Will SMRs change the international nuclear cooperation landscape?

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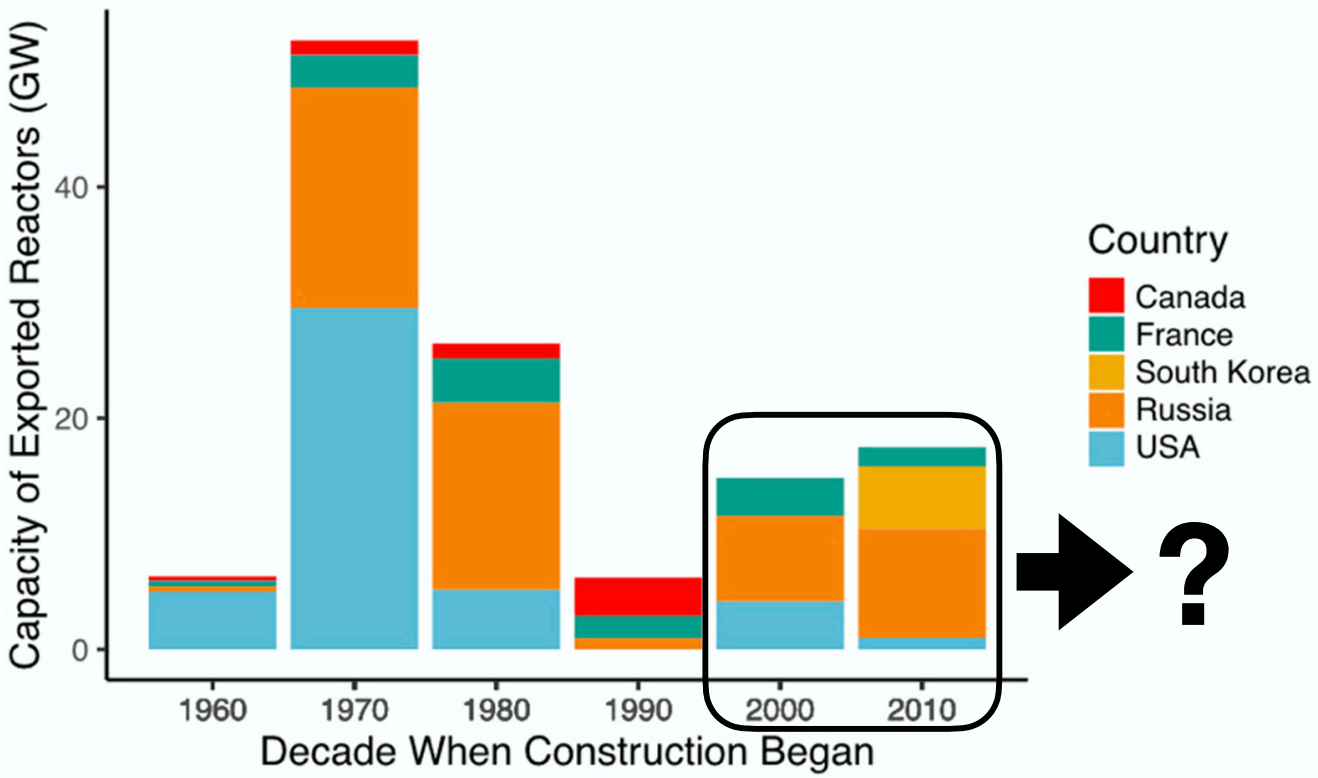
Context of my talk today

Waning US nuclear reactor exports



Lovering et al. 2020

- What is the current international landscape for nuclear cooperation?
- How might this develop in the future with the advance of small-modular reactors (SMRs)?

Unpacking international nuclear cooperation

- What are the main types of international nuclear energy cooperation and how widespread is each type of cooperation?
- Which countries are the main actors in each type of cooperation?

