HARVARD-CHINA PROJECT
on Energy, Economy and Environment

CHINA PROJECT NEWSLETTER

INSIDE THIS ISSUE

CONNECT WITH US

The Project is on the following social media platforms:

@HarvardChinaProject

@Harvard_CN

www.chinaproject.harvard.edu
(English website)

www.cn.chinaproject.harvard.edu
(Chinese website)

The Harvard-China Project is based at the Harvard John A. Paulson School of Engineering and Applied Sciences and receives major support from the Harvard Global Institute on the theme of "China 2030/2050: Energy and Environmental Challenges for the Future."

RESEARCH HIGHLIGHT

Carbon-Negative Power Generation for China:

Reducing CO_2 concentrations and air pollution in the atmosphere

If we're going to limit global temperature increases to 2 degrees above pre-industrial levels, as laid out in the Paris Climate Agreement, it's going to take a lot more than a transition to carbon-neutral energy sources such as wind and solar. It's going to require carbon-negative technologies, including energy sources that actually reduce carbon dioxide levels in the atmosphere.

While most climate researchers and activists agree that carbon-negative solutions will be needed to meet the terms of the Paris Agreement goal, so far most of these solutions have been viewed as impractical in the near term, especially for large, coal-reliant countries like China.

Now, researchers from the Harvard John A. Paulson School of Engineering and Applied Sciences and the Harvard-China Project on Energy, Economy and Environment, in collaboration with colleagues from Tsinghua University in Beijing and other institutions in China, Australia and the U.S., have analyzed technical and economic viability for China to move towards carbon-negative electric power generation.

The research is published in the Proceedings of the National Academy of Sciences.

"This paper is making a bold suggestion that not only can China move towards negative carbon power but that it can do so in an economically competitive way," said Michael McElroy, the Gilbert Butler Professor of Environmental Studies at Harvard and a senior co-author of the paper.

"The system we describe not only offers a carbon-negative alternative to generate electricity in the long run but also brings significant near-term co-benefit to reducing air pollution in China," said Xi Lu, Associate Professor in the School of Environment at Tsinghua University and first author of the paper. Lu is also a former SEAS graduate student and postdoctoral fellow.

"This paper is making a bold suggestion that not only can China move towards negative carbon power but that it can do so in an economically competitive way"

The strategy McElroy, Lu and their colleagues lay out involves the combination of two forms of green energy: coal-bioenergy gasification and carbon capture and storage.

Bioenergy is one of the most important tools in the carbon-negative toolbox. Bioenergy comes from the best CO_2 scrubbers on the planet — plants. As most of us learned in grade school, plants use photosynthesis to convert CO_2 into organic carbon and oxygen. The carbon stored in plants can be converted back into energy through combustion (a.k.a., fire); fermentation, as in the production of ethanol; or through a process known as gasification, which converts carbon-rich materials into carbon monoxide, hydrogen and carbon dioxide for fuels and industrial chemicals.

The process of converting biomass into energy and then capturing and storing the waste CO_2 is one of the most talked-about strategies for negative carbon power. It's known as BECCS, bioenergy with carbon capture and storage. The problem is, in most applications BECCS is not very efficient and requires massive amounts of land to grow the plants needed to power the planet, which would likely result in global food and water shortages.

But what if there was a way to make the process more practical and efficient?

Lu, McElroy and their international team turned to an unlikely solution for green energy: coal.

"If you try to do this with biofuel alone, it's not very effective," McElroy said. "The addition of coal provides an energy source that is really important. If you combine biofuel with coal and gasify the mixture, you can essentially develop a pure source of hydrogen in the process."

By modeling different ratios of biofuel to coal, the researchers found that as long as at least 35 percent of the mixture is biomass and the waste carbon is captured, the

power generated would actually reduce CO_2 in the atmosphere. At that ratio, the researchers found that the levelized cost of electricity would be no more than 9.2 cents per kilowatt hour. A carbon price of approximately $52 per ton would make this system cost-competitive with current coal-fired powerplants in China.

A key component to this strategy is the use of crop residue — the remains of plants after fields have been harvested — as biofuel.

Seasonal agricultural fires, when farmers set fire to their fields to clear stubble after a harvest, are a major source of air pollution in China. Collecting that stubble and using it as biofuels would not only reduce CO_2 but significantly improve air quality in the country. Gasification also allows easier removal of air pollutants from the waste stream.

The researchers acknowledge that developing a system to collect the biomass and deliver it to powerplants will take time but they argue that the system doesn't need to be implemented all at once.

