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Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine

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Since Russia invaded Ukraine in February 2022, the possibility of reducing Europe's energy dependence on Russian resources has been hotly debated. The fossil fuel industries received most attention as European Union leaders first introduced gradual sanctions on Russian coal and later on oil and gas, while Russia responded with supply cuts. However, Russia's role as a major player in the global nuclear power sector has remained largely below the sanctions radar, despite dependencies on Russian nuclear technology, uranium supplies and handling of spent nuclear fuel. Here we analyse the state nuclear company Rosatom and its subsidiaries as tools of Russian energy statecraft. We map the company's global portfolio, then categorize countries where Russia is active according to the degree and intensity of dependence. We offer a taxonomy of long-term energy dependencies, highlighting specific security risks associated with each of them. We conclude that the war and Russia's actions in the energy sector will undermine Rosatom's position in Europe and damage its reputation as a reliable supplier, but its global standing may remain strong.

The 1973 oil crisis shaped our imagination of global energy politics. Since then, fear of *scarcity* has been at the heart of energy security thinking[1]. Following Russia's invasion of Ukraine in February 2022, energy security concerns gained a level of prominence not seen since the 1970s[2–4]. The war in Ukraine was preceded by steeply rising natural gas and electricity prices, which already put European consumers under pressure, threatening the first pillar of energy security: affordability[5]. As a result of the invasion, the physical availability of fossil fuels was also questioned, due to growing fears that Russia would deploy its 'energy weapon'—manipulating supply and prices to coerce political concessions and to retaliate against Western economic sanctions[6,7]. Although those responsible have not been determined, events such as the sabotage against the Nord Stream pipeline in September 2022 have further demonstrated fossil fuel supply vulnerability.

Russia is the world's largest exporter of natural gas, second-largest exporter of oil and third-largest exporter of coal[8]. However, media coverage and political debates have generally omitted another sector where Russia is a major player and that is vital for Russia's global economic and diplomatic posture: nuclear energy. While the Russian shelling and takeover of Ukrainian nuclear power plants has caused an outcry, Russia's portfolio of foreign orders, including reactor construction, fuel provision and other services, spans 54 countries and is claimed by Rosatom to be worth more than US$139 billion over a ten year period[9] and has thus far not been covered by Western sanctions. Although the financial figure is in all likelihood inflated, Russia's involvement in and use of nuclear energy as a tool of energy diplomacy deserves scrutiny.

In this Analysis, we present a dataset of all current and planned international engagements of the Russian nuclear energy supplier Rosatom and its subsidiaries AtomStroyExport and TVEL. The dataset includes information on the different types of agreement, business models, scales of investments, types of reactor being built or planned and their nameplate capacity. As a gauge of the level of dependency upon the Russian nuclear sector that is or will be brought about by these reactors, we registered their share of the future electricity supply in the countries where they are located or planned for construction.

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Because the degree of influence achieved through energy statecraft is conditioned by the character and level of (inter)dependence, we discuss the firmness of dependence of different client states, formulated as 'intensity.' Finally, we propose a categorization of dependency types (Methods).

Rosatom's rise, expansion and comparative advantages

Rosatom—the Russian State Atomic Energy Corporation—is the direct heir to the Soviet Ministry of Atomic Energy, which was established in the aftermath of the Chernobyl nuclear accident. Reorganized as a state corporation in 2007, Rosatom is fully owned by the Russian state, and the president of the Russian Federation determines the company's objectives[10,11]. Since its inception, Rosatom has become increasingly active in the international nuclear power market[12,13] and has become a leading provider of key services[12,14,15]. Construction of as many as ten reactor units started between 2007 and 2017, and between 2009 and 2018, the company accounted for 23 of 31 orders placed and about a half of the units under construction worldwide[11]. Through its subsidiary TVEL, Rosatom also provides fuel supplies, controlling 38% of world's uranium conversion and 46% of uranium enrichment capacity[16,17] in addition to decommissioning and waste disposal. In sum, Russia was the supplier in around half of all international agreements on nuclear power plant construction, reactor and fuel supply, decommissioning or waste between 2000 and 2015. Its main nuclear power competitors—China, France, Japan, Korea and the United States—accounted for another 40%, combined[18].

The 2011 Fukushima accident appeared to have had little impact on Rosatom[19,20]. Neither were the company's operations noticeably impacted by the sanctions against Russia over its occupation of Crimea and the eastern part of Donbas in 2014, judging by the continuing expansion of the international project portfolio. This has led some Western authors to warn of imminent Russian dominance in the global nuclear technology market[21,22], especially if Rosatom manages to achieve economies of scale in reactor production, something that has so far been a major challenge for all nuclear energy developers.

