

HOW THE WAR IN UKRAINE IS CHANGING GLOBAL SCIENCE

Impacts on research are being felt more widely than just in Ukraine and Russia. **By Nisha Gaind, Alison Abbott, Elizabeth Gibney, Alexandra Witze, Jeff Tollefson, Aisling Irwin & Richard Van Noorden**

In just five months, Russia's war on Ukraine has killed thousands of people, displaced millions and ruptured global geopolitics and economics. It is marking science, too. The heaviest impacts are in Ukraine, where researchers have seen their institutions bombed and are facing upheaval and threats to their livelihoods. In Russia, scientists are contending with boycotts and sanctions in response to their country's actions. More widely, the crisis has created economic and political rifts that have already affected research in physics, space, climate science, food security and energy. A prolonged conflict could foment a significant realignment of scientific-collaboration patterns.

Here are seven ways in which the war is already affecting research, and could change it for years or decades to come.

Ukraine's research in crisis

In March, Olena Prysiachna, a plasma physicist at Taras Shevchenko National University of Kyiv, fled Ukraine's conflict for the Netherlands. From there, Prysiachna, like many Ukrainian scientists, has gone to extraordinary lengths to continue her research and teaching – often lecturing online to people logging in from bomb shelters. She's seen war become a daily reality for many researchers. "One of my students said his previous results got burnt," she says.

Since Russia invaded in February, an estimated 4,900 civilians have died in Ukraine, some 6,000 have been injured and more than 5.6 million have left for countries in Europe, creating the region's biggest refugee crisis in a generation. Another 6.3 million people are internally displaced. Among those affected are the country's 95,000 or so researchers: around

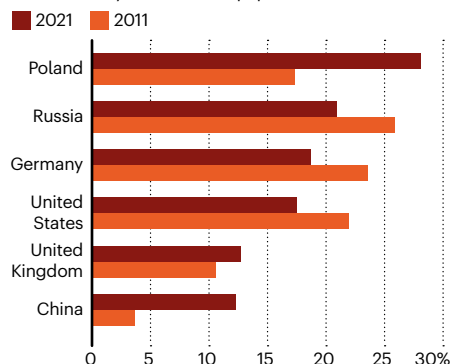
one-quarter of them – 22,000 – have fled the country, estimates George Gamota, a Ukraine-born physicist living in the United States who helped Ukraine to develop its scientific system after it gained independence from the Soviet Union in 1991.

The war has demolished what had been a slowly modernizing research system that was beginning to integrate with European partners. Many universities and science centres have been badly damaged – the Kharkiv Institute of Physics and Technology neutron source was bombed in March and June, for instance. It is likely to take years to restore the scientific infrastructure, said Steve Binkley, principal deputy director of the US Department of Energy's Office of Science, in an April letter encouraging grant-holders to host scientists affected by the conflict.

The US department is one of many organizations helping Ukrainian refugee scientists to continue their work. Neighbouring countries

UKRAINE'S INTERNATIONAL RESEARCH TIES

Poland is Ukraine's largest research partner, according to its share of authorship on Ukraine's internationally collaborative papers*.



*Scopus database: articles and reviews only.



such as Poland, which has taken in more than 1.2 million refugees, have been among the quickest to act: the Polish Academy of Sciences has supported hundreds of Ukrainian scholars. Poland is now Ukraine's largest research partner, having overtaken Russia in 2019 (see 'Ukraine's international research ties').

Within Ukraine, public-health researchers are concerned not only about the immediate loss of life and the health crises caused by the war, but also prolonged trauma. "A lot of people's homes have been reduced to rubble," says Margaret Harris, spokesperson for the World Health Organization's Ukraine team. "There will be an enormous rise in the need for strong psychological care."

Now that Russia has largely withdrawn to the east of the country, life – and research – is resuming in some areas, including Lviv, Kyiv, Dnipro and Vinnytsia. But much of the country still has air-raid alerts every night, and bombs fall indiscriminately. Many people are worried that winter will bring a renewed military offensive by Russia, says Oleksiy Kolehuk, a theoretical physicist who left his job at Taras Shevchenko National University of Kyiv in January (before the invasion) to teach in the United States and who currently has a temporary appointment in Mainz, Germany. Science and education are relatively low priorities, he

SOURCE: SCOPUS



Evacuees flee Irpin, northwest of Kyiv, in March.

DIMITAR DILKOFF/AFP/GETTY

says, but many hope that post-war rebuilding will offer an opportunity for Ukraine to redesign its scientific system and integrate more closely with Europe and the United States. “If we rebuild, we will use this opportunity for making a change,” he says. “But no one can predict when this effort will actually start.”