"Because we've investigated the whole range of coal-to-biomass ratios, we've demonstrated how China could move incrementally towards an increasingly carbon-negative energy source," said Chris P. Nielsen, Executive Director of the Harvard-China Project and co-author of the study. "First, small amounts of biofuel could be used to reduce the net positive carbon emissions. Then, the system could grow toward carbon neutrality and eventually to a carbon-negative system. You don't have to accomplish everything from the get-go."

"This study provides critical information for policy makers seeking to implement carbon-negative energy opportunities in China," said Lu.

The research was co-authored by Liang Cao, Haikun Wang, Wei Peng, Jia Xing, Shuxiao Wang, Siyi Cai, Bo Shen, and Qing Yang; lead author Lu and three other China-based co-authors are alumni of the Harvard-China Project. It was supported in part by a grant from the Harvard Global Institute.

Citation: Xi Lu, Liang Cao, Haikun Wang, Wei Peng, Jia Xing, Shuxiao Wang, Siyi Cai, Bo Shen, Qing Yang, Chris P. Nielsen, and Michael B. McElroy. 2019. "Gasification of coal and biomass: a net carbon-negative power source for environmental-friendly electricity generation in China." Proceedings of the National Academy of Sciences.

This article was written by Leah Burrows, Harvard Paulson School of Engineering & Applied Sciences (SEAS), and originally appeared on the SEAS website.

RECENT PUBLICATIONS

Xi Lu, Liang Cao, Haikun Wang, Wei Peng, Jia Xing, Shuxiao Wang, Siyi Cai, Bo Shen, Qing Yang, Chris P. Nielsen, and Michael B. McElroy. 2019. "Gasification of coal and biomass as a net carbon-negative power source for environment-friendly electricity generation in China." *Proceedings of the National Academy of Sciences*.

S.J. Song, M. Gao, W.Q. Xu, Y.L. Sun, D.R. Worsnop, J.T. Jayne, Y.Z. Zhang, L. Zhu, M. Li, Z. Zhou, C.L. Cheng, Y.B. Lv, Y. Wang, W. Peng, X.B. Xu, N. Lin, Y.X. Wang, S.X. Wang, J. W. Munger, D. Jacob, and M.B. McElroy. 2019. "Possible heterogeneous hydroxymethanesulfonate (HMS) chemistry in northern China winter haze and implications for rapid sulfate formation." *Atmospheric Chemistry and Physics*, 19, Pp. 1357-1371.

Yan Zhang, Xin Bo, Yu Zhao, and Chris P. Nielsen. 2019. "Benefits of current and future policies on emissions of China's coal-fired power sector indicated by continuous emission monitoring." *Environmental Pollution*, 251, Pp. 415-424.

Xingning Han, Xinyu Chen, Michael B. McElroy, Shiwu Liao, Chris P. Nielsen, and Jinyu Wen. 2019. "Modeling Formulation and Validation for Accelerated Simulation and Flexibility Assessment on Large Scale Power Systems under Higher Renewable Penetrations." *Applied Energy*, 237, Pp. 145-154.

Chenghe Guan, Sumeeta Srinivasan, and Chris P. Nielsen. 2019. "Does neighborhood form influence low-carbon transportation in China?" *Transportation Research Part D: Transport and Environment*, 67, Pp. 406-420.

Mengyao Han, Bo Zhang, Yuqing Zhang, and Chenghe Guan. 2019. "Agricultural CH4 and N2O emissions of major economies: Consumption-vs. production-based perspectives." *Journal of Cleaner Production*, 210, Pp. 276-286.

Peng Jiang, Hongyan Liu, Shilong Piao, Philippe Ciais, Xiuchen Wu, Yi Yin, and Hongya Wang. 2019. "Enhanced growth after extreme wetness compensates for post-drought carbon loss in dry forests." *Nature Communications*, 10, 195.

Lin Zhou, Jianglong Li, Yangqing Dan, Chunping Xie, Houyin Long, and Hongxun Liu. 2019. "Entering and exiting: Productivity evolution of energy supply in China." *Sustainability*, 11, 983.

Hongxun Liu, Kerui Du, and Jianglong Li. 2019. "An improved approach to estimate direct rebound effect by incorporating energy efficiency: A revisit of China's industrial energy demand." *Energy Economics*.