Rosatom's main advantage lies in its capacity to be a 'one stop nuclear shop' for all needs, the only supplier providing an 'all-inclusive package'[12]. This comprises reactor construction know-how, training, support related to safety, non-proliferation regime requirements and flexible financing options, including government-sourced credit lines[22]. The company is also uniquely able to offload spent nuclear fuel from overseas customers.

The way Rosatom designs its projects also makes it a convenient partner for nuclear newcomers[23,24]. While details of contractual agreements vary from case to case, the developer takes care of the entire process until the plant is ready to use and can be handed over to local (Russian-trained) nuclear experts to operate. For that reason, nuclear energy can be considered by countries for which it was previously unattainable, especially in the Middle East[25,26], sub-Saharan Africa[27,28] and South America.[29]

Rosatom is also able to make special offers to strategically important partners, such as Turkey[30,31]. It was for Turkey's Akkuyu plant that Rosatom first proposed the innovative business model dubbed Build–Own–Operate (BOO), under which the Russian company retains majority ownership of the plant and a guaranteed price on electricity sales[12] but bears all the financial, construction and operational risks[11]. The BOO model has triggered worry regarding not only nuclear energy safety but also military security issues resulting from the peculiar extraterritorial status of the plants[11,12,21,26,32].

Its comparative advantages as a supplier allowed Russia to launch a global campaign of nuclear energy diplomacy[33] in which Rosatom and Russian government institutions such as the Ministry of Foreign Affairs work in tandem. This potentially gives Russia the capacity to use the broad network of international projects it is involved in[34] and the direct control over reactors and strategic energy infrastructure to exert political pressure and to project power globally[35].

Minin and Vlček, having studied the behaviour of Rosatom and its relationship with the Russian state, argue that the company is primarily a profit-seeking entity with a high degree of autonomy and growing self-sufficiency[15]. According to Thomas, whatever its grandiose expectations, Rosatom could simply be unable to deliver all the projects that it has agreed to, let alone expand further[13]. On the other hand, Aalto et al. observe that 'potential foreign policy influence' by Russia was noted by Finnish and Hungarian opponents of collaboration with Rosatom[33], while Jewell and colleagues argue that some nuclear sector dependencies display more pervasive energy security impacts, long-lasting and difficult to deal with (due to lack of flexibility) than those usually analysed by energy security experts in the petroleum sector[18,36].

Here we consider Rosatom's potential as a tool for the Russian state and debate whether this constitutes a 'nuclear energy weapon' or simply a projection of soft-power diplomacy. We find that Russian nuclear energy statecraft can be seen as a spectrum between these two extremes, but that soft-power diplomacy creates dependencies that can be further expanded and exploited and thus should not be overlooked.

Analysing Rosatom's international activity

Our research, gathered in the dataset available in the Supplementary Data, indicates that upon Russia's invasion of Ukraine, Rosatom boasted as many as 73 different projects in 29 countries. The projects were at very different stages of development from power plants in operation; through construction of reactors ongoing, contracted, ordered or planned; to involvement in tenders, invitations to partnerships or officially published proposals. On top of that, Russian companies have bilateral agreements or memoranda of understanding (MoUs) with 13 countries for services or general joint development of nuclear energy.

Rosatom's projects and involvement have varied in ambition and cost—from India's Tarapur nuclear power plant (NPP) (US$700 million) and Iran's Bushehr-1 (US$850 million) to a gargantuan project in South Africa (US$76 billion) and those in Egypt (US$30 billion) and Turkey (US$20 billion). Finally, 13 countries have a variety of research-oriented agreements with Russian nuclear service providers related to nuclear research centres. Altogether, Russia's nuclear energy diplomacy has been formalized in 54 countries.

While this is impressive, looking into the details of these agreements (particularly the NPP construction projects) reveals a more modest level of international engagement. Many of the projects have been stuck at the planning stage for several years or are merely visions laid out in non-committal MoUs. Competing offers might ultimately be chosen over those from Rosatom. For instance, the expansion of the Dukovany NPP in Czechia saw calls from opposition parties and the Czech secret service to exclude both Chinese and Russian companies from the tender, citing security concerns[37], and Rosatom was explicitly excluded in 2021 following news of Russian intelligence involvement in a 2014 explosion at a Czech ammunition depot[38]. This happened despite Czechia's relatively positive attitude towards Rosatom[39] and the faith of the policymakers in nuclear energy as a foundation for energy security[40,41]. The Russian invasion of Ukraine triggered further cancellation of planned Russian-built nuclear power plants in Finland, Jordan and Slovakia.

