Key Note:
An Overview on the Status of Nuclear Decommissioning

Dr.-Ing. Rebekka Volk

7th NUCLEAR DECOMMISIONING & WASTE MANAGEMENT SUMMIT 2020,

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KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)

The Institute

Institute of Industrial Production (IIP)

Chair of Business Administration, Production and Operations Management (Prof. Dr. Frank Schultmann)

- Techno-economic analyses of industrial value chains

Chair of Energy Economics (Prof. Dr. Wolf Fichtner)

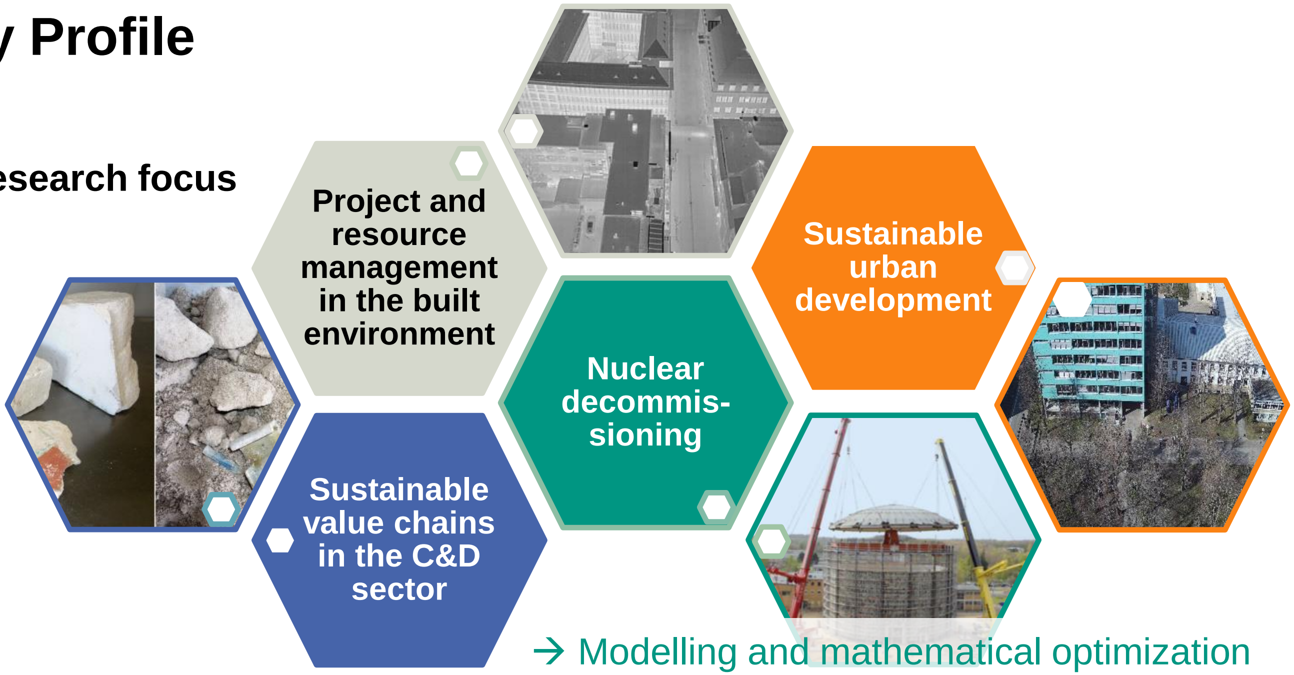
- Techno-economic analyses along the whole energetic value chain

French-German Institute for Environmental Research (DFIU) (Dr. Kira Schumacher)

- Joint research in French-German context in the environmental areas of air, water, land, waste and energy

My Profile

Research focus



→ Modelling and mathematical optimization of decommissioning projects
→ Decision making support for operators, planners, decision/policy makers

Dr.-Ing. Rebekka Volk

Head of research lab:
Project and resource management in the built environment

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Experience

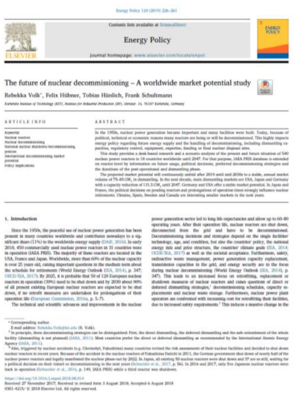
2016: PhD at KIT

2016-today: PostDoc and Head of research lab at KIT

Research Experience:

Projects for the Federal Ministry of Education and Research (BMBF) Germany, especially

- MogaMaR, https://www.iip.kit.edu/english/773_2489.php
- NukPlaRStoR, https://www.iip.kit.edu/english/773_4605.php



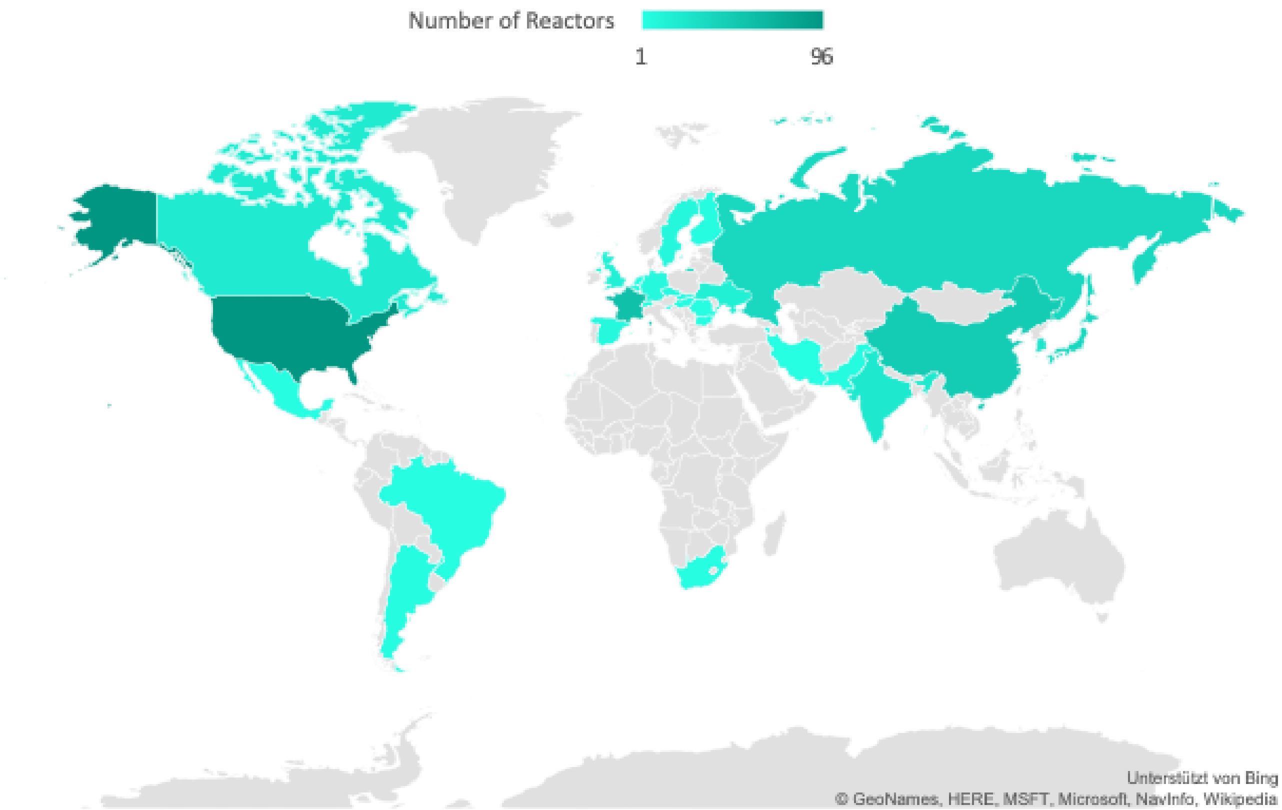
Energy Policy

The future of nuclear decommissioning – A worldwide market potential study

Rebekka Volk*, Felix Hübner, Tobias Hünlich, Frank Schultmann

Volk et al. (2019)