Jianglong Li, Chang Chen, and Hongxun Liu. 2019. "Transition from non-commercial to commercial energy in rural China: Insights from the accessibility and affordability." *Energy Policy*, 127, Pp. 392-403.

Harvard President Bacow Visits China

President Larry Bacow visited China in March on his first overseas trip as Harvard's new president. He gave a speech at Peking University that traced Harvard's historical and ongoing ties to China and highlighted how collaborative relationships between Chinese and American academics can serve as "sources of strength through tough economic, political, and social times."

In the Harvard Gazette's coverage of Bacow's trip, the Harvard-China Project—which has been collaborating with scholars at Chinese universities since 1993—was cited as an example of the type of academic engagement with China that the President had advocated.

Image by Yi Wang, Executive Director of Harvard-Shanghai Center

RESEARCH HIGHLIGHT

Wind Power and Climate Change in India:

Warming waters in the Indian Ocean are weakening monsoon circulation and decreasing wind speeds

The warming of the Indian Ocean, caused by global climate change, may be causing a slow decline in wind power potential in India, according to a new study from the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) and the Harvard-China Project.

India, the third largest emitter of greenhouse gases behind China and the United States, is investing billions in wind power and has set the ambitious goal to double its wind power capacity in the next five years. The majority of wind turbines are being built in southern and western India to best capture the winds of the Indian Summer Monsoon, the seasonal weather pattern that brings heavy rains and winds to the Indian subcontinent.

However, the researchers found that the Indian monsoon is weakening as a result of warming waters in the Indian Ocean, leading to a steady decline in wind-generated power.

"We found that although India is investing heavily in wind power to tackle climate change and air pollution issues, the benefits of these substantial investments are vulnerable to the changing climate," said Meng Gao, a postdoctoral fellow at SEAS and the Harvard-China Project and first author of the study.

The research, published in Science Advances, calculates the wind power potential in India over the past four decades and finds that trends in wind power are tied to the strength of the Indian Summer Monsoon. In fact, 63 percent of the annual energy production from wind in India comes from the monsoon winds of spring and summer. Over the past 40 years, that energy potential has declined about 13 percent, suggesting that as the monsoon weakened, wind power systems installed during this time became less productive.

Photo: India is investing billions in wind turbines like these, in the hopes of doubling its wind power capacity in the next five years. Image courtesy Wikicommons.

Western India, including the Rajasthan and Maharashtra states, where investment in wind power is the highest, has seen the steepest decline over that time period. However, other regions, particularly in eastern India, saw smaller or no decline.

"Our findings can provide suggestions on where to build more wind turbines to minimize the influences of climate change," said Michael B. McElroy, the Gilbert Butler Professor of Environmental Studies, faculty director of the China Project and senior author of the study.

"Our findings can provide suggestions on where to build more wind turbines to minimize the influences of climate change"

Next, the researchers aim to explore what will happen to wind power potential in India in the future, using projections from climate models.

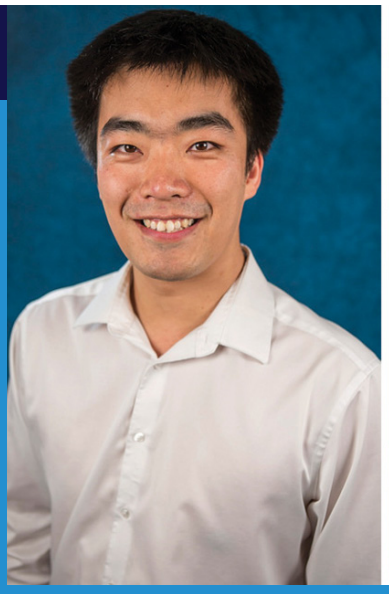
This research was co-authored by Yihui Ding, Shaojie Song, Xiao Lu, and Xinyu Chen. It was supported by the Harvard Global Institute.

Citation: Meng Gao, Yihui Ding, Shaojie Song, Xiao Lu, Xinyu Chen, and Michael B. McElroy. 2018. "Secular decrease of wind power potential in India associated with warming in the Indian Ocean." Science Advances, 4, 12.

By Leah Burrows, Harvard School of Engineering

RESEARCHER SPOTLIGHT

Xinyu Chen, Research Associate



During Xinyu Chen's Ph.D. studies at Tsinghua University, he spent a year working on projects with China's National Development and Reform Commission, which was having trouble building a plan for a modern "smart grid" that incorporated more renewable energy sources. "We found out that the problem was not with the power system itself," says Xinyu. "The problem was actually with the interaction between different kinds of energy systems—like power and heating systems." In Northern China, for instance, there was great capacity in place for wind power, but incorporating those systems with the region's prevalent combined heat-and-power units proved a challenge. "My Ph.D. thesis discussed how to better design an integrated power and heating system to better accommodate wind power," says Xinyu.