However, most cooperation and plans have not been cancelled, and even EU member states Bulgaria and Hungary have, as of January 2023, not cancelled their planned nuclear plants. To understand the potential for wielding an 'energy weapon' embedded in these relationships, we must relate them to the energy systems of the host countries. To do this, we have calculated the share of the prognosed national electricity supply coming from Rosatom-built, owned or operated reactors planned by 2040 (Table 1 and Methods). The highest share

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Table 1 | Russian nuclear client states categorized according to degree of dependence

	Group 1	Group 2	Group 3	Group 4
Dependence on Russian-built/operated nuclear power	High (>10%)	Medium (4–10%)	Low (<3%)	Marginal
Form of relationship	Operation and/or ownership agreement	Operation and/or ownership agreement	Construction and operation agreement	Technical/scientific collaboration or provision of specialized nuclear services (states relying on Rosatom/TVEL for nuclear fuel supplies marked in italics)
States	Armenia, Bangladesh, Belarus, Hungary, Slovakia, Uzbekistan	Egypt, Iran, Turkey[a]	China, India	Azerbaijan, Bolivia, *Bulgaria*, Cambodia, Chile, Congo, Cuba, *Czechia*, *Finland*, Ghana, Kuwait, Mongolia, Paraguay, Poland, Rwanda, Serbia, *Spain*, *Sweden*, Tanzania, Zambia
States that could potentially join this group	Jordan, Nigeria, Sudan	Kazakhstan	Argentina, Brazil, Indonesia, Philippines, Saudi Arabia, South Africa, United Arab Emirates, Vietnam	

[a]Indicates a BOO contract. Supplementary Data provides more details.

of Russian-built (and potentially controlled) nuclear power will be in Armenia. There, the newly refurbished US$2 billion NPP at Metsamor can already generate up to 27% of the country's entire electricity supply, and, if the remaining reactors are built, the Rosatom-built reactors combined could provide up to 111% of prognosed electricity demand. This could mean that Armenia expects to need more electricity than the International Energy Agency (IEA) estimates or plans to export the surplus. Rosatom's reactors would also generate a notable share of power in Hungary (42%), Bulgaria (37%), Belarus (34%) and Uzbekistan (20%). By contrast, the impact of Rosatom's projects on the electricity supply of China and India will be marginal (below 1% and 3% respectively).

Interestingly, among the states where plans for Rosatom's nuclear plants are relatively firm and dependence on Russian-built nuclear energy will be highest (>10% of the electricity supply), we almost only find states that are either former Soviet republics or former East Bloc countries (Table 1). All these states have long-standing relationships with Russia in the nuclear sector. Uzbekistan is a newcomer in the group, but both pre- and post-1991, it was an important source of uranium for the Soviet and later Russian nuclear sector and thus has long-standing ties with the Russian nuclear industry. There is only one exception: Bangladesh, with a 12% share of the electricity supply.

Following the 2014 annexation of Crimea and particularly after the 2022 invasion of Ukraine, Russian economic, political and energy influence has become a fundamental concern in European countries.[42] In countries that plan to base their decarbonization efforts primarily or entirely on nuclear energy (that is, Hungary and Slovakia), the Russian NPP share of the electricity supply can underrepresent Russia's influence: dependencies on nuclear fuel imports from TVEL/Rosatom (which also continues to supply Bulgaria, Czechia and Finland and Poland's research reactor), combined with power-system inflexibility and overreliance on a single large nuclear power plant, exacerbates the vulnerability to supply disruptions. Hungary's political ties to Russia, involving deep energy dependence, have caused substantial concern among its partners in the European Union and the North Atlantic Treaty Organization[43,44], and Slovakia received Russian planes delivering fuel despite a ban on flights imposed by EU countries[45]. The case of Ukraine, which was fully dependent on Russian nuclear fuel until the early 2000s but managed to switch to US fuel, shows that such a shift is possible but takes some time[46].

Egypt, Iran and Turkey are all nuclear newcomers, energy hungry and populous (with between 82 and 100 million inhabitants each). Such states are lucrative markets for low-carbon electricity development. Nuclear developments in two of them (Egypt and Iran), have sparked some international concern, primarily in Israel and the United States[47–49], due to proliferation issues and concerns about political instability and terrorism. However, their vulnerability to nuclear energy supply disruptions is clearly lower than in the first group (only 6–10% of electricity supply is or would be from Rosatom-built reactors). Additionally, in the case of Turkey, other security issues arise on top of power-system vulnerabilities, that is, Russian ownership of strategic infrastructure on the territory of a NATO member state.

Finally, the last pair of Russian nuclear client states, China and India, already have homegrown nuclear industries, have the lowest levels of vulnerability to supply disruptions and, in the case of China, have their own ambitions of international expansion. Rosatom's engagement there is of a more symbolic political nature. The same can be said of the remaining 29 countries where plans for developing nuclear power are still, at most, preliminary or collaboration is limited to research facilities.

While share of the power supply is the primary measure of the vulnerability to accidental or malign disruptions of an energy system, we argue that Russia's energy statecraft in the nuclear sector and elsewhere cannot be reduced to the threat of supply cuts. As others have shown, there are mechanisms of influence that go beyond the physical disruption of power supply[6,18,33].