Aging Nuclear Power Generation Reactors induce a massive change in the energy sector worldwide



Total Number of Operational Reactors

449

Share of Worldwide Energy Supply

11%

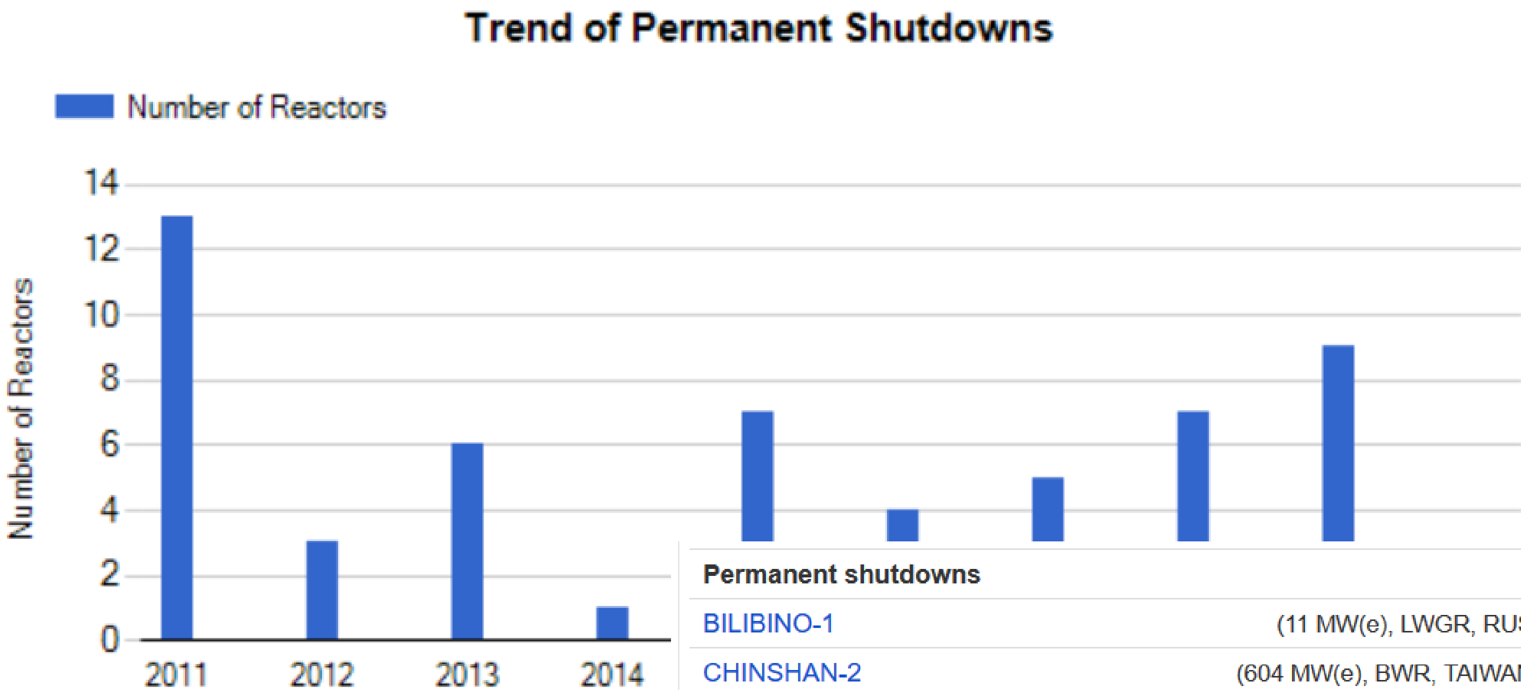
Average Age of Operational Reactors

30 years

- Aging reactors are raising questions about the schedule of their retirements
- Increased focus on retrofitting, replacement or shutdown measures
- Need for decommissioning schedules, dismantling and capacity replacements

Source: DAtF (2017), IAEA PRIS (Status: November 2019)

The Fukushima Shock and the Trend of Permanent Shutdowns (IAEA)



Permanent shutdowns	
BILIBINO-1	(11 MW(e), LWGR, RUSSIA) on 14 January
CHINSHAN-2	(604 MW(e), BWR, TAIWAN,CHINA) on 16 July
GENKAI-2	(529 MW(e), PWR, JAPAN) on 9 April
MUEHLEBERG	(373 MW(e), BWR, SWITZERLAND) on 20 December
PHILIPPSBURG-2	(1402 MW(e), PWR, GERMANY) on 31 December
PILGRIM-1	(677 MW(e), BWR, USA) on 31 May
RINGHALS-2	(907 MW(e), PWR, SWEDEN) on 31 December
THREE MILE ISLAND-1	(819 MW(e), PWR, USA) on 20 September
WOLSONG-1	(661 MW(e), PHWR, KOREA,REP.OF) on 24 December

Source: IAEA PRIS, https://pris.iaea.org/pris/ (Status : January 2020)

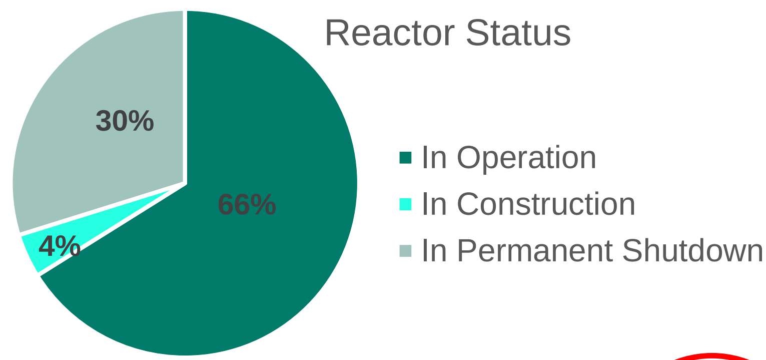
1 What is the **status** of nuclear power generation reactors worldwide and their **grid disconnection and dismantling dates?**

2 What are **interesting nuclear dismantling markets** and how is their expected development over time?

3 What are **consequences** of future nuclear dismantling?

Scope of Nuclear Decommissioning Market Potential Study

Country	Number of reactors in operation [#]	Average age of nuclear reactors [years]
Belgium	7	39
Bulgaria	2	27
Canada	19	33
France	58	31
Germany	7	30
Italy	0	49
Japan	42 (ready-for operation)	28
Lithuania	0	31
Russia	37	30
Slovakia	4	24.5
South Korea	24	19
Spain	7	35.8
Sweden	8	37
Switzerland	5	42
Taiwan	6	35
UK	15	32
Ukraine	15	26.6
USA	99	36



Status	Considered	PRIS	Percentage
In Operation	357	450	79%
In Construction	22	56	39%
In Permanent Shutdown	161	166	97%
Total	**540**	**672**	**80%**

- We considered 18 countries with their nuclear facilities listed in IAEA PRIS database
- The analysis comprises 80% of all listed reactors worldwide.
- We focus on older nuclear facility stocks (e.g. excluding India, China, etc.)

