HARVARD-CHINA PROJECT
on Energy, Economy and Environment

HARVARD-CHINA PROJECT NEWSLETTER

INSIDE THIS ISSUE

3 Three Research Briefs for Non-Specialists
The Briefs explore recent solar, green hydrogen and renewable grid integration research from HCP.

4 Hydrogen from China Can Help Japan Reach its GHG Goals

5 Introducing Our Postdocs
Meet Haiyang Lin and Peter Sherman, recent Ph.D. graduates.

6 Meet Our Visiting Fellows
Our three newest Fellows share their research projects.

7 HCP In the News

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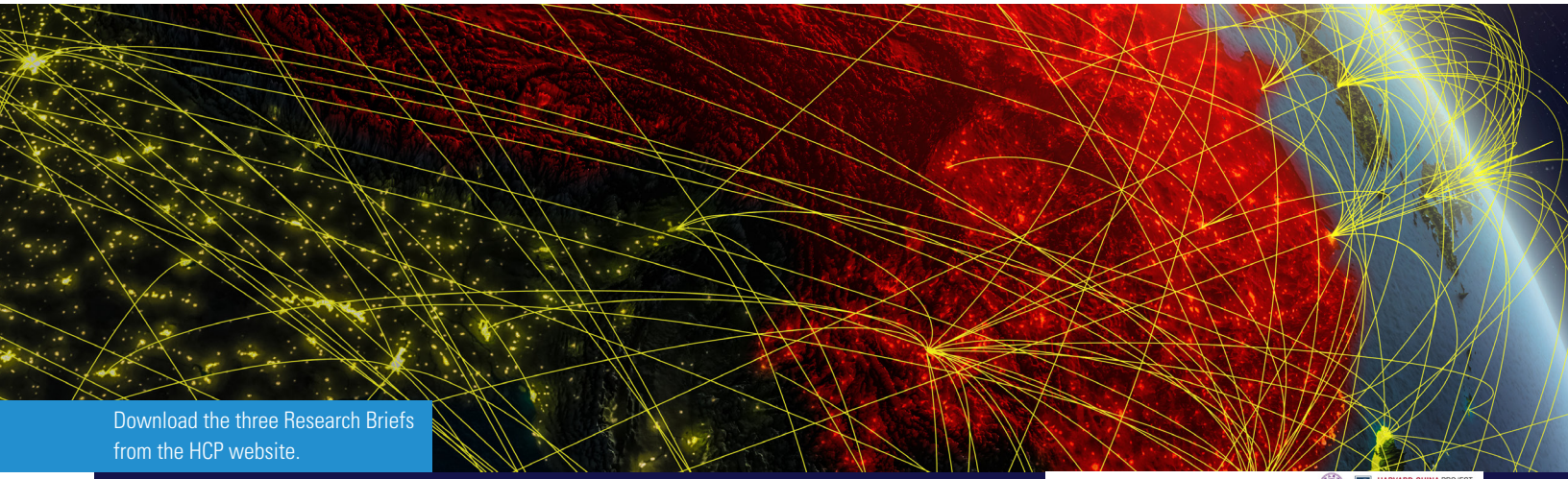


Download the three Research Briefs from the HCP website.

HCP RESEARCH BRIEFS

This fall, the Harvard-China Project created three Research Briefs for Non-Specialists, which detail new studies on solar power, hydrogen, and grid integration of renewable power. These publications, initially created as part of an Energy Foundation China grant, each contain a list of Key Takeaways to summarize the research, and more detailed figures and descriptions in the interior pages. The Key Takeaways are also translated into Chinese. The Research Briefs are available to read and download from our website under the "News" section.

Rising Cost Advantages of Solar Power in China and Coupled Electricity Storage for Greater Grid Compatibility (*PNAS*)

China has already made major commitments to transitioning its energy systems towards renewables, especially power generation from solar, wind and hydro sources. However, there are many unknowns about the future of solar energy in China, including its cost, technical feasibility and grid compatibility in the coming decades. Recent projections of the cost of future solar energy potential in China have relied on outdated and overestimated costs of solar panels and their installation, and storage technologies like lithium-ion batteries.