Conceptualizing a multifaceted 'nuclear energy weapon'

A different order of interdependencies emerges from an analysis of the intensity and level of bilateral *collaboration* in the nuclear sector. This level is represented by shades of blue in Fig. 1 and summarized in Table 2.

We distinguish between four levels of *collaboration*: intensive, medium, low and very low. These levels are not identical with the shares of power supply presented in Table 1 above. On the one hand, the index of intensity of collaboration shows us Russia's energy diplomacy priorities, hence China and India are categorized as engaging in high-level cooperation, together with other geopolitically important partners such as Armenia, Belarus and Turkey. On the other hand, it highlights the fact that the vulnerabilities of partner countries are not solely technical in nature but also result from personal and informal ties that can be used for Russian lobbying or espionage. This especially concerns the 'medium' level of cooperation, which includes several European client states.

The project landscape (Fig. 1) shows that Russia's ability to wield a 'nuclear energy weapon', understood as the consolidation of resources and control over energy supply, varies greatly across the countries where Rosatom is engaged. In countries where Russian-built NPPs will supply a large share of the electricity mix, we can see potential conditions for using an 'energy weapon' in a strict sense, following Smith Stegen's conceptualization[6]. Overreliance on a single provider

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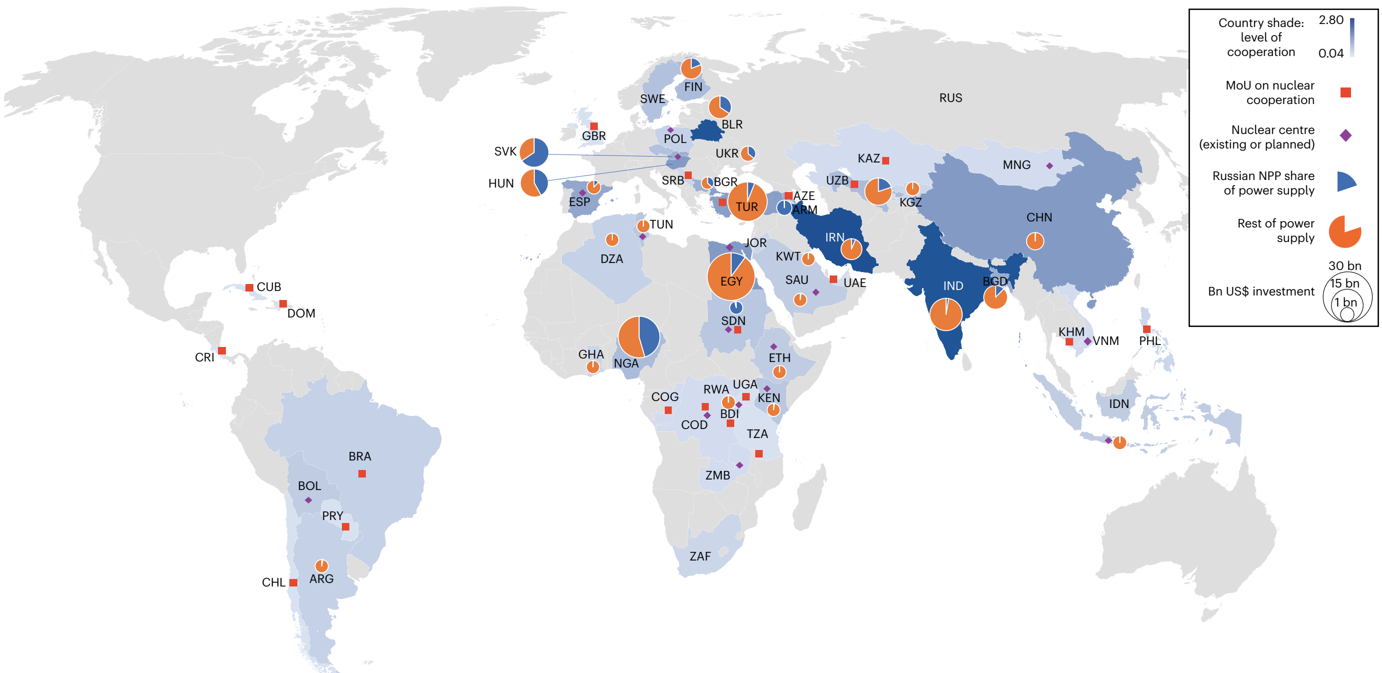