Source: IAEA PRIS (status: April 2018), Volk et al. (2019)

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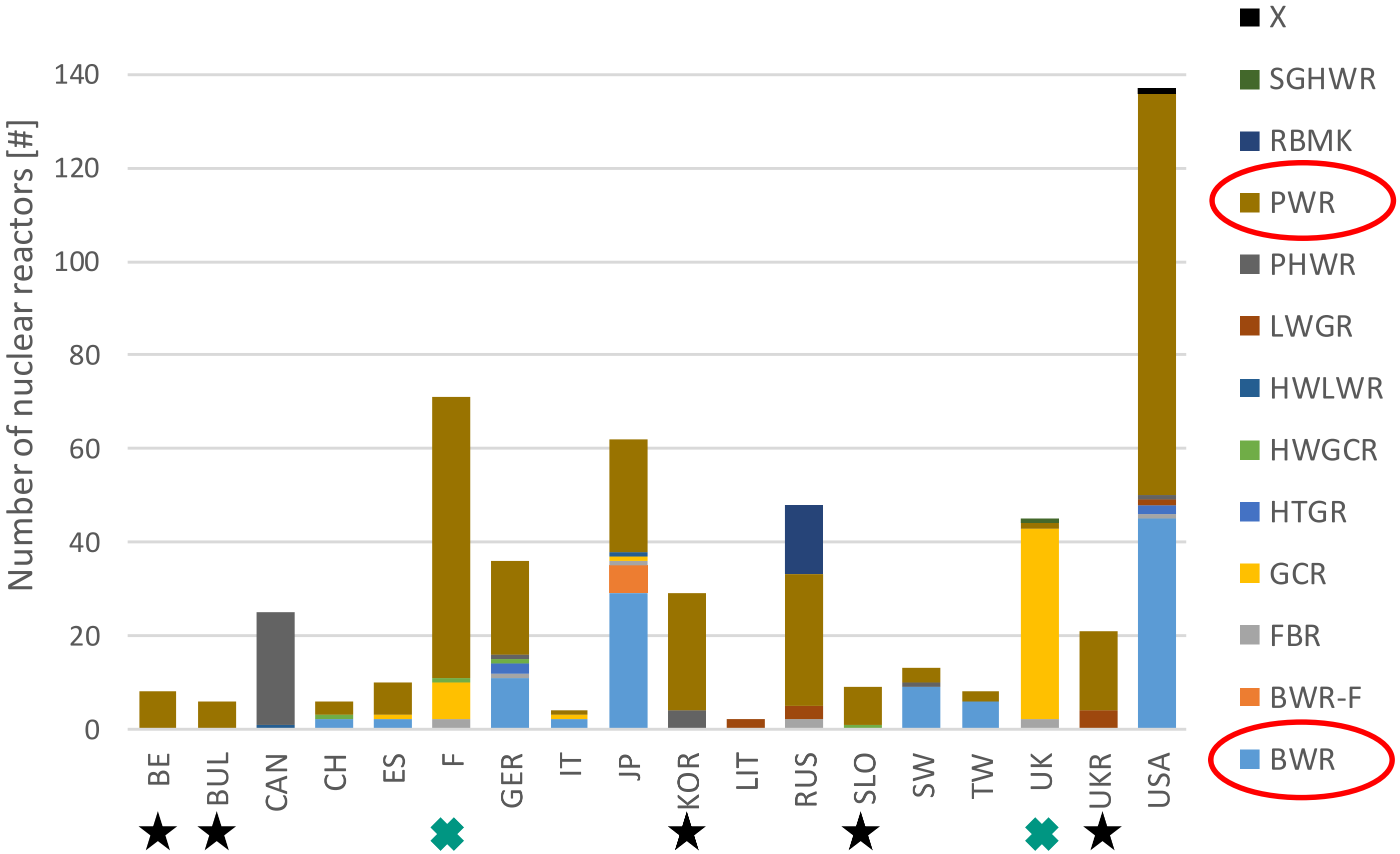
Within the considered Countries different Types of Reactors have to be decommissioned.



- Most reactors are Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR)
- ★Korea, Ukraine, Belgium, Slovakia and Bulgaria have almost exclusively PWR technology
- ✖France and UK have a considerable share of Gas-Cooled Reactors (GCR, HTGR)

Source: Volk et al. (2019) based on IAEA PRIS (status: April 2018)

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Aging Reactors require Decommissioning Schedules, Dismantling and Capacity Replacements

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Age classes [years]	BE	BUL	CAN	CH	ES	F	GER	IT	JP	KOR	LIT	RUS	SLO	SW	TW	UK	UKR	USA	Total
0-5						1			2	6		10	2		2		2	5	30
5-10									1	3		2							6
10-15									3	2		1					2		8
15-20						1			1	4		1	2						9
20-25			1			4			8	5		1				1	1	2	23
25-30		1	3		1	7	3		10	2		2				4	2	6	41
30-35	2	1	7	1	5	24	9		11	5	2	8	2	2	2	6	8	33	128
35-40	2	2	4	1	1	21	5	1	7	1		7	2	4	3		5	14	80
40-45	3	2	4			3	8		13	1		9		5	1	5	1	39	94
45-50			4	3	3	3	6		4			3	1	1		3		20	51
50-55			1	1		5	4	3	2			3		1		12		12	44
55-60	1		1			2	1									11		4	20
60-65												1				3		2	6
Total	**8**	**6**	**25**	**6**	**10**	**71**	**36**	**4**	**62**	**29**	**2**	**48**	**9**	**13**	**8**	**45**	**21**	**137**	**540**

60% (30 years and older); 37% (40 years and older)

- More than 60% of all Reactors are older than 30 years; 37% are older than 40 years
- USA, France and UK have a high number of ageing nuclear reactors
- Decommissioning decisions also depend on the countries' policy and societal acceptance

Source: Volk et al. (2019) based on IAEA PRIS (status: April 2018)

Countries' Policies differ, but ultimately require Dismantling and lead to increasing Market Volume

Country	Normal operation duration [years]	Possibility of prolongation of operation [yes/no] [times]	Prolongation of operation [years]	Duration of post-operational phase [years]	Possibility of deferred dismantling [yes/no]	Duration of deferred dismantling [years]	Planned duration of direct dismantling [years]
BE	40*	Yes, (preferred is 1x)	10	5	Yes, but not probable	No information	No information
BUL	30	Yes, 1x	30	8-12 (for first 2 reactors)	No information	No information	No information
CAN	25	Yes, 1x	30-35	No information	Yes, preferred strategy	30	No information
F	10-yearly review	Yes, 1-5x	10; max. 60 years of operation	5	Yes, but not preferred	No information	No information
GER	40	No	0	5	Yes	No information	No information
JP	40	Yes, 1x	20	5-10	Yes	5-10	3-4
IT	-	No	0	No information	No	0	No information
LIT	No information	No information	No information	No information	No information	No information	No information
RUS	30	Yes	15-30	3-5	Yes	No information	5
SLO	30	Yes, 1x, (linked to EU membership)	0	5	No	0	13 (incl. shutdown, but already delayed)
KOR	30 (Wolsong 1, Kori 1), 40 (others)	Yes, up to 2x	10 (each prolongation)	4	No information	No information	9+2
ES	40**	Yes, no information on the number of times	10 (each prolongation)	No information	Yes, but not preferred	Until 2028 (38 years) for a single reactor	No information

*: Changed in 2014 to maintain national power supply in Belgium

**: This was deleted in 2011 from the law so that currently the Spanish government can decide on the operation duration.

Source: Volk et al. (2019) based on Ake Anunti et al., 2013; Ananiev et al., 2015; ASN, 2016; Barsebäck, 2016; Bruce Power, 2016b; European Commission, 2016b; European Court of Auditors, 2016; Hyung, 2013; IAEA 2015; IAEA, 2004; IAEA, 2015; Joo Hyun Moon, 2013; Kennes et al., 2008; KHNP, 2016; Laraia, 2012; Larsson et al., 2013; OECD and NEA, 2011a; OECD and NEA, 2015; Oskarsson, 2016; RWE, 2016; Schmittem, 2016; Schneider et al., 2016, SOGIN 2016a-d,, SSM, 2008; Ternon-Morin and Degrave, 2012; Wealer et al., 2015; WNA, 2016c; WNA, 2016i; WNA, 2016k; WNA, 2016d; WNA, 2016f; WNN, 2014

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SW	40-50	Yes	10-20	1	Yes, applied in two cases but not preferred	Dismantling is permitted only when a final storage is ready	No information
CH	Unlimited*	No, but adherence to safety regulation required	0	5	No information	No information	No information
TW	40	No	0	8 (for first reactor Chinshan 1)	Not for Chinshan 1, no information for the other reactors	No information	15 (for Chinshan 1)
UK	20 (design life time) with periodical reviews	Yes, up to 4x (but not for the older gas-cooled reactors)	10 (each prolongation)	10 (PWR, gas-cooled)	Yes, deferred dismantling is the main strategy used	85 (gas-cooled reactor)	10 (PWR), no information for gas cooled reactors
UKR	30 (e.g. Rovno 1+2)	Yes	10-20	No information	Yes (Chernobyl)	No information	No information
USA	40	Yes, 1(-2)x	20	2 (or 1-5 dep. on source)	Yes	60 years: max. 50 years waiting time and 10 years dismantling	10