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The international technological nuclear cooperation landscape: A new dataset and network analysis

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Published dataset

	A	B	C	D	E	F	G	H	I	J	K	L
1									Type of cooperation			
2									Technological Concrete			
3	Index	Country1	Country1 type	Country1 Actor	Country2	Country2 type	Country2 Actor	Year	Nuclear Power Plant	Reactor Supply	Nuclear Fuel Cycle	Decomm. and Waste
4	1	Canada	Supplier	Atomic Energy of Canada Limited	Argentina	Client	Nucleoelectrica Argentina S.A.	2009	No	No	No	No
5	2	Argentina	Partner		Brasil	Partner		2008	Yes	No	Yes	Yes
6	3	Argentina	Supplier		Paraguay	Client		2014	No	No	No	No

Building our dataset

Identified 737 "cooperation units" from 2000-2015

- Nuclear cooperation unit includes: nuclear cooperation agreements and non-binding statements of cooperation (MOUs, policy statements and announcements)
- Search strategy:
  - Scan following databases: *World Nuclear Association* Country Profiles, *Nuclear Security Science and Policy Institute* articles, World Nuclear News database, Keeley on nuclear cooperation agreements (2009)
  - targeted searches: ["nuclear agreement" + "country X"] & ["nuclear cooperation" + country X"] for all countries which have at least one cooperation unit, nuclear power or are actively developing nuclear power
- Dataset is publicly available (if you can't access it email me)

								Type of cooperation												
								Technological Concrete				Technological Supportive								
Index	Country1	Country1 type	Country1 Actor	Country2	Country2 type	Country2 Actor	Year	Nuclear Power Plant	Reactor Supply	Nuclear Fuel Cycle	Decomm. and Waste	Knowledge Exchange & Training	Nuclear Safety & Security	Planning, Regulation and Supportive Infrastructure	No Information	Uranium	Formal agreement or Non-binding (MoU or policy statement)	Description	Reference	
1	Canada	Supplier	Atomic Energy of Canada Limited	Argentina	Client	Nucleoelectrica Argentina S.A.	2009	No	No	No	No	No	No	Yes	No	No	Agreement	Feasibility studies to build a NP	Autoridad Regulatoria Nuclear. Presidencia de la Nacion Argentina	
2	Argentina	Partner		Brasil	Partner		2008	Yes	No	Yes	Yes	No	No	Yes	No	No	Agreement	Joint projects: NP construction, waste management, fuel cycle, nuclear applications, regulations	Carnegie Endowment for International Peace	
3	Argentina	Supplier		Paraguay	Client		2014	No	No	No	No	Yes	No	Yes	No	No	Agreement	Development and Research nuclear energy, Regulation cooperation	Comision Nacional de la Energia Atomica	

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Coding cooperation units

We coded all cooperation units non-exclusively

- Concrete versus supportive technological cooperation
  - **Concrete** technological cooperation: nuclear power plant construction and operation; reactor supply; nuclear fuel cycle; and decommissioning and waste management
  - **Supportive** technological cooperation: knowledge exchange and training; nuclear safety and security; planning, regulation, and supportive infrastructure; [no information]
- Also coded Uranium cooperation
- Roles of actors
  - Directional versus partnerships: directionality signaled by words such as "assistance" or "support". Or by explicit imbalance in capacity (e.g. a supplier and newcomer).

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Examples of cooperation

All coding was done non-exclusively

- Korea and Poland: Co-operation between the two countries "will allow the Polish side to benefit from Korea's experience in the area of operating nuclear power stations and treating nuclear waste, as well as staff training and public relations."
    - Directional [Korea-Supplier] | Decommisioning and waste; Knowledge exchange & training

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Different types of cooperation

Supportive versus concrete

Total	737 cooperation units
Supportive	**75%** (558)
Concrete	**34%** (252)

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Different types of cooperation

Total	737 cooperation units
Supportive	**75%** (558)
Knowledge exchange and training	52%
Nuclear safety and security	29%
Planning, regulation and supportive infrastructure	14%
Concrete	**34%** (252)
Nuclear power construction and operation	15%
Reactor supply	10%
Decommissioning and waste	9%