His career has continued to focus on finding the unexpected barriers to progress. In a recent paper for the journal Nature Energy, Xinyu—along with co-authors from the Harvard-China Project, Executive Director Chris Nielsen and Faculty Chair Prof. Michael McElroy—looked at electric vehicle charging in China, and found that the relevant emissions gains were dependent on how the vehicles are charged. "If you charge it during the slow charging period in off-peak hours, it is beneficial," says Xinyu. "But if you mostly use fast-charging stations, it will probably emit more CO_2 and other pollutants." Another core factor: The type of vehicle being charged. "For the sake of reducing air pollution, electrification of buses is actually much more efficient than light-duty vehicles—despite the fact that the number of buses is much lower."

Xinyu's passion for science and math can be traced back to his high school years in Inner Mongolia, which culminated in his winning a national physics contest. "So when I entered college, I chose engineering as a focus, because I felt it was related to physics," he says. He began working with the Harvard-China Project as an exchange student during his doctoral studies, returned as a postdoctoral fellow, and is now a research associate and lecturer. He is currently juggling a number of research projects: exploring how the digitization of China's energy system could improve understanding of the implications of different energy policy designs; what the introduction of market mechanisms into the power systems would mean in real-world practice; and determining the optimal combination of energy sources to help mitigate the variability of the renewables.

Xinyu is also teaching the "Energy Economy for Developing Countries" course this past fall with Prof. McElroy. Xinyu taught a version of the class last year, he says, which was mainly focused on China. "This year, we extended the scope of the course to cover India and Africa as well," says Chen. "We think Indian and African energy demand will continue to grow—probably at a double-digit pace—for several decades to come." The lessons from China's energy experience, he notes, can span borders.

By Dan Morrell

PROGRAMMING

China Project Spring Semester Events

The China Project co-sponsored or participated in a number of cross-university interdisciplinary events this semester. In February it co-sponsored a book talk at Harvard Law School by Barbara Finamore of the Natural Resources Defense Council, on China's global leadership in clean energy development, organized by the East Asian Legal Studies Program.

Two events were co-organized with the Harvard Asia Center. The first was a panel discussion on the implications of climate change for Asia, geared for non-scientists. Moderated by China Project chair Prof. Michael McElroy, it featured professors from the Harvard Paulson School of Engineering and Applied Sciences, Harvard Chan School of Public Health, the Department of Earth and Planetary Sciences, and the Harvard Kennedy School—Elsie Sunderland, Peter Huybers, Steve Wofsy, and John Holdren. The second was a talk by Matsutani Harutoshi of Aichi University (Japan), comparing the social costs of motor vehicle policies in China and Japan.

China Project scientists also participated in an interdisciplinary workshop hosted by the Harvard-Yenching Institute on "Sensation, Perception, and Policy Intervention: Air Pollution in China and Beyond." Organized and chaired by visiting scholar Prof. Hong Wei of Tsinghua University, the workshop brought together leading scholars in anthropology, history, politics, urban studies, geography, and environmental science. Chairing a panel on the governance of air pollution in China and India, Executive Director Chris Nielsen opened with a review of uncertainties in atmospheric and environmental health sciences, and their implications for both policy practice and social analyses.

In addition to these larger events, the China Project continued its research seminar series. Topics this semester included: responses of boreal forests in northeastern China to climate change (Dr. Liu Jialin of the Wofsy-Munger Group on Atmosphere-Biosphere Exchange and the Harvard-China Project); sensitivities of PM2.5 in China to emissions of precursor gases (Li Mingwei of MIT); and the responses of Chinese interprovincial electricity markets to surging renewable power generation (Dr. Li Jianglong of Xi'an Jiaotong University and the Harvard-China Project).

Images, clockwise: Faculty panelists at the "China and Asia in a Changing Climate: Natural Science for the Non-Scientist" Asia Center talk; Attendees gather for the interdisciplinary Harvard-Yenching Institute workshop on "Sensation, Perception, and Policy Intervention: Air Pollution in China and Beyond," which was organized by Tsinghua University visiting scholar Professor Hong Wei; Barbara Finamore of the Natural Resources Defense Council delivers a Harvard Law School book talk.