*: Limitations for specific reactors are proposed by the Swiss government

- Operating life times range from 20 years (UK) to 50 years (Sweden)
- Prolongation range from 0 years (Germany) to 30 (Russia, Canada) and 40 years (USA)
- Germany, Belgium, Taiwan, Spain, Italy, Lithuania, and Sweden decided a nuclear phase-out

Source: Volk et al. (2019) based on BWK, 2016; FAZ, 2016; IAEA, 2015; Schneider et al., 2016; WNA, 2016n; Nuklearforum Schweiz, 2011; Taiwan Power Company, 2014; WNA, 2016q; Bryers and Ashmead (2016); Dep. for Business, Energy & Industrial Strategy, 2016; EDF Energy, 2016; IEA/NEA, 2015; NDA, 2016b; IAEA, 2017a; Kilochytska, 2009; NRC, 2016a; Nuclear Energy Institute, 2016: OECD and NEA, 2015; Reid and McGratz, 2016; WNA, 2016p

A detailed Classification of the Reactor States allow estimating the Nuclear Decommissioning Market Potential

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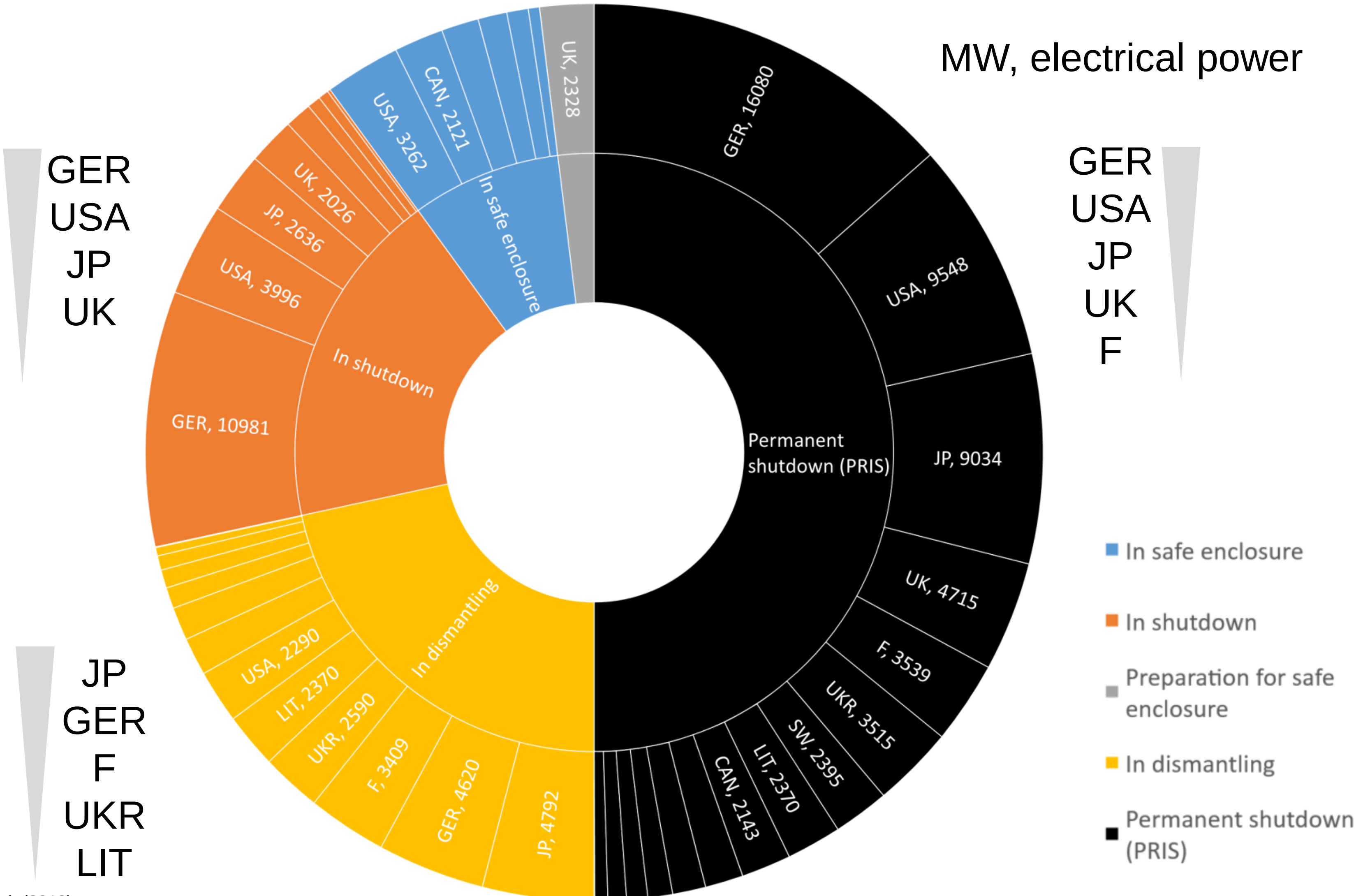
	Our denomination:	PRIS denomination:
0	Decommissioning completed	-*
1	In decommissioning	Permanent shutdown
2	In safe entombment/deferred dismantling	
3	In preparation for safe entombment/deferred dismantling	
4	In shutdown	
5	In operation	Operational
6	Ready for operation	
7	Under construction	Under construction
8	Others	-*

*: This category does not exist in PRIS. When the decommissioning is completed, the reactor will be removed from the database

- A detailed overview of the current reactor states is given
- Enables a better estimation of the decommissioning market potential in the upcoming years
- Foundation for a scenario analysis of the market development over time

Source: Volk et al. (2019), IAEA PRIS

A detailed Classification of the Reactor States allow estimating the Nuclear Decommissioning Market Potential



Source: Volk et al. (2019)

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A detailed Classification of the Reactor States allow estimating the Nuclear Decommissioning Market Potential

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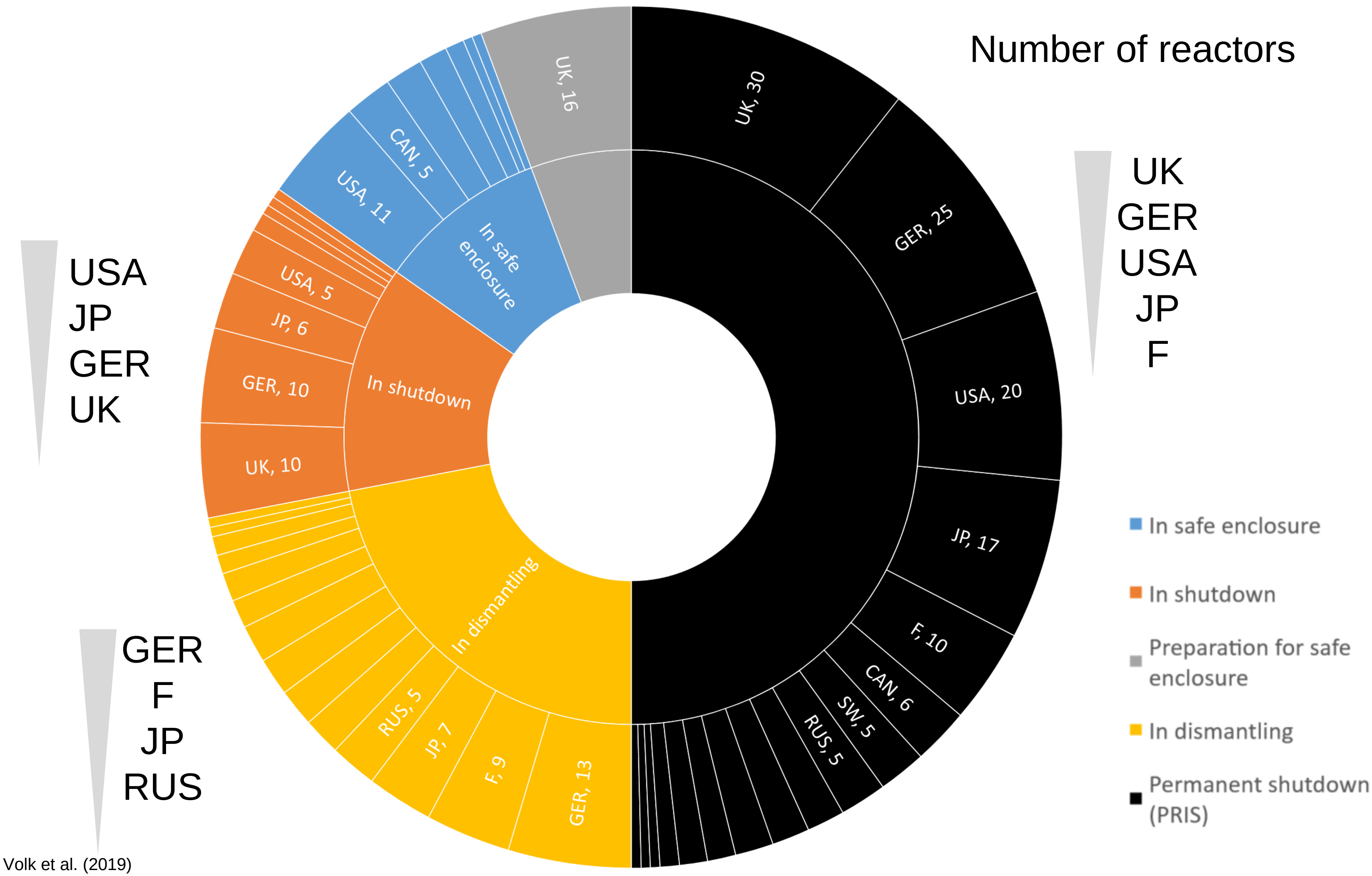