How much will solar power really cost in China in the coming decades, including the challenges its inherent variability poses to the grid?

Researchers from Harvard, Tsinghua University, Nankai University and Renmin University of China have found that solar energy could provide 43.2% of China's electricity demands in 2060 at less than two-and-a-half U.S. cents per kilowatt-hour. For comparison, coal power tariffs in China ranged 3.6 to 6.5 cents per kilowatt-hour in 2019. The research is published as the cover article of the *Proceedings of the National Academy of Sciences* (PNAS).

"The findings highlight a crucial energy transition point, not only for China but for other countries, at which combined solar power and storage systems become a cheaper alternative to coal-fired electricity and a more grid-compatible option," said **Michael B. McElroy**, the Gilbert Butler Professor of Environmental Studies at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) and co-author of the study.

"Today, subsidy-free solar power has become cheaper than coal power in most parts of China, and this cost-competitive advantage will soon expand to the whole country due to technology advances and cost declines," said **Xi Lu**, an alumni of

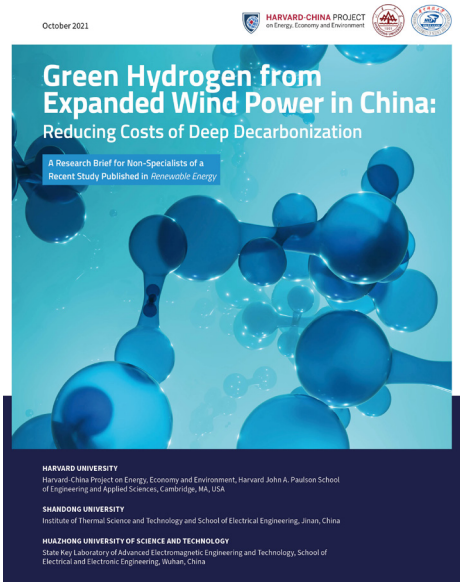
Read the Brief: https://bit.ly/3HI7gKs

SEAS and the Harvard-China Project who is Associate Professor, School of Environment, Tsinghua University and lead author of the paper. "Our results demonstrate that the economic competitiveness of solar power combined with investments in storage systems could provide extra benefits for grid dispatch, which will be especially important for operation of future electric systems in China."

By Leah Burrows | SEAS Communications

New Publication: Xi Lu, Shi Chen, Chris P. Nielsen, Chongyu Zhang, Jiacong Li, Xu He, Ye Wu, Shuxiao Wang, Feng Song, Chu Wei, Kebin He, Michael P. McElroy, and Jiming Hao. 2021. "Combined solar power and storage as cost-competitive and grid-compatible supply for China's future carbon-neutral electricity system." *Proceedings of the National Academy of Sciences*, 118, 42.

Green Hydrogen from Expanded Wind Power in China: Reducing Costs of Deep Decarbonization (*Renewable Energy*)



Read the Brief: https://bit.ly/3GrYoaB

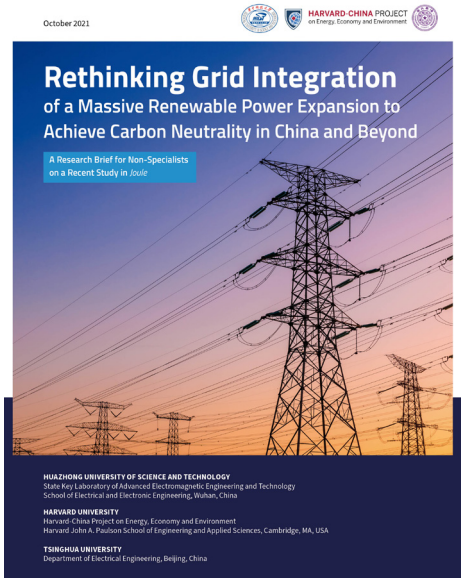
China is the world's largest producer of hydrogen – currently chiefly an industrial feedstock consumed by the chemical and refining industries – and overwhelmingly produces it from coal emitting CO_2, termed "black" hydrogen. China also leads the world in wind power generation, with 61% of its onshore wind capacity located in windy northern regions, where it must sometimes be wasted because the grid cannot accommodate its inherent variability. But renewable power can be used to produce hydrogen without CO_2 emissions, called "green" hydrogen, through electrolysis of water that can be timed to accommodate variations in renewable generation.