Russia becomes a pariah

Researchers in Russia, meanwhile, say that the reaction to the invasion is cutting their country off from international research and that many people have already left for better prospects elsewhere. European and US organizations have cut ties with Russian science, including cancelling joint projects.

“People have been so disgusted by Russia’s actions that the normal slogans of science being international, and of researchers cooperating under all circumstances, have worn thin,” says Loren Graham, a US historian of science in Russia and emeritus professor at the Massachusetts Institute of Technology in Cambridge, who has been in contact with Russian researchers. “The morale of Russian intelligentsia is very low,” he adds.

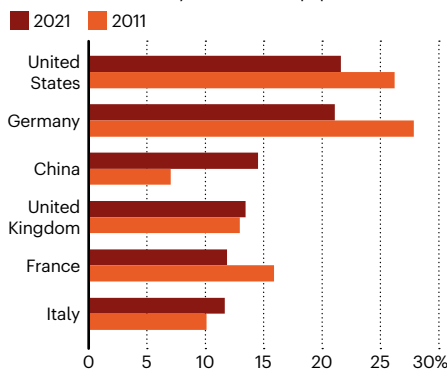
Many Russian academics have signed letters condemning the war, although official bodies, such as the Russian Union of Rectors (which represents hundreds of rectors or presidents

of Russian universities), have supported the invasion.

Sanctions restricting the movement of goods and money are affecting laboratory work, say Russia’s researchers. One scientist who left a post in Europe six years ago to build up a lab in St Petersburg says that crucial supplies of reagents and equipment have been cut off, collaborations with Western colleagues are strained and most of his young scientists want to leave. He is trying to help them do so. “It is

RUSSIA’S INTERNATIONAL RESEARCH TIES

The United States takes first place when it comes to nations’ shares of authorship with Russia in Russia’s internationally collaborative papers*.



*Scopus database: articles and reviews only.

SOURCE: SCOPUS

disastrous,” says the scientist, who asked not to be named because of concern over political reprisals. “Everybody is in shock.”

Russia’s science foundation suggested in April that scientists seek “new funding partnerships” with nations including China, India and South Africa, which have not publicly severed research links with the country. Graham thinks such a shift is likely, but that Russian researchers still hope to reinstate links with US and European colleagues (see ‘Russia’s international research ties’).

Some scientists anticipate that the isolation of Russian researchers will continue for some time, setting the country’s science back 10 or 20 years and causing a huge brain drain of young scientists. Even if Russia were to withdraw tomorrow, too much damage has been done for scientific institutions that have severed their links to recommence their work with the country, especially with institutions that have backed the war, says Robert Feidenhansl, an X-ray physicist at the Niels Bohr Institute at the University of Copenhagen. Regarding the prospect of resuming ties, he says, “I don’t see this as an option.”

Physics and space take a hit

Russia is on the periphery of most international science networks, which has made it easier for Western countries to cut off collaborations. But it does have an important role in some global research. Work done at large-scale physics infrastructures, especially in Europe, could be affected for years.

Russia has a history as a physics powerhouse, and physics has long been at the heart of science diplomacy, with East–West relations continuing throughout the cold war. But physics organizations are among those severing ties in the wake of the invasion. CERN, Europe’s particle-physics research laboratory near Geneva, Switzerland, has suspended new collaborations and contracts with Russian-affiliated scientists and institutions, and has terminated some existing agreements with both Russia and its ally Belarus that end in 2024 – so most scientists affiliated with these countries’ institutions will no longer be able to work at the facility. This might also disrupt planned upgrades: CERN’s ATLAS experiment, for instance, is seeking new suppliers and funding to cover the 3% of material costs that Russian institutions were expected to provide, says ATLAS spokesperson Andreas Hoecker. (An outlier is ITER, the international nuclear-fusion project based in southern France: its governance structure means that there is no way to oust Russia even if international members wanted to do so.)

The break with Russia could hit some organizations financially. The €1.25-billion (US\$1.4-billion) European X-ray Free-Electron Laser (XFEL), for example, has postponed Russian scientists’ ability to access the facility’s



MLADEN ANTONOV/AFP/GETTY

Russia has expertise in gathering permafrost samples, shown here at the Melnikov Permafrost Institute in Yakutsk.

high-energy beam, which researchers use to probe the properties of matter. Russia paid its usual 26% of running costs this year, amounting to €37 million, but some worry that it will decide not to next year. And the Facility for Antiproton and Ion Research (FAIR), a €3.1-billion particle collider being built in Darmstadt, Germany, is likely to face delays and extra costs. It has suspended cooperation with Russian state institutions and is reviewing cooperation with other institutions in the country, including the use of Russian-made components. As well being affected by delays and cost implications, European labs will feel the loss of Russian expertise, particularly in accelerator technology and related fields.

