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Lectures on China's Environment

Xuhui Lee

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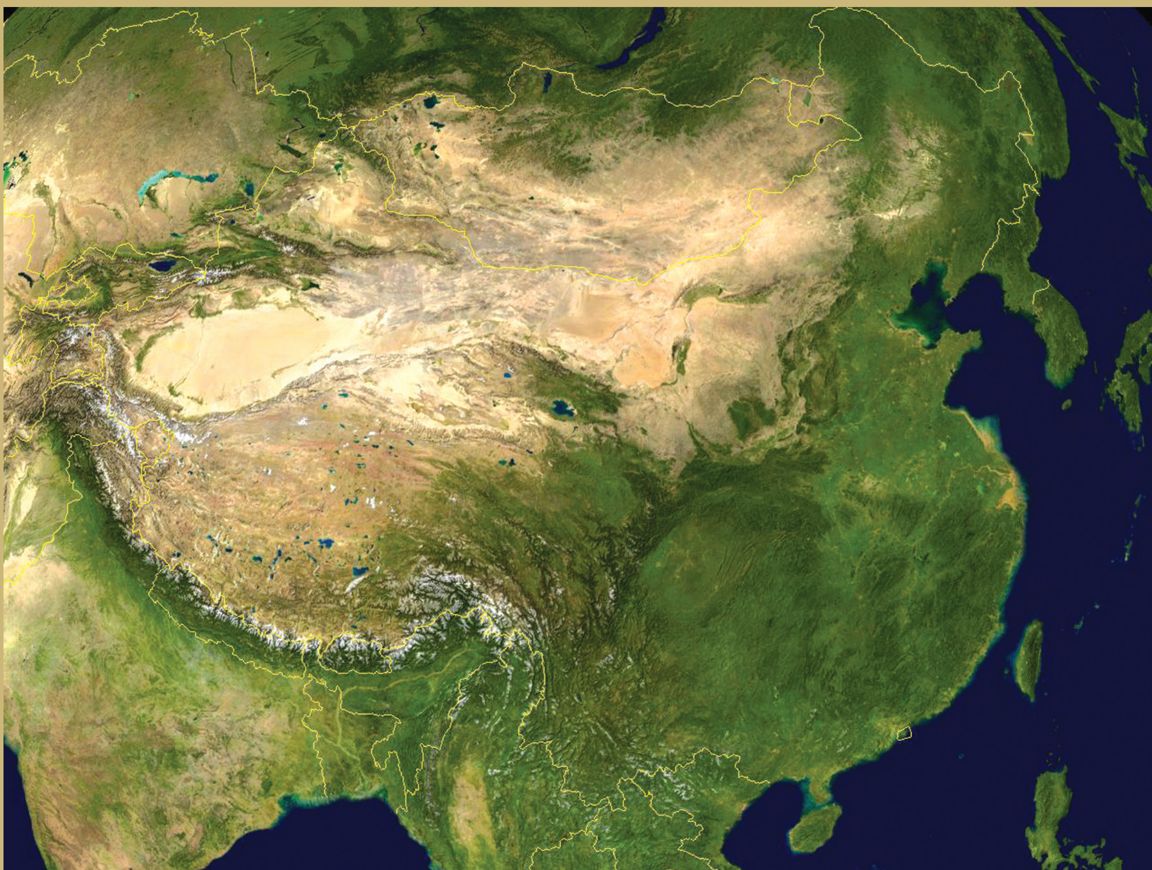
Lectures on China's Environment

Xuhui Lee, EDITOR



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Lectures on China's Environment

Xuhui Lee, EDITOR

Yale School of Forestry & Environmental Studies 2009

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Acknowledgements

This lecture series was supported by the Rice Family Foundation through a generous gift to the Yale School of Forestry & Environmental Studies. I would like to acknowledge all the invited speakers for their participation. I am grateful to my colleagues Dean Gus Speth and Professor Dan Esty for their encouragement and support. Thanks also go to my teaching assistants, Hui-Ju Wu and Xin Zhang, whose superb organization skills made the lecture series an enjoyable experience for the speakers and the students. Finally, I would like to thank Jane Coppock, Editor of the Yale School of Forestry & Environmental Publication Series, and her master's student assistant Owen David, for their work in preparing the lectures for publication.

Xuhui Lee
June 5, 2009

Biosketch of Editor and Photo of Class

Professor Xuhui Lee 李旭辉 received his undergraduate training at the Nanjing Institute of Meteorology, China (now renamed the Nanjing University of Information, Science and Technology) and his Ph.D. from the University of British Columbia, Canada. He joined the faculty of the Yale School of Forestry & Environmental Studies (F&ES) as an assistant professor in 1994 and was promoted in 2002 to the rank of full professor with tenure. Professor Lee has been the recipient of several awards, including the U. S. National Science Foundation CAREER award, an award for excellence in teaching at the Yale School of Forestry & Environmental Studies, and an award for outstanding young scientist from the Chinese National Science Foundation. In addition to his teaching and research, he serves as the F&ES faculty coordinator for global change science and policy and editor-in-chief of an international journal, Agricultural and Forest Meteorology.

Class photo with Professor Alice Newton: front row from left (sitting): Yi Luo, Angel Hsu, Marissa Matsler, Jiaona Zhang, Hui-Ju Wu; back row from left: Xuhui Lee, Baihai Wu, Yang Qiu, Xin Zhang, Alice Newton, Ranran Wang, Benjamin Jacobs, Alison Hoyt, Jun Yao, Yong Zhao (Elaine Yu was not in this photo)

Photo credit: Yong Zhao

CHAPTER **1**

Introduction

Professor Xuhui Lee
Yale School of Forestry & Environmental Studies

This volume is a collection of essays based on a lecture series course taught in the School of Forestry & Environmental Studies at Yale University in the fall semester of 2008. The course explored the environmental ramifications of economic growth in China and the challenges that growth poses to protecting China's natural resources and preserving its biodiversity. The course discussed the scientific foundation for environmental decision-making and strategies for engaging the Chinese government, private, and non-government sectors in sustainable development. Eleven prominent environmental scholars were invited to Yale to present lectures and join the course discussion with Yale faculty and students. Their presentations and the subsequent discussions, written up by students in the course and approved by the scholars themselves, form the basis for the individual chapters in the book. A short biography of each scholar appears at the end of the chapter presenting his or her material, along with a short biography of the student author.

The lecture series was motivated by three broad questions: 1) What are the most pressing environmental problems China faces now and in the future? 2) Which problems are confined to China's national boundaries and which have a global footprint? 3) How can the international community contribute to China's environmental reform?

The rationale for the lecture series was simple. China is the fastest growing economy in the world. Associated with its rapid growth are environmental pollution, loss of biodiversity, and depletion of natural resources. The central government of China, in recognition of these environmental challenges, is seeking policies and regulations that can promote sustainable development "in harmony with nature." Some of the environmental damages are not confined to China's national boundaries. In our opinion, it is imperative that developed countries play a constructive role in helping China meet these challenges. The fusion of western environmental thinking with China's reality will help promote stewardship of natural resources in China and worldwide.

The course was a 3-hour weekly lecture and discussion. In the first half of the meeting, which was open to the whole Yale community, the invited speaker lectured on a topic in his or her area of expertise. In the second half, the speaker and I led a discussion with participating students. A cheese and wine gathering that followed the lecture gave the invited guest an opportunity to interact with the faculty and students in an informal setting.

Professor Jianguo Liu (middle) speaking to students at the reception after his lecture

Photo credit: Yong Zhao

Active student participation was an exciting aspect of the course. Prior to each class meeting, all the students wrote a detailed critique of the background readings, which was very helpful in framing the issues for an in-depth class discussion. The students had the opportunity to play host to invited speakers, arranging one-on-one meetings as well as social events during their visits, and were each assigned the role of moderating one discussion session. The students were also tasked with writing an essay on the assigned topic.

The book chapters represent a joint effort between the students and the speakers. The writing was carried out by the student author and was based on the lecture given by the speaker and supplemented with ideas raised during the class discussion. For the benefit of a non-technical readership, several chapters contain additional background information provided by the student authors that was not covered by the lecture.

Professor Jiming Hao (center, front row) attending dinner hosted by students

Photo credit: Yong Zhao

The book is organized as follows. Chapter 2 explores the developing environmental relationship between the U.S. and China. Chapter 3 discusses partnerships between non-state actors in EU universities and research institutes and their Chinese counterparts. Chapter 4 argues that many seemingly unrelated factors of human and natural systems are vital to understanding how best to protect the environment. In Chapter 5, lessons of a Beijing-based environmental NGO are analyzed to provide insights into how non-governmental actors can effectively participate in environmental management. Chapter 6 discusses the role of the circular economy, circular industry, and ecocities in meeting the challenges arising from industrialization and population growth. The next two chapters (Chapters 7 and 8) deal with air pollution and global warming issues related to energy use and consumption habits. Chapter 9 takes the reader to China's west where a balancing act is played out between human and wildlife needs. Chapter 10 evaluates scenarios of environmental impacts associated with livestock farming. Chapters 11 and 12 present an analysis of two specific pollution cases, the first on the status of air pollution in the Pearl River Delta in southern China and the second on water pollution in Lake Taihu in central China. The last chapter (Chapter 13) is a synthesis of the cross-cutting themes that have emerged out of the individual chapters. A Chinese version of Chapter 13 is appended at the end of the book.

CHAPTER 2

Greening the Dragon: The U.S.-China Environmental Relationship*

Dr. Gary Waxmonsky
*U.S. Environmental Protection Agency***

Benjamin Jacobs
Yale College

CHAPTER SUMMARY

In the words of Daniel Esty, Professor of Environmental Law and Policy at Yale and former adviser to President Obama's transition team, there is good and bad news regarding China's environmental trajectory: "The good news is, from a global environmental perspective, if we get China on the right course, almost nothing else matters. But the bad news is, if we don't get China on the right course, almost nothing else matters." For this reason, the United States-China environmental relationship is arguably the most important bilateral effort of the 21st century.

This chapter explores the developing environmental relationship between the United States and China, drawing upon Dr. Waxmonsky's extensive experience in the Environmental Protection Agency's (EPA) Office of International Affairs. After providing background information on China's environmental issues and the history of U.S.-China environmental policy, the chapter focuses upon new bilateral efforts, such as the Strategic Economic Dialogue (SED), that attempt to tackle both short-term and long-term environmental issues in Asia's largest country.**

Thanks to bilateral efforts like the SED and China's internal elevation of its environmental agency to ministry status, the outlook for U.S.-China bilateral relations is bright. Strides have been made in areas such as water pollution, air particulates, and even complex issues like climate change. However, such achievements have come at the behest of particular political actors on both sides, so maintaining their efforts through political transitions will be key for the next group of U.S.-China environmental leaders.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on September 15, 2008 by Dr. Waxmonsky as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Benjamin Jacobs, a student in the course, and has been approved by Dr. Waxmonsky. The paper incorporates material from the lecture, the discussion session after the lecture with Dr. Waxmonsky, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

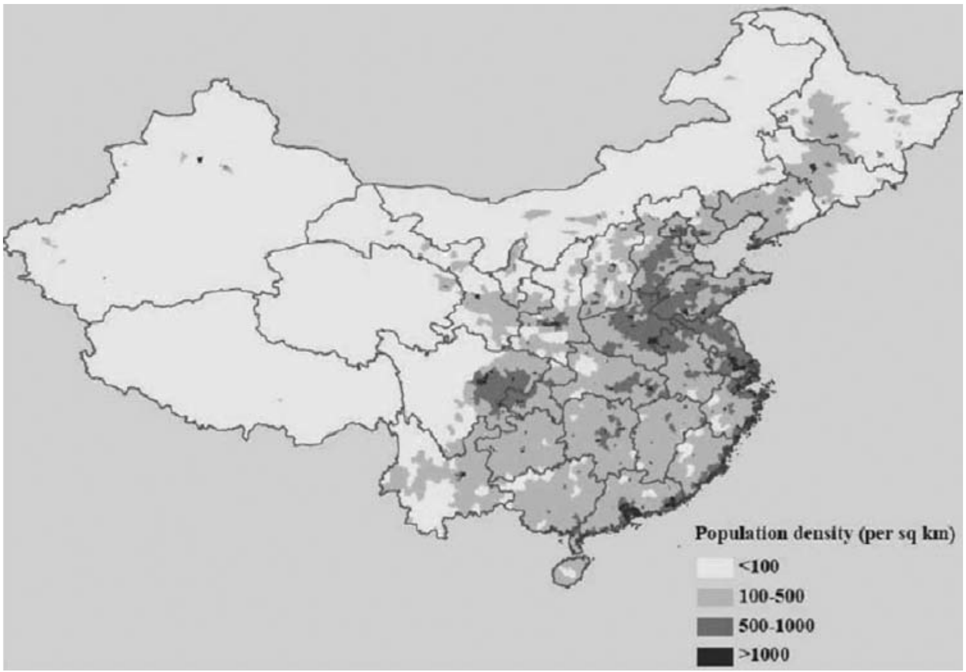
** The views expressed in this chapter are those solely of the two authors, Dr. Waxmonsky and Mr. Jacobs. In particular, the views expressed herein do not represent those of the EPA or any other arm of the U.S. government.

CHINA'S ENVIRONMENTAL CRISIS

> *"If you care about global environmental quality, no single nation is more important than China." –Gary Waxmonsky*

China's environmental issues are well documented. The country is riddled with both short-term (e.g. water pollution) and long-term (e.g. climate change) environmental problems. The short-term problems are often highly localized, while the long-term ones are increasingly dispersed. The responses of the multilayered Chinese party-state reflect these differences. Short-term, point-source environmental crises are typically dealt with swiftly to assuage an anxious public. Long-term, complex issues involving multiple sources, on the other hand, tend to fall by the wayside. While every level of Chinese government is increasingly focused upon environmental concerns, it is difficult to quantify the impacts of issues that span multiple regions or years. In most cases, economic incentives continue to trump environmental concerns for leaders at the county and provincial levels.

Figure 1 Population densities in China (number of people per square kilometer)



Source: China County Population Census (ACMR 2004)

To a certain extent, the scale of China both geographically and demographically explains its unique environmental challenges. China is a large continental region like the United States, Canada, Russia, and Brazil, which means that there are stark regional differences across a number of metrics. China's western regions contain 40 percent of the landmass but only 10 percent of the population. The country's increasingly developed eastern areas house the remaining 1.2 billion citizens, with some urban areas maintaining the highest population densities in the world (see Figure 1 above). In addition to this uneven population distribution, China's provinces exhibit extreme differences in GDP per capita, property values, water resource availability, vulnerability to climate change impacts, and energy use per capita. Due to the structure of China's government at the city, county, provincial, and central levels, these differences can often serve as roadblocks to effective environmental policy in interprovince issues.[1]

[1] Sources for this section include CFR and the World Bank. A full citation for each of these references is available in the Works Cited page at the end of the paper.

BACKGROUND ON U.S.-CHINA RELATIONS

> *"Getting the U.S. to cooperate with and understand China's multiple challenges—enormous development alongside of its pollution control and natural resource management issues—is one of the great issues of our era."*
> *—Daniel Esty*

Joint efforts between the United States and Chinese governments on environmental issues began shortly after China's great opening to the world in the late 1970s, paralleling economic collaboration at the time. China has maintained a national environmental policy center since the late 1970s (although its name and position have changed considerably), and the first formal bilateral undertaking with the U.S. was achieved in 1980. This was the U.S.-PRC Environmental Protection Protocol (EPP), which outlined environmental initiatives and formalized the structure for cooperation. It followed shortly after the 1979 U.S.-PRC Science and Technology (S&T) Agreement, which established similar guidelines for government-to-government scientific exchange. It is worth noting that, through the 1980s, U.S.-China environmental cooperation was largely limited to joint research on problems such as the health effects of indoor air pollution. Collaboration on environmental policy, law, and governance would come only much later. Subsequent iterations of both the U.S.-PRC EPP and U.S.-PRC S&T Agreement remain guiding documents for bilateral cooperation today.

Collaboration on environmental issues in both the public and private spheres increased in China for the following two decades, as the country continued its socioeconomic opening. But the next significant event in terms of China's international environmental policy did not occur until 1998, when the Chinese Communist Party (CCP) elevated the status of the National Environmental Protection Administration (NEPA) to the State Environmental Protection Administration (SEPA). This shift sent a signal to the international community that the CCP would be newly dedicated to environmental issues, and the party's commitment was reflected accordingly with additional resources for SEPA. Direct exchange between the PRC's SEPA and the U.S. Environmental Protection Agency

(EPA) then increased during the final years of the Clinton administration and the first years of the Bush administration.

Increased bilateral efforts resulted in a formative international agreement signed in December 2003. This instrument, known as the U.S.-China Environmental Memorandum of Understanding (MoU), established the policy and administrative rules that have governed bilateral environmental relations to date. Most significantly, it established a Joint Committee for Environmental Cooperation (JCEC), which is to meet every two years in plenary session. In this forum, the U.S. EPA Administrator, China's Minister of Environmental Protection, and their senior deputies come together regularly to review cooperation under the MoU's various annexes and to prioritize efforts for the coming years. The JCEC structure ensures that cooperation is fully coordinated across all relevant units of the EPA and the Ministry of Environmental Protection and accurately reflects the capabilities and interests of both agencies. However, cooperation under the JCEC is limited to the domestic mandates of both agencies, whereas environmental challenges in large, complex economies are often related to factors outside the purview of environmental regulators. This problem has become increasingly apparent over time.[2]

[2] For more on this, see the annual hearings of the U.S.-China Economic and Security Review Commission in the Works Cited section.

Table 1 Goals and achievements of the Tenth Five Year Plan (2000-2005)

Indicators	Actual 2000	Planned 2005	Actual 2005 (completed by 6/17/06)	Comparison with Planned 2005 (+/- %)
Air Pollution				
SO_2 emissions	19.9	17.9	25.5	42
Industry	16.1	14.5	21.7	50
Domestic	3.8	3.5	3.8	9
Soot Emissions	11.7	10.6	11.8	11
Industry	9.5	8.5	9.5	12
Domestic	2.1	2.1	2.3	10
Industrial Dust Emissions	10.9	8.98	9.1	1
Water Pollution				
COD discharge	14.5	13.0	14.1	8
Industry	7.0	6.7	5.5	18
Domestic	7.4	6.5	8.6	32
Ammonia Nitrogen	1.8	1.65	1.5	-9
Industry	0.8	0.7	0.525	25
Domestic	1.1	0.9	0.973	8

Source: Estimations based upon China Environmental Yearbook 2001 and 2006, the 10th Five Year Plan for Environmental Protection and status of the China environment report, 2005 (see Yearbook for units of emission amounts).

In November 2005, the JCEC convened in Washington, D.C., during an unexpected time of change in Chinese environmental policy. Shortly after the plenary session, the Songhua River spill occurred and SEPA Minister Xie Jinhua was removed from his post by the CCP. Notwithstanding this major development, cooperation under the MoU continued apace. In 2006, China's Eleventh Five-Year Plan (FYP) began and built upon the environmental progress of the Tenth FYP (see Table 1 above). Notable goals of the

Eleventh FYP include: a 20 percent national reduction in energy intensity (energy used per unit of GDP), and a 10 percent reduction in "major contaminants" (including sulfur dioxide in the air and Chemical Oxygen Demand, or COD, in the water). These significant goals are both slated to be achieved by the end of the FYP in 2010.

In September 2006, the Bush administration established the U.S.-China Strategic Economic Dialogue (SED). This bilateral initiative, which was administered by the office of then Treasury Secretary Henry Paulson, represents an unprecedented effort to energize and coordinate meaningful bilateral policy in every arena except security. The SED will be discussed in detail here, but there is one more significant change to note before moving forward to bilateral goals and achievements. In March 2008, the CCP elevated the SEPA to full ministry status, re-naming it the Ministry of Environmental Protection (MEP). Some claimed that this elevation was merely environmental window dressing before the 2008 Summer Olympic Games in Beijing. Regardless of the intent, the change signifies China's increased political commitment to addressing environmental issues, and the MEP has received increased symbolic, economic, and political capital.[3]

[3] For more information, see Paulson 2008 and World Bank 2007.

TODAY'S BILATERAL RELATIONS

While the U.S. EPA's relationship with China dates to the early 1980s, only fairly recently have bilateral efforts shifted from long-term joint research to real-time issues like regional air quality management and enforcement of environmental regulations. In short, the role of the EPA shifted from scientific liaison to strategic consultant. Through the development of both institutional and personal relationships, U.S. governmental actors gained the access necessary to provide advice on high-impact environmental policy. Over the past decade, the Chinese have been increasingly receptive to such advice as motivations for the bilateral relationship have developed on both sides.

Media reports in the West often cite the transfer of air pollution across the Pacific from China to the U.S., which could serve as one motivation for bilateral environmental efforts. While hemispheric transfer is certainly a factor, it is worthy of note that to date the EPA lacks empirical evidence about the percent or types of air pollution in the U.S. that can be directly attributed to China. However, there are several other more measurable factors on the U.S. side. The American government is interested in Chinese performance in multilateral environmental regimes (MERs). Washington remains concerned about the safety of U.S. imports from China and the environmental components associated with that issue. Looking at the long term, U.S. political actors seek to understand China's position regarding greenhouse gas reductions. The U.S. remains concerned about China's environmental footprint both in the Asia Pacific region and in developing areas like Africa. In terms of economic development, the U.S. government seeks to establish political ties as a point of entry for private firms that sell green goods and services. And finally, the U.S. has a global interest in increased transparency, accountability, and public participation, related to both environmental issues and political development more generally.

Cooperation under the EPA-MEP MoU currently addresses the following categories: (1) air pollution (2) water pollution (3) toxic substances (4) hazardous and solid wastes and (5) environmental law and enforcement. The structure of the current MoU mandates the creation of different annexes, each of which addresses one of these issue areas and is led by a different part of EPA. The annexes have had different impacts depending upon the needs of the Chinese and the abilities of the EPA, as well as each party's willingness to partake in information exchange. Regardless of the differences between annexes, the premise behind each of these partnerships is that China can benefit from U.S. experience—both positive and negative—and wants to do so.[4]

[4] Works cited for this section include Paulson 2008 and U.S.-China Economic and Security Review Commission 2008.

THE SED – A REVOLUTIONARY APPROACH

The Strategic Economic Dialogue (SED) represents the best effort to date between the U.S. and PRC on high-level and high-impact environmental efforts. The first discussions about the SED occurred in August 2006—only one month after Henry Paulson, Jr. became Secretary of the Treasury. The SED is essentially a process whereby the Secretary of the Treasury meets with one of the four Chinese Vice Premiers every six months to discuss everything in U.S.-China relations that does not directly deal with security affairs. On the U.S. side, this dialogue is informed by what the administration views as core values: transparency, the rule of law, and responsible international engagement. The discussion ranges from issues like currency reform and foreign direct investment to clean energy and climate change. The EPA and SEPA/MEP have been involved in the policy-making process and the semiannual meetings since the program's inception.