Now a team of researchers from Harvard University, Shandong University and Huazhong University of Science and Technology have explored the potential harnessing of China's wind energy to produce carbon-free green hydrogen at a cost lower than that of coal-derived black hydrogen. If green hydrogen can prove cost-competitive with black carbon for existing industrial uses, it may have even greater decarbonization potential as a zero-carbon energy source in key sectors that are otherwise difficult to decarbonize, including iron & steel production, cement making, and heavy-duty transportation.

The researchers chose Western Inner Mongolia, with its high wind power generation and large coal and black hydrogen production, as a representative region to estimate the technical and economic feasibility of producing green hydrogen using wind power. The results show that green hydrogen produced from wind power is competitive with black hydrogen, with large production levels possible at less than US$2/kg – a widely recognized threshold for cost-competitiveness. And by 2030, shifting black hydrogen to green hydrogen derived from Western Inner Mongolia's growing wind power for use as industrial feedstocks alone could reduce about 100 million tons of CO_2 emissions per year, equal to roughly half of the entire carbon footprint of the megacity of Beijing.

By Kellie Nault

New Publication: Haiyang Lin, Qiuwei Wu, Xinyu Chen, Xi Yang, Xinyang Guo, Jiajun Lv, Tianguang Lu, Shaojie Song, and Michael B. McElroy. 2021. "Economic and technological feasibility of using power-to-hydrogen technology under higher wind penetration in China." *Renewable Energy*, 173, 569-580.



Read the Brief: https://bit.ly/3uC1VRi

Rethinking Grid Integration of a Massive Renewable Power Expansion to Achieve Carbon Neutrality in China and Beyond (*Joule*)

There are many uncertainties about pathways to mid-century carbon neutrality in China and other major emitting nations, but one fundamental aspect is certain: they will require massive expansions of wind and solar power to displace coal- and gas-fired power. The problem is not the cost and feasibility of sufficient renewable generation, but rather the challenges it introduces into the grid because of its variability: the wind doesn't always blow and the sun doesn't always shine.

Now, in a new paper published in *Joule*, a team of researchers from Harvard University, Huazhong University of Science and Technology and Tsinghua University have developed a cross-sector, high-resolution model to find the best and most cost-effective way for China's power system to become carbon neutral by 2050. A comprehensive strategy moving beyond conventional planning assumptions to include large offshore wind generation, power storage, electric vehicles, green hydrogen production, and expanded transmission to balance power on a national basis can sharply reduce costs of integrating renewable power into the grid. In fact, the results show that realizing the carbon neutrality of China's power system by 2050 is not only feasible but need not necessarily cost more than reliance on coal- and gas-fired power, with no carbon constraints at all, to meet future electricity demands.

New Publication: Xinyu Chen, Yaxing Liu, Qin Wang, Jiajun Lv, Jinyu Wen, Xia Chen, Chongqing Kang, Shijie Cheng, and Michael B. McElroy, 2021, "Pathway toward carbon-neutral electrical systems in China by mid-century with negative CO2 abatement costs informed by high-resolution modeling." *Joule,* 5, 10, 2715-2741.

