as China just ordered four VVER-1200 and India already turned to Russia for imports of VVER-1200, too.

But: will current administration loosen security restrictions?

Rick Perry in 2018 about Westinghouse’s future: “*Nobody in the world makes better reactors than Westinghouse. They had some challenges in the past from its business practices. We leave that where it is. The bottom line is, that’s all behind them. They are lean and mean and ready to get to the work*.”

Ratio planned nuclear capacity (2015) and overall capacity (2015) vs. Freedom Index (2015)

XXXX



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Main Findings

1) Nuclear electricity has never been "economic"

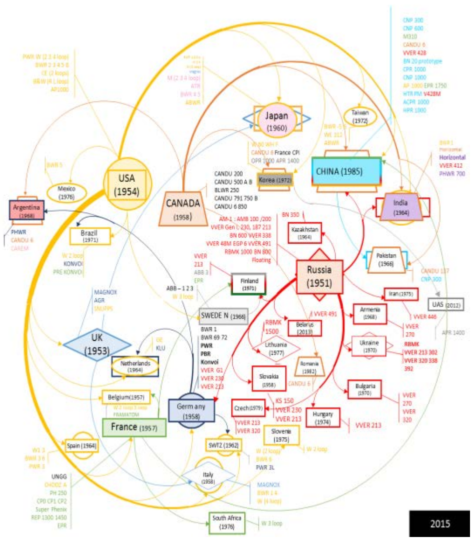
2) "Economies of scope" can explain the nuclear paradox, i.e. high number of (uneconomic) projects

3) Nuclear power "resource curse" hypothesis: Positive relation between nuclear "newbies" and low level of civil and political liberties

22nd REFORM Group Meeting,
August 26-31, Salzburg

Nuclear weapons and nuclear strategies: "Economies of scope", country case studies (US, China and Russia), and the "nuclear resource curse" hypothesis

Sou



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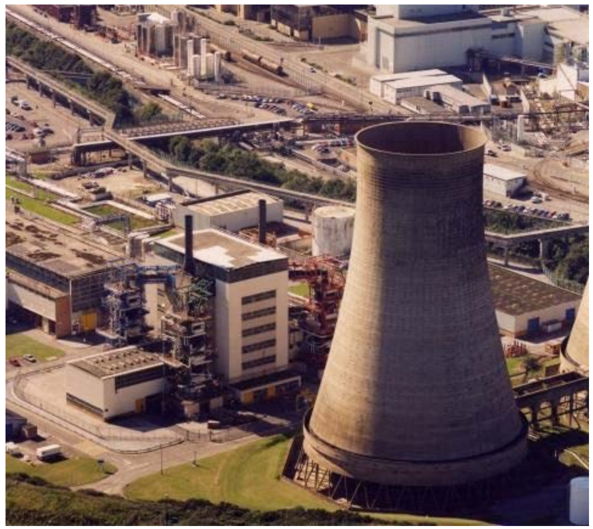

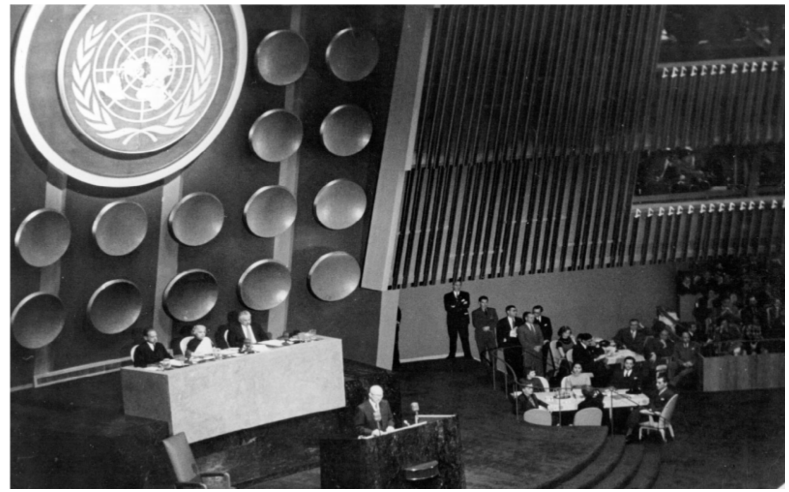

Ben Wealer, Simon Bauer, and Christian von Hirschhausen