Figure 2 Agreeing to the ten-year E&E Framework

U.S. Treasury Secretary Henry Paulson(right) and Chinese Vice Premier Wang Qishan shake hands after signing the U.S.-China 10-year cooperation agreement on energy and environmental protection during the press conference at the U.S. Treasury Department in Washington, June 18, 2008. (Xinhua Photo)

The significance of the SED meetings cannot be overstated. High-ranking officials from both the U.S. and PRC spend approximately two days together at each semiannual session, presenting information from their respective agencies in order to plan policy for the future. This type of engagement is unprecedented and unparalleled between a Western actor and China, and its continued success is seen by many as crucial to the overall bilateral relationship. As we discuss later in greater detail, the SED currently rests largely on the shoulders of Secretary Paulson and his personal rapport in China. Whether this type of relationship is sustainable depends largely upon the ability of the next U.S. administration to leverage Secretary Paulson's achievements and build upon them. In China, personal relations retain the utmost importance, so the staff changes in the new administration will present an even larger challenge to actors on the U.S. side.

For the most part, energy and environmental issues have been addressed in tandem under the SED. Both sides have viewed China's energy consumption and environmental issues as inextricably linked, so approaching these issues from a joint policy perspective would be more meaningful than examining each in isolation. The clearest connection between energy and environment in China is air pollution, since it tends to be the direct outcome of increased energy production and consumption (i.e., the use of fossil fuels). Finally, another reason for this paired approach to energy and environment is that both sides view this aspect of the SED as "low-hanging fruit," where compatible interests are clearer than on such issues as currency reform, capped gas prices, and intellectual property rights.

At the fourth SED session in 2008, both parties finalized a document called the Ten Year Framework for Energy and Environmental Cooperation. Secretary Paulson developed the idea for the Framework in 2007 in order to insure a long-term legacy of the SED—one not tied to any individual political actor. The Framework goes far beyond the topics addressed under the EPA-MEP MoU. In addition to clean air and clean water, it encompasses clean and efficient electricity generation, clean and efficient transportation, and specific topics of nature conservation (e.g., protected areas management). Energy efficiency is likely to be added to this menu in 2009. The Framework also introduces the concept of "EcoPartnerships," which seek to pair nongovernmental entities on each side. Due to the recent signing of the Framework, it is still difficult to determine its effectiveness. This question, like many others, still largely depends on resources and political commitment. One larger goal of the Framework is a trickle-down impact on other aspects of U.S.-China bilateral relations, such as technology transfer in non-green industries and increased economic collaboration between state and corporate actors. In short, if the Framework establishes formalized channels of coordination on energy and the environment, these channels can potentially facilitate similar exchange between nongovernmental organizations (NGOs), local communities, and private corporations in each country.[5]

[5] For more on the SED, see Paulson 2008 and U.S.-China Economic and Security Review Commission 2008.

CONSTRAINTS ON ENVIRONMENTAL COLLABORATION

> *"The resource limitations are not just financial—a few motivated, bilingual employees can accomplish a lot more than dozens of less-motivated employees that don't know the language or the culture. But getting that kind of talent into a domestic agency is not that easy, and it's the China relationship now that needs that kind of support." –Gary Waxmonsky*

A major obstacle in any cooperative international relationship is limited resources. Despite its recent elevation, the MEP still maintains a relatively small staff of about 500 people in Beijing. The issue of resources is equally significant in terms of the U.S. EPA. There is no central appropriation for international environmental cooperation within the EPA, whether with China or any other country. Thus, the needs of a collaborative program like the SED compete directly with the domestic needs of the EPA, particularly in an era of increased environmental concern at home and increasingly restrictive budget constraints.

Once information is exchanged between the EPA and the MEP, an additional constraint is implementation within China. This constraint arises for two interrelated reasons: (1) limited institutional capacity and (2) the fragmentation of the Chinese governmental structure. Despite the elevation of the MEP to ministry status, its funding remains miniscule compared to the departments charged with economic and infrastructure development in China. Even if the MEP is financially able to push through environmental legislation at the central level, enforcing it throughout China's fragmented governmental structure presents another challenge. This fragmentation is both vertical and horizontal. Horizontally, the MEP has to work with other actors like the Ministry of Water Resources (MOWR), the Ministry of Urban-Rural Construction (MOC), and the National Development and Reform Commission (NDRC) in order to accomplish meaningful policy changes. Vertically, the centralized MEP has to coordinate with various actors at the provincial, county, and even township levels, particularly local Environmental Protection Bureaus (EPBs). The decentralized fragmentation supports an imbalanced incentive structure, one that favors energy- and pollution-intensive economic development. To date, the EPA has seen little evidence of provincial officials disciplined for failing to meet an environmental or energy efficiency metric. Thus, there is a real danger that talks sparked by the JCEC and SED will remain precisely that—talk.

OTHER INTERNATIONAL ACTORS

While this chapter has focused upon bilateral environmental efforts between the U.S. and PRC governments, various other international efforts related to China's environment are under way. The totality of bilateral interaction between the U.S. and China is a more complex picture, including the work of governments, corporations, and nongovernmental organizations. This chapter has focused mainly on official governmental relationships. In China's highly centralized one-party political system, this focus allows insight into the negotiations with the largest and most immediate impact. However, additional environmental partnerships with China can be found in new multilateral agreements or in activities of established international organizations.

Significant efforts in this regard include: the Asia Pacific Partnership (APP) on Clean Development and Climate, which is a 2006 effort of the Bush administration toward clean development in the region; Methane to Markets (M2M), which is an international partnership established in 2004 with the goal of safely harnessing methane from coal plants and mines and recycling it as an energy source; the United Nations Environment Programme (UNEP), which includes most nations of the world including the U.S. and China; and the "Major Economies" Process, which is a multilateral effort of the largest greenhouse gas emitting countries to incorporate clean technologies. China is also both a recipient and provider of funds to the Asian Development Bank (ADB), which has invested hundreds of millions of dollars in support of China's environmentally sound development.

There are significant international relationships affecting China's environmental policy in which the U.S. holds no influence. The European Union (EU) is the most instructive example of this fact. The EU has played a similar role to the U.S. in China through the investment of both economic and human capital in green efforts. The EU is currently drafting a multilateral agreement with China on environmental governance, which when finalized will provide significant resources to support EU-China partnerships of an environmental nature. It is worthy of note that another constraint on effective international environmental cooperation is the lack of meaningful coordination between international "donors." To date, significant actors such as the EU, U.S., and Japan have failed to fully coordinate their environmental efforts in China. This failure appears to stem from the economic incentive structure, as each country attempts to position its government and corporations first in China's expanding green market.[6]

[6] For more on the significance of additional international actors, see Chapter 3 in this volume, which was coauthored by Dr. Alice Newton.

LOOKING AHEAD

> *"What will happen to the management of U.S.-China relations [through the current U.S. political transition] is very much in play right now." –Gary Waxmonsky*

The largest question regarding the future of U.S.-China bilateral relations, environmental or otherwise, remains the next U.S. administration. The Obama administration will need to decide whether or not to continue the SED and the relationships established within it, and will have the opportunity to refashion bilateral environmental relations as China formulates its next (twelfth) Five-Year Plan. The new administration will probably not dismantle the SED for fear of being seen as downgrading a vital bilateral relationship. But at the same time, it may not choose to infuse the relationship with the dynamism and political commitment that Secretary Paulson brought to it. Without strong central leadership, centrifugal forces are likely to reassert themselves. The strategic nature of the relationship, and the important role of energy and environmental cooperation in this relationship, may diminish in the months and years ahead.

There are areas of environmental cooperation with China that hold promise regardless of whether the SED continues in its current form. These include environmental information management, environmental finance/"green credit," greening supply chains, tariff relief for environmental goods and services, and sustainable ports and shipping. Some of these areas will involve a shift away from purely government-to-government cooperation, in an effort to infuse Chinese firms with increased environmental awareness. An instructive example is "green credit," which entails making environmental performance a criterion in access to bank loans for Chinese entrepreneurs. Such financial incentives will be critical in moving China toward credible economy-wide or sectoral greenhouse gas (GHG) reductions. China's SED commitment to launch national sulfur dioxide emissions trading by the beginning of the next FYP in 2010 should also help position the country for eventual adoption of GHG emissions trading. Still, the success of this type of market mechanism requires a foundation of reliable, publicly accessible information and consistent enforcement.

In China, the CCP is striving to improve coordination between levels of government and to strengthen environmental incentives for officials. Some of this change has been bottom up, since economic growth has harmed certain segments of the population and prompted social action. In such cases, the human impact of environmental degradation catalyzed government action. To prevent increased social unrest, the CCP seems prepared to accommodate increased transparency and accountability. The recent establishment of the Ministry of Environmental Protection's six regional environmental supervision centers around the country (Beijing, Xi'an, Shenyang, Chengdu, Guangzhou, and Nanjing) has the potential to enhance enforcement of China's national environmental goals across the various provincial and local jurisdictions, just as EPA's regional offices are designed to do in the U.S. The jury is still out, but the U.S.-China environmental relationship seems headed in the right direction.

DISCUSSION QUESTIONS

1. *Best approach? (economic, political, health, cultural)*

Which approach is most effective to address these issues with Chinese leaders today? Does the CCP respond to quantitative, economic analysis like the World Bank's? Are bilateral discussions phrased in terms of the health of the environment, or the health of the Chinese people? Are culture and ethics used to frame the discussion as well as economic costs?

2. *Top-down vs. bottom-up*

To what extent does the U.S. government, American nonprofits, and other non-private organizations work with these actors on bottom-up approaches? Furthermore, what improvements can be made to their approach? Thus, is it possible that change in China is also coming from the grassroots level? Are the public and NGOs acting in opposition to, or in step with, the central government? Does the U.S. engage these actors on environmental issues as well as senior CCP officials?

3. The development of the rule of law and free flow of information in China

Why do we focus on making China look legally and administratively like the U.S. when the U.S. appears to be unable (or unwilling) to mitigate climate change? Does mitigation, and therefore environmental stewardship and improvement in general, involve something more than an established rule of law, federalism, transparency, etc.? And if this is true, how does this change the U.S.-China environmental relationship? What concrete strides have been made in terms of the transparency of government action and information?

4. The relationship between environmental policy and economic development

To what extent does economic development need to be at the forefront of environmental discussions? Or can we define a set of environmental priorities as separate from development goals? Are economic discussions powerful places to bring in the environment or are environmental issues more effectively addressed directly? For example, the SED is set up to facilitate top-down economic discussion. How does this shape the direction of environmental discussions? What are the pros and cons?

Works Cited

American Bar Association. 2008. *International Environmental Law Committee Newsletter* 10(4). [Articles herein by various authors and cited as such].

Organization for Economic Co-Operation and Development (OECD). 2007. OECD environmental performance reviews: China. OECD Publishing. [Available at http://www.oecd.org/document/47/0,3343,en_2649_34307_37809647_1_1_1_1,00.html].

Paulson Jr., Henry M. 2008. A strategic economic engagement: Strengthening U.S.-Chinese ties. *Foreign Affairs* 87(5): 59-77. [Available at: http://www.foreignaffairs.org/20080901faessay87504/henry-m-paulson-jr/a-strategic-economic-engagement.html].

U.S.-China Economic and Security Review Commission. Hearing on China's energy policies and their environmental impacts - August 13, 2008. http://www.uscc.gov/hearings/2008hearings/hr08_08_13.php.

Woodrow Wilson International Center for Scholars. China environment forum. http://www.wilsoncenter.org/index.cfm?topic_id=1421&fuseaction=topics.categoryview&categoryid=EE4F578C-D321-2150-ABD87895FEF607D8.

World Bank and the State Environmental Protection Administration of the People's Republic of China. 2007. *Cost of pollution in China: Economic estimates of physical damages [conference edition]*. The World Bank.Washington DC.

Zissis, Carin and Jayshree Bajoria. 2008. China's environmental crisis. *Washington Post*, August 7. [Available at: http://www.washingtonpost.com/wp-dyn/content/article/2008/08/07/AR2-008080702003_pf.html].

BIOSKETCHES OF AUTHORS

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CHAPTER 3

EU Collaboration with China in Environmental Capacity Building*

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CHAPTER SUMMARY

While Chapter 2 in this book discussed the United States' cooperation with China on environmental concerns, this chapter explores similar efforts by the European Union. Bilateral collaboration can take various forms. For example, the dialogue in Chapter 2 with Gary Waxmonsky focused on government cooperation through the Strategic Economic Dialogue. This chapter, on the other hand, explores partnerships between non-state actors in Chinese and EU universities and research institutes. Alice Newton discusses how capacity building in the Chinese environment aligns with the research priorities of the European Union under the Seventh Framework Programme (FP7). Recognizing that many environmental problems that the EU faces are transboundary in nature and global in scope, the EU has made working with Chinese counterparts in the area of scientific research a key element of their strategy to address environmental challenges.

On-the-ground partnerships for knowledge exchange and capacity building are important for giving the Chinese tools to effectively manage their environment. Newton brings the perspective of a practitioner who has had years of experience working hand-in-hand with Chinese partners on various research activities. One example of capacity building is the Erasmus Mundus education exchange program, which sponsors students from China to study in European universities and European students to study in Chinese universities. The program also funds Chinese scholars to teach in European universities and European scholars to teach in Chinese universities. While the program clearly represents only one specific

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on October 13, 2008 by Dr. Newton as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Angel Hsu, a graduate student in the course, and has been approved by Dr. Newton. The paper incorporates material from the lecture, the discussion session after the lecture with Dr. Newton, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

example of capacity building, the Erasmus Mundus program can serve as a potential model for other industrialized nations.

This chapter explores four main points: Why collaboration with China on environmental issues is important; how the EU research priorities align with China's environment, focusing on one particular aspect of China's environment, coastal and marine ecosystems; how EU capacity building works through the Erasmus Mundus program; and how EU-China collaboration in the environment can be improved.

> *"This lecture is really about how science policy and management [go] global. We really need to see how we can negotiate between countries to come together and to share joint research interests in order to move forward."* –Alice Newton

INTRODUCTION: CHINA'S POSITION IN THE GLOBAL ENVIRONMENT

Harmony is a key principle in Chinese philosophy, and "harmonious development" a core goal of Chinese growth policy. Since Deng Xiaoping introduced market reforms in 1978, China's economy has grown tenfold and experienced double-digit average GDP growth rates annually. This growth, however, has challenged the idea of harmonious development with respect to the country's environment. The statistics are not unfamiliar—China is home to sixteen of the world's twenty most polluted cities; half of the country's rivers are severely polluted; China's carbon dioxide emissions and energy consumption are among the highest in the world; and high sulfur and nitrous dioxide emissions are causing acid rain and acute air pollution.

China's ruling "technocrats" are well aware of the environmental consequences of the country's rapid industrialization. In 2004, the State Environmental Protection Agency (SEPA) and the National Bureau of Statistics launched a "Green GDP" initiative to calculate economic losses associated with China's environmental degradation. They estimated that a loss of $64 billion in 2004, or 3.05 percent of China's GDP, could be attributed to environmental degradation. The report also said that approximately 1.08 trillion RMB (roughly 135 billion U.S. dollars) would be needed to clean up all the industrial pollution and household waste produced, but that the Chinese government was only investing a fraction of the actual cost—190 billion RMB (24 billion U.S. dollars).[1] Although the results of the 2006 report were never released for political reasons, officials said that the methodologies used to calculate the "Green GDP" were low estimates of environmental damage to health and did not account for ecological impacts. However, politics aside, the preliminary results of the report attempted to place China's dire environmental situation in a common, easily understood vernacular.

[1] Du, Jing. 2006. Green GDP accounting study report 2004 issued. SEPA.gov.cn, September 11. http://english.gov.cn/2006-09/11/content_384596.htm.

When placed in the global context, China's environmental problems are becoming increasingly transboundary in nature. At the root of many of these transboundary pollution problems is China's reliance on coal. China depends on coal for 60 percent of its energy production, which is more coal intensive than the United States, Europe, and Japan combined.[2] The country burns over 2.7 billion tons of coal per year and is anticipated to burn 25 percent more by 2020. The effects of China's appetite for coal are manifested not only in the country's growing contribution to global greenhouse gas emissions, but also in the sulfur dioxide and particulate matter felt by neighboring countries such as South Korea and Japan, as well as the western United States. China's migratory air pollution problems epitomize why China's environmental challenges are becoming a global concern.

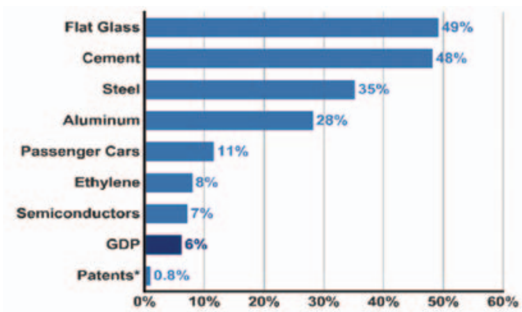
[2] Bradsher, K. and D. Barboza. 2006. Pollution from Chinese coal casts a global shadow. New York Times, June 11.

Reflective of China's Olympic motto—"One World, One Dream"—China's environmental problems necessitate outside engagement to collectively find solutions. Since countries such as those in the European Union have already industrialized and "cleaned up" their environments, we argue that this imbalance between the European Union and China "colors" the relationship between the two with regard to science and policy. Are developed countries simply exporting their pollution to developing countries like China and being hypocritical in chastising such countries for poor environmental performance? Industrialized countries must take leadership roles if they expect China to follow suit.

Chinese industry represents an area that could benefit from the experience of international counterparts. While China in 2006 produced a sizeable portion of global steel, cement, aluminum, and other energy- and greenhouse-gas-intensive goods (Figure 1), the Chinese manufacturing processes for these commodities are often less energy efficient than those found in other countries. For instance, the Chinese steel and cement industries consume 20 and 45 percent more energy, respectively, than the international average. Clearly, if Chinese industrialization is to follow a sustainable trajectory, international experience and partnerships can help China move toward its goal of more sustainable, harmonious development.

This seemingly bleak overview of China's environment is the reason why global coordination is needed to help China address its complex growth challenges. Many of the environmental problems China faces cannot be solved without the experience and leadership of other countries who historically have followed very similar development paths. However, given China's 1.3 billion people and increasing consumption patterns, the question then arises as to whether China can afford to industrialize like its predecessors.

Figure 1 China's global share of production in selected sectors



Source: Rosen and Houser 2007

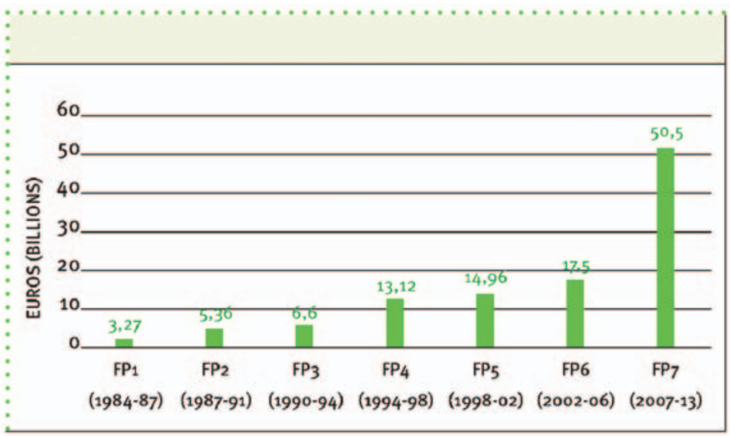
EU RESEARCH PRIORITIES AND THE CHINESE ENVIRONMENT

In recognition of China's importance in the global environment, collaboration with China on environmental research has become an important aspect of the EU agenda. To support research initiatives, the European Union created Framework Programmes for Research and Technological Development, referred to as Framework Programmes (FP). The first FP was initiated in 1984 with the idea of fostering transnational joint research projects by requiring EU-financed projects to have at least more than one EU member state[3] on a research team. While environmental concerns have been a component of the FPs since their inception, the FPs have since taken a more multidisciplinary systems approach to environmental research, incorporating economic and social dimensions. The ultimate goal of the EU Framework Programmes is to build a European Research Area based on education, research, and innovation that promotes cooperation across national borders.

[3] For a full listing of EU member states, see http://europa.eu/abc/european_countries/index_en.htm.

Structured in three-year increments, the EU Framework Programme is now in its seventh iteration, otherwise known as FP7. As demonstrated by the near exponential growth of the program's budget (Figure 2), the European Union is investing heavily in scientific research to address the challenges of global change. The main environmental research objective of FP7 is to promote sustainable management of both the environment and natural resources. To accomplish this goal, FP7 seeks to further knowledge on complex interactions between the climate, ecosystems, and human activity and to develop appropriate technological solutions.

Figure 2 The budget for the EU Framework Programmes from 1984 to the present day



Source: European Commission 2008

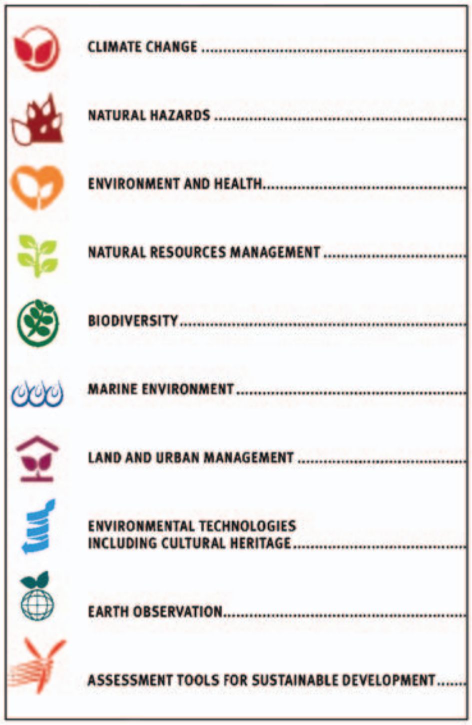
Specific points of action focus on:

- forecasting changes in the global climate, ecology, earth and ocean systems;
- developing tools and technologies for monitoring, prevention, and mitigation of environmental risks and pressures, including environmental health;

- sustaining both the natural and human-influenced environment.

Climate change is at the top of the list of research priorities for FP7 (Figure 3). The European Union has been cautious in its approach to working with China in the area of climate change. As one of the world's largest emitters of greenhouse gases, China is both sensitive to its contribution to global climate change and interested in the impacts, particularly in relation to coastal cities and agriculture. Rather than pointing blame at the Chinese for their growing greenhouse gas emissions, the dialogue regarding cooperation on climate change research should focus on win-win scenarios and payoffs for both parties. Thus, as the European Union seeks to mitigate China's greenhouse gas emissions, one of the primary aims of such cooperation should concentrate on how China can effectively manage the effects of climate change.

Figure 3 Research areas of the FP7



Source: European Commission 2008

Another critical research area in which there is potential for EU-China collaboration is environmental health. China faces a huge challenge with regard to environmental health. The World Bank estimates that there are 750,000 premature deaths per year due to pollution, while 500 million in China do not have access to safe drinking water.[4] With these staggering numbers, environmental health represents an opportunity for the European Union to engage China in dialogue regarding joint

[4] World Bank. 2007. Cost of pollution in China: Economic estimates of physical damages. Washington, DC: World Bank. [Available online at: http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf]

research. However, issues of environmental health remain a controversial and politically sensitive topic within the Chinese government.