In space projects, the ExoMars project, a €1.3-billion Europe–Russia mission, has been particularly affected. It was set to fly on a Russian rocket later this year and use Russian-designed landing gear to deliver Europe's first rover to the Martian surface. But the European Space Agency (ESA) has now terminated its cooperation with Russia. ExoMars is now likely to be delayed until at least 2026 and, more realistically, 2028. ESA is looking into designing its own landing gear, potentially with NASA's help, but the future of the mission (which has been delayed twice before) rests on whether ESA's member states will pay enough to cover the redesign and maintain the ready-to-launch rover for several more years.

One rare area of mostly ongoing international cooperation is the International Space Station (ISS), the Earth-orbiting outpost that was born in a 1990s-era relationship between the United States and the former

Soviet Union and is now run by the space agencies of the United States, Russia, Europe, Japan and Canada. While head of the Russian space agency, Dmitry Rogozin made blustery threats about pulling Russia out; last week, he was dismissed from his post. Also during his tenure, the agency released a photo of cosmonauts on the ISS holding flags of Luhansk and Donetsk, territories that Russia occupies in Ukraine. Yet astronauts and cosmonauts have continued to travel to and from the ISS, including on Russian transport vehicles, and research continues aboard the football-field-sized station. (The station is designed to be inter-reliant, with the NASA-built side providing electricity for the Russian-built side, and the Russian-built side providing the main ability to periodically boost the orbit so that the ISS doesn't burn up in the atmosphere.)

Arctic science changes course

Among the highest-profile areas of collaboration between scientists in Russia and elsewhere is Arctic research, particularly when it comes to climate change. The Arctic is warming at least three times as fast as the global average, and Russia makes up roughly half of the circumpolar Arctic.

The Arctic Council, which is the main forum for Arctic geopolitical cooperation and which Russia currently chairs, suspended its official work in early March. Seven of its eight members agreed in June to resume limited work without Russia. Many Arctic researchers, especially in Europe, have had to suspend collaboration with scientists in Russia owing to restrictions imposed by their funding agencies

or institutions. A number of field experiments, including efforts to monitor thawing permafrost and changing landscapes for reindeer herders, have pivoted to work in the North American or European Arctic, rather than the Russian Arctic.

Some work can be done remotely, but not all. Researchers outside Russia can use Earth-observing satellites to monitor many aspects of global change, such as Siberian wildfires, from afar. But on-the-ground measurements are often needed to confirm the accuracy of what satellites are seeing – and those data, usually gathered by scientists in Russia, might not be shared with non-Russian scientists any time soon.

“To study the Arctic climate we need data from the entire Arctic,” says Kim Holmén, a climate scientist at the Norwegian Polar Institute in Tromsø. “If we cannot share data and measurements freely, the quality of our research will deteriorate.”

Climate responses disrupted

More widely, the war seems likely to have a far-reaching effect on the world's response to climate change. It has contributed to the largest energy shock in decades, driving up oil and gas prices and reshaping the global energy system. That could have both positive and negative consequences for the transition to cleaner energy.

Europe is struggling with its heavy reliance on Russia's fossil fuels, which puts it in the awkward position of subsidizing Russia's invasion with billions of dollars in monthly fuel purchases. The European Union has banned

imports of coal and other solid fossil fuels from Russia after 10 August; another measure will phase out most Russian oil imports only by the end of the year. However, China and India have purchased much of the Russian oil left on the market by Western embargoes, and Russia is exporting more oil now than it was before the war started, according to Simone Tagliapietra, an economist at Bruegel, a think tank based in Brussels.

It's less clear whether Europe can wean itself off Russian natural gas without severe economic consequences. It has cut down on some imports (see 'Europe's gas supplies'), but that is mainly because Russia itself reduced the flow, notes Tagliapietra: Russia has cut off supplies to several countries that refused its demand to pay for energy in roubles, and it has reduced shipments to Germany, which also affects supplies for Italy, France and Austria.

In the short term, many researchers fear that higher prices and rising concerns about energy security could translate into new investments and subsidies for fossil fuels and less money for nearly everything else. The most obvious example is coal-fired power, which is getting a boost in Europe as Germany, the Netherlands and other countries brace for a winter without their usual natural-gas reserves; there could be impacts globally, too, including investments for coal in places such as southeast Asia.

Still, European countries are also trying to use the situation as an opportunity to accelerate their transition from dirty fossil fuels to clean energy; Germany, Italy, Netherlands and the United Kingdom have all announced plans to accelerate electricity generation from renewable energies. The European Commission has presented a plan to quickly transition EU countries away from Russian energy, including by scaling up renewables and promoting hydrogen production. "Long term, I'm cautiously optimistic that it's going to be beneficial," says David Victor, a political scientist at the University of California, San Diego.