RESEARCH UPDATES

Hydrogen Produced from Offshore Wind in China Can Help Japan Reach it's GHG Emission Goals

Japan's Green Growth strategy signals a commitment to net-zero greenhouse gas emissions by 2050 – and hydrogen produced from renewable energy can play an important role in this shift. A team of researchers from Harvard University, Shandong University, China University of Petroleum Beijing and Huazhong University of Science and Technology have explored the possibility of producing hydrogen by electrolysis using power generated from offshore wind in China.

"This research helps build the case that it is not only possible for Japan to meet the formidable challenge of transitioning to net-zero emissions, it also could be cost-competitive," explains lead author **Shaojie Song**, Research Associate in the Harvard-China Project. "Our research shows that Chinese-produced hydrogen could be delivered at a volume and cost consistent with Japan's future projections."

The team analyzed the potential for a green hydrogen supply chain to Japan delivered from offshore wind produced in China on an hourly basis from every Chinese coastal province, considering several possible wind investment levels, electrolysis technologies and transport mechanisms. The generated hydrogen could be delivered to Japan either as liquid hydrogen, bound to a chemical carrier such as toluene, or as a component of ammonia.

The researchers determined that offshore wind power from China could provide potentially as much as 12 petawatt-hours of electricity annually. They modeled the cost implications of the offshore wind location; chemical conversion processes; and storage, transport, and delivery methods. The team found that Chinese sources could supply cost-competitive hydrogen to Japan for 2030 even if offshore wind deployment follows a high-cost scenario.

New Research: Shaojie Song, Haiyang Lin, Peter Sherman, Xi Yang, Chris P. Nielsen, Xinyu Chen, and Michael B. McElroy. 2021. "Production of hydrogen from offshore wind in China and cost-competitive supply to Japan." *Nature Communications*, 12, 2021, 6953.

Modeling Emissions Pathways for India's Climate Amid COVID-19 Recovery

As the global economic recovery from COVID-19 continues, decisions regarding emissions strategies can have important implications on regional climate change. A new paper in *Environmental Research Letters* explores the impact of such decisions in India, modeling the effects of COVID-19 emissions recovery pathways on India's summertime climate.

"Anthropogenic emissions can be linked to extreme weather events in India and beyond," explains **Peter Sherman**, a postdoc in the Harvard-China Project on Energy, Economy and Environment in the Harvard University John A. Paulson School of Engineering and Applied Sciences and recent Ph.D graduate in Harvard's Department of Earth and Planetary Sciences. "This study provides an important discussion on how India – a nation which is likely to be particularly susceptible to climate change over the coming decades – may be affected by emissions changes as the world transitions out of the COVID-19 pandemic."

The team of researchers—which include Harvard undergraduate Jonathan D'Souza as first author and two high school students from Cambridge Rindge and Latin School (mentored by Harvard University and University of Cambridge researchers) as contributing authors—modeled the impact of three different scenarios on India's climate: fossil-based recovery, a strong renewable-based recovery and a moderate scenario in between the two.

The team found that a fossil fuel-based recovery pathway leads to higher summertime aerosol concentrations in the long term, in contrast to greener scenarios. The greener scenarios may actually drive a positive feedback loop, where the solar PV capacity factor improves with reduced air pollution – incentivizing further investment in renewables which should further reduce aerosol emissions.

The researchers also found that extreme temperature and precipitation events in India are expected to increase in magnitude and frequency regardless of the emissions commitments going forward. However, the spatial patterns of these changes as well as the extent of the change are pathway dependent. They found that while decreasing fossil fuel emissions will reduce the greenhouse effect (and consequently extreme temperature events), concurrent emissions reductions in aerosols and their precursors may balance these effects at the regional level.

New Research: Jonathan D'Souza, Felix Prasanna, Luna-Nefeli Valayannopoulos-Akrivou, Peter Sherman, Elise Penn, Shaojie Song, Alexander Archibald, and Michael B. McElroy. 2021. "Projected changes in seasonal and extreme summertime temperature and precipitation in India in response to COVID-19 recovery emissions scenarios." *Environmental Research Letters,* 16, 11, 114025.