Fig. 1 | Russian nuclear engagements around the world. Authors' elaboration based on the dataset presented in the Supplementary Data. bn, billion; ARG, Argentina; ARM, Armenia; AZE, Azerbaijan; BDI, Burundi; BGD, Bangladesh; BGR, Bulgaria; BLR, Belarus; BOL, Bolivia; BRA, Brazil; CHL, Chile; CHN, China; COD, Democratic Republic of the Congo; COG, Republic of the Congo; CRI, Costa Rica; CUB, Cuba; DOM, Dominican Republic; DZA, Algeria; EGY, Egypt; ESP, Spain; ETH, Ethiopia; FIN, Finland; GBR, Great Britain; GHA, Ghana; HUN, Hungary; IDN, Indonesia; IND, India; IRN, Iran; JOR, Jordan; KAZ, Kazakhstan; KEN, Kenya; KGZ, Kyrgyzstan; KHM, Cambodia; KWT, Kuwait; MNG, Mongolia; NGA, Nigeria; PHL, Philippines; POL, Poland; PRY, Paraguay; RUS, Russia; RWA, Rwanda; SAU, Saudi Arabia; SDN, Sudan; SRB, Serbia; SVK, Slovakia; SWE, Sweden; TUN, Tunisia; TUR, Turkey; TZA, Tanzania; UAE, United Arab Emirates; UGA, Uganda; UKR, Ukraine; UZB, Uzbekistan; VNM, Vietnam; ZAF, South Africa; ZMB, Zambia. Technical details are provided in Methods.

Table 2 | Levels of nuclear cooperation with Russia[a]

High		Medium		Low		Very low	
Iran	2.8	Bulgaria	1.0	Bolivia	0.5	Azerbaijan	0.2
Belarus	2.7	Slovakia	1.0	Ethiopia	0.5	Cambodia	0.2
India	2.7	Nigeria	0.8	Indonesia	0.5	Congo	0.2
China	1.4	Uzb.[b]	0.8	Rwanda	0.5	DRC[b]	0.2
Egypt	1.4	Finland	0.8	S. Arabia[b]	0.5	Kazakhstan	0.2
Hungary	1.4	Czechia	0.7	Algeria	0.4	Mongolia	0.2
Turkey	1.3	Sweden	0.7	Argentina	0.4	UAE[b]	0.2
Spain	1.2	Kenya	0.6	Brazil	0.4	Vietnam	0.2
Armenia	1.1	Sudan	0.6	Poland	0.4	Zambia	0.2
Banglad.[b]	1.1	Tunisia	0.6	Jordan	0.3	Burundi	0.1
				Philip.[b]	0.3	Chile	0.1
				Serbia	0.3	Costa Rica	0.1
				Ghana	0.3	Cuba	0.1
				Kuwait	0.3	Dom. Rep.[b]	0.1
				Kyrgyz.[b]	0.3	Paraguay	0.1
				S. Africa[b]	0.3	Tanzania	0.1
						Uganda	0.1
						UK[b]	0.1

[a]Methods provide details of scoring system, and the Supplementary Data 'Scoring' table provides source data. [b]Country abbreviations: Uzb. is Uzbekistan, DRC is Democratic Republic of the Congo, S. Arabia is Saudi Arabia, UAE is United Arab Emirates, Banglad. is Bangladesh, Philip. is Philippines, Dom. Rep. is Dominican Republic, Kyrgyz. is Kyrgyzstan, S. Africa is South Africa and UK is United Kingdom.

and large, centralized power generators that supply a large share of a country's electricity is an energy security risk in itself, regardless of who the provider is. Russian nuclear fuel supplies could become a problem even in the absence of political intentions, for example, due to increased demand or temporarily reduced supply due to an accident or problems paying for fuel due to economic sanctions. The recent experience of Ukraine, which managed to switch from TVEL-supplied fuel to Westinghouse supplies, indicates that this threat can be overcome. Both Westinghouse and Framatome are working towards a position where they can replace Russian fuel. However, we should keep three things in mind. First, the process took Ukraine over a decade. Second, Western production capacity is limited in the short term. Lastly and most importantly, the United States itself relies on Rosatom subsidiaries and Russian-controlled supply chains for almost a half of its uranium supplies; the same applies to 40% of EU imports.[50] Although it would be possible to adapt, an abrupt halt of these supplies would impact the entire global nuclear energy sector in the short term.

Occasional reactor malfunctions and unplanned maintenance shutdowns are not uncommon, even without major accidents. In the extreme cases of Armenia and in Hungary, the dependence on Russian-built nuclear energy would be so high that any supply disruption would be catastrophic. However, even a loss of 10–20% of the electricity supply can cause a blackout and undermine regular economic and societal activity.