Water quality, management, and scarcity issues are also of prime importance for China's environment. Three hundred cities in China are facing acute water shortages, and many of China's rivers and lakes are severely polluted. One recent example of the deteriorating condition of China's lakes is the May 2007 algal bloom of Lake Taihu in the Yangtze Delta Plain, bordering Zhejiang and Jiangsu provinces. High algal blooms (HAB) such as the Lake Taihu incident occur primarily due to anthropogenic activity and are a threat to the health of humans and organisms living in and around the lake. The hypoxia, or oxygen deprivation, that leads to HABs is the result of eutrophication, an influx of chemicals into a marine ecosystem that alters the nutrient balance of estuaries and coastal zones and reduces dissolved oxygen, on which some organisms depend. The following section discusses an example of EU-China joint research on China's coastal ecosystems.

ONE EXAMPLE OF EU-CHINA COLLABORATION: THE ERASMUS MUNDUS PROGRAM

Collaborative research is one mechanism by which implementation of capacity building occurs. In line with this strategy is the European Union's educational exchange initiative called the Erasmus Mundus program. Appropriately named after Erasmus, a renowned fifteenth-century Dutch scholar and humanist, and *mundus*, the Latin word for "world," the Erasmus Mundus program convenes world scholars for cooperation in higher learning. The European Commission first introduced the program in July 2001 with the goal of promoting intercultural understanding through exchanges with third-world countries.[5] Students can select from a range of master's courses.[6] Erasmus Mundus supports study in the natural sciences, geography, agriculture, forestry, engineering, and technology.

[5] http://ec.europa.eu/education/programmes/mundus/programme/back_en.html

[6] http://ec.europa.eu/education/programmes/mundus/projects/index_en.html

Figure 4 The hypoxic area in the Yangtze (Changjiang) River estuary

Source: Xiao et al. 2007

An example of an outcome of the Erasmus Mundus program is an academic study in which Professor Newton worked with Chinese academics to conduct a survey of one of China's river estuaries—the Yangtze (Changjiang).

The Yangtze River estuary (Figure 4) faces serious eutrophication and hypoxia: between 1959 and 2006, hypoxia increased in the estuary from 1,800 km^2 to over 15,000 km^2. Being one of the largest rivers in the world, the Yangtze River estuary is also confronting problems of eutrophication and hypoxia in the adjacent area. The Chinese partners employed an internationally developed tool called Assessment of Estuarine Trophic Status (ASSETS), which determined the amount of eutrophication in the estuary using a pressure-state-response model based on three main indices: influencing factors, overall eutrophic condition, and future outlook. The study concluded that the ASSETS tool was a more useful way of evaluating coastal and estuarine systems in China than previous Chinese methods (Xiao et al. 2007).

THE FUTURE OF EU-CHINA COLLABORATION

> *"There's a tricky balance between policy and politics. You have to be careful not to step over that line." –Alice Newton*

Programs like FP7 and Erasmus Mundus are indicative of the European Union's progression toward more science-based approaches to environmental policy. An example of this shift over the last few decades is the Land Ocean Interactions in the Coastal Zone (LOICZ) project,[7] which aims to build capacity and provide training for water and coastal management. A core project under the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP), LOICZ provides projects and internship opportunities for Erasmus Mundus students interested in water and coastal management.

LOICZ connects scientists from around the world who investigate changes in the biology, chemistry, and physics of the coastal zone. Although it primarily started as a network for research scientists in 1993, LOICZ has since expanded to include social, political, and economic sciences to reflect anthropogenic influences as well. Grounded in science-based approaches, the LOICZ consortium strives to bridge academic knowledge and policy. Newton admits that environmental decision making is often based on consultation of environmental managers rather than the scientific community. Therefore, if more knowledge-based training can be provided to environmental managers, the link between science and policy will also be strengthened. LOICZ recently opened a regional office or node in Yantai, China, and held a conference on continental margins research in Shanghai in September 2007. Chinese scholars have made a valuable contribution to the LOICZ program and are increasingly engaged in collaborating on international research.

A similar capacity-building effort in coastal zones and management is the SPEAR (Sustainable options for People, catchment and Aquatic Resources) initiative,[8] which

[7] http://www.loicz.org

[8] http://www.biaoqiang.org

has been in place since 1983 under FP4 as part of the EU's International S&T Cooperation Programme (INCO). INCO's research objectives focus on health and health systems, sustainable use of natural resources, food security, and cultural heritage. The SPEAR program's goals are to develop and test an integrated framework for interpretation of coastal zone structure and dynamics in communities that are predominantly dependent on marine resources. In China these systems include Sanggou Bay, which is part of a rural watershed, and Huangdun Bay, which is situated in an industrial zone south of Shanghai. Both of these systems are characterized by community dependence on large-scale cultivation of seaweed, shellfish, and finfish for economic livelihood. The SPEAR project's analytical approach attempts to assess optimal management for such areas, accounting for complex interactions between ecological processes and human activities. European Union scientists work closely with Chinese partners to provide a science-based approach to better management in these areas, building the capacity of local officials to sustainably grow and manage the natural resources of the area.

While the European Union aims to expand collaboration with China in environmental capacity building, there are several challenges that confront future developments. As Waxmonsky of the U.S. EPA also admits,[9] language is a barrier that plagues relationships between EU and Chinese actors. Two-way Erasmus Mundus exchanges, where EU students can study in China and receive intensive language training, could facilitate better cooperation in the future. Another challenge lies in determining the right partners for capacity-building exercises in China. Newton suggests that a "mapping exercise" of scientific laboratories and research institutions could ensure ideal matches and best fits between researchers in the European Union and China. Lastly, although the tide is slowly changing, more direct linkages between academics involved in capacity building in key countries like China and policy makers in the European Union would enhance the policy-making process. Perhaps the European Union could learn from the Chinese experience on this point. Many of China's leaders, such as President Hu Jintao and Premier Wen Jiabao, as well as a high number of other government officials, have engineering degrees. Furthermore, the Chinese government frequently consults Chinese academic institutions for policy research and advice.

[9] See Chapter 2 in this volume, coauthored by G. Waxmonsky and B. Jacobs.

Despite these challenges, Erasmus Mundus and other academic research programs are a model for on-the-ground collaboration between Chinese and EU counterparts. These programs represent practical implementation of capacity building rather than high-level, often-abstract dialogues between governments regarding environmental issues. Additionally, academic research is often viewed as nonpolitical and nonthreatening. As relatively "objective" exercises, scientific collaboration can in some ways be a more effective means of capacity building than other efforts, which must first navigate bureaucratic or political channels.

CONCLUSION

This chapter explored the importance of bilateral cooperation in researching and understanding China's environment, particularly coastal ecosystems, and how capacity building works through academic exchange. While serving as potential model for other industrialized countries to engage with China on environmental issues, the Erasmus Mundus program and other similar efforts by the European Union can be improved, perhaps first through the realization that capacity building can be bidirectional.

This perspective does not touch on the varied channels by which actors in both contexts join together to improve the global environment. Some of these actors include non-governmental organizations (NGOs), local government institutions, and private corporations. Albeit limited in scope, the experience described in this chapter is complementary to the Chinese goal of advancing a "scientific outlook on development" to achieve a more harmonious society. Building the capacity of Chinese academics to apply more quantitative tools and approaches will help China move toward a more sustainable growth trajectory.

Primary References

European Commission. 2008. *EU RESEARCH FOR THE ENVIRONMENT 2007-2013*. Brussels: European Commission. [Available online at: http://ec.europa.eu/research/environment/pdf/978-92-79-09386-9_en.pdf]

Steffen, W., A. Sanderson, P.D. Tyson, J. Jäger, P.A. Matson, B. Moore III, F. Oldfield, K. Richardson, H.J. Schellnhuber, B.L. Turner II, and R.J. Wasson. 2004. *Executive summary of global change and the earth system: A planet under pressure*. New York: Springer-Verlag.

Xiao, Y., J.G. Ferreira, S.B. Bricker, J.P. Nunes, M. Zhu, and X. Zhang. 2007. Trophic assessment in Chinese coastal systems: A review of methods and application to the Changjiang (Yangtze) Estuary and Jiaozhou Bay. *Estuaries and Coasts* 30(6): 901-918.

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CHAPTER 4

China's Environment and Globalization: Unexpected Connections*

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CHAPTER SUMMARY

Many seemingly unrelated factors of human and natural systems are in fact tightly connected and vital to understanding how best to tackle the enormous challenge of environmental protection in China. This is evidenced by multiple recent trends: an increasing divorce rate leading to increased environmental degradation; increased GDP from product exports increasing toxic pollution domestically; increased sprawl and household construction leading to biodiversity loss in nature reserves; and increased domestic forest cover leading to increased deforestation internationally.

Governmental programs and goals conceived from separate studies on natural and human systems often do not take into account underlying issues like those identified above, although the Chinese government has been trying to promote harmonious relationships between humans and nature. Suggested is an "environmental revolution" in China that takes a holistic approach to environmental protection in the context of globalization.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on September 29, 2008 by Professor Liu as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Marissa Matsler, a graduate student in the course, and has been approved by Professor Liu. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Liu, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

INTRODUCTION: SETTING THE STAGE FOR A DRAMA

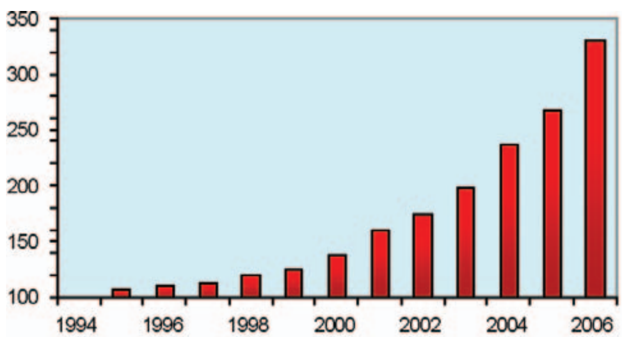
China is in a unique place in history. The economic standard of living of its citizens has increased dramatically over the past three decades, while at the same time its environmental quality is among the worst in the world. Amazing growth in gross domestic product (GDP) and international trade has made China one of the pivotal producers of the world's goods, while a variety of industrial emissions poison its people and environment. Massive forestation policies are allowing China to begin to restore ecosystems while at the same time increasing its dependency on foreign wood imports and destroying forests elsewhere (Liu and Diamond 2005).

The gap between an environmentally healthy and an economically prosperous China appears to grow larger every day (Liu and Diamond 2005; Liu and Diamond 2008; Liu et al. 2003; Lehrer 2008). As will be explored in the next few sections, there are many complex processes behind this gap. The traditional delineation of research into increasingly specified fields of social sciences and natural sciences has produced some understanding of the issues facing society and the natural world. However, this traditional approach to research often ignores the complicated relationship that society has with the natural world. This paper will focus on some complex and seemingly unrelated relationships by integrating social sciences and natural sciences via the Coupled Human and Natural Systems (CHANS) approach, in hopes of bringing about greater understanding and change for more effective environmental protection (Liu et al. 2007; Lehrer 2008).

China's environmental woes

Environmental damages in China span all ecosystem types and have effects that reach beyond political boundaries. The most internationally visible pollution issue in China is air pollution. The 2008 Olympic Games in Beijing raised awareness of this quality-of-life concern to a much larger global audience than ever before. Unfortunately, water pollution and biodiversity loss are also of serious environmental concern (Liu and Diamond 2005).

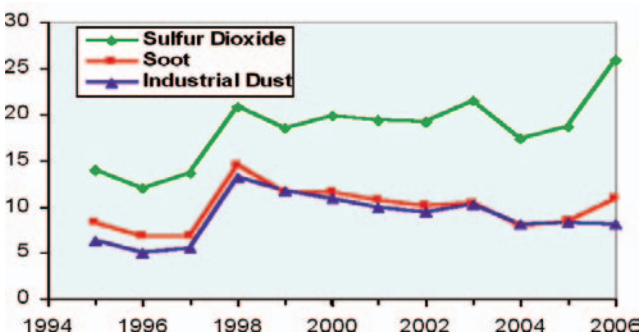
Figure 1 Growth of total industrial waste gas emissions in China, 1994-2006 (amounts in 10 billion m³)



Source: China Statistical Yearbook 2007

Air pollution in China has been increasing at dangerous levels for quite some time. This is due mainly to the steady increase of industrial emissions over the past fifteen years, as summarized in Figure 1 and Figure 2. Since 2000, China has been the world leader in SO_2 emissions (Liu and Diamond 2005).

Figure 2 Comparison of particulate matter and gaseous industrial emissions in China, 1994-2006 (in million metric tons)



Source: China Statistical Yearbook 2007

As depicted in Figure 3, this has resulted in severe increases in acid rainfall, which now affects about a quarter of China's land. It is estimated that more than 400 million urban residents breathe "bad", heavily polluted air in China (Pan 2007).

Figure 3 Distribution of acid rain in China in 2006

Source: http://showchina.org

Water is also of extreme concern. Exponential increases in industrialization have greatly increased the demand for water and caused more severe water shortages. On the other hand, industrial wastewater, combined with agricultural runoff, has wreaked havoc on the natural hydrologic cycle of China's waterways, causing 75 percent of China's lakes (Liu and Diamond 2005) as well as 70 percent of its rivers to be polluted (Pan 2007). The increase in wastewater output also affects marine systems in China. Eutrophication of China's seas due to industrial and agricultural pollution has driven the number of red tides up from only 2-4 per year in the 1960s to nearly 100 per year at the beginning of the 21st century (Liu and Diamond 2005).

A third environmental woe is biodiversity loss. Because China's territory encompasses many different bioregions, there are a great number of unique species in China. From coastal monsoon climates to seemingly inhospitable extreme desert ecosystems, there is a huge variety of life (Liu et al. 2003). Ten percent of the world's terrestrial vertebrate and higher plant species are found within China's boundaries (Liu and Diamond 2005). That's more than 2,300 terrestrial vertebrates and over 30,000 higher plant species, half of which are found only in China (Liu et al. 2003). Unfortunately, 15-20 percent of them are endangered or threatened (Liu and Diamond 2005; Liu et al. 2003) due to environmental pollution, habitat destruction, and other human activities.

Impact on the people

Of course, the people of China are directly bearing the brunt of the country's environmental problems. It is estimated that environmental degradation accounts for a 7-20 percent loss of GDP across China's provinces. For scale, that was approximately $200 billion in 2005 (Liu and Diamond 2008). This high price only takes into account effects that can be directly attributed to environmental problems, such as large environmental clean-ups related to pollution. For example, just before the 2008 Olympics sailing competition in Qingdao, military forces were sent to remove macro algae by hand that had bloomed uncontrollably and made the race route impassible. The labor-intensive and time-consuming cleanup also involved more than 1,000 local volunteers. According to the *People's Daily*, overall, the government of Qingdao planned to spend "over 200 million U.S. dollars every year, nearly 3 percent of the city's annual GDP," for environmental cleanups from 2003 to 2008.

There are many other monetary effects of pollution on the Chinese workforce that are not included in the estimates of financial losses, due to the difficulty of accurate measuring. These unaccounted-for monetary losses include missed days of work and medical expenses from hospital visits due to illness caused by poor environmental quality.

China is also paying for its environmental situation more than monetarily. It is estimated, astonishingly, that more than 700,000 deaths a year can be attributed to the air pollution alone in China (Liu and Diamond 2008). Another disturbing statistic shows that half of Chinese urban children have blood lead levels that exceed the World Health Organization's (WHO) standard maximum blood lead level, which is set at 100 micrograms per liter (Wu 2000). Recent studies have shown that even blood lead levels as low as 50 micrograms per liter can result in a variety of debilitating brain conditions (Lanphear 2000). This may cause a range of potential problems in China's society as this generation of children grows up dealing with the effects of lead poisoning on their mental capacities.

Social issues extend beyond human health and impede the progress of one of China's most sacred governmental goals: harmonious society. Environmental degradation has caused increased numbers of social conflicts in recent years. A total of 51,000 severe social clashes were recorded in 2005 alone that were associated with environmental complaints. The number of appeals to the government for help dealing with environmental issues is also on the rise, totaling 400,000 from the general public in 2005 (Pan 2007).

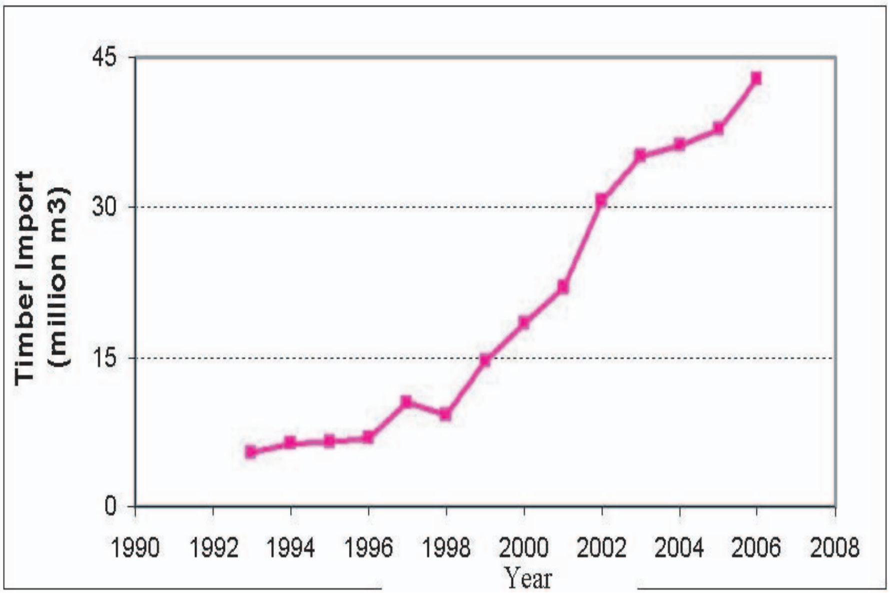
GLOBALIZATION: A DOUBLE-EDGED SWORD

China's environmental challenges are not just domestic. They have increasingly been becoming global challenges as a result of globalization. On the one hand, globalization has played a pivotal role in China's economic miracle and exports of cheap products to many other countries. On the other hand, globalization has become a major driver of environmental degradation in both China and many other countries around the world.

Imports and exports of goods and products

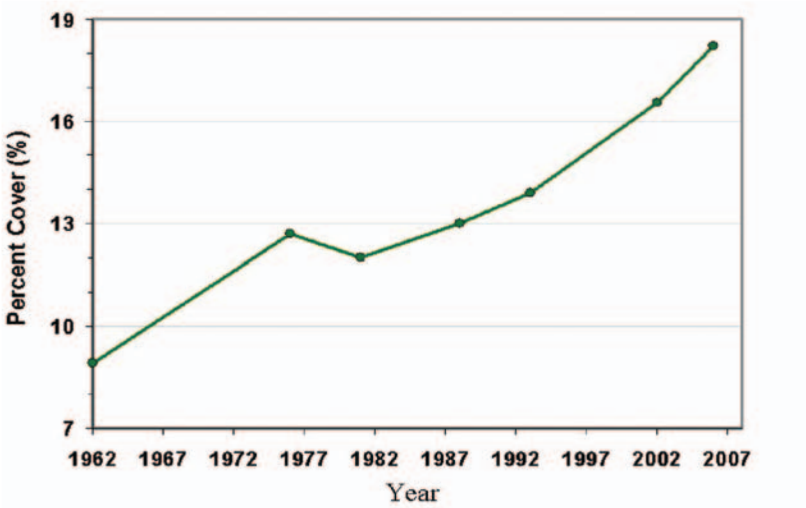
China has the third-highest timber consumption in the world (Liu and Diamond 2005). Timber imports have increased exponentially since 1998, when the logging ban in China took effect (Figure 4). In other words, the logging ban has had the unintended and unfortunate effect of exporting deforestation to other tropical regions of the world, negating many of the positive aspects of the observed Chinese reforestation (Figure 5) (Liu and Diamond 2005; Liu et al. 2008).

Figure 4 Imports of timber to China, 1993-2006



Source: International Tropical Timber Organization

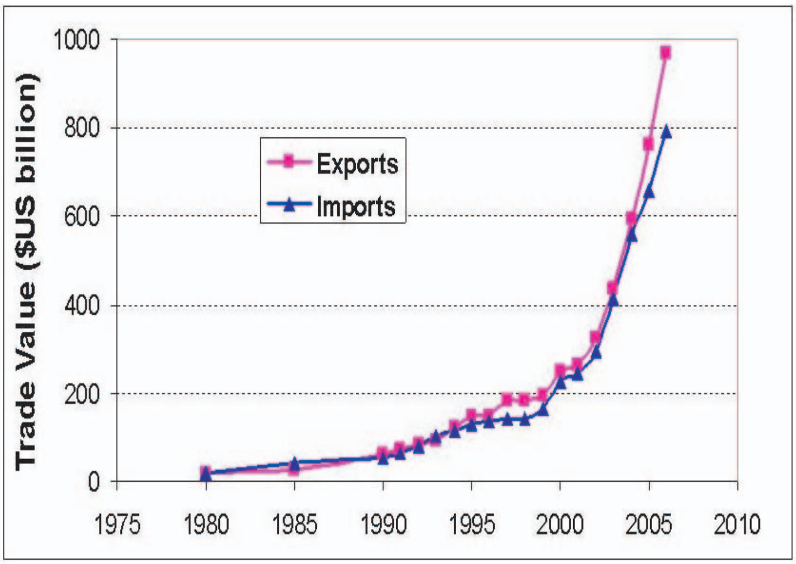
Figure 5 Percent forest cover of total land cover in China, 1962-2006



Source: China Statistical Yearbook 2007

Exports have played an even larger role than imports in environmental degradation. In recent decades, China has become a "world factory," producing an increasingly large amount of goods for other countries around the world (Liu and Diamond 2005). As shown in Figure 6, this has brought increased monetary wealth to China. However, exports are of great concern because of pollution they create (Liu and Diamond 2005).

Figure 6 Total value of imports and exports in China, 1980-2006



Source: China Statistical Yearbook 2007

Many of the factories involved in the production of exports use a variety of hazardous materials and create a great amount of greenhouse gas emissions. While the factories' products are exported around the world, the hazardous waste used to produce them stays within the country. Production for industrial exports accounted for one-third of 1,700 million tons of CO_2 emissions in China in 2005 (Weber et al. 2008).

Cultural imports

The importation of the western lifestyle and habits has increased the level of consumption, not only in urban areas of China, but also in ecologically sensitive rural regions. For example, automobiles have become increasingly popular in China over the past few decades as a symbol of status and modernity. With rising standards of living, a continually increasing number of Chinese citizens are able to purchase cars (Liu and Diamond 2005). It is estimated that there were already 37 million vehicles on the road in 2006. The number of vehicles has continued to increase explosively. These automobiles have become increasingly important CO_2 emitters in China.

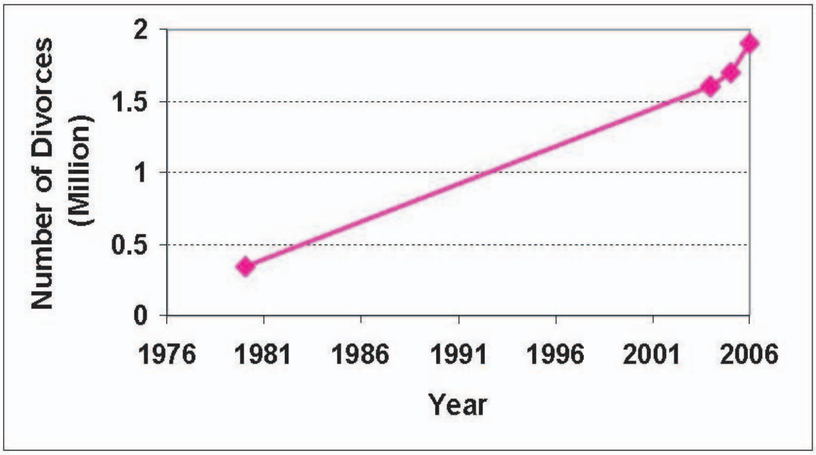
Household proliferation (rapid increase in the total number of households) has also spread across China. Traditionally, population growth was singled out as a primary driver of the problem. But recent studies suggest that household proliferation appears to play a more important role, especially in ecologically sensitive regions such as biodiversity hotspots. This is due to the realization that even when population growth levels off or declines, households continue to increase in number in many places in the world (Liu et al. 2003).