INTRODUCING HCP'S NEWEST POSTDOCS

Haiyang Lin, Ph.D. Shandong University

Haiyang Lin, HCP postdoc and recent Ph.D. graduate in Power Engineering and Engineering Thermophysics from Shandong University, grew up in city of Shouguang, Shandong Province, China. Shouguang is known as the hometown of vegetables, and from a young age Haiyang saw all kinds of fruits and vegetables grow from cultivation to maturation, which Haiyang says is the most ancient and natural energy process for humans to use solar energy. So it was only natural for him to combine his natural aptitude for mathematics and physics with his energy interests in his current role as a Harvard-China Project postdoctoral fellow.

Haiyang has worked on integrated energy system simulation and optimization for the past several years, where he studies the characteristics of energy supply and demand. "My work here aims to address the economic feasibility and decarbonization potential of renewable power, biomass energy and green hydrogen application by combining a techno-economic model for optimal design and operation of a low carbon energy system," explains Haiyang. He is studying the decarbonization strategies for China, Japan and India, in which hydrogen is considered to play a key role in facilitating the transition to a future deeply decarbonized energy system, and can help accommodate higher penetrations of renewables in the power system.

As Haiyang continues his work as an energy researcher, he appreciates the interdisciplinary nature of the Harvard-China Project. "Integrated energy system studies require inputs from multiple disciplines, such as electricity, economics, climate, transportation and so on," he explains. "In this group, I have access to these experts and can fill in the blanks of my study easily. It is remarkable that so many people with different expertise are working towards the same goal."

Peter Sherman, Ph.D. Harvard University

Peter Sherman, HCP postdoc and recent Ph.D. graduate from Harvard's Department of Earth & Planetary Sciences, says he looks back at his graduate years at Harvard with gratitude for his mentorship role of undergraduates and local high school students. "Giving younger people the opportunity to learn about (and occasionally struggle with!) research has helped me refine my pedagogical but also scientific perspectives in ways I did not envision when I started mentoring," Peter explains. "From these experiences, I have learned how to better synthesize and present research in ways that can more easily 'stick' with people learning about the science of climate change." Peter's enthusiasm for energy and climate change research translates to his new role as Harvard-China Project postdoctoral fellow, where he is working to help understand the scope of the climate crisis and offer solutions that could be implemented to mitigate these issues.

Peter's focus is on how regional climate change impacts people and how we can try to reduce some of the major consequences by decarbonizing our energy system – much of which builds upon his Ph.D. research. "We are particularly focused on means of decarbonizing the electricity sector as well as some of the harder-to-abate sectors, and have a few projects in mind that aim to follow up on the past research we have done on India's electricity sector and green hydrogen," says Peter. "I am also interested in projects focusing on the intersection of climate and energy, and am currently working on a smaller project looking at the impacts of climate change on future air conditioning demand (and the consequent impacts on the electricity grid because of it)."

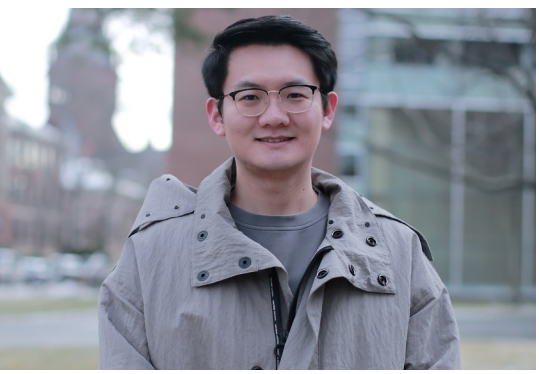
Peter looks forward to continuing his collaboration with Harvard-China Project colleagues, noting that "the group as a whole is fantastic because there are experts from all sorts of fields, from climate, to atmospheric chemistry to energy systems planning. This fosters an environment that is incredibly intellectually stimulating, where conversations in group meetings can quickly lead to major cross-disciplinary projects. We never run out of things to research!"