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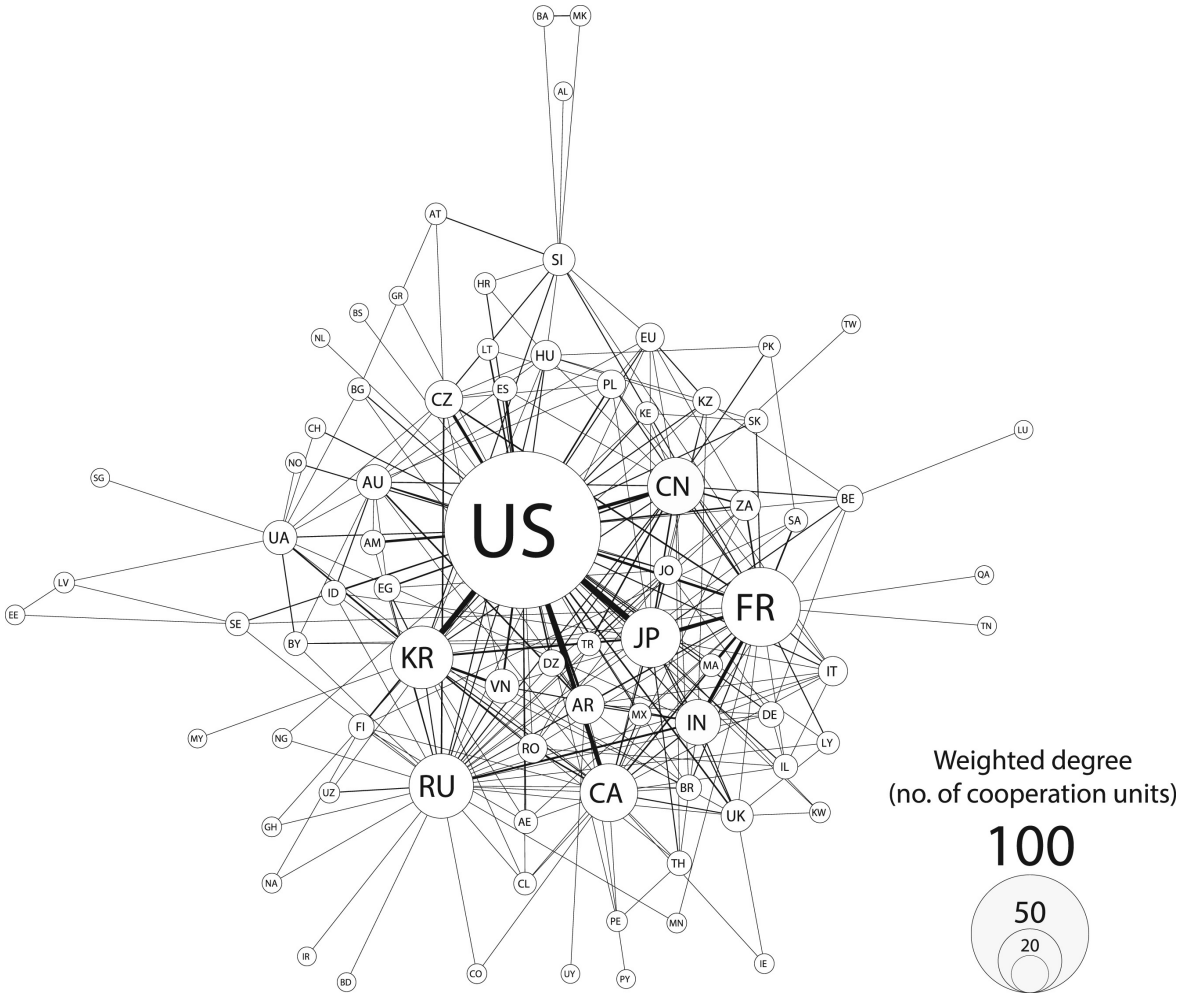
US dominates supportive technological cooperation



Weighted degree
(no. of cooperation units)