> *"Environmental scientists have been paying a lot of attention to population size, which is important in terms of environmental impacts. But what we find is that in some areas, even with declining population size, not just a declining population growth rate, there has been a substantial increase in the number of households." –Jianguo Liu*

Demand from more households sets off a chain reaction of production, such as cement and other building materials as well as household goods. Production of all of these goods greatly increases the environmental stress on China and the rest of the world (Liu, Daily, et al. 2003; Yu 2007). The amount of floor space per capita has grown from approximately 7 m^2 in 1978 to nearly 30 m^2 in 2006. This means that larger housing units have been built despite that fact that average household size (number of people in a household) has been declining, further decreasing efficiency and increasing emissions of pollutants such as CO_2 (Liu 2008).

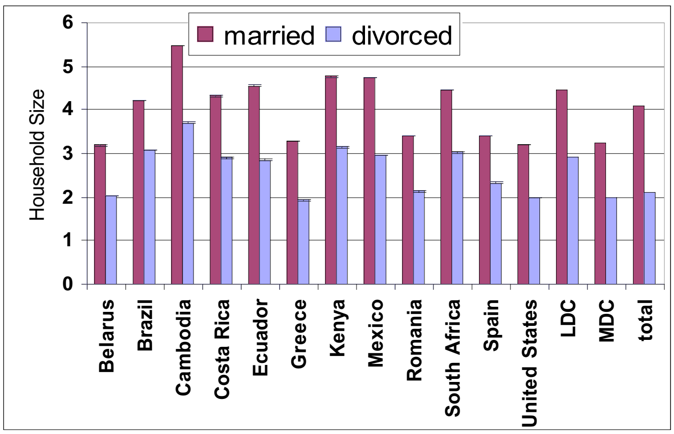
One of the intriguing findings has been a connection between this growth in the number of households and the spillover of divorce as a cultural norm to China (Figure 7). Traditionally divorce was rare in China, but the numbers of divorced couples had jumped to almost 1.9 million in 2006. Divorce splits one household into two, thus increasing the number of households and reducing the number of people in each household. A study on the global effects of divorce on household size showed that the average numbers of people in divorced households were 27-41 percent smaller than those of married households in the twelve different countries sampled (see Figure 8). To put that into perspective, if the average household size had stayed the same as the married household size over the studied time period from 1998-2002, 7.4 million fewer households would have been created. These 7.4 million households represent an enormous amount of embodied energy and natural resource use, all of which is due to a purely social and cultural act (Yu 2007).

Figure 7 Number of new divorces in China 1979-2006



Source: China's Ministry of Civil Affairs

Figure 8 Household size in married and divorced households around 2000

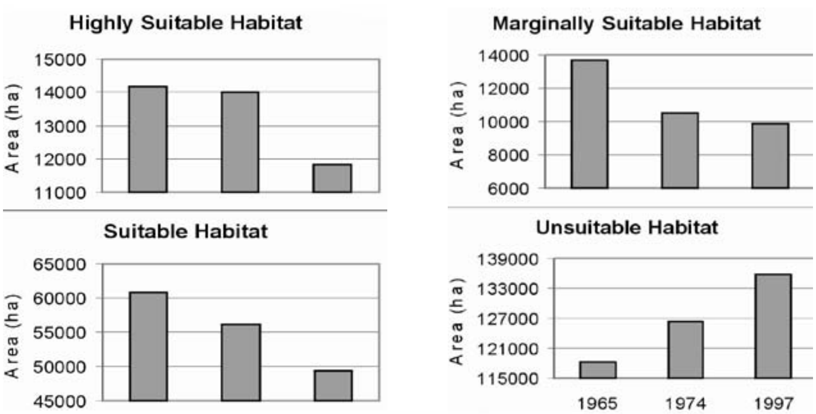


Source: Jianguo Liu

Globalization has also unintentionally affected China's nature reserve system (Liu et al. 2003; Liu and Diamond 2005; Liu, Ouyang, et al. 2003; Lehrer 2008). The Wolong Nature Reserve in southwestern China is an illustrative example of this phenomenon. Established in 1975, the Wolong Nature Reserve is approximately 200,000 hectares. Its primary goal is to protect giant panda habitat (Lehrer 2008). When the reserve was mapped during its first twenty-five years of existence to track panda habitat, it was found that good habitat had actually decreased (see Figure 9) since the establishment of the reserve. These were very disturbing results. When probed further, the reason for this continued habitat degradation was discovered.

Like most other nature reserves in China, there are villagers inside Wolong. The human population size increased by about 70 percent from 1975 to 1997 and the number of households more than doubled. These rapid increases in the numbers of villagers and households led to more intensive and extensive human activities, such as collection of fuelwood (major energy source) in panda habitat, agriculture, house construction, and road construction. After the reserve's establishment, the reserve was transformed from a basically closed economy to an open economy, including international tourism. The added domestic and foreign tourists on the land were themselves a stress on the environment, and the income gain to the villagers in the reserve due to tourism generated more demand for consuming natural resources and increased degradation further.

Figure 9 Degradation of panda habitat before and after Wolong Reserve establishment



Source: Jianguo Liu

To mitigate the effect of these villagers on the protected areas, an "eco-hydropower plant" was completed in 2002 and villagers are given government subsidies through two new conservation programs that began in 2000 and 2001. These subsidies are meant to help the villagers afford the use of electricity and minimize the use of fuelwood. They are also designed for villagers to return cropland on sleep slopes to forestland, and to monitor and protect forests from illegal harvesting. These new policies have been quite effective and panda habitat has begun to recover.

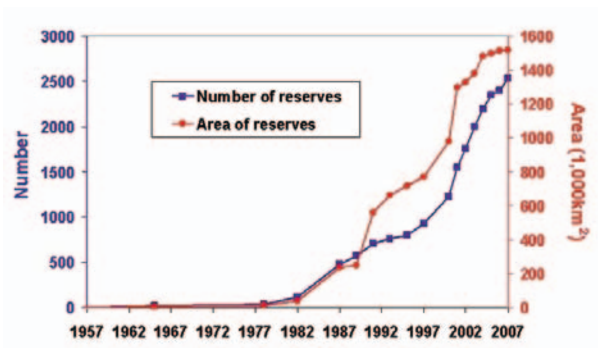
ENVIRONMENTAL PROTECTION EFFORTS: A GLIMMER OF HOPE

The Chinese government has responded to the rapid environmental degradation within its country by implementing many remediation programs. These programs aim to control air pollution, reduce water pollution, mitigate biodiversity loss, and reduce soil erosion and desertification. Many of these programs also provide global environmental benefits by increasing vegetative cover, lowering pollution to other countries, reducing timber import from and forest degradation in other countries, and enhancing carbon sequestration. Below we highlight three of these national programs with significant global importance.

The Natural Forest Conservation Program (NFCP) manifests itself as a strict nationwide ban on logging natural forests that started in 1998. Monetary incentives are offered as compensation to halt all logging activities in natural forests, which began with twelve provinces in the 1998 pilot program and expanded to eighteen provinces in 2000 (Liu et al. 2008). 'Mountain closures' also ensure that not only logging is stopped, but that all human activity including grazing and the gathering of fuelwood is prohibited in these areas. This is intended to mitigate the effects of erosion as well as to prevent natural disasters caused by deforestation (Liu et al. 2008). In fact, NFCP was a direct response to an enormously destructive flooding event that occurred in 1998 (Liu and Diamond 2005; Liu et al. 2008). The lack of vegetation in many areas greatly exacerbated the flooding effect, and official statistics put the death toll at approximately 4,000. Response to this flood illustrates the highly reactive and crisis-control-oriented environmental policy in China.

A second major project started in China, the Grain to Green Program, also attempted to mitigate erosion and desertification and increase forest cover. It began as a pilot program in only three Chinese provinces in 1999 and grew to a full-fledged program in over twenty-five provinces by 2002. Farmers are paid in grain to convert their cropland to grasslands and forests. Farmland qualifies for conversion if it has over fifteen or twenty-five degrees of slope. Farmers are also supplied with tree seedlings and some cash for miscellaneous expenses. These farmers can then afford to plant and maintain a tree plantation on cropland that previously would have lost a great deal of nutrient-rich soil due to erosion.

Figure 10 Increase in number and size of China's nature reserves from 1957- 2007



Source: China Statistical Yearbook 2007

Nature reserves are a third environmental program undertaken by the Chinese government. As displayed in the Figure 10, the number of nature reserves in China has grown exponentially since the initiation of the program in the 1950s. Likewise, the area of each nature reserve has also grown impressively. By 1997, the total area of nature reserves was 800,000 square kilometers, approximately twice the area of California. Amazingly, this number doubled by 2007 with total reserve area at nearly 1,600,000 square kilometers, an area that could comfortably fit the state of Texas twice within its borders with room to spare.

Aside from these three examples of government efforts, there have been many other environmental programs put in place. Environmental awareness among the general public has been increasing. A wide range of new and more environmentally friendly technologies imported from developed countries have been in operation. The efficiency in using energy and many other resources has been improving. These are encouraging signs, but much more needs to be done to make fundamental changes in China's environment.

MOVING FORWARD: "ENVIRONMENTAL REVOLUTION"

> *"In order to fundamentally improve China's environmental protection, we need a revolution—an environmental revolution."* –*Jianguo Liu*

As discussed above, there is a variety of complex factors that play into each specific manifestation of environmental degradation. Reforming the administrative structure and changing the model of economic development are key to making fundamental improvements in China's environment (Liu and Diamond 2008). In addition, changing the angle at which the environment is viewed, and researching it from a holistic perspective, could greatly strengthen environmental management (Liu et al. 2007).

Reforming the administrative structure and changing the model of economic development

Changing the incentive structure for government leaders in China would be a place to start the environmental revolution. Officials have traditionally been selected and promoted on the basis of their economic performance. If officials were also evaluated on their environmental performance, they would be compelled to devote resources to monitoring factory and business cleanliness as opposed to turning a blind eye to cut corners that increase gross domestic product but degrade the environment (Liu and Diamond 2008).

Giving environmental governing bodies the authority to properly enforce pollution standards would also add strength to China's environmental programs. At present, fines for polluting are ineffectual. It is easier and cheaper for a company to pay the fines than to clean up their factories (Liu and Diamond 2008). However, the recent elevation of China's State Environmental Protection Administration to the higher level Ministry of Environmental Protection (MEP) is a step in the direction of increased authority and enforcement of emission standards.

The administrative structure could also be enhanced by high-level cooperation. At the moment, many government agencies in China do not work together and consider many environmental standard violations outside of their jurisdiction. For example, the MEP is not responsible for all environmental sectors. The State Forestry Administration, for one, is the body that concerns itself with forest-related policy, limiting the reach of the MEP into forestry affairs. Because of this, many violations fall through the cracks and are not dealt with by the government. If a national body could be formed to coordinate all the disparate environmental agencies of China, environmental protection would improve drastically (Liu and Diamond 2008).

During the past three decades, China's main goal was to promote rapid growth in GDP. The dominant development model must be transformed from inefficient resource use and high pollution to high efficiency and low/no pollution for both environmental and socioeconomic sustainability. One way to achieve this goal is to fully evaluate short- and long-term socioeconomic costs of environmental degradation. Once people realize these costs, it would be easier to treat environmental protection as an integral part of sustainable economic development.

Interdisciplinary approaches

A few other suggestions for increasing environmental protection efficacy stem from interdisciplinary thinking and integration of social and natural sciences. They both stray from the traditional regulation path and attempt to treat the root illness as opposed to merely mitigating symptoms (Liu et al. 2007).

The first suggestion is regularly undertaking systematic assessments of the recently developed ecological function zones. The assessments would dynamically rank all the regions of China by ecosystem fragility, level of ecosystem services, economic productivity, socioeconomic and demographic conditions, vulnerability to human activities, and so on. This dynamic ranking system could then be incorporated into economic decisions in the future. If this is done, human activities that cause high environmental stress on an ecosystem can be moved to robust and resilient locations and fragile ecological function zones that are providing crucial ecosystem services could be left alone.

Working hand in hand with the protection of ecological function zones is the nationwide implementation of "eco-compensation," or payments for ecosystem services. The Chinese government has already started a pilot eco-compensation program, but this program needs to be more widespread and effectively enforced. In this eco-compensation system, households and institutions would receive payments for their effort and outcome in protecting ecosystems. For example, headwater communities would receive funds from the government or other sources (e.g., beneficiaries in lower reaches) if they kept their environment clean and pollution free. If they improved the baseline quality of the area, they would receive even greater compensation. This is an incentive scheme that benefits not only the community receiving subsidies but also all downstream communities in the entire region (Liu and Diamond 2008).

Another important way to reduce stress on fragile ecosystems is to provide valid relocation options to rural communities in sensitive regions. In many previous cases, this eco-migration of communities has proved difficult. Most rural communities have lived in the same location for many generations and cannot manage to acclimate to their relocation communities. Even past attempts at retraining populations have been unsuccessful and many villagers have decided to move back to their rural communities.

However, in an attempt to stop the trend of cultural transfer that brings increased numbers of households and inefficient energy use to rural villages in fragile ecosystems, an eco-migration of citizens away from such villages is necessary. Interviews with rural youth in Wolong Nature Reserve have suggested that 90 percent of young people want to move away from their village. The biggest obstacle standing in their way is opportunity. This is where education can come into play. If the youth of rural villages are given access to quality education, then they are more likely to attend universities in urban areas and find jobs in the city as well. At the same time that they are moving their career paths in a new direction, they move their environmental impact in a direction away from the fragile ecosystem of their village to less environmentally sensitive areas. In this new social position, they are better able to earn higher wages to send home to the older generation remaining in the village, allowing the village to update itself to current environmental standards. This type of eco-migration is a win-win situation for the people and environment of China.

CONCLUSION

Although China's environmental problems are complex, it is possible to find creative solutions based on the great body of knowledge generated by both social and natural scientists. More research using a Coupled Human and Natural Systems (CHANS) approach is needed to continually connect seemingly unconnected dots and fundamentally improve China's dire environmental situation.

In this globalizing world, China's environmental revolution cannot be achieved without assistance from other countries, especially developed countries. These nations have contributed to and also have suffered from China's environmental degradation. They can provide a range of assistance, from providing environmentally friendly technologies, investing in industries with clean and efficient resource use, to increasing environmental awareness and pollutant emission standards. The joint efforts between China and the rest of the world can lead to a green China and a sustainable planet.

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References

Lanphear Bruce P., Kim Dietrich, Peggy Auinger, and Christopher Cox. 2000. Cognitive deficits associated with blood lead concentrations <10 mg/dl in U.S. children and adolescents. *Public Health Report* 115(6): 521-9.

Lehrer, Jonah. 2008. Ecological freakonomics. *Conservation Magazine*, July-September.

Liu, Jianguo. 2008. Integrate disciplines. *Nature* 454: 401.

Liu, Jianguo, and Jared Diamond. 2005. China's environment in a globalizing world: How China and the rest of the world affect each other. *Nature* 435: 1179-1186.

______. 2008. Revolutionizing China's environmental protection. *Science* 319: 37-38.

Liu, Jianguo, Gretchen C. Daily, Paul R. Ehrlich, and Gary W. Luck. 2003. Effect of household dynamics on resource consumption and biodiversity. *Nature* 421: 459-558.

Liu, Jianguo, Thomas Dietz, Stephen R. Carpenter, Marina Alberti, Carl Folke, Emilio Moran, Alice N. Pell, Peter Deadman, Timothy Kratz, Jane Lubchenco, Elinor Ostrom, Zhiyun Ouyang, William Provencher, Charles L. Redman, Stephen H. Schneider, and William W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317: 1513-1516.

Liu, Jianguo, Shuxin Li, Zhiyun Ouyang, Christine Tam, and Xiaodong Chen. 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. *PNAS* 105(28): 9477-9482.

Liu, Jianguo, Zhiyun Ouyang, Stuart L. Pimm, Peter H. Raven, Xiaoke Wang, Hong Miao, and Nianyong Han. 2003. Protecting China 's biodiversity. *Science* 300: 1240-1241.

Pan, Yue. 2007. *Thoughts about China's environmental issues*. Beijing: China Environmental Culture Promotion Association.

People's Daily. 2003. Qingdao to clean up its environment for Olympic Games. *People's Daily*, June 16.

Weber, Christopher L., Glen P. Peters, Dabo Guan, and Klaus Hubacek. 2008. The contribution of Chinese exports to climate change. *Energy Policy* 36: 3572-3577.

Wu, Yiqun. 2000. The accumulation of harmful substance in human body: The national dynamic study. Institute of Environmental Monitoring, Chinese Academy of Preventive Medicine (unpublished data).

Yu, Eunice, and Jianguo Liu. 2007. Environmental impacts of divorce. *PNAS* 104(51): 20629-20634.

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CHAPTER 5

The Role of Environmental NGOs in Shaping a Green China*

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CHAPTER SUMMARY

This chapter argues that, as a result of the historical development of China's environmental management system, environmental non-governmental organizations (ENGOs) are playing an important role as environmental information disseminators, law facilitators, and communication promoters among four groups of players: the central government, local governments, manufacturers (polluters), and civilians (pollution victims). The analysis of a successful Beijing-based ENGO, the Institute of Public & Environmental Affairs (IPE), provides insights into how ENGOs can effectively participate in the environmental management system. From the success and lessons of IPE and the projected demand from civil society for a better environment, we suggest that localization of ENGOs in China, the government's endorsement, and broad trust from government, manufacturers, and civilians are essential for the future development of Chinese ENGOs.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on November 3, 2008, by Ma Jun as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Yong Zhao, a graduate student in the course, and has been approved by Mr. Ma Jun. The paper incorporates material from the lecture, the discussion session after the lecture with Mr. Ma Jun, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

INTRODUCTION

Since the 1970s reform and open-door policy, China has experienced great changes in many aspects of the society. The environmental crisis resulting from economic development has become a serious threat to the sustainable development of China into a harmonious society. Traditional top-down control from the central government alone cannot effectively manage the environment. Thus new partners and methods are needed to face the challenge. Environmental non-governmental organizations (ENGOs) have become an important player in China's environmental management by filling the gap between the top-down control system and the requirements of reality on the ground.

An objective of this chapter is to give a short account of the development of China's ENGOs from the perspective of historical institutional change. In addition, the current function of and future outlook for China's ENGOs will be discussed. An illustrative case analysis will be made of the Institute of Public & Environmental Affairs (IPE).

ENVIRONMENT NGOS IN CHINA: ORIGIN, ROLE, AND DEVELOPMENT

On March 31, 1994, the Chinese ENGO Friends of Nature (FON) was founded in Beijing by Conjie Liang, a member of the Chinese People's Political Consultative Conference (Figure 1). Since then, the number of ENGOs has grown rapidly. By the end of 2006, among 345,000 NGOs in China, there were 2,786 ENGOs, including 1,382 government-organized NGOs (GONGOs), 202 civilian-organized NGOs, 1,116 student-initiated NGOs, and 68 NGOs outside the mainland, either internationally or based in Hong Kong, Macau, and Taiwan (Niu and Pan 2007). These ENGOs participated in a broad range of activities related to environmental protection, such as environmental education, species protection, policymaking, and environmental monitoring.

Figure 1 On June 5, 1993, more than forty young people participated in an informal meeting about environmental protection in Linglong Park in the southern suburb of Beijing. It is said that this meeting was the first non-governmental voluntary environmental protection meeting. In the photo, the man giving the lecture is Congjie Liang, founder of FON, and the surrounding listeners are the first members of FON.

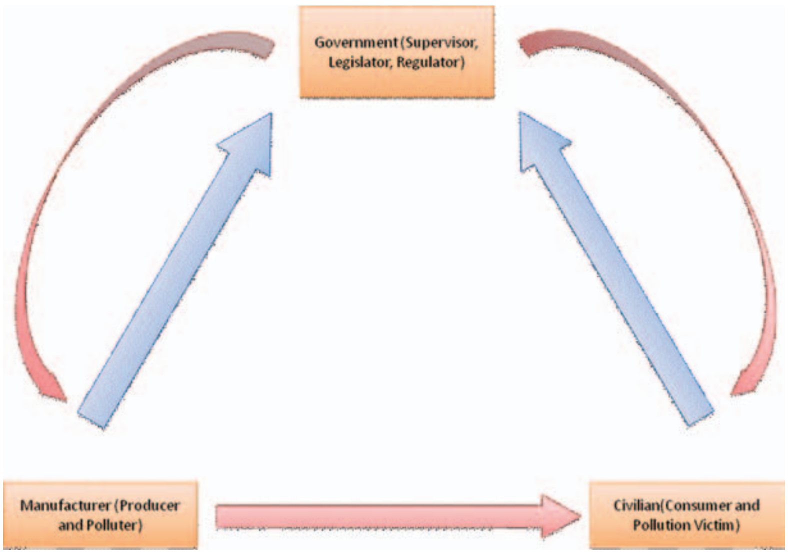
Source: Friends of Nature 1993

Origin of ENGOs: A greening government and an awakening civil society

The emergence and development of ENGOs in China were connected to several major societal changes in the early days of implementing the country's open-door policy. The institutional change in government since the reform and open-door policy in the late 1970s set the stage for citizens to participate in environmental affairs. Before the reform, the government was the sole supervisor, legislator, and regulator for environmental management (Figure 2). In this system, there was no direct interaction between the manufacturers and the consumers. The manufacturers, being mainly state-owned factories, were politically driven rather than revenue driven. The power balance was one sided among the three groups of actors in environmental affairs.

The government had strict control of both the polluter and the consumer (see curved arrows in Figure 2). The manufacturer and the civilian had little power in influencing the government's policymaking (straight arrows). The civilian was the recipient of the impact of pollution produced by the manufacturer, but had no oversight power over the latter's unsound environmental practices.