Source: Volk et al. (2019)

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A Scenario Analysis projects the Electrical Capacity that will be shut down in the 18 Countries until 2047

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Scenario parameters

Scenarios	Start of shutdown (on reactor-level)	Post-operational phase durations (on national level)	Dismantling phase durations (on national level)
Scenario 1 (expected)	Expected start date	Moderate duration (5.5 years*)	Moderate duration (10 years*)
Scenario 2 (intermediate)	Expected start date	Minimum duration (5 years*)	Minimum duration (9 years*)
Scenario 3 (earliest decommission)	Earliest start date	Minimum duration (5 years*)	Minimum duration (9 years*)
Scenario 4 (intermediate)	Expected start date	Maximum duration (6 years*)	Maximum duration (11 years*)
Scenario 5 (latest decommission)	Latest start date	Maximum duration (6 years*)	Maximum duration (11 years*)

*: default value, if no national value is available

Source: Volk et al. (2019)

The highest Decommissioning Market Potential can be seen in the USA, Japan and Germany

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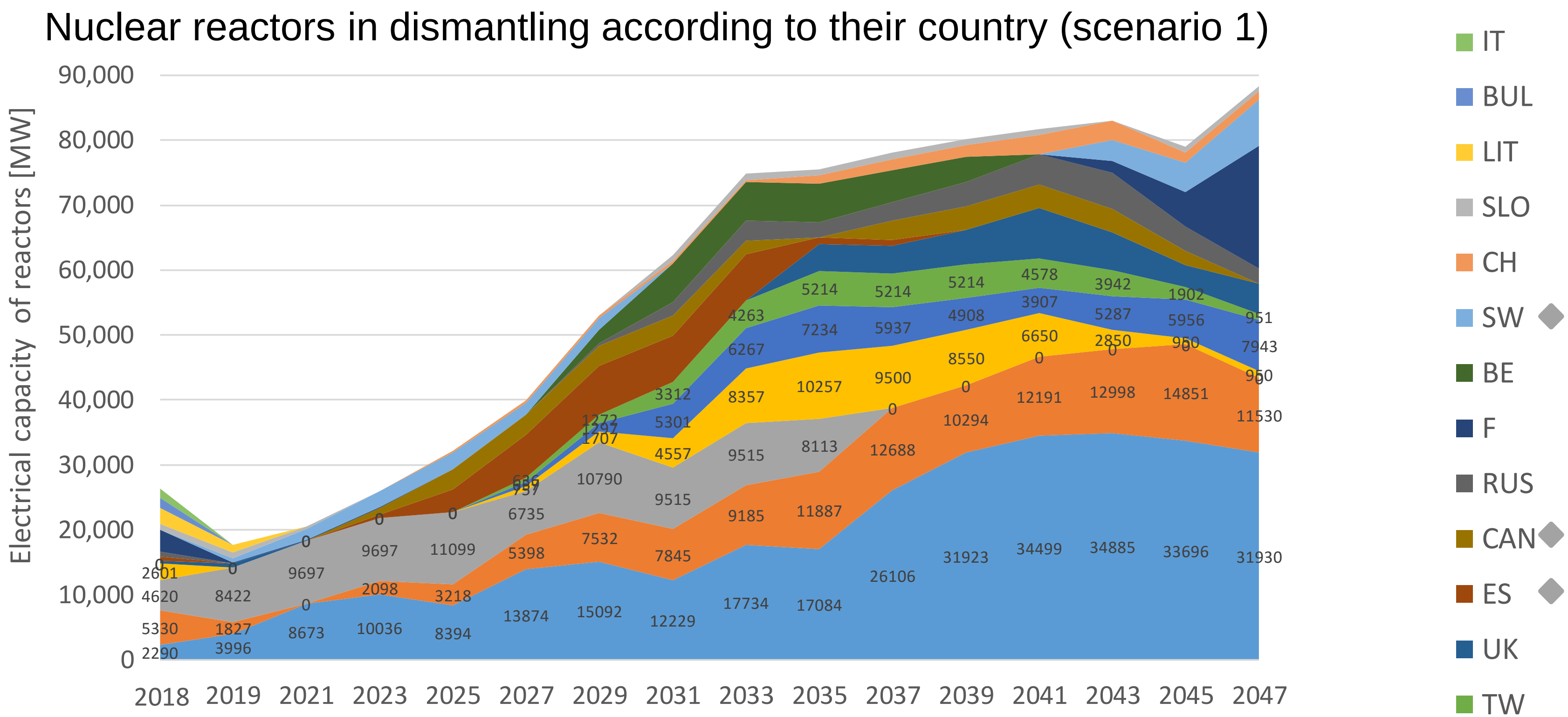
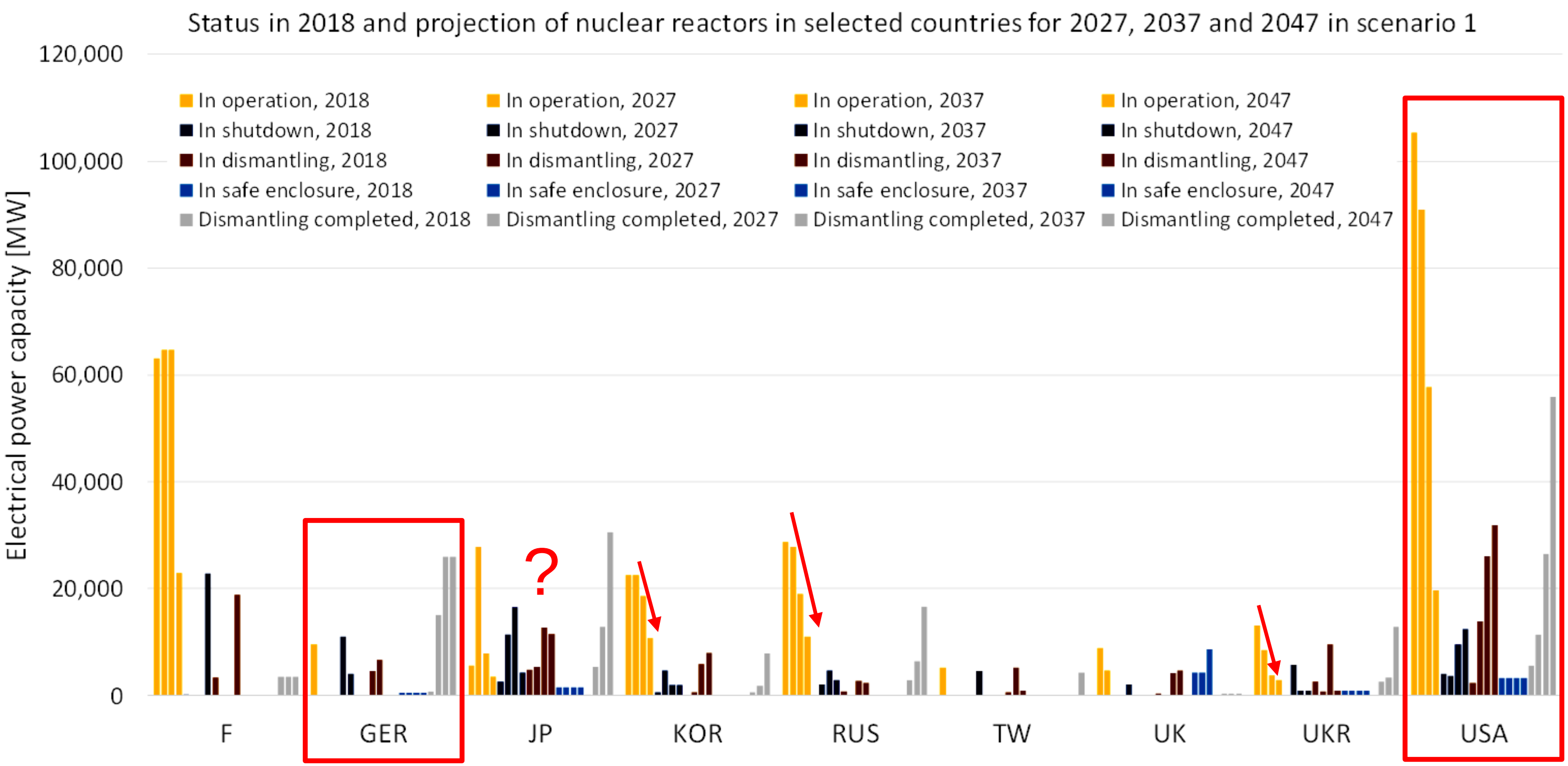