The situation is different in Groups 3 and 4 in Table 1, where direct energy dependence is marginal. However, in those cases, Rosatom's activity is still creating other types of long-term interdependency. As Jewell and colleagues point out, 'these interdependencies are insufficiently documented and poorly understood'[18]. We propose a categorization of these interdependencies and suggest that they

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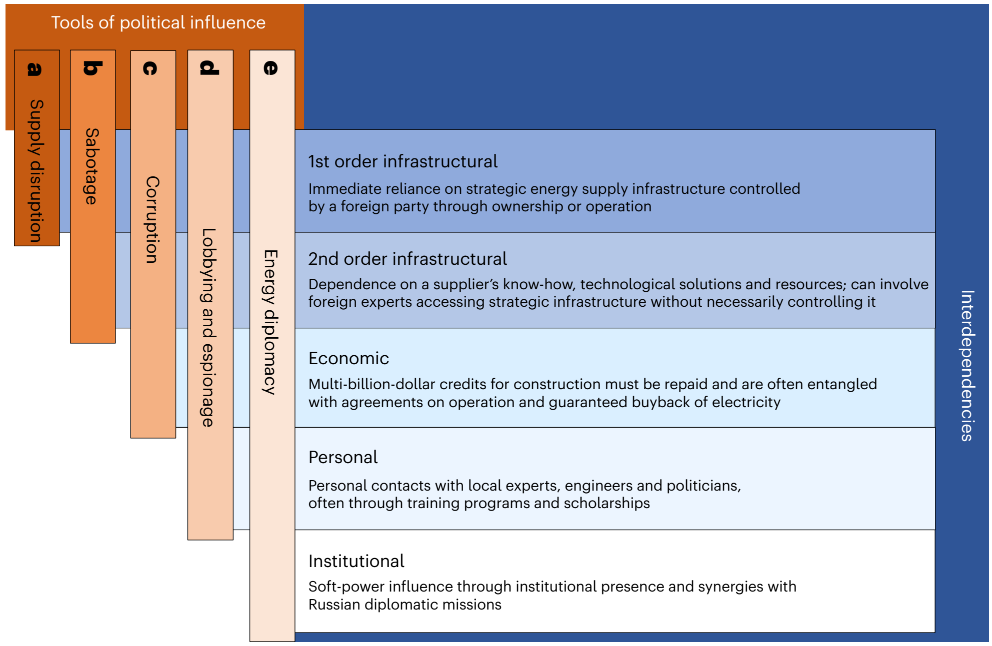

Fig. 2 | A conceptualization of interdependencies and corresponding tools of political influence. a–e, Interdependencies are detailed based on tools of political influence—supply disruption (**a**), sabotage (**b**), corruption (**c**), lobbying and espionage (**d**) and energy diplomacy (**e**).

all come with specific security risks for the client state—and tools of political influence for the patron state (Fig. 2 and Methods).

The most direct and consequential risk stemming from first-order infrastructure dependencies (that is, large power share coming from Rosatom's reactors) is *supply disruption* (Fig. 2a). As Smith Stegen notes[6], this does not have to be an overt 'turning off the tap' or 'switching off the light' and is more likely to be cast as a coincidental malfunction or unplanned event sufficiently credible to ensure plausible deniability, as in the case of the Nord Stream 1 pipeline temporary closure for apparent technical maintenance[51] or the 2005 incident in which TVEL allegedly supplied the Ukrainian Energatom with defective fuel assemblies[50].

But even if Rosatom does not fully control flows and there is only a second-order infrastructural dependency, the presence of foreign engineers and/or construction workers on critical national infrastructure sites can increase the likelihood of *sabotage* (Fig. 2b)[52,53]. Furthermore, we must consider the broad area of informal practices that emerge around large energy projects and large state investments. Economic dependencies create opportunities for large-scale *corruption* (Fig. 2c). An extreme example related to Russian nuclear diplomacy is the case of South Africa. Earmarked for Rosatom's biggest engagement globally (the price tag for the reactor rollout was US$72–76 billion), the project resulted in a political scandal. High-level corruption led to a pushback from South Africa's media and civil society[54]. Personal-level dependencies are a gateway to powerful *lobbying* (Fig. 2d), as in the case of Hungary's Paks-2 reactor[50], or *espionage*, as in the case of two German civil servants working on the Nord Stream project[55].

Finally, institutional (inter)dependencies create the networks through which *energy diplomacy* (Fig. 2e) can be formalized and soft power projected[33]. Although there is nothing uncommon in this sort of energy diplomacy, analysts and scholars argue that European and US inaction will lead to these dependencies becoming more entrenched[12,25,56].

This is part of a broader toolkit of soft power, which enables Russia to present itself as a technologically advanced, modern, benign global power, able to support middle- and low-income nations around the world and offer a non-ideological, 'see no evil' approach, that is not shying away from informal, non-transparent practices, corruption and not attaching normative clauses about good governance or rule-of-law requirements to business contracts[57]. Rosatom's aggressive strategy of signing agreements—which are more concrete than mere letters of intent and MoUs but not yet project contracts[11]—enables Russia to build a network of contacts and maintain high visibility as the first-choice provider of nuclear energy technology and financing. The soft-power arsenal is complemented by knowledge transfers, for example, in the form of Russian scholarships granted to junior nuclear experts from Africa and Latin America.