WELCOMING HCP'S VISITING FELLOWS

Zheng Wang

For **Zheng Wang**, a Ph.D. candidate from Peking University, an interest in energy was a fabric of his childhood. Growing up in Yan'an, Shaanxi Province, China, where "water can be burned (oil)" was recorded during the Eastern Han Dynasty (around 32 AD), the first oil well in China was built in 1905 in Zheng's elementary school. "Growing up, I had close contact with fuel and energy, which has given me a certain understanding of the role of energy in industrial development and socio-economic progress, and energy's role as one of the main sources of income for the local government," explains Zheng. "This made me curious about the real role of energy in the socio-economy."

Zheng sees the shifting role of energy in society firsthand, as his hometown transitions to renewable energy sources like wind and solar power. He plans to continue his renewable energy research while at Harvard. He first plans to calculate the capacity potential of Chinese onshore and offshore wind power under various scenarios (e.g. grid connection, diverse energy storage) at different times (2030, 2060). He will use this data to explore the efficiency and economic costs of wind power at different altitude levels, and compare Chinese wind power and photovoltaic costs. Zheng also plans to combine climate change models and land surface model simulations to consider the calculation of capacity requirements for long-term energy storage for wind-PV-storage systems in different regions.



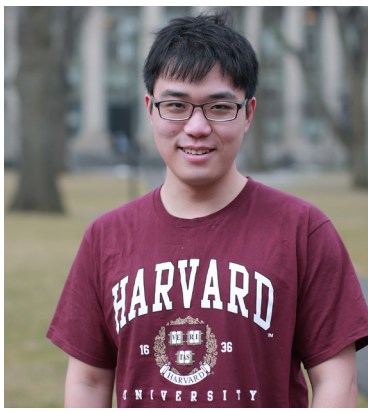
Chen Xiang

For Hong Kong University Ph.D. candidate **Chen Xiang**, it was an environmental volunteerism trip to Antigua, Guatemala where she worked on water filtration that sparked her career in environmental governance. "Despite the fact that I tried to approach as many local people as possible to share information on mitigating water contamination, I realized the limitations of my own effort – without an improvement of institutional arrangement and state capacity (a top-down approach), it would be very difficult to improve the quality of drinking water in the least developed states," explains Chen. "This was my 'Aha!' moment: applying what I have learned from global governance and politics, and adopting an approach of environmental governance to solve real-life issues and address environmental justice."

Later, while studying the process and mechanism of how the EU helped China build its own emissions trading system, Chen further cemented her career interests. "My research seeks to understand the role of carbon markets as a means to overcome weak incentives of carbon emissions mitigation in China," says Chen. She is also working on a second project that surveys public attitudes toward climate change to explore how China's global climate leadership aspirations are disconnected across different local scales.

Xinyang Guo

While in junior high school, distributed solar PV street lamps and small-scale wind turbines appeared in **Xinyang Guo**'s hometown of Xingyang, Hubei Province. "At that time, I felt that this way of power generation was very novel," he said. "Later, I learned that nature has endless renewable energy, which could be easily converted into electricity." A few years later he met his current advisor, Professor Xinyu Chen – also a former Harvard-China Project researcher. Together, they explored offshore wind as a means towards decarbonization. "I realized that offshore wind power was indispensable for the ambitious target of carbon neutralization, and the construction of trans-continental interconnections in Northeast Asia," he says. It was these experiences that led him to pursue his current coursework as a Ph.D. candidate at the Huazhong University of Science and Technology, and continue to develop his research on carbon neutrality of energy systems while a Harvard-China Project Visiting Fellow. At Harvard, he is drawing on input from other researchers, including Professor Michael B. McElroy. "What has impressed me most is the communication with Professor Mike. His thinking on research points and story lines is very original and in-depth."