100

50

20

Country	Percentage
US	33%

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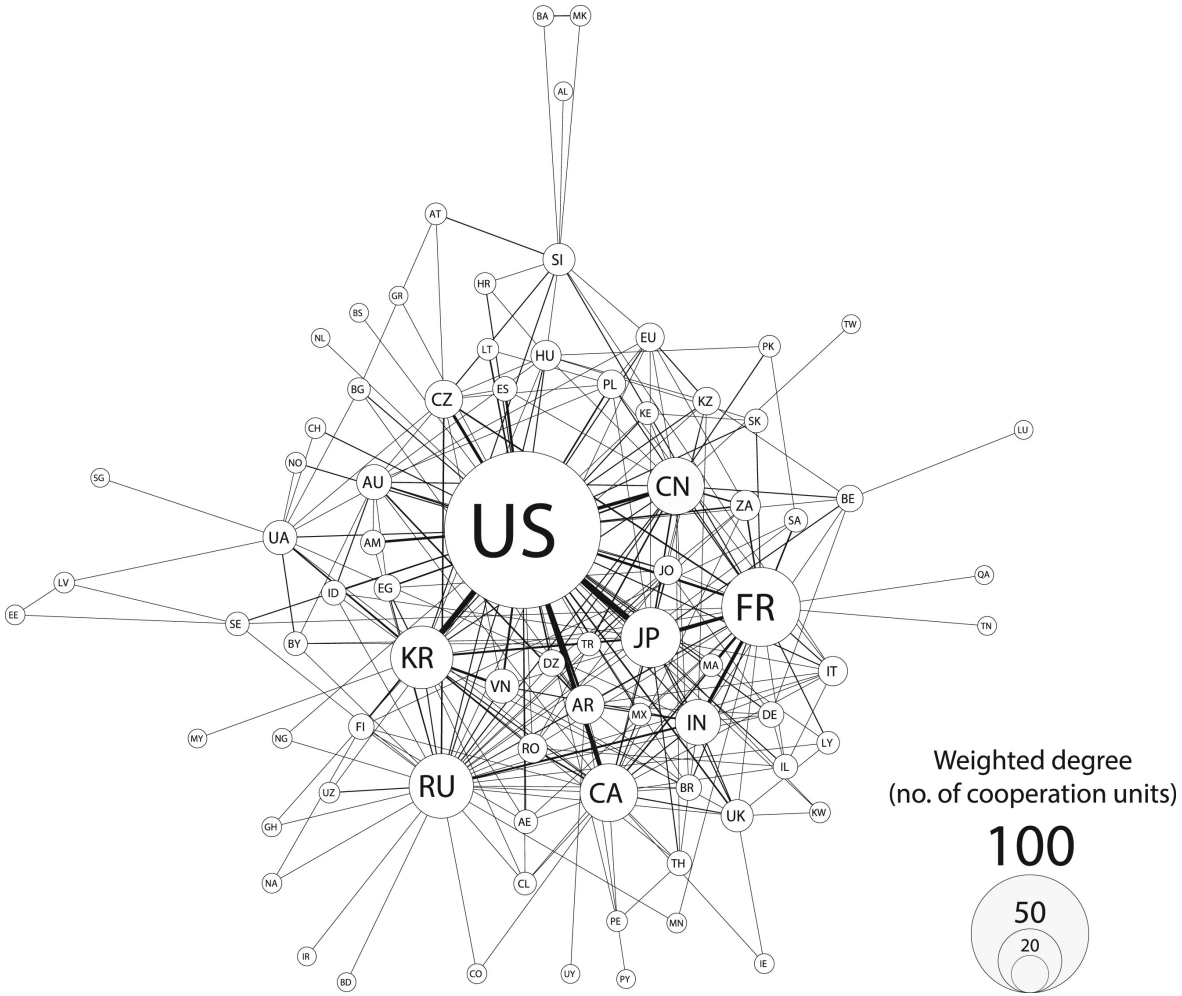
US dominates supportive technological cooperation



Weighted degree
(no. of cooperation units)

100

50

20

Country	Percentage
US	33%
France	14%
Russia	11%
Korea	11%
Japan	10%
Canada	9%
China	9%
India	7%