International tensions might also bleed into the United Nations climate-convention talks. It's possible that worries about national security and economic competitiveness

could undermine global cooperation on climate-related issues. That happens to be one of the scenarios, SSP3, developed for the latest assessment by the Intergovernmental Panel on Climate Change. Model projections in that scenario, called "regional rivalry – a rocky road" and defined by trade wars and a resurgence of nationalism, tend to show the world blowing past its climate targets and hitting around 4 °C of warming this century.

Sustainable-development setback

In April, António Guterres, secretary-general of the United Nations, argued that the war could throw one-fifth of humanity – 1.7 billion people – into poverty, destitution and hunger on a scale not seen in decades. The most immediate concern was food insecurity, owing to disruptions in food and fuel exports from Ukraine and Russia as well as export bans by nations elsewhere as they shore up their own supplies. But the diversion of aid budgets and global attention to Ukraine, paired with rising interest rates to curb inflation and the global economic downturn, also seem likely to impair development funding.

More broadly, Guterres says that the confluence of wars, the COVID-19 pandemic and the climate crisis is jeopardizing progress towards the United Nations' 17 sustainable development goals (SDGs), and warns of a "lost decade" of development for poor countries.

That's a bleak picture for researchers who work on global health and sustainable development. "All indications point towards a dramatic reversal in nearly all indicators due to the Russian invasion," says Adam Rogers, formerly a senior adviser for the UN Development Programme, and now an independent consultant on sustainability issues, in Washington DC.

But the crisis could lead to renewed focus on overlooked areas of research. Studies on the efficient use of fertilizers, and on alternatives to inorganic fertilizers, for instance, are suddenly in vogue: in June, US President Joe Biden announced a 'Global Fertilizer Challenge', to raise money for this field. As with the energy shock, the Ukraine invasion could lead to research into food security getting more of the attention that it deserves.

Global science reshaped?

Science has an ingrained international character, because researchers recognize the importance of maintaining the free flow of knowledge even during conflict, says Jon Agar, who studies the history of science and technology at University College London.

But wars tend to change those priorities, he adds, with scientists often rallying to national aims. The First World War, for instance, led to long-lasting divisions that reorganized European science around two camps, with British and French researchers in one and German and Austrian in another.

International collaborations in science ultimately tend to follow geopolitical alignments. So a long-lasting Western diplomatic split with Russia could be mirrored in research, too, with Russia shifting towards more collaboration with China and India. That idea is speculative, in part because it's not clear that China has much to gain. In a July policy paper on the geopolitics of global science, researchers from organizations including the Harvard Kennedy School in Cambridge, Massachusetts, concluded that China's leadership would gain more from maximizing global scientific collaboration than it would from risking dam-

“ALL INDICATIONS POINT TOWARDS A DRAMATIC REVERSAL IN NEARLY ALL INDICATORS.”

age to its Western partnerships by entering a bipartite research engagement with Russia, a country with an "ailing position in international science" (see go.nature.com/3nwduvb).

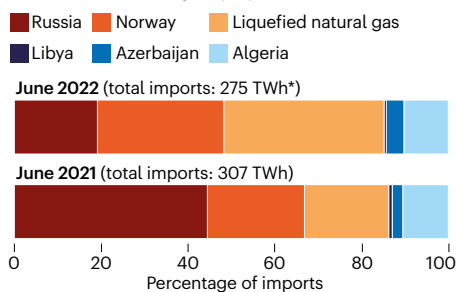
Still, the Russia boycotts come at a tense time for global science, says Kieron Flanagan, a science-policy researcher at the University of Manchester, UK. Many countries, including the United Kingdom and United States, have tightened controls over the export of key technologies and introduced stricter guidance on international collaborations with some countries, such as China. "We can detect moves towards greater protectionism or techno-nationalism, which clearly may have implications for how open countries are towards global scientific collaboration," he says. But Flanagan suspects that some of these measures might be directed more towards a desire to control leading-edge technologies than to a lack of appetite for global research.

Even so, a world of rockier geopolitics and sanctions seems likely to slow cross-border collaboration. If the war is prolonged, "I'd expect research collaboration to realign", says Agar.

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EUROPE'S GAS SUPPLIES

This June, Russia supplied less than 20% of the European Union's natural gas, down from more than 40% in the same month last year. (Many individual countries receive a higher proportion.)



*TWh, terawatt hours.

Correction

This feature erroneously stated that Russia had not paid its share of XFEL's running costs.