who turned to third-party services that provide scientific text and data, or who bought and sold papers, according to reports published between March and September that detail the outcome of 42 investigations.

Researchers in China might turn to paper mills to buy papers or data because they need scientific publications to get promotions. Paper mills have been thrust into the spotlight over the past year as scientific journals have retracted hundreds of articles suspected of coming from them.

In March, *Nature* reported that 370 such articles had been retracted since January 2020, all from authors at Chinese hospitals (see *Nature* **591**, 516–519; 2021); that tally is now, by *Nature*'s count, at least 665.

Scientists had previously been reprimanded for using paper mills, but in 2017 a major scandal rocked the Chinese scientific community. The journal *Tumor Biology* retracted 107 research papers because many were associated with fabricated peer-review reports or had been churned out by paper mills.

Policy in action

As a result, China's ministry of science and technology vowed to crack down on breaches of research integrity, and in 2018 announced reforms to tackle misconduct. Last year saw the launch of the new research-misconduct policy, which for the first time explicitly mentioned paper mills. Under the policy, serious violations of the rules must be made public.

The recent actions by several funders suggests that the policy is being put into practice. In March and July, the NSFC published the details of 13 misconduct investigations, 6 of which involved paper mills. The remaining cases involved peer-review fraud, plagiarism and data falsification. Between June and September, the NHC reported nearly 30 other misconduct cases, including paper-mill use.

Sanctions for researchers found to be using paper mills ranged from lectures of admonishment to suspending all funding applications for up to seven years and opportunities for promotion for up to six years.

Futao Huang, a Chinese researcher working at Hiroshima University in Japan, agrees with Chen that the punishments doled out to researchers using paper mills are too light, and that China's academic evaluation system needs an overhaul, particularly in hospitals.

To reduce the pressure felt by Chinese researchers to publish papers, "more flexible and diverse research-evaluation schemes should be developed", he says.

Chen would like to see a crackdown on the paper mills themselves. "I have read reports by Chinese domestic media investigating paper mills, but have not seen any punishment any paper mill has faced," he says.

Additional reporting by Richard Van Noorden.

China's pledge on overseas coal — by the numbers

On 21 September, Chinese President Xi Jinping stated at a United Nations summit that his country would stop financing new coal-fired power plants abroad. The announcement has raised hopes that the world could soon wean itself off the most carbon-intensive fossil fuel. But although this is a positive step from the world's biggest emitter of carbon, researchers say that China is a long way from phasing out its massive domestic use of coal.

"China's economy still relies heavily on coal," says Ottmar Edenhofer, director of the Mercator Research Institute on Global Commons and Climate Change in Berlin. "Stopping coal finance abroad is an important step, but China is a long way from phasing out coal altogether."

Despite the country's plans to become carbon neutral by 2060, its domestic coal production has nearly tripled since 2001. By contrast, the amount of coal produced in the United States and Europe has roughly halved over this time. China accounted for more than half of the 7.7 billion tonnes of coal produced globally in 2020, dwarfing the contributions of the next biggest producers (see 'World's biggest coal producers').

But China also finances the construction of coal-fired power plants in many other countries, to help Chinese energy businesses profit from overseas markets. Overall, China finances enough coal power abroad to produce 42 gigawatts of electricity — sufficient to power at least 30 million homes.

Most of this financing flows to Bangladesh, Vietnam, Mongolia and Indonesia, but many African countries and some European nations also receive significant amounts (see 'Coal financiers and recipients').