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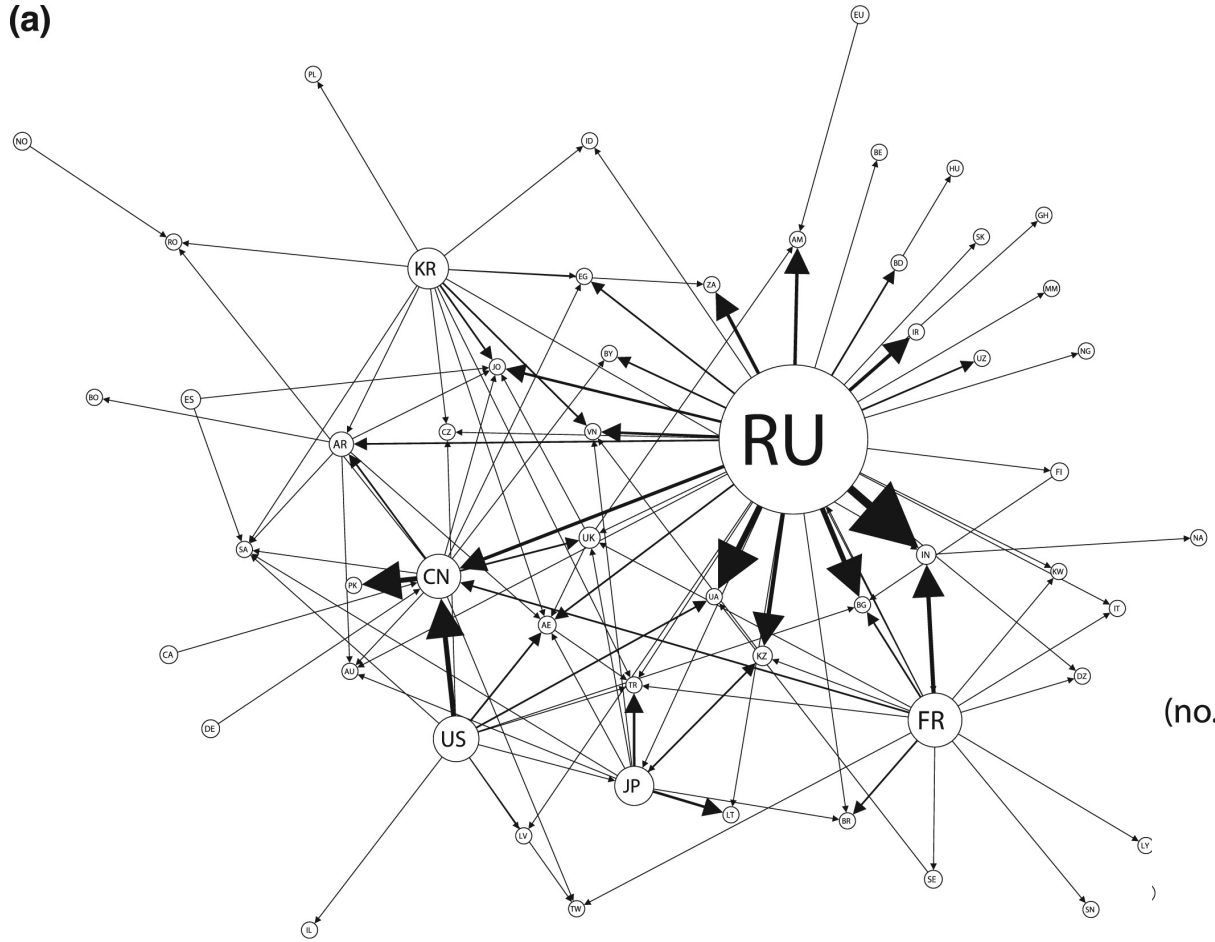
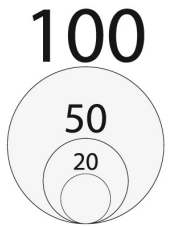
Russia is the main supplier in concrete technological cooperation

(a)



Country	Percentage
Russia	46%

Weighted degree
(no. of cooperation units)