Conclusions

Does Russian global nuclear energy diplomacy constitute a potential 'energy weapon' or is it merely an example of economic and soft power? We believe that in the context of the war in Ukraine and Russia's use of energy statecraft for political influence, juxtaposing the 'hard' energy weapon and 'soft power' is misleading. Instead, we suggest thinking of Rosatom's international activity in terms of a continuum of energy statecraft tools, as its global presence creates different kinds of (inter) dependencies through varying intensity of collaboration.

Nuclear energy could be Russia's overlooked trump card in a decarbonizing world. But positive assessments of Rosatom's international nuclear energy engagements appear more naive after the invasion of Ukraine, at least in Europe, which is both heavily dependent upon Russian fossil fuels and staunchly opposed to the invasion of Ukraine. For most Western-aligned states, it will be inconceivable to enter into any type of new dependence or even non-dependent cooperation with Russia in the nuclear energy sector. Consequently, alternative sources and supply chains will need to be found that eventually will lead to a reduction of the global dependency on Rosatom's nuclear fuel-production capacity.

The big question for the future is whether non-Western countries will also turn away from Russian nuclear power. Currently, many developing countries take a positive view of Russia and tilt towards its view of the conflict in Ukraine. Immediately after the invasion of Ukraine, seven of the 14 countries with high- or medium-cooperation

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levels in our analysis did not approve United Nations Resolution ES 11/1 condemning Russian aggression, and several of these (for example, Bangladesh, China, India, Iran) were categorized as 'neutral or Russia-leaning' shortly after the war began[58]. Over time, however, the interruption of energy supplies to the European Union may undermine the reputation of Russian energy companies as primarily economic actors independent of national security politics, also outside Europe. Non-Western perspectives on the war in Ukraine and the reliability of Russia and Russian technology may also change over time.

Methods

Database construction

To build a comprehensive database of Rosatom projects, we created a hierarchy of data sources to ensure the inclusion of the most valid data[59–63]. Rosatom annual reports for 2015–2021 formed the starting point for the data gathering and enabled us to establish a preliminary list of all Rosatom projects outside Russia. The annual reports are information rich but also contain gaps and discrepancies that we used other data sources to resolve. The Power Reactor Information Systems database maintained by the International Atomic Energy Agency helped fill many of the gaps, but some uncertainties remained. To eliminate them, we used the World Nuclear Association website, the NucNet portal and academic papers and reports. In the final stage of data gathering, we filled in the still-missing information (mainly project costs) using information from the mass media and press releases. The resulting data cover 108 operating, constructing, planned, contracted, proposed or cancelled Russian-made nuclear reactors and nuclear centres, fuel supplies, cooperation agreements and MoUs.

Operationalization of energy dependence

We operationalized energy dependence in terms of the share of Russian-supported nuclear power in the future electricity mix of client states. This is visualized as pie charts in Fig. 1. For the purpose of this projection, we treat all planned projects as possible to realize, so it is to be understood as a max scenario. The share was estimated by summing up the capacity of existing and planned Russian-supported nuclear power plants, adjusting for the capacity factor and relating the resulting power generation to the projected national electricity supply in 2040. We used Rosatom's own estimation of the average capacity factor of Russian nuclear power plants, 0.798 (ref. [64]). Estimates of the national electricity supply in 2040 are taken from the IEA's regional projections[65], adapted to the individual countries in which Russian nuclear power plants are planned. Although, inevitably, not all discussed or planned reactors will be completed, this measure is a way of profiling the potential future dependence of individual client states on Rosatom-designed, -operated and/or -owned reactors for power production and the potential risks this involves.

Intensity of international nuclear cooperation

To add another dimension to energy security, we introduce the concept of the intensity of international nuclear cooperation. This is represented by the shading of countries in the map in Fig. 1, with the underlying scores listed in Table 2. The shading is based on a composite score that is calculated according to the scorecard in Table 3.

The scorecard in Table 3 is inspired by Jewell et al., who define international nuclear cooperation as 'activities in which two or more states share, exchange or combine material resources, knowledge or information related to the development of nuclear energy technologies'[18]. However, unlike Jewell et al., our aim is not a network analysis of international agreements but mapping the level of cooperation in dyadic relationships between Russia and its nuclear client states. We refer to this as 'intensity.' As we were not aware of an existing framework available for making such an assessment, we developed a system for scoring different forms of cooperation. This system considers the volume and level of cooperation and the level of commitment and its realization. A country can accumulate points across multiple criteria and nuclear projects. However, scores for each of the categories (types of agreement or cooperation) are given only once so that, for instance, multiple nuclear reactors in operation still give a score of 1. This is to distinguish the measurement of intensity of cooperation from the analysis of energy system dependency presented in Table 1, as the latter already captures the magnitude of dependence and the former is meant to capture the *level* of cooperation.