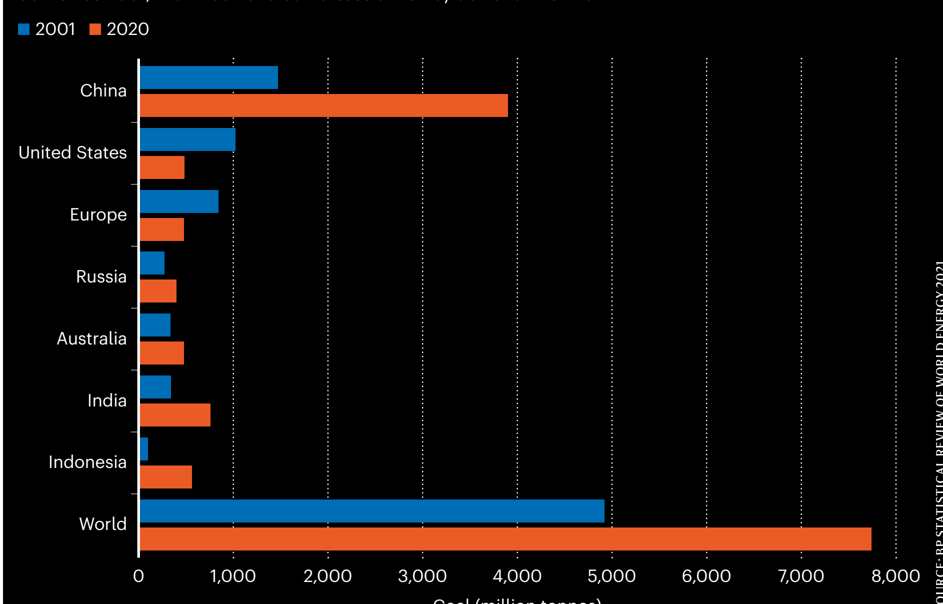
China commissioned 38.4 GW of new coal plants last year, 76% of the global total of new coal-fired power plants, according to the non-profit organization Global Energy Monitor.

Experts say that halting the financing of these coal-power projects is a good start, but add that the emissions such schemes produce are dwarfed by those generated by the 1,000 GW of coal power that China generates domestically. This is more than four times the capacity of either India or the United States, which are the next biggest generators of coal power.

"China's current and future domestic coal power is more important for the climate than anything that is likely to be built abroad in the future," says Jan Ivar Korsbakken, an energy-policy specialist at the Centre for

WORLD'S BIGGEST COAL PRODUCERS

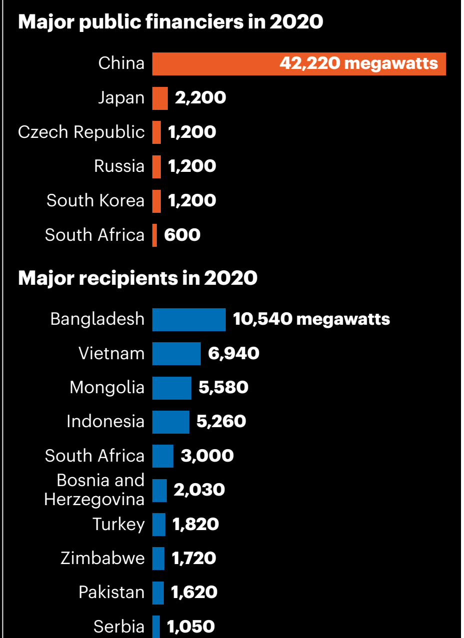
The amount of coal the world produces annually has increased by nearly 60% since 2001, with much of that increase driven by demand in China.



Data story

COAL FINANCIERS AND RECIPIENTS

In 2020, China was by far the world's biggest public financier of coal-fired power plants abroad, with most of that money flowing to other Asian nations.



SOURCE: GLOBAL ENERGY MONITOR

International Climate Research in Oslo.

In Europe and the United States, coal power has been declining noticeably in recent decades. Despite former US president Donald Trump's promise to revive the industry, very little capacity was added during his four-year term, whereas coal-fired plants that generated a total of 52.4 GW were retired.

The phasing out of coal has been slower in Europe, but European Union countries have retired more than 17 GW of capacity since 2019 — led by Spain, which closed half of its coal-fired power stations in 2020.

Leaders of the G7 group of advanced economies — consisting of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States — agreed in May to halt the international financing of coal projects.

But the almost 2,500 coal-power stations operating in the world today might still emit more than 200 billion tonnes of carbon dioxide over their lifetimes, making it hard to rein in global warming to 1.5 °C above pre-industrial temperatures.

"The 1.5 °C goal is out of reach if coal-fired plants aren't replaced by cleaner energy technologies very soon," says Edenhofer. "Alas, an end of coal is not yet in sight."