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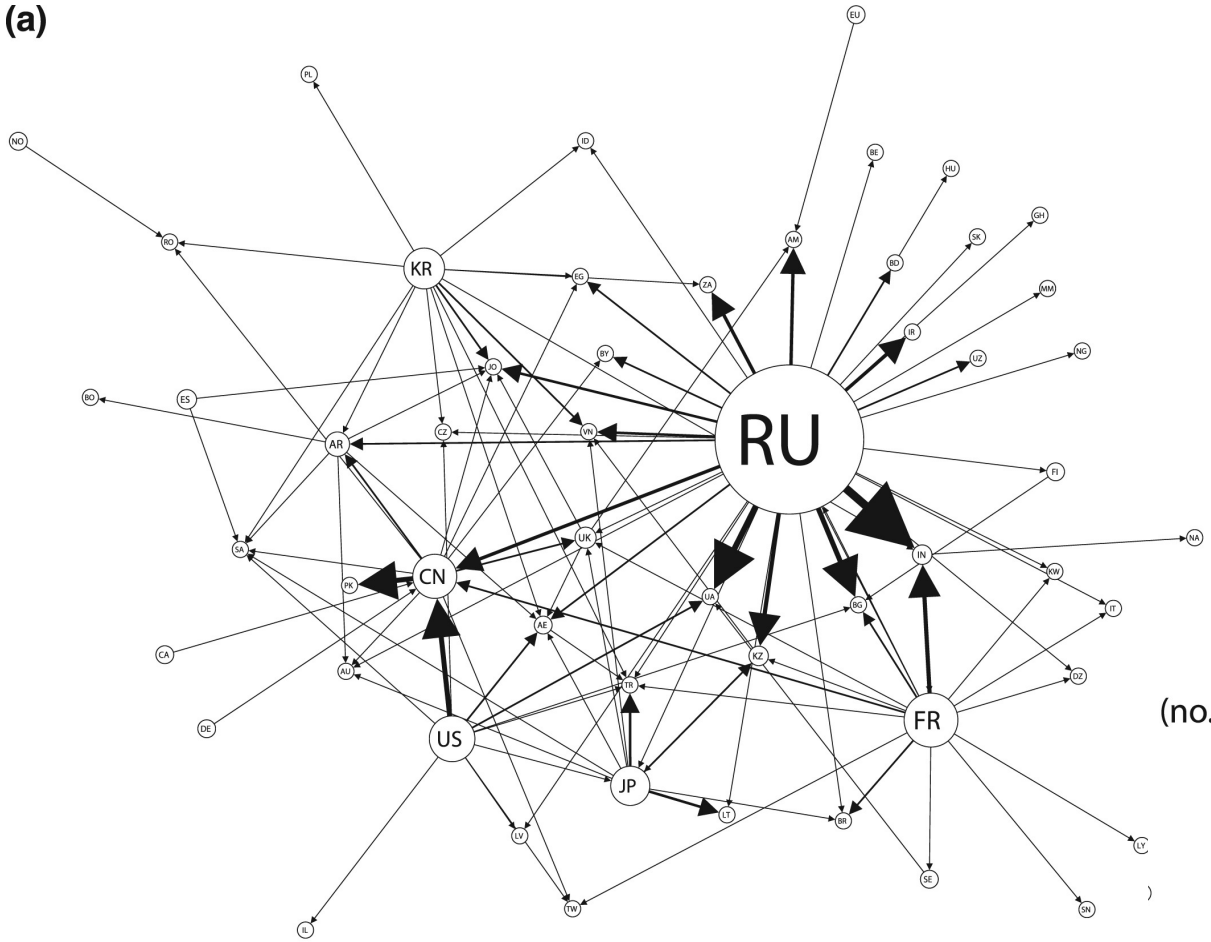
Russia is the main supplier in concrete technological cooperation

(a)



Weighted degree
(no. of cooperation units)

100

50

20

Country	Percentage
Russia	46%
France	13%
US	10%
China	10%
Korea	8%
Japan	8%
All others	total 12%