HCP IN THE NEWS

OCT 13 South China Morning Post

'Key to China's power future': cost of solar to match coal power by 2023, scientists say
By Holly Chik | Photo: Xinhua

SOLAR POWER, when paired with adequate storage capacity, could meet more than 40 per cent of the country's electricity demands by 2060, say researchers.

Decarbonizing the energy system is a priority for China to deal with air pollution at home and global climate change, according to the Chinese-US paper.

Full article at https://bit.ly/3tRLwb1

NOV 03 ClimateWire

Here to save the day: 'Supergrids' in China and the U.S.
By John Fialka | Photo: Adobe

A MASSIVE GRID that can route electricity over long distances may not seem like a useful response to climate change. But experts say so-called supergrids are critical to the mass adaption of renewable energy sources — and China and the United States both have made strides recently to help turn this vision into reality.

"I would be very surprised if the Chinese government would not be extremely interested in this," said Michael McElroy, a Harvard University professor.

Full article at https://bit.ly/3GAtq06

Nov/ Dec Harvard Magazine

China's Excess Wind Energy
By Jacob Sweet | Photo: Taylor Callery

THERE'S A PROBLEM with sustainable energy, and it will only grow with time. The problem is intermittency—what to do when the wind dies or the sun goes down.

Storing extra energy in batteries can alleviate some intermittency problems, but Professor Michael McElroy believes that using renewable energy produced by utilities in working power grids to make hydrogen—a portable, storable fuel source that produces only water as a byproduct when burned in a fuel cell—is a better solution.

Full article at https://bit.ly/3rE6jw3

Prem Shankar Jha, HCP Visiting Fellow, Earns Lifetime Achievement Award by Mumbai Press

Prem Shankar Jha, an Indian journalist, writer, economist and Harvard-China Project Visiting Fellow, was recognized for his distinguished writing career and significant contributions to the journalism field. Jha was presented a RedInk Award for Lifetime Achievement, given by the Mumbai Press Club in India. This annual collection of awards celebrates excellence in journalistic achievements, as determined by an accomplished jury. The award was presented to Jha by the Chief Justice of India NV Ramana.

"It is profoundly gratifying for any writer to be appreciated by his readers, but it is even more so when the recognition comes from one's peers," says Jha. "One thing that I always followed in my journalism career was that I never overruled my consciousness to protect my career. In this age of digitization, everyone can be tracked all the time; we journalists should be careful and fight for the truth."

To learn more about the Harvard-China Project community of collaborators, please visit our website: https://chinaproject.harvard.edu/contributors

MEET HCP UNDERGRADUATE RESEARCHERS

Jack Walker '24

An eighth-grade science project sparked a commitment to study clean energy for **Jack Walker** '24. Tasked to present on a specific alternative energy source, Jack creatively parodied rapper Drake's "Views From the Six" album, which Jack renamed "Fuels From the Six." Says Jack of the project, "Parodying the songs actually helped me understand nuclear fission to a much higher degree; I discovered new facts and perspectives on nuclear energy."

Jack maintained his focus on alternative energy throughout high school, culminating with a research stint into microbial electrolysis cells for hydrogen fuel production at the Frederick National Lab. Now, as a Chemistry and Environmental Science & Public Policy dual concentrator, Jack is working as an HCP Research Assistant on decarbonizing the global shipping industry, a project that builds upon his HCP Summer Research Assistantship. Jack's summer research analyzed the potential for modern sailing, green hydrogen, green ammonia, and electric battery propulsion. His team discovered that a hybrid propulsion mechanism might be the best option for the majority of the maritime sector—using an electric battery for in-port maneuvering and green ammonia/hydrogen combustion for open-sea travel.

Following graduation, Jack will commission as a 2nd Lieutenant in the US Air Force.

Candice Chen '22

Spending her freshman year summer in Santiago, Chile, **Candice Chen** '22 studied smog's impact on respiratory health.