- The dismantling markets in the USA and Japan increase continuously until the 2040s
- The German market is limited to the complete decommissioning of its reactor stock in 2037
- A peak around 2040 and a following stagnation of the total dismantling market are expected
- Ukraine, Spain, Sweden and Canada are interesting smaller markets in the next years
- Starting 2030: Belgium and Switzerland rises; Starting 2040: France is following.

Source: Volk et al. (2019)

Operating Reactors Power Capacity will be in Decommissioning and has to be substituted



- All 17 German reactors will be dismantled completely in 2037 (capacity reduction: 100%)
- The Japanese market depends on the political decisions (projected capacity reduction: 91%)
- Until 2047, 55 nuclear reactors will be dismantled in the USA (capacity reduction: 81%)
- In this study, around 260 GWe are expected to be retired until 2047

Source: Volk et al. (2019)

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Reactor shutdowns lead to Business Opportunities, increase political Stress and Pressure to Innovate

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Key Findings	*Required R&D*

Key Findings

- Need for **technology innovations** and **large investments** in reactor refurbishments or alternative energy systems and infrastructure **to overcome large scale reactor shutdowns** by 2047
- **Upcoming project, job and business opportunities** with increasing decommissioning activities
- **Increased pressure** on governments **to establish safe storage** for radioactive material
- Potential **bottlenecks** are **expertise**, **dismantling/cleaning equipment** and shifts to deferred dismantling.

Required R&D

- **Impact of new constructions and retrofit investments** in prolongation of operating time of reactors
- Extension of study to **all countries** worldwide and all types of nuclear facilities
- Investigation of **entry barriers** for markets to define competition
- **Efficient technologies and project management** for nuclear decomissioning required

Source: Volk et al. (2019)

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MogaMaR:

Development of an integrated project management system for nuclear decommissioning

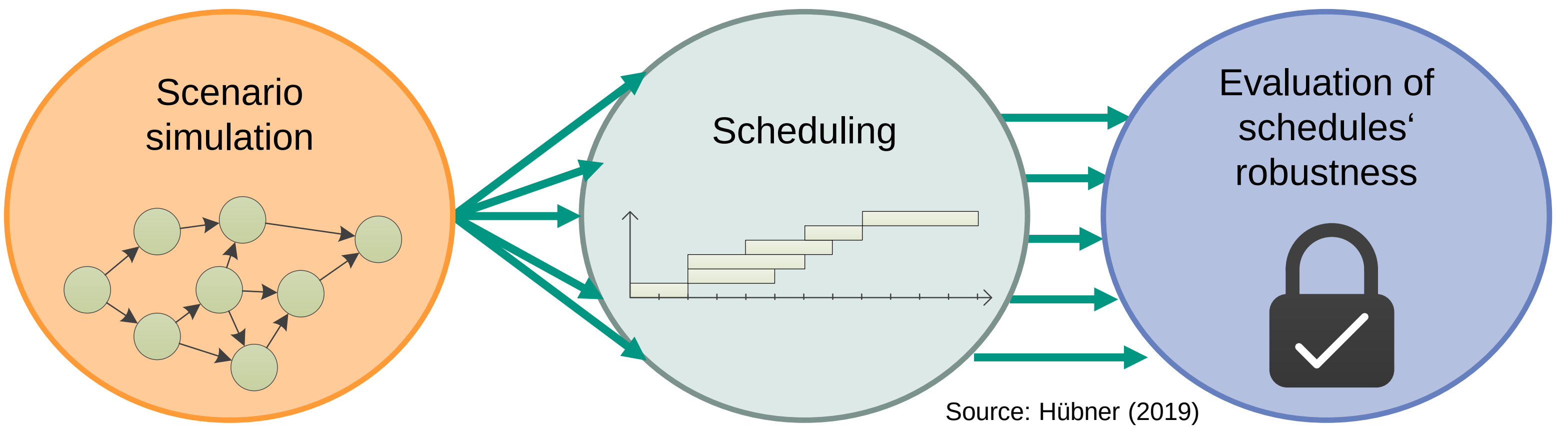
Duration: 01/01/2014 – 31/03/2017 Partners:

Funding code: 02S9113A

Info: http://www.iip.kit.edu/english/773_2489.php

Project goals:

- Integrated consideration of time, cost and resources in planning
- Cost-optimization
- Consideration of uncertainties during planning



Source: Hübner (2019)

- Integrated consideration of time, cost and resources as well as uncertainty and buffers
- Availability of alternative schedule in the case of changes

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NukPlaRStoR:

Development of a user-friendly cost- optimizing planning tool for nuclear dismantling projects taking into account material flows for resource planning

Duration: 01/06/2019 – 31/05/2022 Partners: iip, R, GIS IHR DIGITALISIERUNGSSPEZIALIST, VND Member of Dornier Group