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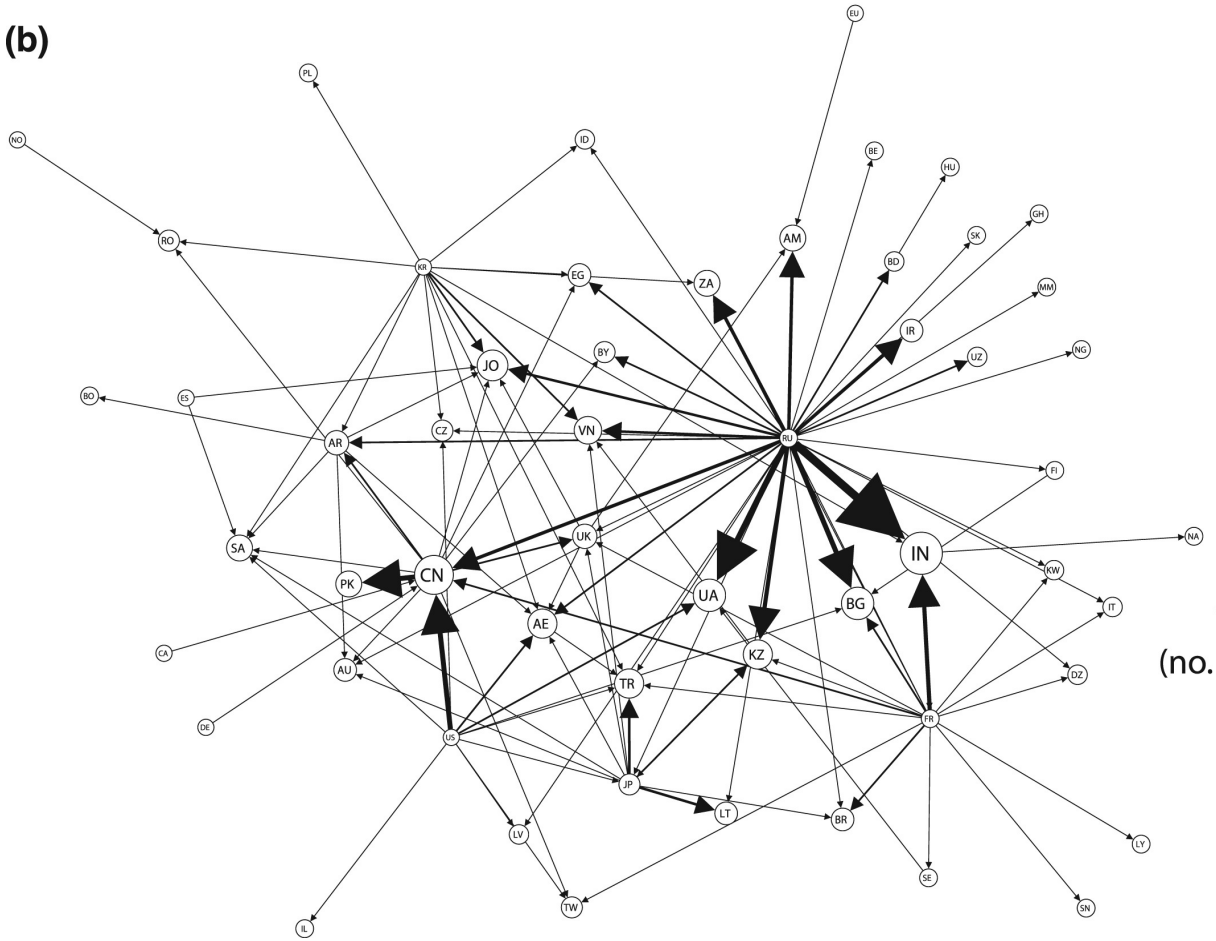
Top clients in concrete technological cooperation



Weighted degree
(no. of cooperation units)

100

50

20

Country	Percentage
India	9%
China	8%
Bulgaria	6%
Jordan	5%
Kazakhstan	4%
Turkey	4%
UAE	4%
Vietnam	4%
All others	≤3% (total 42%)

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Small modular reactor's and tomorrow's landscape

Who will new clients and suppliers be?