Figure 2 The relationship between various actors in environmental management before the reform and open-door policy of the late 1970s

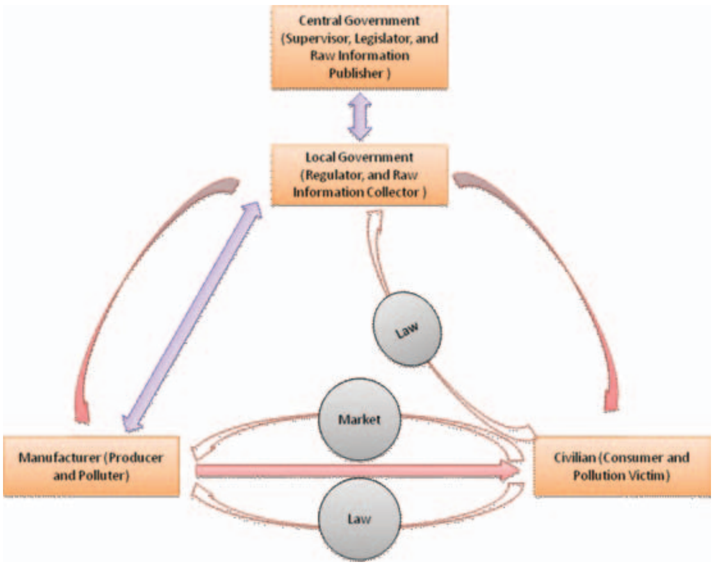


The goal of the reform and open-door policy was to adapt market economy practices to a socialist system in order to liberate the productivity of the Chinese people. This was a major turning point in Chinese history, and all aspects of China's society have changed to facilitate or to adapt to the new national strategy. Realizing that the former tight control of its people was no longer effective in managing a market-oriented society, the government started to move away from micro-managing civil affairs and instead concentrated its efforts on national strategy, policy, and lawmaking. In March 1998 at the Ninth People's Congress, Luo Gan, the Secretary-General of the State Council, declared that "the government has taken up the management of many affairs which it should not have managed, is not in a position to manage, or actually cannot manage well" (Saich 2000; Ho 2001). The retreat of the government from civil affairs not only successfully stimulated economic productivity and efficiency, but also left some fields blank for other social forces to fill in. Environmental protection was one of these blank fields.

In the meantime, the government structure went through a decentralization process, a process that actually had a negative impact on environment protection. Schwartz (2004) argues that at the central government level, staff reduction left the State Environmental Protection Agency (SEPA) unequipped to provide crucial services such as regulation enforcement, environment monitoring, education and training.

Figure 3 illustrates the institutional change in the environmental management field owing to the reform and open-door policy. The roles of various actors are inseparable.

Figure 3 The relationship between various actors in environmental management before the reform and open-door policy without the participation of ENGOs. Open arrows indicate weaker interactions than filled arrows.



In this system, the central government not only supervises local government, but also relies on the local government to implement environmental policy and law and monitor environment performance. However, at the local level, officials are reluctant to establish environmental protection goals because the funding and resources for achieving these goals have become a local responsibility, and because economic development is usually the primary criterion for performance evaluation. From an institutional perspective, since the local government has a large responsibility for implementation of environmental laws and regulations (Dasgupta et al. 2001; Wang 2000), it is susceptible to corruption, given the strong incentive to pursue economic development at the cost of pollution. Such an incentive results in an increase in the negotiation power of polluters in environmental management. On the other hand, local victims of pollution only have weak negotiation power to counter the industrial interest groups because they are usually incapable of suing the polluter and the local government and because the industrial interest groups and the local government have shared interests. In addition, local civilians cannot effectively exert buying power because the polluting manufacturers usually do not rely on local markets to make a profit. Thus, this institutional change weakens the negotiation power of civilians in environmental management.

While there has been institutional degeneration of environmental management capacity, economic development, a major achievement of the government institutional change, has also brought great challenges for environmental protection. In the 1990s, industrial output increased at a rate of more than 15 percent annually, contributing 45 percent of China's GDP in 2001 (Dasgupta et al. 2001). In 2008, China maintained its world dominance in manufacturing many products (Table 1). This economic growth comes at the cost of environment degradation. In 2008, more than 60 percent of China's fresh water was contaminated and more than half of China's major cities failed to meet modest national air quality standards. In response, citizens started to complain to different levels of the government. During the period from 1991 to 1993, the government received over 130,000 complaints annually (Dasgupta and Wheeler 1996). Some of these complaints developed into protests. Recognizing that environmental degradation could undermine its goal of social stability, the government is now willing to go green in order to prevent further social unrest.

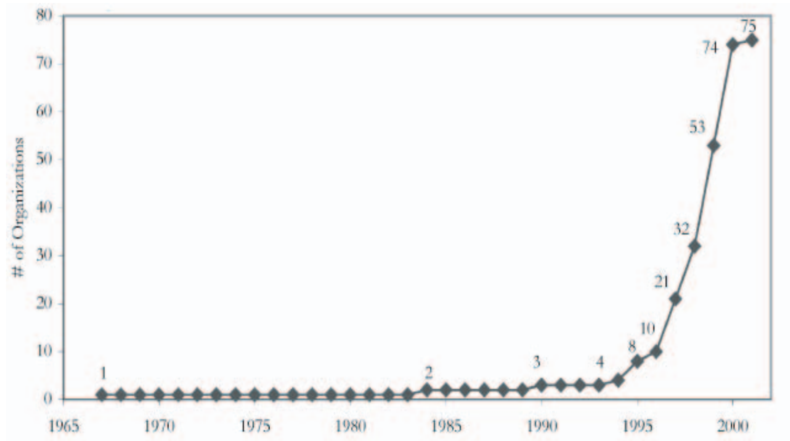
Table 1 China's manufacturing output in 2008, as a percentage of global total

Item	Percentage
Toys	70%
Shoes	66%
air conditioners and copy machines	>60%
chemical fibers	>50%
color TVs and digital cameras	50%
cell phones	47%
crude steel	36%
computers and refrigerators	33%

Source: Ma et al. 2008

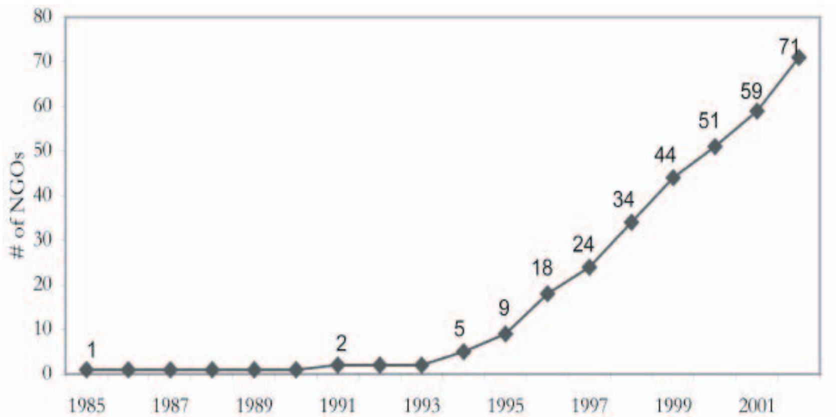
The worsening environmental crisis demonstrates the deficiency of the top-down environmental management system. The government feels the necessity of having a strong civil society to achieve its social agenda. The civil society also senses the necessity and possibility for NGOs to contribute to the solution of environment problems. The changing relationship between the government and civil society is evidenced by the well-publicized story of the establishment of FON and the rapid development of ENGOs afterwards. From only nine ENGOs, four of which were student organizations in 1994, the number increased dramatically to 184 student environmental organizations and 73 non-student ENGOs in 2001 (Figures 4 and 5).

Figure 4 Growth in student environmental organizations, 1967–2001



Source: Yang 2005

Figure 5 Growth in (non-student) environmental organizations, 1985–2002



Source: Yang 2005

ENGOs are diverse in organizational form. According to the classification by Yang (2005), there are seven types, as shown in Table 2.

Table 2 Main types of environmental NGOs in China

Organizational Type	Registration status	Examples
Registered NGOs	Registered as social organizations (社会团体) or private, nonprofit work units (民办非企业单位)	Friends of Nature; Green River Institute of Public & Environmental Affairs; Green Earth Volunteers
Nonprofit enterprises	Registered as business enterprises but operate as nonprofit organizations	Global Village of Beijing; Institute of Environment and Development
Nonprofit work unit	Unregistered organizations that function as NGOs	China's Green Beats
Web-based groups	Unregistered groups that operate mainly through the Internet	Green-Web; Greener Beijing
Student environmental associations	Registered with campus Youth Leagues yet function and are perceived as NGOs	Sichuan University Environmental Volunteer Association
University research centers and institutes	Affiliated with institutions of higher learning but operate as NGOs	Centre for Legal Assistance to Pollution Victims, China University of Political Science and Law
Government-organized NGOs (GONGOs)	Social organizations established by government agencies, also known as state-owned NGOs (SONGOs)	China Environmental Science Association

Source: Yang 2005

The role of ENGOs in environmental management and protection

In China's environmental management system, the government plays a much more important role than the market and civil society. From the perspective of institutional development, the rise of ENGOs in environmental management is closely related to the development of the government management system. In some fields, such as transportation pollution control, natural resource extraction, and land use change, the government relies on command and control policies. For the major pollution generation sector—industrial pollution—the situation is much more complicated, and the Chinese government deploys two instruments: pollution levies and pollution permit trading.

China has been collecting pollution levies since 1982 (Wang 2000). The government wants to use the levy to add external costs to polluters so that they have the incentive to change their polluting behavior. In principle, the levy collected will be used for the improvement of the environment. However, this mechanism has several defects. For one thing, the environment has a limited carrying capacity, and simply adding external costs cannot necessarily prevent the environment from being severely degraded. According to the analysis of Wu (2005), because the levy is typically priced at 10-15 percent of the true cost to control pollution, the polluter may simply consider the levy as part of the production cost and add it into the sales price. Furthermore, 80 percent of the collected levy goes back to the polluter, supposedly to fund efforts to improve its environmental performance. Therefore the polluter does not really feel the pressure to change its behavior.

The Chinese government has also tried to implement a pollution permit trading system, but progress is slow. In 1999, after several years' discussion between the Chinese government and Environmental Defense Fund of the U.S., China initiated SO_2 emissions trading in two industrial cities, Benxi and Nantong. In March 2002, the "4+3+1" project to implement an emissions trading system in four heavily polluted provinces, three major cities, and one major energy company (China Huaneng Group) was officially carried out by SEPA together with Environmental Defense Fund. Finally in December 2008, the first set of permits—in the amount of 50 tons of SO_2 emission— was bid on by seven buyers in the Tianjin Pollution Permit Trading Center, resulting in a transaction of 150,000 RMB.

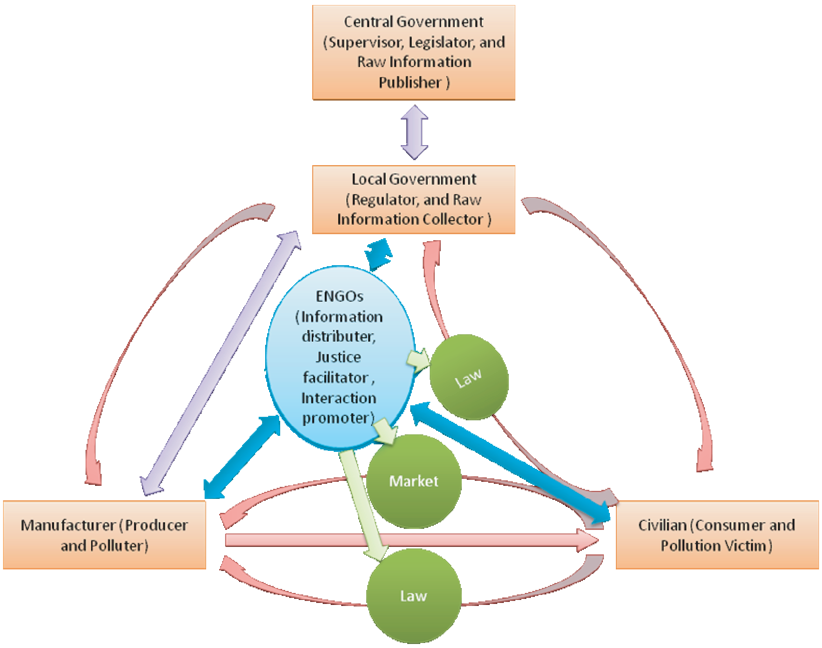
Compared to the pollution levy system, the pollution permit trading system has several advantages. First, the polluters have more incentive to implement a better pollutant control system because extra pollution permits can be traded or stored. Because the local government is no longer the permit provider, which requires less participation, the likelihood of corruption is lower than in the levy system. Second, local people and ENGOs can contribute to pollution reduction by buying the permits locally.

The trading system also has problems of its own. It is difficult to calculate the total allowable amount of pollutants and to distribute emission permits in an equitable manner, especially in China, whose regions vary greatly in terms of economy, culture, and environment. Another difficulty is that the regulatory system is unable to manage the trading market with proper instruments such as laws and trading taxes. Furthermore, a standardized market did not exist at the inception of the system. Although some people believe that emissions trading is more effective than the levy system, its implementation is complicated by the fact that the right to issue these permits still rests in the hands of local governmental officials. The incentive for them to protect the polluter to enhance economic performance may compromise the integrity of the system.

From the analysis above, it is clear that the government's two instruments are not sufficient to control industrial pollution. This is where ENGOs can play an important part (Figure 6). As information distributors, justice facilitators, and interaction promoters, they can help strengthen environmental laws and market instruments. ENGOs can work on the popularization of environmental laws and facilitation of public prosecution, making the legal instruments more active in environmental management. They can take the responsibility for uniting civilians to interact with polluters and local governments. For this reason, ENGOs with professional negotiation skills can act as representatives of pollution victims. As a result, they strengthen the role of civilians to directly counter the power of polluters.

Similarly, ENGOs can strengthen market instruments by disseminating pollution information. Market forces cannot be functional unless environmental information reaches a critical level of transparency so that consumers with concern about environment and health can make choices about what to purchase. It is therefore essential that public have adequate access to the information. Using a model to compare the implicit price of pollution from community pressure and the explicit price in the form of the pollution levy, Wang (2000) demonstrates that the implicit price, which measures the attitude of the local community, is at least as high as the explicit price charged by the government. Consumers are less likely to purchase the products if they know that the firms that produce them are heavy polluters. Investors also react significantly to environmental news when deciding how to invest their portfolios. Heavy emissions may signal that a firm's production techniques are inefficient (Wang et al. 2004). The behavior of consumers and investors will not amount to a positive force unless the information can be easily accessed by the public.

Figure 6 Same as Figure 3, but with an active participation of ENGOs. Because of the communication and interaction between ENGOs and other parties (two-sided arrows connecting to the ENGOs box), market instruments and environmental laws are strengthened.



In summary, the presence of ENGOs not only improves the function of the market and legal systems in environmental management but also provides alternative ways to mediate the interactions between the government, manufacturers, and civilians.

Action: Repertoires, limitations, and opportunities for ENGOs

ENGOs in China have now expanded into many aspects of environmental protection, such as environmental education, species protection, policymaking, and environmental monitoring. They organize public lectures, workshops, conferences, field trips, media campaigns, and Internet publications and communications (Yang 2005). Most of them avoid confrontational methods in their actions (Ho 2001; Lee and Ma 2008).

ENGOs face several challenges, including funding, registration, data access, membership recruitment, establishment of local branch offices, and recruitment of capable staff. Among these limitations, two major constraints are funding and registration. Fundraising is difficult for ENGOs, and even for GONGOs. The funding situation is so poor that more than 60 percent of ENGOs do not have office space. Many of them have to look outside the country to foreign governments, philanthropists and corporations for support (Schwartz 2004). Some of them do not have a strong and charismatic leader, which is necessary to engage in successful fundraising during the startup phase, and can become a problem that hampers their long-term development (Ho 2001).

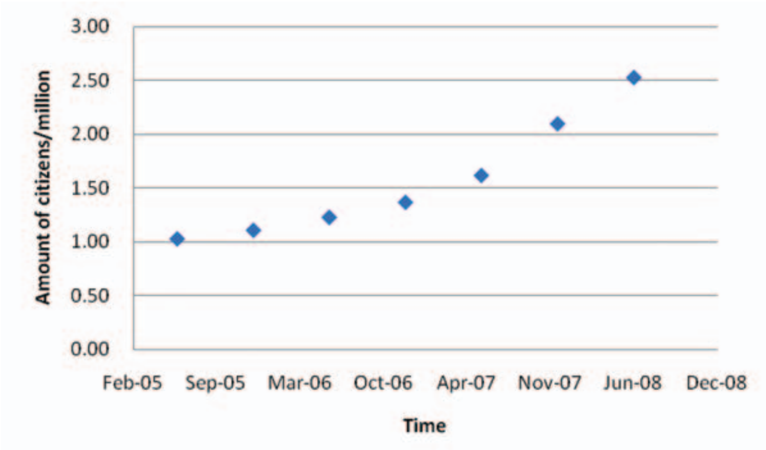
The second difficulty is related to ENGO registration. In 1998, to control the power of civil organizations, the central government issued a proclamation called *Regulations for the Administration and Registration of Social Organizations.* Under this regulation (Ho 2001), registration is a tedious and difficult process. Prior to registration, the NGO must be approved by a sponsoring institution (主管部门).

Therefore it is essential that the leader of the proposed NGO has already established a good relationship with the government so that they can find officials willing to sponsor them. The total number of staff in an NGO should be more than fifty individuals or more than thirty non-government units (单位团体). The NGO must have a fixed address, specialized staff, and financial resources of RMB 100,000 for a national office or RMB 30,000 for a regional (provincial level and lower) office. Within the same administrative area, no more than two social organizations with the same or similar scope of business are allowed to apply for registration, eliminating the possibility of ENGOs uniting in dealing with the same issue. There is no right of appeal if an application is rejected for failing to meet any of the conditions mentioned above. To date, a large number of organizations remain unregistered, and others operate within a different registered category such as "nonprofit organization." Ironically, the 1998 regulation has resulted in more difficulty for the government in controlling the ENGOs (Ho 2001).

Many Chinese ENGOs act as information distributors, and the funding and registration limitations these ENGOs face can be partially overcome by the development of Internet sites. The Internet makes it much easier to run web-based environmental groups. The rapid increase in Internet use allows them to gain instant access to millions of users (Figure 7). These web-based groups can be functional without registering with the government. It is also difficult for the local government to manipulate the information posted on the Web. Furthermore, they need less staff, little or no office space, and a lower budget for maintenance. Because people can access the information and share it with their neighbors, these web groups will be a major force that determines environmental performance locally.

ENGOs have also been helped by the Government Information Disclosure Bill, a regulation implemented by the State Council in 2007 that strengthens civil society's right to acquire environmental information. For a long time, environment information was not accessible to the public because it was considered a state secret. The public had to rely on imprecise visual cues such as visibility instead of quantitative pollution data to judge environmental quality. Although in principle the bill grants the public the right to access this information, various government agencies have yet to determine how to present the raw data in a form meaningful to the public. This presents an opportunity for ENGOs to participate in information disclosure.

Figure 7 Growth in Internet users in China, 2005–2008



Source: CNNIC 2008

INSTITUTE OF PUBLIC & ENVIRONMENTAL AFFAIRS: A CASE ANALYSIS

The Institute of Public & Environmental Affairs (IPE) is a good example of an organization that utilizes the new opportunities mentioned above. The NGO, established by Ma Jun in 2006, is a Beijing-based nonprofit think tank with a focus on environmental policy and governance research. In the following we provide a brief overview of its operation.

Political background

Facing the challenge of massive environmental degradation, the Chinese government has introduced a "scientific outlook" approach to achieving sustainable economic growth. The Eleventh Five-Year Plan has laid out clear goals related to environmental protection, including reduction of energy consumption per unit of GDP by 20 percent and major pollutants by 10 percent relative to the 2005 levels by the end of 2010. However, several barriers exist in the process of translating the plan into action. At present, polluting enterprises far outnumber the monitoring capacity of local governments. Because the cost of regulatory violation is lower than the cost of compliance, there is little incentive for the polluters to clean up their acts. To overcome these barriers, the government has started to push for greater transparency on corporate violations and to improve the public's access to environmental information. It is against this political background that the IPE was founded.

The IPE can be considered an element of a new form of environmental governance whose point of departure is improved access to environmental information. There are several policy and legal bases for this. On the government side, the relevant legal or regulatory documents include the *Environmental Impact Assessment Law* (2003-09-01), the *State Council's Guidelines on the Comprehensive Implementation of Administration Bylaw* (2004-03-22), the *Provisional Measures on Public Participation in Environmental Impact Assessment* (2006-03-18) and the *Environmental Information Disclosure Measures* (2008-05-01). On the corporate side, the important legal documents include the *Cleaner Production Promotion Law* (2003-01-01), the *Rules on Major Enterprises' Cleaner Production Auditing Process* (2005-12), and the *Environmental Information Disclosure Measures* (2008-05-01). These regulations provide the legal basis for open information access.

IPE's goal and operational strategy

The mission of IPE is to improve environmental information openness and public awareness by increasing the public accessibility to environmental data. In doing so, it exerts pressure on local governments and private companies, especially multinational corporations, to improve their environmental performance. Local governments lack the incentive to protect the environment because economic growth is more important for their performance. With the information IPE provides, local people are able to judge environmental quality. It helps focus local government's attention on some of the specific local environmental problems. On the other side, the private companies, especially multinational companies, would be concerned about their public image if the infraction record were published. In essence, IPE promotes green practices by using a bottom-up approach that complements the relatively weak top-down regulatory system.

IPE's operational strategy consists of three parts. First, it collects data from accredited sources only and makes them public in a non-discriminating manner. The accredited sources include central and local government branches across the country and media reports that cite documents or statements from officials or agencies in charge. In doing so, IPE has gained the reputation of being fair and neutral. Although the accuracy and completeness of the government-released data are arguable, because they come from the government, government officials and private companies would have difficulty in challenging the validity of the data, greatly reducing the NGO's institutional costs.

Second, IPE uses a user-friendly website to house its database. It offers people easy access to the information and displays the data in an understandable way. Although the website can reach only those people who have the capability to use the Internet, it is a better platform than traditional media outlets such as TV and newspapers. Users can search for environmental information on water quality, air quality, names and locations of polluters, rankings of regional environment quality, remediation records, and records of violation. In addition, users can report violators so that IPE can track the violators down.

Third, IPE uses its database as an instrument to shift the supply chain toward greener practices. The database contains the pollution record of the suppliers in various tiers of a supply chain, such as that of Wal-Mart. If a major retailer commits to purchasing products or services only from those suppliers that achieve compliance with relevant environmental regulations, databases such as IPE's make it possible to track the environmental behavior of suppliers efficiently.

The two most powerful products of IPE are China's water pollution and air pollution maps (Figure 8). These maps are based on environmental quality data and more than 40,000 infraction records released by government agencies. There is a user-friendly interface between the raw data assembled by the IPE staff and the public.

Figure 8 Interface of China Air Pollution Map

Source: Institute of Public & Environmental Affairs 2006a

By clicking a specific region on the map, the user can find data on water and air quality, pollutant discharges by amount and type, and names of violators at the national, provincial, or municipal level. The user can also rank provinces and municipalities using information on such indices as industrial wastewater discharge, industrial waste gas emission, and domestic sewage discharge to find pollution hotspots. As a successful case, after Hunan Province was ranked first for cadmium and five other heavy metals and toxics in 2006, the provincial government took actions to clean it up. IPE has recently added digital geographic information to the database so that a user can locate the violator on a digital map and determine the distance of the violator from another point of interest on the map (Figure 9).

The health interface portal explains in simple terms the health consequences of pollution to the lay public (Figure 10). For each major pollutant, it provides definitions, source categories, health hazards, treatment methods, environment standards, and historical cases of pollution incidents.