Funding code: 15S9113A

Info: http://www.iip.kit.edu/english/1064_4605.php

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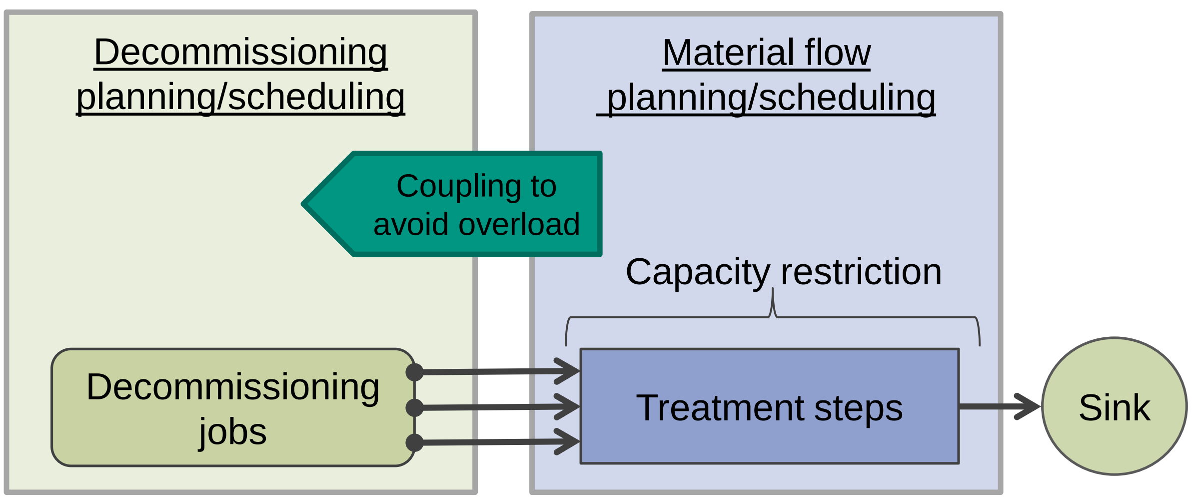
Project goals:

- Integrated consideration of dismantling and material flow planning
- Cost-optimizing time and logistics planning
- Development of a user interface and interfaces to project management software



Source: Forschungszentrum Jülich GmbH

Source: EWN Energiewerke Nord GmbH

➕ Integrated planning of decommissioning and its material flows

References

Ananiev, A.; Zimin, V.; Korneev, I. (2015): Planning for the decommissioning of Leningrad NNP units N 1, 2. Moskau. http://www.atomeco.org/mediafiles/u/files/2015/Materials/Zimin.pdf, last access: 13.12.2016.

Anunti, A.; Larsson, H.; Edelborg, M. (2013): Decommissioning study of Forsmark NPP. http://www.skb.se/upload/publications/pdf/R-13-03.pdf, last access: 28.12.2016.

ASN, Autorité de sûreténucléaire (2016): ASN report on the state of nuclear safety and radiation protection in France in 2015. Chevet, Peirre-Franck. Montrouge. Online: www.french-nuclear-safe-ty.fr/content/download/103003/758456/version/10/file/ASN+Report+on+the+state+of+nuclear+safety+and+radiation+protection+in+France+in+2015.pdf, last access: 28.11.2016.

Barsebäck (2016): Activities on the site. http://www.barsebackkraft.se/en/About-Barseback/Plant-service-and-other-activities/, last access: 28.12.2016

Bruce Power (2016b): Life-Extension Program. http://www.brucepower.com/about-us/life-extension/, last access 27.12.2016.

Bryers, J.; Ashmead, S.: Preparation for Future Defueling and Decommissioning Works on EDF Energy's UK Fleet of Advanced Gas Cooled Reactors 2016. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/47/061/47061284.pdf, last access: 16.12.2016.

BWK (2016): Stilllegungsprojekt. Stilllegung des Kernkraftwerks Mühleberg. Hg. v. BWK Energie AG. Bern. https://bkw-portal-static.s3.amazonaws.com/Webcontent/bkw.ch/fileadmin/user_upload/19_KKM/Hauptbericht_-_Stilllegungsprojekt_v1.1.pdf, last access: 20.12.2016.

DAtF, Deutsches Atomforum e.V. (2017): Kernenergie in Zahlen 2017. https://www.kernd.de/kernd-wAssets/docs/service/621kernenergie-in-zahlen2017.pdf, last access: 25.11.2019.

Department for Business, Energy & Industrial Strategy (2016): Digest of United Kingdom Energy Statistics. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577712/DUKES_2016_FINAL.pdf.

EDF, Électricité de France (2016): Pressedossier Das Kernkraftwerk Cattenom. https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-cattenom/presentation/Dossiers%20de%20presse/dossier_de_presse_2016_allemand_maj_15062016.pdf, last access: 30.11.2016.

European Court of Auditors (2016): EU nuclear decommissioning assistance programmes in Lithuania, Bulgaria and Slovakia: some progress made since 2011, but critical challenges ahead. Luxemburg, Publications Office of the European Union, 2016 (Special Report /, No. 22), ISBN 978-92-872-5467-2, ISSN 1977-5679. http://doi.org/10.2865/50913, https://www.eca.europa.eu/Lists/ECADocuments/SR16_22/SR_NUCLEAR_DECOMMISSIONING_EN.pdf (last access: 01.08.2018)

European Commission (2016b): Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for the opinion of the European Economic and Social Committee. Commission Staff Working Document.Hg. v. European Commission. https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf.

Hyung Kook, K. (2015): Comparative Study of the Politics of Nuclear Decommissioning between Great Britain and South Korea. Department of Political Science and International Relations Chung AngUniversity, Korea. England. https://www.psa.ac.uk/sites/default/files/conference/papers/2015/KIM%20hyung%20Decommissioning_btw%20GB%20and%20KOR.pdf.

Hübner, F. (2019): Planung und Modellierung des Rückbaus kerntechnischer Anlagen unter der Berücksichtigung von Unsicherheiten – Ein Beispiel zur Planung von Großprojekten / Planning and modelling nuclear decommissioning under uncertainty – an example for planning large-scale projects, Dissertation, KIT Scientific Publishing, Karlsruhe. doi:10.5445/KSP/1000091848

References

IAEA (2004): Status of the decommissioning of nuclear facilities around the world. Vienna: International Atomic Energy Agency (STI/PUB, 1201). http://www-pub.iaea.org/MTCD/publications/PDF/Pub1201_web.pdf, last access 20.12.2016.

IAEA, International Atomic Energy Agency (2015): Country nuclear power profiles. 2015 edition. Vienna: International Atomic Energy Agency. http://www-pub.iaea.org/MTCD/Publications/PDF/CNPP2015_CD/pages/index.htm, last access: 27.07.2018.

IAEA, International Atomic Energy Agency (2017a): Nuclear Power Reactors in the World, Reference data series No. 2, 2017 Edition, International Atomic Energy Agency, Vienna, ISBN 978–92–0–104017–6, http://www-pub.iaea.org/MTCD/Publications/PDF/RDS_2-37_web.pdf (last access: 10.10.2017)

IEA/NEA (2015): Technology Roadmap Nuclear Energy, Edition 2015. https://www.iea.org/media/freepublications/technologyroadmaps/TechnologyRoadmapNuclearEnergy.pdf (last access: 06.10.2017).

Joo Hyun Moon, G. (2013): Estimated decommissioning cost for the 23 opera-ting nuclear power reactors in Korea. In: ATW - Internationale Zeitschrift für Kernenergie 2013 (58 (7)), S. 420–422. http://www.kernenergie.de/kernenergie-wAssets/docs/fachzeitschrift-atw/2013/atw2013_07_moon-decommissioning.pdf.

Kennes, C.; Mommaert, C.; Schmidts, O. (2008): Bel V activities in the Belgian context of dismantling research reactor and fuel cycle facilities. (ed.)Eurosafe.https://www.eurosafe-forum.org/sites/default/files/Presentations2008/Seminar%203/Slides/3.3_Bel%20V_presentation_seminar_3.pdf, last access: 17.10.2017

Kilochytska, T. (2009): Decommissioning of nuclear facilities in Ukraine, State Nuclear Regulatory Committee of Ukraine, Annuale Forum for Regulators and Operators in the field of decommissioning, Nov 2-6, 2009, Vienna, Austria, https://www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN/meeting2009/session1/Ukraine.pdf, last access: 10.10.2017

KHNP, Korea Hydro & Nuclear Power (2016): Nuclear | Continue Operation. http://cms.khnp.co.kr/eng/content/554/main.do?mnCd=EN030301, last access: 21.12.2016.

Laraia, M. (Ed.) (2012): Nuclear decommissioning. Planning, execution and inter-national experience. Philadelphia, Pa: Woodhead Pub (Woodhead Publishing series in energy, no. 36). http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=683131.

Larsson, H.; Anunti, A.; Edelborg, M. (2013): Decommissioning Study of Oskarshamn NPP. http://www.skb.se/upload/publications/pdf/R-13-04.pdf, last access: 28.12.2016.