This drove Candice to enroll in atmospheric chemistry courses, ultimately enrolling as a dual Environmental Science and Engineering and Earth and Planetary Sciences concentrator. "I found my love for climate and environmental science because I loved exploring questions fundamental to Earth's habitability and human wellbeing under anthropogenic climate change," says Candice.

Now, as an HCP Research Assistant, Candice is studying the shift to natural gas from coal in the Beijing region. "This work will inform estimates of CH_4 leakage, informing cost-benefit analyses on the coal-to-gas conversion and mitigation strategies," explains Candice.

RECENT PUBLICATIONS: NOVEMBER TO FEBRUARY

Shaojie Song, Haiyang Lin, Peter Sherman, Xi Yang, Chris P. Nielsen, Xinyu Chen, and Michael B. McElroy. 2021. **"Production of hydrogen from offshore wind in China and cost-competitive supply to Japan."** *Nature Communications*, 12, 2021, 6953.

Xinyu Chen, Yaxing Liu, Qin Wang, Jiajun Lv, Jinyu Wen, Xia Chen, Chongqing Kang, Shijie Cheng, and Michael McElroy. 2021. **"Pathway toward carbon-neutral electrical systems in China by mid-century with negative CO2 abatement costs informed by high-resolution modeling."** *Joule*, 5, 10 (20 October), 2715-2741.

Jonathan D'Souza, Felix Prasanna, Luna-Nefeli Valayannopoulos-Akrivou, Peter Sherman, Elise Penn, Shaojie Song, Alexander Archibald, and Michael B McElroy. 2021. **"Projected changes in seasonal and extreme summertime temperature and precipitation in India in response to COVID-19 recovery emissions scenarios."** *Environmental Research Letters,* 16, 11, 114025.

Yingying Lyu and Ann Forsyth. 2021. **"Planning, aging, and loneliness: Reviewing evidence about built environment effects."** *Journal of Planning Literature*, August.

Yu Zhao, Mengxiao Xi, Qiang Zhang, Zhaoxin Dong, Mingrui Ma, Kaiyue Zhou, Wen Xu, Jia Xing, Bo Zheng, Zhang Wen, Xuejun Liu, Chris P. Nielsen, Yang Liu, Yuepeng Pan, and Lei Zhang. 2022. **"Decline in bulk deposition of air pollutants in China lags behind reductions in emissions."** *Nature Geoscience*.

Faan Chen, Chris P. Nielsen, Jiaorong Wu, and Xiaohong Chen. 2022. **"Examining socio-spatial differentiation under housing reform and its implications for mobility in urban China."** *Habitat International*, 119, January, 102498.

Jianglong Li and Mun Ho. 2022. **"Indirect cost of renewable energy: Insights from dispatching."** *Energy Economics*, 105, January, 105778.

Jianglong Li, Mun S. Ho, Chunping Xie, and Nicholas Stern. 2022. **"China's flexibility challenge in achieving carbon neutrality by 2060."** *Renewable and Sustainable Energy Reviews*, 158, April, 112112.

Haiyang Lin, Caiyun Bian, Yu Wang, Hailong Li, Qie Sun, and Fredrik Wallen. 2022. **"Optimal planning of intra-city public charging stations."** *Energy*, 238, Part C, 121948.

Shaodan Huang, Shaojie Song, Chris P. Nielsen, Yuqiang Zhang, Jianyin Xiong, Louise B. Weschler, Shaodong Xie, and Jing Li. 2022. **"Residential building materials: An important source of ambient formaldehyde in mainland China."** *Environment International*, 158, January, 106909.

Rong Tang, Jing Zhao, Yifan Liu, Xin Huang, Yanxu Zhang, Derong Zhou, Aijun Ding, Chris Nielsen, and Haikun Wang. 2022. **"Air quality and health co-benefits of China's carbon dioxide emissions peaking before 2030."** *Nature Communications*, 13, 1008.