Figure 9 Illustration of the pollution map search engine

Source: Institute of Public & Environmental Affairs 2006b

Figure 10 Interface of environment and health

Source: Institute of Public & Environmental Affairs 2006c

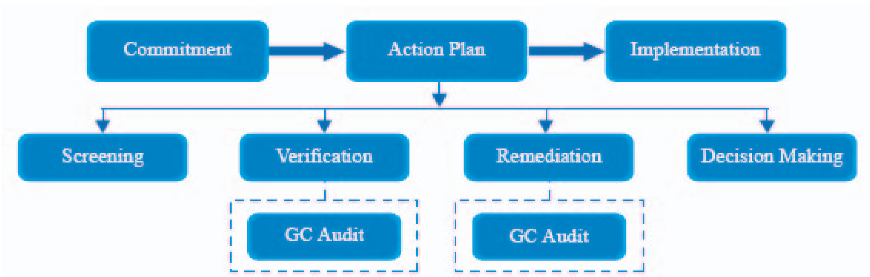
The Green Choice Alliance Program

Based on the thinking that informed consumer choice could affect corporate environmental behavior, IPE launched the Green Choice Initiative in 2007 along with 20 other local NGOs. It has two main components: one is about enabling informed consumers to make smarter choices at shops and markets; the other is about encouraging major companies to factor environmental standards into their sourcing practice.

Solid progress was made on the responsible supply chain side. A factory's presence on the IPE database list as a violator of environmental compliance poses risks to the reputation of its client company. Large companies aware of such risks, especially multinational corporations, have begun integrating environmental standards into their sourcing criteria. The Green Choice Alliance Program (GCA) is designed to help these companies green their supply chains. A company can request that their suppliers be removed from the violator list after they have made improvements to their environmental performance. The improvement must be verified by a third party (consulting firms or research institutes) under the supervision of local NGOs such as IPE.

As a mechanism for responsible supply chain management, GCA uses the steps shown in Figure 11 to influence a polluter's behavior. The central goal of GCA is to press big retailers and large corporations openly to commit not to sourcing from polluters for their supply chain. Since its inception, some major companies have started using it to screen their supply chain system. For example, Wal-Mart has made a commitment to not sourcing goods from local suppliers with infraction records related to pollution. Major companies such as GE, NIKE and Esquel are also using the database to monitor the performance of their suppliers.

Figure 11 Green Choice Alliance program



As Figure 11 illustrates, after the company has made the commitment, it must draft an action plan to fulfill it. The action plan will be disclosed to the public through the GCA website. As a GCA member company, it should accomplish a number of steps. It should first screen its supplier list using the GCA violator database and report the screening results back to GCA. The second step, supplier verification, consists of a document review process and an on-site GCA audit. The audit results may indicate that further environmental remediation measures are needed. In general, remediation measures are expected to be completed within six months after the problem supplier has been identified. A follow-up audit may be required for the assessment of the remediation measures. The member company is required to cease purchasing from the supplier if it is unwilling to achieve or incapable of achieving compliance with environmental legal requirements (Ma et al. 2008).

The GCA audit is performed by a third-party, accredited auditing entity and observed by the GCA ENGO members, so as to ensure external validity and to enhance transparency. In order to verify compliance status and the capacity to achieve compliance, the GCA audit focuses on three aspects: (1) Have the specific violations identified by environmental agencies been resolved? (2) Does the supplier have an adequate environmental management system? (3) Does the supplier's treatment facility have sufficient capacity to deal with waste discharge? By the end of 2008, the GCA audit had already been successfully utilized nineteen times. All but one of the audits resulted in removing the violator from the list.

Lessons from IPE

IPE owes its success not only to hard work,[1] but also to its unique operational strategy. Unlike some NGOs that deploy confrontational methods, IPE maintains a cordial relationship with the government at different levels. Its agenda is one of non-activism. Its data come from governmental and accredited media sources, helping it maintain its neutrality and non-activist position. In some ways, IPE is an ally of the central government to achieve its goal of harmonious and sustainable development. The proactive approach of GCA maximizes the utility of the IPE database. The broad alliance it has built with other NGOs, companies, and the government provides incentives to improve environmental performance at the local and firm levels.

[1] In 2008, there were only five full-time staff members at IPE.

IPE recognizes several areas in need of improvement. Local government officials may have the first-hand data on pollution discharge, but are reluctant to release them. Data availability is especially problematic in those provinces with low GDP and heavy pollution loading. Unless the information disclosure regulations are strictly enforced there, the data availability problem is not going away anytime soon. The GCA program is not effective in influencing small polluters such as small mines, chemical factories, and paper mills. Often these polluters are invisible to consumers and make up too small a portion of companies' supply chains to feel the pressure from the GCA member retailers. Most notably, CGA has virtually no effect on small energy producers since energy is not labeled in the supply-chain scheme. That these small but heavy polluters are not bound by GCA may drag down the enthusiasm of other better-performing companies to participate in the audit program.

CONCLUDING REMARKS

China is undergoing rapid economic and social transformation. On the one hand, economic growth will bring new challenges for environmental management. Pollution sources will spread from industrialized areas to undeveloped areas. Emissions from industrial and household pollution will continue, and so will the depletion of natural resources. On the other hand, social change will bring improvement to the management system for the environment: new environmental laws and regulations will emerge to curb environmental degradation; the manufacturing system will become more energy efficient and cleaner; and civil society will see increased participation in environmental policy making. A group of strong ENGOs is essential to balance these two opposing factors.

References

China Internet Network Information Center (CNNIC). 2008. *Statistical survey report on the Internet development in China: Abridged edition*. China Internet Network Information Center, Beijing.

Dasgupta, S., B. Laplante, N. Mamingi, and H. Wang. 2001. Inspections, pollution prices, and environmental performance: Evidence from China. *Ecological Economics* 36(3): 487-98.

Dasgupta, S., and D. Wheeler. 1996. Citizens' complaints as environmental indicators: Evidence from China. Policy Research Working Paper. Washington, DC: World Bank.

Friend of Nature. 1993. http://old.fon.org.cn/

Ho, P. 2001. Greening without conflict? Environmentalism, NGOs and civil society in China. *Development and Change* 32(5): 893-921.

Institute of Public & Environmental Affairs. 2006a. China air pollution map. (http://en.ipe.org.cn/

_____. 2006b. China water pollution map. http://en.ipe.org.cn/

_____. 2006c. Environment and health. http://en.ipe.org.cn/

Ma, J., H. Xie, and C. Boyle. 2008. *The Green Choice Alliance for responsible supply chain management*. Beijing: PUBLISHER.

Niu, F. and J. Pan. 2007. The function of NGOs in the development of city harmony. China city development report No. 1.

Saich, T. 2000. Negotiating the state: The development of social organization in China. *China Quarterly* 161: 12-141.

Schwartz, J. 2004. Environmental NGOs in China: Roles and limits. *Pacific Affairs* 77(1): 28-49.

Wang, H. 2000. Pollution charges, community pressure, and abatement cost of industrial pollution in China. *World Bank Policy Research Working Paper No. 2337*, Washington DC

Wang, H. et al. 2004. Environmental performance rating and disclosure: China's GreenWatch program. *Journal of Environmental Management* 71(2): 123-33.

Yang, G. 2005. Environmental NGOs and institutional dynamics in China. *The China Quarterly* 181: 46-66.

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CHAPTER 6

Toward Sustainability: Circular Economy and Ecocity Development in China*

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CHAPTER SUMMARY

This chapter argues that a circular economy approach offers China the best prospect for meeting its socioeconomic goals during its process of industrialization and urbanization without disrupting environmental stewardship. It is argued that the "3r" principle of "reduce, reuse, and recycle" should be replaced by the "3R" principle of "rethinking, reform, and renovation" as the ecological rationale for a circular economy.

Within the realm of circular economy are circular industry and ecological cities, or "ecocities." Circular industry is the implementation of circular economy strategies at the firm level or industrial system level. The foundation of circular industry is industrial ecology, which means that the waste and by-products of one stage serve as raw materials for the next stage of the whole product line. Ecocity construction is the implementation of circular economy principles at the community level. The concept of an ecocity is based on the belief that cities are the solution to the challenges arising from urbanization associated with population growth.

Several cases are examined to illustrate the application of the 3R principle at the firm and city levels. The last section of this chapter presents a summary of the key points that were discussed after the lecture between Professor Wang and participating students.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on November 17, 2008, by Professor Wang as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Baihai Wu, a graduate student in the course, and has been approved by Professor Wang. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Wang, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

INTRODUCTION

Over the past thirty years, China has made great progress in socioeconomic development. China's gross domestic product (GDP) increased at a startling rate of 9.6 percent per year from 1979 to 2004.[1] Its income per capita jumped to $1,489 in 2004 and life expectancy was 72.5 years in 2005.[2] The number of Chinese people living on one dollar per day decreased from 250 million in 1978 to 15 million in 2008, or in other words, more than 235 million people were lifted out of absolute poverty and now enjoy living standards above the poverty line.[3]

These changes, however, have come at the heavy cost of environmental deterioration. China is one of the top emitters of carbon dioxide in the world. Ninety percent of its rivers through urban areas have been heavily polluted, and 75 percent of its lakes are in a state of eutrophication. These examples of environmental degradation weigh heavily on China's economic development. The Ministry of Environmental Protection estimated that in 2003, the cost of environmental damage was equal to 15 percent of the nation's total GDP (Zhenhua 2005).

In general terms, these environmental problems are caused by weak law enforcement, unhealthy levels of consumerism, and environmentally unsound technology. They can trace their roots back to industrialization and urbanization. It is against this backdrop that the principles of circular economy and ecological cities, or "ecocities," have come to occupy a central position in China's efforts to reconcile economic development with environmental protection. The most attractive aspect of these principles is that, while reconciling environmental and economic imperatives, they do not require fundamental changes to the basic ownership arrangements and the political system. Circular economy and ecocities can work as environmentally sound mechanisms to respond to environmental challenges arising from industrialization and urbanization.

The objective of this chapter is to examine the characteristics of and the relationships among the notions of circular economy, circular industry, and ecocities in China. Several examples are reviewed in the context of the 3R principle. In the final section, various questions on circular economy and ecocities are explored.

CIRCULAR ECONOMY IN CHINA

> *"Human society is a multi-scale, multi-attribute, and multi-objective eco-complex bridging man and nature; we call it Social-Economic-Natural Complex Ecosystem (SENCE)." –Rusong Wang*

The notion of "circular economy" is subject to different interpretations. In 1999, Dr. Tim Cooper first explored the concept of circular economy in his article entitled "Creating an Economic Infrastructure for Sustainable Product Design" (Cooper 1999). In his critique of the existing "linear industry," he proposed a new form of

[1] 《关于我国国内生产总值历史数据修订结果的公告) See (*Bulletin on Final GDP Estimates in China*), the general investigation data of GDP by National Bureau of Statistics of China.

[2] Data collected from *China Statistical Yearbook* (2004 to 2007), National Bureau of Statistics of China.

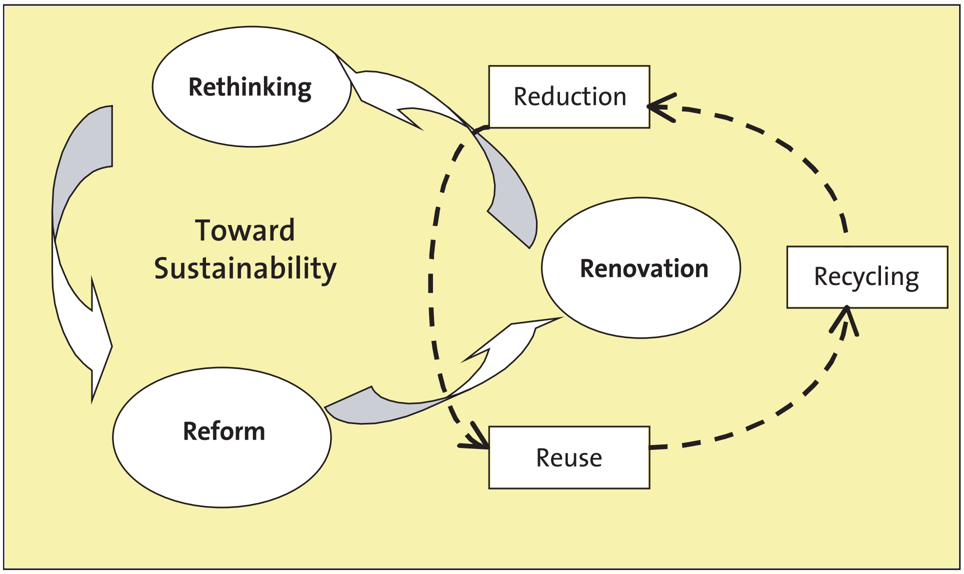
[3] See Wen Jiabao's keynote speech from the United Nations' High-Level Meeting on the Millennium Development Goals (MDGs), September 25, 2008. Available online at: http://www.gov.cn/ldhd/2008-09/26/content_1106073.htm

industry, termed circular industry, “in which the ‘throughput’ of energy and raw materials is reduced,” and “in such [a circular] economy there would be a shift in activity from the manufacturing sector to service sector activities such as reuse, repair, upgrading and recycling.” In China, the term circular economy means different things to different people. For some, it represents a new form of ecological economy, which is most similar to industrial ecology. For others, it denotes an integrated ecosystem with a comprehensive range of functionalities related to nature, economy, and society (Sun 2007). In the recently issued *Law on Accelerating Circular Economy of the People’s Republic of China*, circular economy refers to waste reduction, reuse, and recycling carried out during the processes of production, transportation, and consumption.

Although circular economy is a trendy term in China now, the practice of circular economy can actually be traced to ancient China. Thousands of years ago, farmers raised fish in ponds, used silt from the bottom as fertilizer for mulberry trees, collected mulberry leaves to feed silkworms, and used leaf chips left by the silkworms as a food source for the fish. This circle is a perfect example of circular economy at the elemental level. A more recent example is the recycling and reuse of metal and other materials among different industries in the 1950s, which occurred when China began its industrialization under a highly centralized planning economy. In another example, in 1958, the Jiangmen Sugar Refinery reused sugarcane bagasse for papermaking. At that time, people called this kind of recycling symbiotic use and applied it to many industries (Sun 2007). Unfortunately, though, these practices were disrupted by the Cultural Revolution. Since the late 1970s, China’s industrialization and urbanization have been accelerating at a startling rate. This remarkable progress is accompanied by the increasing challenge of environmental deterioration. This environmental cost is forcing China to shift its strategy from an approach that is only focused on the economy to one that is more sustainable. During this period of time, the concept of circular economy has been successfully applied in the industrialized world, especially in German and Japan. Their achievements have rekindled China’s interest in circular economy.

Circular economy is operated according to the principle of ecological economics, whose characteristics are totality, coevolution, recycling, and self-reliance. Circular economy also uses resources very efficiently and is in harmony with surrounding life-supporting ecosystems. The ecological rationale for circular industry is not the “3r” micro principle of “reduce, reuse, recycle,” but the “3R” macro principle of “rethinking, reform, and renovation” (Figure 1). First, rethinking in this context requires that the industry change from reductionism to holism, from environmental exploitation to ecological symbiosis, from open-ended material cycles to closed ecological cycles, and from external control to self-reliance. The second “R” in the 3R principle (reform) means that the industry should change from a chain-link structure to one of life-support-oriented vertical and serial coupling, from fragmented and isolated to food-web-based horizontal and parallel coupling, from locally independent to ecosystem-based regional coupling, and from a rigid and nonadaptive structure to a flexible and adaptive production structure. Third, renovation requires that we apply the 3r micro principle of "reduce, reuse, recycle" to institutional and technological development.

Figure 1 Relationship between the 3R and 3r principles



A well-functioning circular economy is driven by a number of factors. The first one concerns energy resources and the research and technology that explore these resources. The second is related to the flow of capital in the banking and market sector. The third is power structure, including institutions and governance. The fourth and final factor is spirituality, consisting of culture, education, and tradition. A key function of circular economy is recycling, which in the broad sense includes material recycling, renewable energy use, information feedback, regional symbiosis, long-term sustainability and efficient monetary circulation.

Circular economy in China is constructed at three different levels: the firm, the community, and society. At the firm level, entrepreneurs have almost complete discretion to use market tools in their day-to-day operations. At the community and society levels, government intervention plays a larger role. In fact, local government has strict oversight over almost all of China's industrial parks, in which related industries are located together. In China, the governmental role is the most distinct feature of circular economy. The government essentially serves as an "enabler," encouraging technological innovation and resource conservation through policies and regulations. How this "enabling" role interferes with market mechanisms is a subject of debate (Zhu and Liu 2005).

FROM LINEAR INDUSTRY TO CIRCULAR INDUSTRY

Within the realm of circular economy is circular industry. The notion of circular industry challenges the traditional idea that negative effects on the environment are an inevitable outcome of industrialization and urbanization. Rather, it suggests that economic development is not incompatible with environmental protection (Wang 2005). On one hand, China's future economic prospects increasingly depend on achieving and maintaining high standards of environmental governance, especially energy conservation. On the other hand, integrating environmental governance with industrialization can create a transformative kind of industry, that is, circular industry.

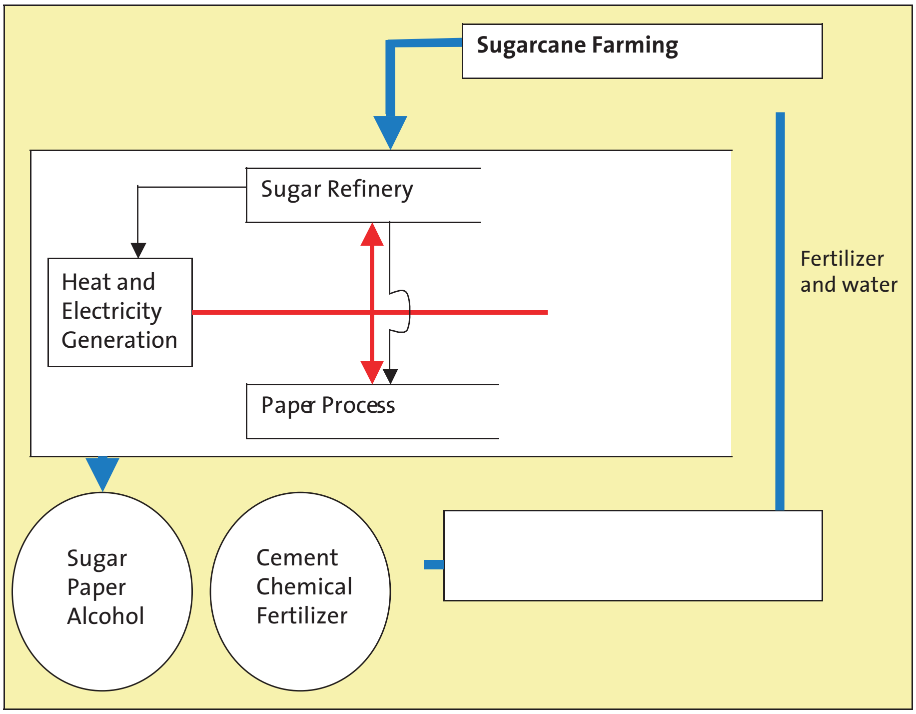
One tenet of circular industry is to integrate the 3r principle throughout the entire industrial process. In this sense, circular industry has nearly the same meaning as industrial ecology, namely "the flows of materials and energy in industrial and consumer activities, or the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources" (Allenby and Richards 1994). Circular industry, sometimes referred to as eco-industry, distinguishes itself from traditional linear industry in several ways. Linear industry converts material into product and waste. It is inherently unsustainable. In circular industry, production of primary goods, manufacturing, distribution, consumption, and reuse are physically integrated into one industrial complex. Production processes are linked like a food web in order to allow efficient sharing of resources and information and to minimize negative environmental impacts.

On a regional scale, neighboring communities, major enterprises and small businesses are integrated into one large industrial ecosystem so that environmental costs are internalized and wastes are assimilated within the system itself. Such a system also includes social and cultural components, providing local people with work opportunities and a chance to participate in the management of the enterprises and cultivating a harmonious coexistence between the companies and the community's culture. An important attribute of circular industry, be it at the complex scale or regional scale, is that it possesses multiple production functions. In other words, circular industry is flexible and adaptive; its products are diversified and can be easily changed, rather than rigid and specialized. Related to this flexibility is the capacity to switch from product- and profit-generating—("hardware"-producing)—industry to service-oriented industry, whose outputs are "software," or services, and "mindware," or cultural enrichment. A healthy circular industry must enhance capacity building in the form of R&D (research and development), I&C (incubation and consultation), S&T (service and training), and E&E (experience and expertise). Finally, a circular industry is not complete without respect for human dignity. In circular industry, working is a learning process that fosters innovation, an opportunity for social interaction, and something that is enjoyable, rather than a process in which workers are enslaved by machines.

A good example of circular industry is the Guitang Group in Guangxi Province, China. The Guitang Group is an eco-industrial park within which the flow of materials is circular (Figure 2). The Guitang Group is a pillar industry in Guigang City and sustains the livelihoods of 65 percent of the city's population. Its principal business is the manufacturing and sales of sugar, paper, and related by-products, such as alcohol (liquor), light calcium carbonate, and water-reducing agents. Since 1995, Guitang has been transforming its traditional industry into circular industry with two key product lines.

In the first product line, Guitang plants sugarcane as a raw material for refined sugar, uses the by-product of sugar syrup to produce alcohol, and uses the waste alcohol to make composite fertilizer for the sugarcane plantation. In the second product line, Guitang creates refined sugar from the sugarcane first, and then uses sugarcane bagasse to produce pulp and paper. During this process, the pulp waste is used for making alkali, and the by-products of white lime and mud are used to produce cement. In both lines, the by-product from one section is recycled as raw material for the next section. The transformation to circular industry has increased Guitang's productivity, improved the conservation of energy and water, and greatly reduced its wastewater output.

Figure 2 Circular industry at the firm level in Guitang Group



Source: Modified from http://www.guitang.com

The successful application of the circular industry principle by the Guitang Group depends on a number of factors. As a city-owned corporation, it has broad discretion to experiment with new concepts and technology. It has also received strong support from the city government for its circular industry strategy in terms of favorable tax treatment and financial aid.

AN ECO-CITY WITH CHINESE CHARACTERISTICS

> *"[Eco]cities are the solution for humanity's future, if we can establish an eco-polis on the basis of the 3R principle of "rethinking, reform and renovation." –Rusong Wang*

Urbanization is the inevitable outcome of industrialization. In China, rapid urbanization is also caused by an exponentially growing population. A fast-growing proportion of this expanding population now lives in or near cities. China's urban population tripled from 13.2% of the total in 1979 to 39.1% in 2002 (Wang 2004). With the acceleration of urbanization, today the country's urban population has increased to 0.6 billion, almost half of total population of 1.3 billion.[4] This urbanizing trend is expected to continue, even though the rates of industrialization and population growth are projected to slow down.

The urban explosion in China has a profound and negative impact on the natural environment, the economy, and society. China's interest in the "ecocity" concept was motivated by the pressure to reconceptualize the relationship between city and nature. Hoping to continue its urbanization without disrupting environmental protection or economic development, China wishes to transform its cities to ecocities, a sustainable and self-reliant conjunction of nature, society, and culture.