We developed the scores in a bottom-up manner on the basis of our empirical research, so that they reflect the realities of Russian nuclear energy diplomacy after the invasion of Ukraine. Tracing the evolution of Rosatom's agreements and cooperation with client states over time enabled us to create a hierarchy of variants of cooperation reflecting the likelihood that early cooperation will develop into a full-scale project and the interdependencies generated at various stages from an MoU to operating an actual nuclear power plant. For example, bilateral agreements are more concrete than letters of intent and MoUs but not as strong as project contracts. The scores in such a system inevitably involve an element of subjectivity. The advantage of the system, however, is that it is transparent and can easily be replicated and/or modified, and this can be done using the source data in Supplementary Data.

MoUs are loose, open-ended documents that often do not result in actual projects. Nonetheless, they reflect Russian energy diplomacy activity and communication. Thus, they are an indicator of attempted cooperation and priorities in terms of regions and partner countries. In the context of the war in Ukraine, it is interesting that (and which) countries choose to maintain even something as non-committal as an MoU. Finally, while MOUs are not binding or necessarily very important, normally no further steps are made without this initial one. We have therefore not removed them entirely from our analysis but given them the lowest score: 0.1. The same score is given to personnel-training agreements and projects that were more advanced but were shelved or frozen– an important category following the invasion of Ukraine. The remaining categories and their growing scores reflect ever more concrete agreements and increasingly advanced stages of projects, all the way to NPPs in operation, which receive the highest score: 1.

Table 3 | Scorecard for intensity of nuclear cooperation with Russia

Personnel-training agreement	0.1
MoU not mentioning NPP or nuclear research centre	0.1
NPP agreed but shelved	0.1
MoU on construction of a nuclear research centre/research reactor/ small modular reactor	0.2
Strategic documents mentioning construction or renovation of NPP	0.3
Full-scale nuclear reactor concretely agreed or planned	0.4
Research reactor/research centre under construction or operating (+ fuel supply)	0.4
Nuclear fuel supply	0.7
Full-scale nuclear reactor under construction	0.7
Full-scale nuclear reactor operating	1.0

Taxonomy of interdependencies and tools of influence

To move beyond just implying security risks and allow for comparison of energy statecraft across technologies and resources, we propose the following taxonomy of long-term (inter)dependencies, each of them related to specific tools available for patron states (Fig. 2).

(A) *First-order infrastructural dependency (physical)*: The immediate reliance on strategic energy supply infrastructure, which is the focus of most energy security concern in the oil and gas

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sector and relates to supply security. It is related to the control of a foreign party over supply channels through ownership or operation.

(B) *Second-order infrastructural dependency (technical)*: Discussed by Jewell and colleagues looking specifically at the nuclear sector[18]. This includes dependence on a supplier's know-how, unique technological solutions and resources but also involves the presence and access of foreign experts to elements of strategic infrastructures without necessarily controlling them, which opens the door to sabotage.

(C) *Economic dependencies*: Large-scale energy projects are large investments that involve billions of dollars of state and private-equity funding. On average, Russian nuclear projects have a value of several billion US dollars with different degrees of co-financing. Credits for construction must be repaid either before the plants become operational or through long-term agreements on operation and guaranteed buyback of electricity. Taken together, these dependencies allow Russian nuclear energy diplomacy to rely on what Stulberg called 'strategic manipulation' as a means of constraining or rewarding certain choices available to client-state policymakers[66].

(D) *Personal-level dependencies*: Rosatom's vast global network of activities also includes building personal contacts with local experts, engineers and politicians. Training programmes and scholarships often influence careers and underpin informal relations. In peacetime, this creates a pool of sympathetic and possibly like-minded individuals who may, even without seeking financial gain, act as lobbyists or informers or may be recruited as assets for industrial espionage. In a situation of conflict, such individuals can also be potential espionage assets.

(E) *Institutional (inter)dependencies*: The very presence of Rosatom and its subsidiaries in over 70 countries, backed by the Russian Ministry of Foreign Affairs and the president[67], adds a further layer to the other relations described above and creates channels of communication with relevant counterparts, other institutions and interest groups in the partner countries. This opens up channels for soft-power influence which may, with time, lead to higher-level dependencies (personal and economic). As Aalto and colleagues note drawing on the Finnish, Hungarian and, partly, Turkish cases, Russian nuclear energy diplomacy has 'managed to remove some institutional constraints by skillfully preparing the ground for the emergence of joint ventures and other interests', which, in turn, has 'enabled Russian actors to use soft power to shape perceptions in the target country'[33].

Data availability

The dataset generated during the current study is available as Supplementary Data.

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Author contributions

K.S. contributed with project design and conceptualization of interdependencies, prepared the first draft, edited subsequent versions and participated in the data analysis. I.O. led the data analysis and conceptualization, edited all versions of the paper and wrote parts of the text. The authors jointly contributed to the operationalization of energy security dependency and levels of collaboration in the nuclear sector.

Competing interests

The authors declare no competing interests.

Additional information

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