- What we know about the expansion of new technologies
- New technologies diffuse from core to periphery [Hägerstrand 1967]
- The timing and speed of this process depends on market attractiveness and ease of diffusion [Griliches 1957]

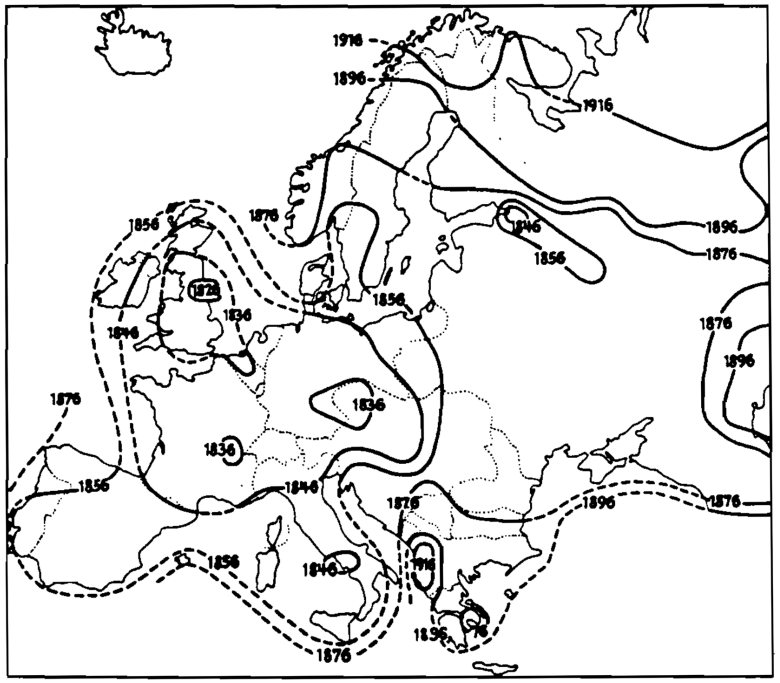

Figure 3.2.4. Spatial diffusion of the European railway network, in isolines of areas having railway networks by a given date (in 10-year time intervals). (Source: Godlund, 1952.)

Grubler 1990

Market attractiveness for SMRs and potential clients

Wealthy industrialized democracies

- Coal phase out
- Ambitious electrification of industry, transport and building sectors
- Liberalized markets

Austria

Belgium

Denmark

Germany

Italy

Japan

Spain

South Korea

Sweden

Switzerland

United Kingdom

Market attractiveness for SMRs and potential clients

Wealthy industrialized democracies

- Coal phase out
- Ambitious electrification of industry, transport and building sectors
- Liberalized markets
- No nuclear

Austria

Belgium

Denmark

Germany

Italy

Japan

Spain

South Korea

Sweden

Switzerland

United Kingdom

Market attractiveness for SMRs and potential clients

Large emerging economies

- Large demand growth
- Weaker decarbonization commitments
- Not fully liberalized markets
- Cost of capital is higher

Bangladesh

China

India

Indonesia

Pakistan

South Africa

Turkey

Vietnam

Market attractiveness for SMRs and potential clients

Small developing countries

- Large demand growth
- Weaker decarbonization commitments
- Not fully liberalized markets
- Cost of capital is higher
- **Periphery of all new technologies**

Ghana

Kenya

Sudan

Tanzania

Uganda

Zambia

Potential SMR suppliers

Insights from development of other technologies

- Technological innovation systems overlap
  - Logical to assume that suppliers of SMRs will be the same as large reactors
  - But the balance may be different
- Factors shaping the shift in balance
  - Availability of a domestic market
  - Existing supply connections and agreements
  - Matching structures of potential suppliers with potential clients

Conclusions

- To understand the future of SMRs, we need to understand how nuclear and other technologies diffused in the past
- Global market for nuclear technologies is dominated by Russia and a handful of other major suppliers with emerging economies as the main clients
- The US dominates a large network of supportive cooperation
- How SMRs will shape the global international landscape is determined by not only who comes up with the best technology but also
  - attractiveness of client markets
    - industrialized
    - large emerging economies
    - and small developing
  - existing connections between suppliers and clients