The emergence of ecocities in China is the application of the circular economy notion at the community level. Professor Wang argues that ecocities are the solution for humanity's future if we could establish an eco-polis on the basis of the 3R principle of "rethinking, reform and renovation." Thus, cities that fulfill the 3R principle are termed "ecocities." In the administrative unit of an ecocity, there exists an economically productive and ecologically efficient metabolism, a socially harmonious culture, and a physically beautiful and functionally vivid landscape.

A well-functioning ecocity should be a Social-Economic-Natural Complex Ecosystem (SENCE) consisting of three subsystems (Wang 1984). The natural subsystem of an ecocity is material flow of minerals, biomass, water, energy, and land, which can be symbolized by the five traditional Chinese elements: metal, wood, water, fire, and soil. Its economic subsystem includes the components of production, consumption, reduction, transportation, and regulation. Its social subsystem covers technology, institutions, and culture (Wang 2005).

Guiyang City, the capital of Guizhou Province, is an example of applying the 3R principle at the municipal scale.[5] Guiyang's economy used to depend heavily on natural resources, namely phosphorus, coal and aluminum ores. Industrial exploitation produced a great deal of waste and pollution. From 1996 to 2003, the total amount of all pollutants increased from 3.2 million tons to 4.6 million tons. At this rate of increase, by 2020 the pollution discharge will be triple today's amount, threatening the very existence of the city. In response, in 2002 the central government added the transformation of Guiyang into an ecocity at the top of its agenda.

[4] See 2008 Census on Population, National Bureau of Statistics of China. Available online at: http://news.sina.com.cn/c/2009-02-16/074415168603s.shtml

[5] This description and analysis on Guiyang City as an ecocity are based on the data and documents in the following website: http://www.guiyang.cn/zhuanti/jsst/

Guiyang's shift toward circular economy has resulted in great progress in both economic development and environmental protection. The first task Guiyang City undertook was to use technology innovation to change its linear industry to circular industry. For example, Kaiyang Phosphorus Ore, one of the three phosphorus mining operations in China, was once a big polluter with an annual polluted water discharge of nearly one million tons, solid waste weighing 1 million tons, and air pollution of 0.3 billion cubic meters. Thanks to technological innovation, its phosphorus production increased from 0.6 million tons in 2002 to 3 million tons in 2008, and its revenue increased from 2.4 to 8 billion RMB. The recycling of yellow phosphorus contributed greatly to these increases. Now Guiyang has established a new circular industry structure covering the agricultural, industrial, tourism, and infrastructure sectors.

The second task the city embarked on was restoring the ecosystems within the city and the surrounding environment. The two key eco-projects were the restoration of the Nanming River and the reforestation of a greenbelt surrounding the city. Guiyang City has also reformed its environmental policy and law to support its ecocity building efforts. Guiyang City was the first one in China to create an indicator system for ecocities and pass a local law on ecocities: the *Statute on Ecocity Construction of Guiyang City*.

Guiyang City is one of several ecocity experiments initiated since 2002. Currently the experimentation is occurring at different scales. At the megalopolis level, Beijing, Tianjin, and Shanghai are promoting ecocity construction. Twenty other smaller metropolises and thousands of county-level cities have received approval from the government to implement ecocity strategies as well.

Table 1 Advantages and weakness of ecocity development in China

Advantages	Challenges
1. High priority in decision making	1. Low ecological public awareness
2. Efficient land use	2. GDP-dominated urban sprawl
3. Long tradition of resource saving and reuse	3. Weak bottom-up activities from NGOs
4. Fewer slums through diversified service jobs	4. Strong initiation and weak continuity
5. Decentralized eco-engineering tradition	5. Fragile natural ecosystem and limited water resource
6. Strong international cooperation	

Professor Wang cautions that China's ecocity movement has its advantages but also faces difficult challenges (Table 1). For example, public awareness of the ecocity movement is currently weak. Because local officials are held accountable by their superiors, not by private citizens, the public lacks interest in the ecocity initiatives put forth by these officials. Yet active public participation is crucial for the success of ecocity design and management.

CONCLUDING REMARKS

China is at a crossroad with respect to industrialization, urbanization, and environmental reform. As public awareness of environmental deterioration increases, large numbers of private enterprises, cities, and provinces are taking steps toward the goal of eco-civilization through an ecologically sound development strategy. The approaches of circular economy and ecocity development offer the best prospects for China to reconcile the goal of environment stewardship with those of industrialization and urbanization.

CONVERSATION WITH PROFESSOR WANG ON CIRCULAR ECONOMY AND ECOCITIES

Circular economy

What is the precise definition of circular economy?

Circular economy is defined differently under different circumstances. In Japan, the concept focuses on recycling by consumers. In Germany, the concept focuses on recycling of wastes. In China, the concept of circular economy is also described in various ways, such as a "recycling-based economy" or an economy that fulfills the 3R principle as discussed above.

The law on circular economy in China goes beyond the concept of recycling, requiring a network approach and adaptive strategy to deal with situations including social, natural, and economic factors. It emphasizes totality, integration, human adaptation to the environment, and self-reliance. In other words, the legal definition appears to focus on technical side (products) and less so on enforcement.

Can the green GDP matrix be applied to circular economy?

In general, green GDP calculations are not compatible with the notion of circular economy. In Professor Wang's view, green GDP is a bad concept. Green GDP is a linear, additive approach to integrating environmental costs with economic benefits. If all environmental losses are considered, the GDP estimates could be negative. Negative GDP is not realizable. To avoid negative numbers, people have to restrict damage calculations to a subset of sectors and ignore other sectors. A better approach is to define a polygon of indices. You could combine the indices into one measure or keep track of how the polygon shape is changing over time.

Related to the calculation of green GDP is the importance of educating average citizens and decision makers on holistic thinking. Since 1840, the single indicator of wealth has replaced some traditional values, such as family, and cultural and religious traditions as the indicator of success and social status. Since the introduction of economic reform in the late 1970s, China has been using GDP as the sole indicator of social and economic achievement. More recently, however, increasing concern about environmental deterioration has led to the reevaluation of this development pattern. Teachers are promoting environmental conscience in young kids. More education is needed to influence decision makers. However, this shift from the existing pattern to a new approach is undermined by systemic constraints, in particular the inaction of local governments. Ecology is a hollow slogan without real substance at local levels of government. To them, the measure of social and economic success is still GDP growth.

Ecocities

How do people measure ecocity functionality?

The Ministry of Environmental Protection (MEP) has developed its own indices that cover environmental, ecological, economic, and institutional indicators for sustainable cities on both large and small scales. The applicability of these indicators varies geographically. For example, some of these indicators are more suitable for the coastal zone than the interior. Some of the MEP ecological indicators include size of wetland area and its change over time, green land area and structure (i.e. percentage of native species), and green roofs (in southern China). These indicators are revisited every 5-10 years for updating and adjustment. Changes in leadership at the MEP may cause the redefinition of these indicators. For example, new leadership has the tendency to create the impression of a "new direction" by relabeling things.

One point of caution is that an overemphasis on greening the landscape can also give rise to undesirable outcomes. In some places, in order to "green" the city, big parks are dotted with large trees transplanted from elsewhere, and historic houses are replaced by eye-pleasing modern buildings. (Aware of the importance of cultural heritage, the city of Yanzhou, Jiangsu Province, took good care of its local community and historical buildings. Ironically, though, it was not designated as an "ecocity" by the MEP because of its relatively low GDP.) In some other cities, rooftops are painted green to create the impression of green space.

Furthermore, ecocity functionality should be realized by institutional change. Shanghai is the first city to replace its old fragmented sector-by-sector management system with a truly integrated bureau of city management.

At which spatial scale is an ecocity optimal?

In China, ecocities vary in size, from towns measuring several kilometers across to metropolises like Beijing, Shanghai, and Tianjin. However, since ecocity is a buzzword, it is misused in almost every sector. For instance, realtors use this concept as a marketing tool to make expensive housing more appealing to consumers.

At the larger end of this scale range, the designated ecocity zone must contain a good mixture of ecological towns, each having different functionalities. Within its administrative boundary there should be urban land and rural land, each requiring a different ecological strategy. By necessity, every ecocity should set its own priority for the purpose of planning. For example, the overriding goal of Beijing is water conservation.

How do ecocities and circular industry relate to one another?

The principle of circular industry should be integrated into ecocity development. One good example is green building with specifications for energy conservation. In

Shenzhen, all new buildings must have solar panels in the real estate business. Another example is ecological sanitation. In the process of urbanization, use of human waste by farmers as a source of fertilizer, an old practice in rural China, is discouraged or totally phased out and replaced with a sewage system. This trend is being reversed in some local communities. Green microfinancing, which is used as a tool to encourage sustainable development in some developing countries, does not yet exist in China.

How important is public participation in the ecocity movement?

Public participation is crucial to the ecocity movement. At the moment, the public is not paying much attention, partly because the government retains tight control over Chinese society. However, in recent years, NGOs and semi-NGOs are playing an increasing role in public participation. Semi-NGOs such as the Ecological Society of China and other professional societies are gaining influence. Members of these organizations are critiquing governmental behaviors, raising the public's environmental awareness, monitoring and supervising the business sector. In some instances, the government deliberately delegates tasks such as certification, environmental assessment, and eco-labeling to these semi-NGOs.

International cooperation

How should the international community help China develop its circular economy and ecocities?

International cooperation can provide an infusion of new ideas and knowledge in the development of circular economy and ecocities. However, such ideas and knowledge must be adapted to local situations in China, or else they are likely to fail. For example, some German companies proposed nice ecocity concepts to Shanghai, but they were difficult to apply, explaining why the ecocity (district) in Shanghai is slow in making progress. Another example is that in Tianjin, planners responsible for ecocity construction are all local, with little advanced knowledge. Foreign help is needed to inspire them.

Primary References

Allenby B.R. and D. J. Richards. 1994. *The Greening of Industrial Ecosystems.* National Academy Press, Washington DC.

Cooper, Tim. 1999. Creating an Economic Infrastructure for Sustainable Product Design. *Journal of Sustainable Product Design* 8: 7-17.

Li, Feng and Rusong Wang. 2005. Comprehensive concept planning of urban greening based on ecological principles: a case study in Beijing, China. *Landscape and Urban Planning* 72(4): 325-336.

Li, Wenhua. 2004. *Ecological Agricultural Theories and Practices of China's Sustainable Agriculture*, Beijing, 2004, Chemical Industry Press.

Platt, Rutherford H., Rowan A. Rowntree, and Pamela C. Muick, eds. 1994. *The ecological city: Preserving and restoring the urban and biodiversity*. Amherst, MA: University of Massachusetts Press.

Sun, Xiaohua. 2007. China drafting first "circular economy" law. *China Daily*, March 20. [Also available online at http://www.worldwatch.org/node/4963.]

Sun, Youhai. 2007. Making the circular law on the basis of the reality in China (根据我 国的实际需求制定循环经济法). White paper for People's Congress of China. http://www.npc.gov.cn/npc/bmzz/huanjing/2007-08/30/content_1383684.htm

Wang, Rusong and S. Ma. 1984. Social-Economic-Natural Complex Ecosystem. Acta *Eco. Sinica.* 4: 1-9.

Wang, Rusong and Jinsong Yan. 1998. Integrating hardware, software and mindware for sustainable ecosystem development: Principles and methods of ecological engineering in China. *Ecological Engineering* 11: 277-289.

Wang, Rusong. 2004. Eco-city development in China. *AMBIO* 33(6): 341-2.

______. 2005. Ecological misunderstanding, integrative approach, and potential industries in circular economy transition. *Chinese Journal of Applied Ecology* 16(12): 2439-2446.

Suggested Sources

Ding, Ding and Dongbao Dai. 2008. Development of a low-carbon economy in China. *International Journal of Sustainable Development and World Ecology* 15(4): 331-6.

Economy, Elizabeth. 2005. China's environmental challenge. *Current History* 104(683): 278.

Fang, Yiping and Raymond Cote. 2007. Industrial sustainability in China: Practice and prospects of eco-industrial development. *Journal of Environmental Management* 83(3): 315-328.

Geng, Yong and Brent Doberstein. 2008. Developing the circular economy in China: Challenges and opportunities for achieving "leapfrog development." *International Journal of Sustainable Development and World Ecology* 15(3): 231-9.

Jiang, Yihong. 2007. The politics of China's "Green GDP." *Journal of Current Chinese Affairs* 36(5): 25-40.

Pomeranz, Kenneth. 2002. Political economy and ecology on the eve of industrialization: Europe, China, and the global conjuncture. *The American Historical Review* 107(2): 425-46.

Wang, Jun and Hui Li. 2006. The development of circular economy in China. *Aquatic Ecosystem Health and Management* 9(1): 99-103.

Xu, Ming. 2007. Material flows and economic growth in developing China. *Journal of Industrial Ecology* 11(1): 121-140.

Yuan, Zengwei, Bi Jun and Yuichi Moriguchi. 2006. The circular economy: A new development strategy in China. *Journal of Industrial Ecology* 10(1): 4-8.

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CHAPTER 7

Modern Energy Use and Air Pollution in China: Challenges and Opportunities*

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Elaine Yu
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CHAPTER SUMMARY

Two main challenges lie at the forefront of energy use in China: (1) diminished national security due to heightened dependence on foreign oil, and (2) increasing energy demand and limited supplies. In confronting these challenges, China's energy path, which is reliant on heavy industrial processes and fossil fuels, will increasingly affect air quality on a domestic and global level. Growing vehicle populations, outdated coal-fired power plants and other heavy industries are the primary sources of increasing sulfur dioxide (SO_2), nitrogen oxide (NO_X), particulate matter (PM), volatile organic compounds (VOC), mercury (Hg), and carbon dioxide (CO_2) emissions. These air pollutants emitted from multiple sources over multiple spatial scales have led to a complexity of interrelated air quality problems—primarily acid deposition, photochemical smog, ozone, regional haze and reduced visibility, global mercury dispersion, and climate change. Strategies to maximize energy production and abate emissions will require targeting industrial processes for improvements in energy efficiency and strengthening air pollution regulations. Professor Jiming Hao offers three policy recommendations: (1) develop a national air pollution control plan based on World Health Organization air pollution targets, utilizing a multi-pollutant control strategy and regional coordination system; (2) regulate total coal consumption in heavily polluted areas; and (3) enhance vehicle pollution control in China's megacities.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on October 27, 2008, by Professor Hao as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Elaine Yu, a graduate student in the course, and has been approved by Professor Hao. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Hao, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

INTRODUCTION

The country that is home to a quarter of the world's population has been tied to economic and industrial development over the last thirty years in an urgent quest to cultivate better living standards. Rushing to center stage as an economic powerhouse, China is maintaining the trajectory that modern energy use will fuel the nation's material economy. Energy from coal, oil, natural gas, solar, wind, biomass, hydroelectric dams, and nuclear fission is transmuted into modern comforts such as heated buildings, improved health facilities, lighting, refrigeration, transportation, and electronic communication. Empirical studies from the UN Development Program show a positive correlation between the human development index and a country's per capita energy consumption, as well as a positive correlation between modern energy use per capita and GNP per capita (UNDP 2005). Pursuing this trajectory, China will unquestionably expand its energy infrastructure to lift poorer, rural populations in the nation's western expanse.

The energy used to fulfill China's dream, however, has come with the sizeable cost of air pollution. Growing vehicle populations, coal-fired power plants, and other energy-intensive industries such as cement and steel production produce a spectrum of pollutants—namely sulfur dioxide, nitrogen oxides, and particulate matter. These are the primary causes of local and regional air pollution problems such as acid rain, photochemical smog, ozone, regional haze and diminished visibility. In addition, China's emissions are going global. Greenhouse gases and mercury emitted into the atmosphere contribute to climate change and mercury deposition in other countries.

China's current air quality control measures have yet to overcome these challenges. However, data-driven analysis brings opportunities to strengthen China's air pollution regulations and bolster energy use. In this chapter, we provide a brief diagnostic of current and future energy challenges that the nation faces. We will also perform a review of China's current air quality status, which will be followed by a discussion of three policy recommendations for air quality improvement. Three case studies are also included to bring the reader up to date on the status of mercury pollution in China, multiple-control strategies, and air quality during the 2008 Beijing Olympic Games.

ENERGY CHALLENGES: NATIONAL SECURITY, INCREASING ENERGY DEMAND, AND LIMITED ENERGY SUPPLIES

In recent years, oil has been a focal point in foreign dependency issues, military tensions, price shocks, and long-term resource scarcity. The United States, for example, which has a long history of dependence on foreign oil, must rely on military and political means to protect access to oil reserves abroad. The connection between energy use and national security was a talking point in President Barack Obama's inauguration speech, as he proclaimed, "each day brings further evidence that the ways we use energy strengthen our adversaries and threaten our planet." The reality of transnational terrorism and the violent disruption of oil supplies have led an increasing number of national leaders to look toward domestic and renewable sources of energy in order to forge greater energy independence.

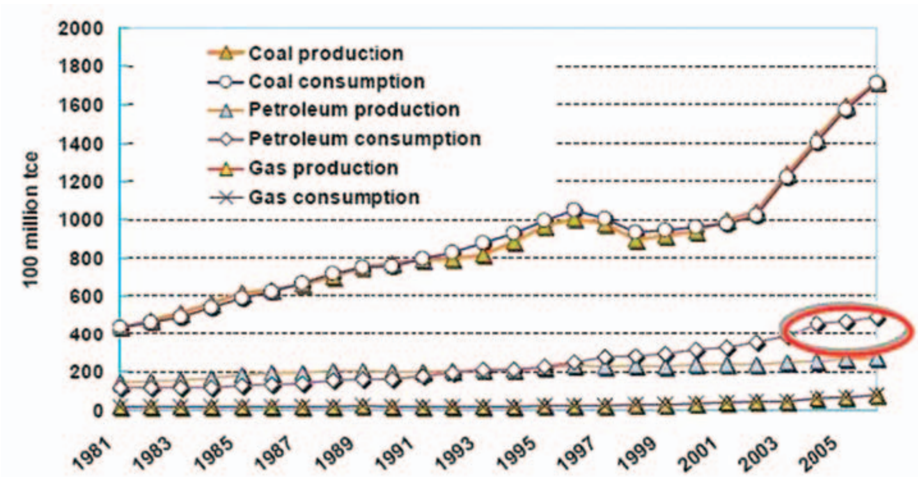
Oil is increasingly fueling China's economy. Insufficient oil production capacity in China has left Chinese companies to pursue oil acquisition overseas. To China's benefit, the country's crude oil comes from a diverse portfolio of twenty-eight countries—as of the end of 2008—to feed petroleum demands and moderate risks (People's Daily 2009). However, China is nevertheless a nation prone to oil market instability. Currently about 50 percent of China's oil imports originate in the Middle East, while other oil imports come from transitioning economies in Africa, including civil war-afflicted Sudan. The Chinese National Petroleum Company (CNPC) has further intensified China's import opportunities in the Middle East by signing a $2.9 billion contract with Iraq, which will allow CNPC to explore and develop an oil field over the next two decades (People's Daily 2009). China's oil partnerships may improve the economic welfare of petroleum-exporting nations and provide promise for China's energy future, but China may also risk becoming caught in future internal conflicts. China must also wrestle with the prospect that oil imports may not meet long-term demands for oil consumption, given the nation's expected rate of vehicle population growth. In 2007, for instance, China increased its total foreign oil imports by 12.4 percent over the previous year, while its vehicle output increased by 22.6 percent (Table 1 and Figure 1).

Table 1 Oil production and vehicle output in China

	Production in 2007	Percent increase over 2006
Domestic production	187×10^6 tons	1.87
Imported petroleum	163×10^6 tons	12.4
Output of vehicles	6.33×10^6	22.6

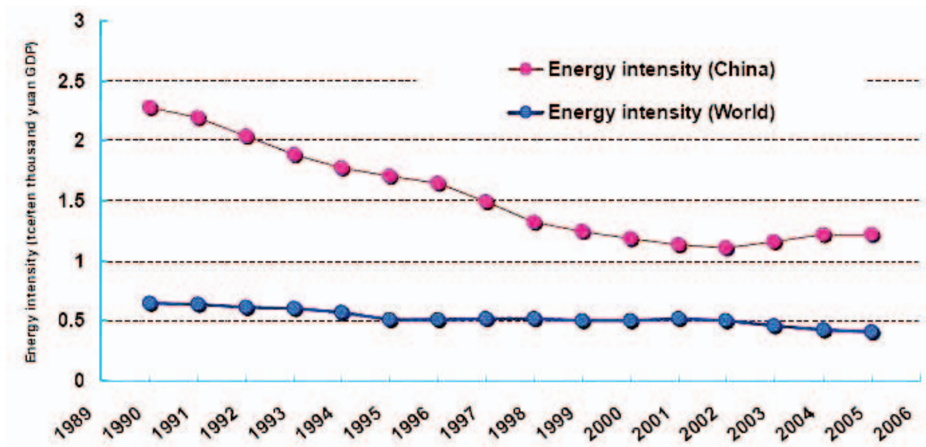
Source: Chinese Bureau of Statistics

Figure 1 Trends of coal, petroleum and gas production and consumption in China



Aside from oil in the energy matrix, China's energy efficiency also deserves attention. In 2006, China experienced an 8.4 percent increase in primary energy consumption, using about 1.7 billion tons of oil equivalent that year, equating to 15.6 percent of primary global energy utilization (China Daily 2007). The rural population of western China, which has yet to enjoy a lifestyle supported by intensive energy use and urban infrastructure, can double China's current energy usage. One straightforward way to improve energy security is to improve energy efficiency. Advancing energy efficiency is often less expensive, less ecologically damaging, and more feasible than building new energy plants. China has made notable improvements in energy efficiency over the past few decades, but the country's energy intensity, which is energy consumption relative to total economic output, still remains high compared to the global average. In 2006, China's energy intensity was 2.8 times the world average (Figure 2). China's industry, comprised of heavy sectors such as steel, cement, and thermal electricity production, and consuming more than 50 percent of the nation's total energy production, is a formidable obstacle for energy efficiency improvement. Efficiency efforts can be maximized by examining sector-by-sector energy savings potential and engaging in international cooperation with energy efficiency leaders such as Japan via platforms such as the Japan-China Energy Conservation Forum.

Figure 2 Energy intensity in China and the world. Energy intensity is measured in tons of coal equivalent (tce) per unit GDP.

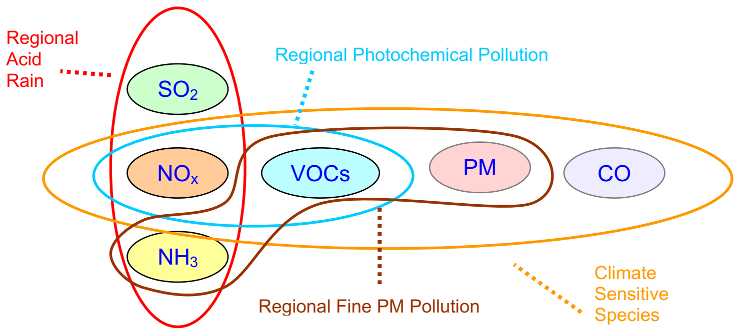


Source: Chinese Bureau of Statistics

CURRENT AIR POLLUTION STATUS IN CHINA

Air pollution refers to a complex variety of airborne substances in the atmosphere that originate from multiple sources. Primary pollutants—pollutants that are emitted directly from a source, such as exhaust pipes and chimneys—include sulfur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), and carbonaceous and noncarbonaceous particles. Secondary pollutants—contaminants formed in the atmosphere through chemical reactions—include ozone and secondary particulate matter (PM). Fossil fuel burning and industrial processes are the leading culprits of excess emissions in the environment that combine to produce an assortment of local, regional and global air quality problems (Figure 3). For instance, PM contributes to regional haze and plays an important role in climate change, while NO_x contributes to climate change, regional haze, and regional acid deposition (WHO 2005).