NDA, Nuclear Decommissioning Authority (2016b): Strategy. Effective from April 2016. London: The Stationery Office. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/512836/Nuclear_Decommissioning_Authority_Strategy_effective_from_April_2016.pdf.

NRC, Nuclear Regulatory Commission (2016a): Backgrounder: Reactor License Renewal. http://www.nrc.gov/docs/ML0506/ML050680253.pdf, last access: 06.10.2017.

Nuclear Energy Institute (2016): Decommissioning Nuclear Power Plants. http://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Decommissioning-Nuclear-Energy-Facilities, last access: 14.11.2016.

Nuklearforum Schweiz (2011): Taiwan will aus der Kernenergie aussteigen. http://www.nuklearforum.ch/de/aktuell/e-bulletin/taiwan-will-aus-der-kernenergie-aussteigen, last updated: 22.12.2016, last access: 22.12.2016.

References

OECD/NEA (2015): Nuclear Development/ Développement de l'énergie nucléaire 2015, Nuclear Energy Data / Données sur l'énergie nucléaire 2015, NEA No. 7246, Nuclear Energy Agency (NEA), Organisation For Economic Co-Operation And Development (OECD), https://www.oecd-nea.org/ndd/pubs/2015/7246-ned-2015.pdf, last access: 05.04.2018).

OECD; NEA (2011a): Nuclear Legislation in OECD and NEA Countries - Japan. https://www.oecd-nea.org/law/legislation/japan.pdf, last access: 01.12.2016.

Oskarsson, M. (2016): Decommissioning of Nuclear Power Plants – what are the challenges? Magnus Oskarsson BU Nuclear Decommissioning. Hg. v. Vattenfall. https://www.chalmers.se/en/centres/snec/societyandindustry/snecday/snecday2016/Documents/05.%20Magnus%20Oskarsson%20-%20decommissioning%20challenges.pdf, last access: 28.12.2016.

Reid, R.; McGratz, R. (2016): EPRI Guidance for Transition from Operations to Decommissioning. Hg. v. Electric Power Research Institute. https://www.oecd-nea.org/rwm/wpdd/predec2016/docs/S-1-5___FP_SNYDER.pdf.

RWE (2016): Mit ganzer Kraft - Pressemitteilungen. http://www.rwe.com/web/cms/de/2320/rwe-power-ag/presse-downloads/pressemitteilungen/pressemitteilungen/?pmid=4015287, (last access: 22.12.2016).

Schmittem, M. (2016): Nuclear Decommissioning in Japan. Opportunities for European Companies. http://cdnsite.eu-japan.eu/sites/default/files/publications/docs/2016-03-nuclear-decommissioning-japan-schmittem-min_0.pdf, last access: 03.12.2016.

Schneider, M.; Froggatt, A.; Hazemann, J.; Fairlie, I.; Katsuta, T.; Maltini, F.; Ramana, M. V. (2016): The World Nuclear Industry. Status Report 2016. http://www.worldnuclearreport.org/ (last access: 10.10.2017).

SOGIN (2016a): Caorso nuclear power plant – Piacenza. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/caorso-nuclear-power-plant-%E2%80%93-piacenza.html, zuletzt aktualisiert am 30.12.2016, zuletzt geprüft am 30.12.2016.

SOGIN (2016b): Garigliano nuclear power plant – Caserta. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/garigliano-nuclear-power-plant-%E2%80%93-caserta.html, last access: 30.12.2016.

SOGIN (2016c): Latina nuclear power plant – Latina. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/latina-nuclear-power-plant-%E2%80%93-latina.html, last access: 30.12.2016.

SOGIN (2016d): Trino nuclear power plant Vercelli. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/trino-nuclear-power-plant-vercelli.html, Last access: 30.12.2016.

SSM, Stralsäkerhetsmyndigheten (2008): The Swedish Radiation Safety Authority's Regulations on Planning before and during Decommissioning of Nuclear Facilities. http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Forfattning/Engelska/SSMFS-2008-19E.pdf, last access: 28.12.2016.

Taiwan Power Company (2014): Decommissioning Plan for Nuclear Power Plants in Taiwan 沒有投影片標題. (ed.). Taiwan Power Company. http://www.cieca.org.tw/ConferenceData.aspx?mrid=536, last access: 27.12.2016.

Ternon-Morin, F.; Degrave, C. (2012): Long Term Operation For EDF Nuclear Power Plants: Towards 60 years… IAEA.Frankreich. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/43/070/43070836.pdf, last access: 31.12.2016.

References

Thierfeldt, S.; Schartmann, F. (2012): Stilllegung und Rückbau kerntechnischer Anlagen. Erfahrungen und Perspektiven. 4. Aufl. https://www.ptka.kit.edu/downloads/ptka-wte-e/WTE-E-Entsorgungsforschung-Broschuere_Stilllegung-und-Rueckbau_BRENK.pdf.

Volk, R.; Hübner, F.; Hünlich, T. Schultmann, F. (2019): The future of nuclear decommissioning – a worldwide market potential study, Energy Policy 124, pp 226-261, https://doi.org/10.1016/j.enpol.2018.08.014.

Wealer, B.; Gerbaulet, C.; Seidel, J. P.; von Hirschhausen, C. (2015): Stand und Perspektiven des Rückbaus von Kernkraftwerken in Deutschland. (ed.) Deutsches Institut für Wirtschaftsforschung. Berlin. https://www.diw.de/documents/publikationen/73/diw_01.c.519393.de/diw_datadoc_2015-081.pdf.

WNA, World Nuclear Association (2016b): Nuclear Development in the United Kingdom. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/appendices/nuclear-development-in-the-united-kingdom.aspx, last access: 16.12.2016.

WNA, World Nuclear Association (2016c): Nuclear Energy in Italy: Italian Nuclear Power. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/italy.aspx, last access: 30.07.2018.

WNA, World Nuclear Association (2016d): Nuclear Energy in Sweden. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx, last access: 27.12.2016.

WNA, World Nuclear Association (2016f): Nuclear Power in France. http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx, last access: 28.11.2016.

WNA, World Nuclear Association (2016i): Nuclear Power in Lithuania. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/lithuania.aspx, last access: 27.12.2016.

WNA, World Nuclear Association (2016j): Nuclear Power in Russia. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, last access: 12.12.2016.

WNA, World Nuclear Association (2016k): Nuclear Power in Slovakia, Slovakia Nuclear Energy. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/slovakia.aspx, last access: 30.07.2018.

WNA, World Nuclear Association (2016m): Nuclear Power in Spain | Spanish Nuclear Energy. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/spain.aspx, last access: 30.12.2016.

WNA, World Nuclear Association (2016n): Nuclear Power in Switzerland. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/switzerland.aspx, last access: 28.12.2016.

WNA, World Nuclear Association (2016o): Nuclear Power in the United Kingdom. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx, last access: 15.12.2016.

WNA, World Nuclear Association (2016p): Nuclear Power in the USA. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx, last access: 02.06.2017.

WNA, World Nuclear Association (2016q): Taiwan Nuclear Power. http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx, last access: 22.12.2016.

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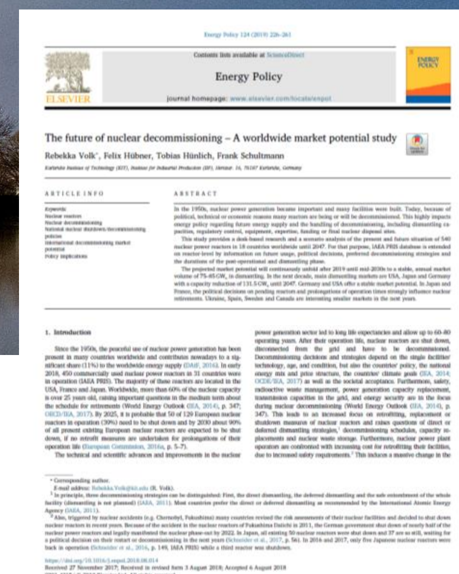
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ABSTRACT

1. Introduction

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