By Quirin Schiermeier

SOLID MADE OF ELECTRONS IMAGED FOR FIRST TIME

Graphene trick allows physicists to take snapshots of 'Wigner crystals'.

By Davide Castelvecchi

If the conditions are just right, some of the electrons inside a material will arrange themselves into a tidy honeycomb pattern — like a solid within a solid. Physicists have now directly imaged these 'Wigner crystals', named after the Hungarian-born theorist Eugene Wigner, who first imagined them almost 90 years ago.

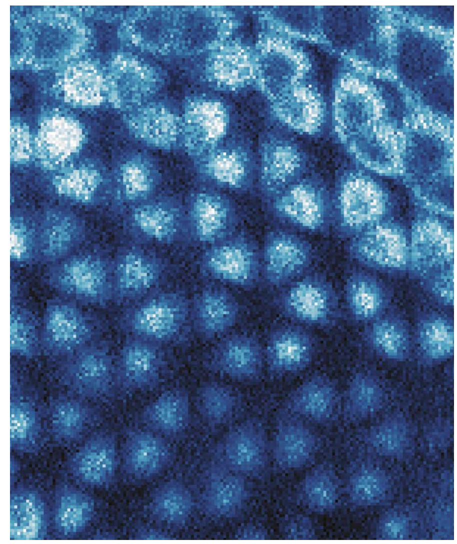
Researchers had convincingly created Wigner crystals and measured their properties before, but this is the first time that anyone has actually taken a snapshot of the patterns, says study co-author Feng Wang, a physicist at the University of California, Berkeley. "If you say you have an electron crystal, show me the crystal," he says. The results were published on 29 September in *Nature* (H. Li *et al. Nature* **597**, 650–654; 2021).

To create the Wigner crystals, Wang's team built a device containing atom-thin layers of two similar semiconductors: tungsten disulfide and tungsten diselenide. The team then used an electric field to tune the density of the electrons that moved freely along the interface between the two layers.

In ordinary materials, electrons zoom around too quickly to be significantly affected by the repulsion between their negative charges. But Wigner predicted that if electrons travelled slowly enough, that repulsion would begin to dominate their behaviour. The electrons would then find arrangements that minimize their total energy, such as a honeycomb pattern. So Wang and his colleagues slowed the electrons in their device by cooling it to just a few degrees above absolute zero.

A mismatch between the two layers in the device also helped the electrons to form Wigner crystals. The atoms in each layer are slightly different distances apart, so pairing them together creates a honeycomb 'moiré pattern', similar to that seen when overlaying two non-identical grids. That repeating pattern created regions of slightly lower energy, which helped the electrons to settle down.

The team used a scanning tunnelling microscope (STM) to see this Wigner crystal. In an STM, a metal tip hovers above the surface of a sample, and a voltage causes electrons to jump down from the tip, creating an electric current. As the tip moves across the surface, the changing intensity of the current reveals the location of electrons in the sample.



H. LI ET AL./NATURE

This scanning tunnelling microscope image of a graphene sheet reveals that a 'Wigner crystal' — a honeycomb arrangement of electrons — has formed inside a layered structure underneath.

Initial attempts to image the Wigner crystal by applying the STM directly to the double-layer device were unsuccessful, Wang says, because the current destroyed the fragile Wigner arrangements. So the team added a layer of graphene, a single-atom sheet of carbon, on top. The presence of the Wigner crystal slightly changed the electron structure of the graphene directly above, which was then picked up by the STM. The images clearly show the neat arrangement of the underlying Wigner electrons. As expected, consecutive electrons in the Wigner crystal are nearly 100 times farther apart than are the atoms in the semiconductor device's actual crystals.

"I think that's a great advancement, being able to perform STM on this system," says Carmen Rubio Verdú, a physicist at Columbia University in New York City. She adds that the same graphene-based method will enable STM studies of a number of other interesting physical phenomena beyond Wigner crystals. Kin Fai Mak, a physicist at Cornell University in Ithaca, New York, agrees. "The technique is non-invasive to the state you want to probe. To me, it is a very clever idea."