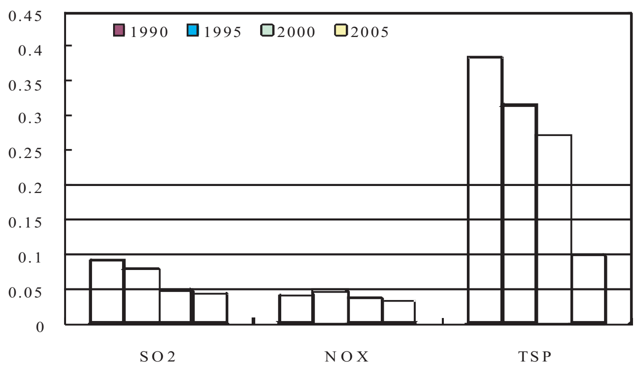
Figure 3 Air pollutant species and their contributions to regional air quality problems



Source: Elaine Yu

SO_2, NO_x, and PM deserve close attention for their large contribution to a range of environmental effects. Although SO_2 and NO_x can be formed from natural processes (e.g., SO_2 from volcano eruption and NO_x from lighting), in much of China they are largely products of combustion of coal and petroleum for power generation. PM, on the other hand, comes from a wide variety of sources, comprising a wide range of chemical compositions. PM is typically classified by size, from coarse large particles such as windblown soil to ultra-fine particles—under 2.5 mm in diameter—produced in chemical industries (WHO 2005).

Figure 4 Annual average concentrations of air pollutants in Chinese cities, mg/m3

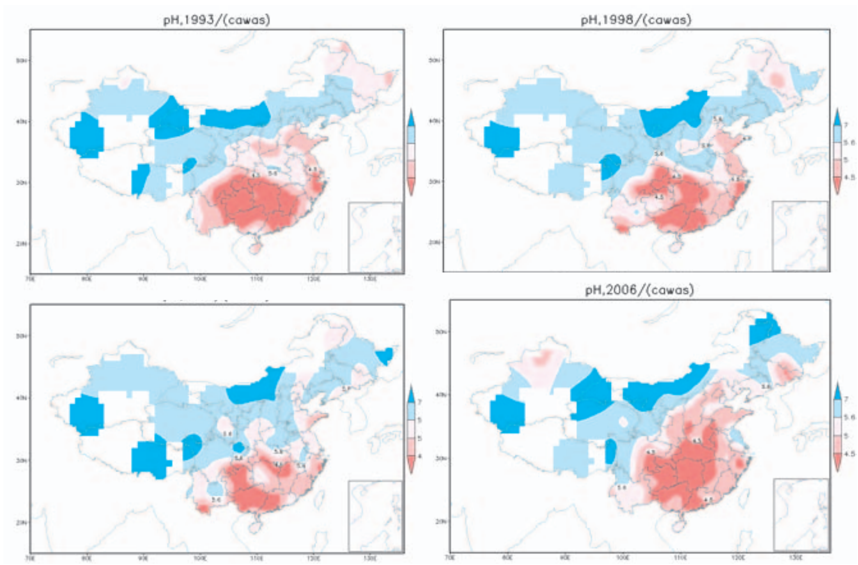


Source: Hao 2009

In China, SO_2 and PM emissions are predicted to decrease and NO_x emissions are expected to rise. Currently, NO_x levels in Chinese cities are comparable to those of developed nations, while SO_2 and PM_{10} (particulate matter with diameter less than 10 μm) concentrations are about 4-6 times the level in developed nations (Hao 2009; manuscript in preparation). From 1995 to 2005, nationwide total suspended particles (TSP) and SO_2 concentrations decreased due to the rapid phasing out of traditional coal combustion technology. NO_x levels during that time period remained relatively constant, except for reported increases in southern China, particularly in the Pearl River Delta (Figure 4; Chapter 11).

Acid rain is largely a product of SO_2 and NO_x molecules that combine with atmospheric water to form sulfuric and nitric acids. Acid deposition damages plants, soil, fish, and human health, and causes gradual erosion to buildings and historical monuments. The Chinese Meteorological Science Institute estimates that acid rain regions (areas with precipitation pH lower than 5.0) accounted for about 30-40 percent of China's landmass from 1993 to 2006 (Hao 2009). Generally this percentage has remained steady (Figure 5). Some areas with severe emissions even observe pH levels declining below 4.5. Although the chemicals primarily responsible for acid deposition are SO_2, NO_x, and NH_3 (ammonia), air pollutant control measures in China have mainly focused on SO_2 abatement (Hao 2009).

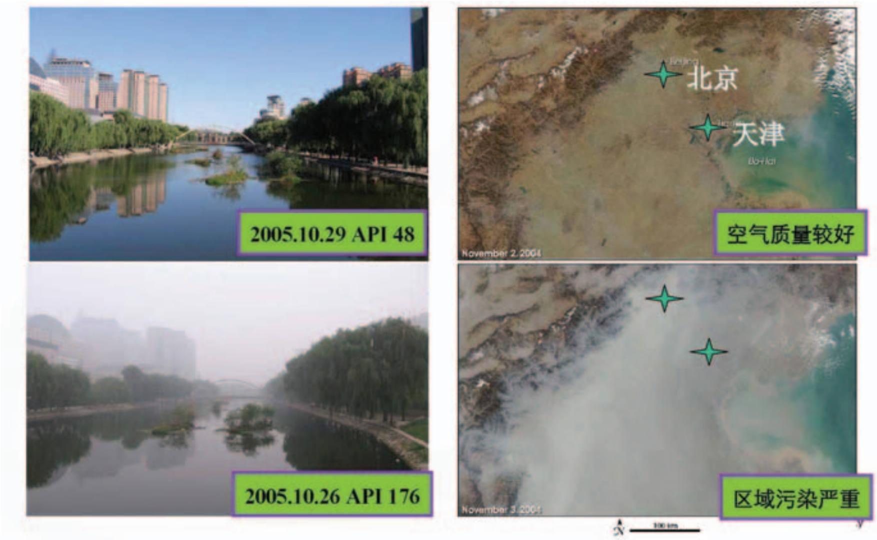
Figure 5 The distribution of precipitation pH values in China for 1993, 1998, 2000, and 2006



Source: Hao 2009

Regional haze is a frequent occurrence in China. Dust, smoke, and other particles produce a brownish haze that impairs visibility and contributes to respiratory health problems (Figure 6). $PM_{2.5}$ (particulate matter with diameter less than 2.5 μm) contributes the most to regional haze and decreased visibility. The average visibility diminished at a rate of 0.24 kilometers per year in China from 1957 to 2005—an approximate loss of 10 kilometers over about five decades (Hao 2009). The problem is severe in northern Chinese cities: their $PM_{2.5}$ levels are 0.08-0.10 mg/m^3, about 5-6 times the U.S. ambient air quality standard (0.015 mg/m^3). Cities in southern China are a little cleaner: their $PM_{2.5}$ levels are at 0.04 – 0.07 mg/m^3, but are still above the U.S. air quality standard (Hao 2009).

Figure 6 Changes in regional haze and visibility. The left panels show visibility and air pollution index (API) in Beijing. The right panels are satellite images showing the change in haze level in the north-eastern region. The two crosses mark the locations of Beijing and Tianjin.

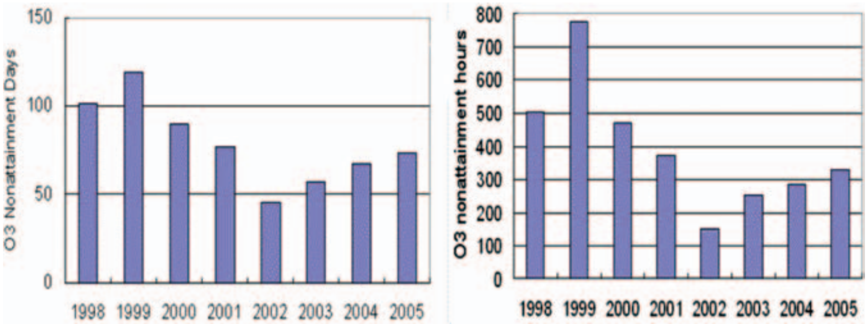


Source: Hao 2009

Low winds, high temperatures, and an abundance of NO_x and hydrocarbons in the air are recipes for ground-level ozone (O3) pollution and photochemical smog. The effects of high ozone concentrations include harm to the human respiratory system. China's national ozone standard of 93.3 ppb (200 µg/m^3) is frequently violated (Hao 2009). For instance, in Beijing in 2005, about one out of five days was a non-attainment day (Figure 7). In some cities the maximum hourly average often surpasses the European alarm levels. The Pearl River Delta and Beijing are particular hotspots for high ozone levels (Hao 2009).

Global pollutants such as mercury (Hg) and carbon dioxide (CO_2) are receiving an increasing amount of attention from the international community. Mercury is known for its toxic effects on humans and wildlife, and CO_2 for its heavy contribution to the anthropogenic greenhouse effect. China's contribution to global Hg deposition has been substantial, and long-distance transport of mercury may actually hamper domestic efforts in the U.S. to bring the pollution problem into regulatory compliance (Steding and Flegal 2002; Seigneur et al. 2004). It is estimated that Asia exported 21 percent of global mercury to the U.S. in 1998 (Seigneur et al. 2004), and China's coal industry comprised 25 percent of total global Hg emissions in 1995 (Pacyna et al. 2002). China will also soon surpass the U.S. as the world's largest greenhouse gas emitter. In fact, in 2006 China emitted about 115 million more metric tons of carbon dioxide than the U.S. (EIA 2006).

Figure 7 Ozone non-attainment days and hours in Beijing



Source: Hao 2009

Box 1: Mercury Pollution in China

Our understanding of mercury emission intensity is improving, but more research is necessary. An inventory study estimates that in 1999, 536 (±236) metric tons of mercury were released in China from anthropogenic sources (Streets et al. 2005). Nonferrous metals smelting, coal combustion, and other activities (predominately battery, fluorescent lamp, and cement production) contributed 45 percent, 38 percent, and 17 percent of the country's Hg emissions, respectively. Fifty-six percent of the emitted mercury was in elemental form (Hg), 32 percent as gaseous divalent mercury (Hg^{2+}), and 12 percent as particulate mercury (Hg^{p}) (Streets et al. 2005). Southwest regions of China suffer the most from mercury contamination in local rivers and ecosystems. Areas producing the highest mercury emissions include small-scale coal burning plants lacking pollution control technologies in Guizhou and metal smelting industries in Liaoning and Guangdong provinces (Figure 8) (Streets et al. 2005).

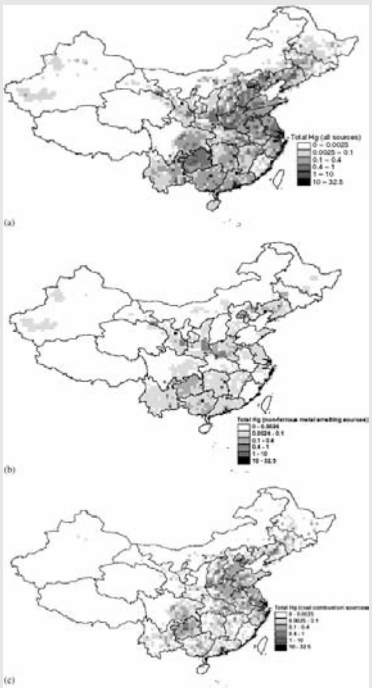


Figure 8 (a) Gridded total Hg emissions for the year 1999 (all sources together, 30 x 30 km minimum resolution, unit: t yr-1 per grid cell). (b) Gridded Hg emissions from coal combustion for the year 1999. (c) Gridded total Hg emissions from nonferrous metals smelting for the year 1999

MAKING BETTER AIR QUALITY A REALITY: POLICY SUGGESTIONS, MEASURES, AND TARGETS

Even though China's pollution problems seem daunting, improvement of air quality is feasible. In this section, we present a set of strategies and recommendations for how to move forward. Successful air pollution control management requires a national call to action. The first policy suggestion is to develop a national air pollution control plan. The plan will require: (1) a study of best methodologies for emissions inventory, (2) scientifically-based targets and standards, (3) systemic, real-time air quality monitoring, and (4) a regional and urban air quality management system.

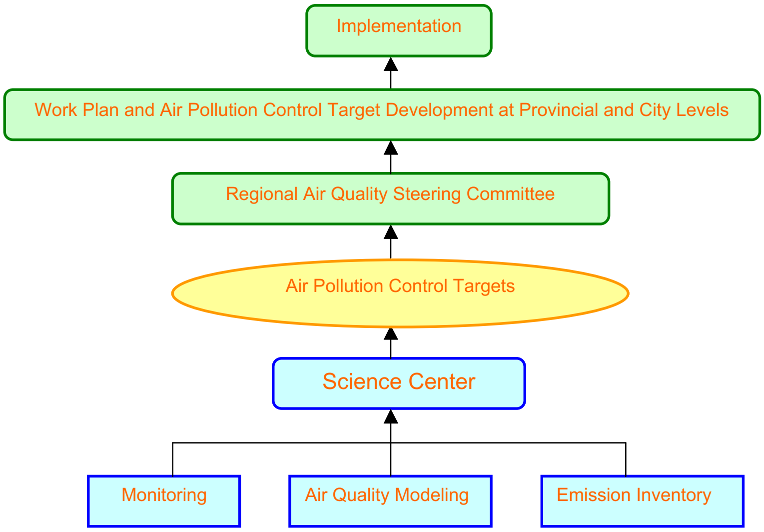
Professor Jiming Hao is a part of an expert group on the State Council of China that is focused on climate change, energy savings, and pollution emission control. According to Hao, the China's strategy for air pollution control indicates that by the year 2050, most areas in China should meet the WHO guidelines for public health and ecological safety. Right now, China is in Phase I of meeting these guidelines. By 2020, 95 percent of cities in China should be expected to meet China's national class II ambient air quality standard, with some achieving Phase II of the WHO guidelines. By 2030, 80 percent of Chinese cities should meet the Phase III targets of the WHO guidelines. By 2050, most cities would be expected to meet the WHO guidelines. To fully achieve the directive phase targets, SO_2 emissions should be reduced by 60 percent from the 2005 level, NO_x by 40 percent, PM_{10} by 50 percent, and VOCs by 40 percent (Table 2).

Table 2 WHO ambient air quality guidelines, μg/m³

<table>
<tr><th></th><th colspan="2">PM_{10}</th><th>O_3</th><th colspan="2">NO_2</th><th colspan="2">SO_2</th></tr>
<tr><th></th><th>Annual average</th><th>24-hour average</th><th>8-hour average</th><th>Annual average</th><th>Hourly average</th><th>Hourly average</th><th>10-minute average</th></tr>
<tr><td>Phase I</td><td>70</td><td>150</td><td rowspan="3">160</td><td rowspan="4">40</td><td rowspan="4">200</td><td>125</td><td></td></tr>
<tr><td>Phase II</td><td>50</td><td>100</td><td>50</td><td></td></tr>
<tr><td>Phase III</td><td>30</td><td>75</td><td></td><td></td></tr>
<tr><td>Directive</td><td>20</td><td>50</td><td>100</td><td>20</td><td>500</td></tr>
</table>

Because China suffers from numerous air quality problems over several spatial scales, the cleanup efforts should go beyond minimizing a few airborne pollutants. In other words, China will need a multipollutant control strategy and a regional framework. In particular, heavily industrialized regions, such as the Beijing municipality, the Yangtze River Delta and the Pearl River Delta, should be targeted for regional coordination (Figure 9). More details on multipollutant regulation approaches are provided in Box 2, and a case study for regional harmonization to meet air quality goals is supplied in Box 3.

Figure 9 A framework for regional coordination



Box 2 Multiple Control Strategy for Primary Pollutants

Sulfur Dioxide (SO

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[1] Thirty-six percent of all NO_x emissions in China come from thermal power plants.

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[2] Coal burning units with FDG technology not only have the ability to capture SO2, but also to dissolve Hg^{2+}.

2. Develop technologies to capture and control Hg and CO_2.[2]
3. Develop management systems and incentives to reduce Hg and CO_2.
4. Increase international collaboration to manage these pollutants and share strategies for abatement.

Box 3 Managing air quality for the 2008 Beijing Olympic Games

The 2008 Beijing Olympic Games were a defining moment for China. The world was focused not only on global athletes but also on China's efforts to improve Beijing's air quality. Most of the public media focused on the short-term air pollution reduction strategies such as reducing on-road vehicles by about 30 percent in Beijing and the closing of some factories during the Games. However, Beijing's air quality improvement strategy was extensively planned.

Professor Jiming Hao notes, "Most people see the short-term [air pollution reduction efforts] in July and August . . . but for the Olympic Games, China had been preparing for ten years." In 1999, Hao visited prior Olympic Games sites in Los Angeles, California, and Atlanta, Georgia, with Beijing's delegation to learn about their air pollution control strategies. The central government has taken on four main actions for long-term Olympics preparation: (1) improving energy use – e.g. fueling cooking stoves and small heating boilers with natural gas instead of coal; (2) requiring new in-use vehicles to meet European IV emission standards; (3) moving heavy industries such as steelworks out of Beijing; and (4) implementing ecological projects in western China for dust control. Researchers concluded that without the air pollution abatement efforts of the last decade, China could not have met air quality standards for the Beijing Games.

Prior to the Games, Hao and his colleagues also predicted that regional scale pollution transport posed a threat to Beijing's air quality, the level of threat depending on weather conditions. The community multiscale air quality (CMAQ) modeling system predicted that 35-60 percent of ozone during high ozone episodes and 34 percent of $PM_{2.5}$ at the Olympic Stadium originate from areas outside Beijing (Streets et al. 2006). Surrounding areas such as Tianjin municipality and Hebei and Shandong provinces were predicted to contribute significantly to Beijing's air quality problems. In response, local neighboring governments took on special initiatives for the Games as well as for long-term environmental improvements. For instance, Hebei's provincial environmental bureau reported fifty-six pollution abatement projects for the province's chemical industries, the installation of thirty-four FGD systems in power plants, and the construction of twenty-three central heating facilities to reduce coal consumption—a combined effort projected to cut 550,000 tons of SO_2 in the region (Xinhua 2008).

The capital's clean air strategy was a success. Air quality was much improved during the Games. Perhaps more importantly, the strategy highlights the role of regional coordination in air quality management.

A second policy suggestion is to control coal consumption in heavily polluted areas. Coal is China's number one source of energy and a significant emitter of air pollutants. The number of coal-fired power plants in China grew rapidly from 2000-2005 (Zhao et al. 2008). As a consequence, the SO_2, NO_x and PM emissions increased by 1.5, 1.7, and 1.2 times, respectively, during this period. Sulfur dioxide emissions from coal-fired power plants are expected to decrease by 2010 due to the widespread installation of flue gas desulphurization (FGD) devices (Table 2). On the other hand, NO_x emissions from coal plants are projected to rise by 39 percent from 2005-2010 because of a lack of rigorous control measures. Overall PM concentrations in the Chinese coal industry will decrease in 2010 due to FGD technology, but $PM_{2.5}$ will increase to some extent due to the poor ability of FGD technology to control fine particulates. There are numerous coal-fired plants less than 300 megawatts in China. These small plants have no FDG units installed and low combustion efficiency, and they collectively contribute the most to the total Chinese coal emissions. Future regulations will need to focus on these small polluters as well as larger coal-fired plants.

Two steps are recommended to reduce China's reliance on coal. In the first step, all coal-fired units under 25 megawatts should retire by 2010. Under this scenario, it is estimated that SO_2, NO_x, and TSP would decline by 2173, 622, and 540 kt, respectively (Zhao et al. 2008). A second step requires that all new coal plants utilize the latest, most efficient production technology to maximize energy savings and minimize pollution. Examples of clean technologies include FGD, coal washing, and gasification.

Table 2 Total Chinese coal-fired power plant emissions for 2005 and projected emissions for 2010 (kilotons)

	2005	2010	% Change
SO2	16,097	11,801	-27
NOx	6,965	9,680	+39
TSP	2,774	2,540	-8
PM10	1,842	1,824	-1

Source: Hao 2009; manuscript in preparation

A third policy suggestion is to improve vehicle pollution control in megacities. In 2007, the number of vehicles reached 160 million, which is roughly twice the vehicle population in 2002 (Hao 2009). Vehicle emissions can be controlled through a number of options tailored to each city, depending on commuter needs and pollution levels. One suggestion would be to expand subway systems and other forms of public transit to reduce congestion, reduce emissions, and save fuel. In this regard, valuable lessons can be learned from the highly utilized, efficient public transportation systems in other populated countries such as Japan. For instance, cutting-edge companies such as East Japan Railway, which currently serves large metropolitan areas such as Tokyo, have introduced a line of fuel-cell hybrid railcars to reduce the impact of on-road transport and capture energy savings (JR East Group 2008).

China should also improve their fundamental inspection and maintenance program to control vehicle emissions. Strict emission standards should be adhered. Sulfur content in fuel oil should be reduced. In addition, China can promote "clean energy" vehicles using market-based incentives. For instance, fuel taxes on the automotive industry or heavy taxes on polluting vehicles can stimulate green choices and encourage public transportation use. Finally, China can cap the total number of vehicles in heavily congested cities. Cities suffering the most from air pollution may want to mimic Shanghai's vehicle population control policy through a license auctioning system.

SUMMARY

China's goal of economic development rests on secure energy supplies. Oil is expected to play a large role in its energy mix for decades to come, but dependence on foreign oil reduces energy security in the midst of increasing energy demand. Energy efficiency improvements in the industrial sector are vital to reducing China's energy intensity and can produce immediate energy savings. Sharing technical expertise through international coordination will also catalyze China's energy efficiency endeavors.

In incremental steps, China can begin by codifying its leadership's commitment to update environmental policies and creating the organizational capacity to effectively manage air quality. Given the transboundary nature of air pollutants, a national, multipollutant control strategy with regional harmonization will be crucial. The joint efforts among neighboring provinces during the 2008 Beijing Olympic Games demonstrate the feasibility of action to reduce emissions at a regional scale. For mercury and greenhouse gases, a global synchronized effort will also be key to tackle the effects of climate change and mercury deposition. Additional details on this control strategy are provided in Box 2 above.

Coal will remain an abundant domestic source of energy for years to come. Retiring coal-fired power plants with low combustion efficiency and those without FDG control units will significantly reduce SOx, NOx and TSP levels. New coal-fired power plants should be updated to modern efficiency and stringent emissions standards.

Furthermore, the reduction of vehicle emissions in megacities is vital in the face of rapidly growing demand for cars. Improved inspection and maintenance programs for passenger vehicles, use of energy efficient railway systems, and market-based incentive policies are among the measures that could be used to achieve a decline in on-road emissions.

References

Streets, David G. et al. 2005. Anthropogenic mercury emissions in China. *Atmospheric Environment* 39(40): 7789-7806.

Streets, David G. et al. 2007. Air quality during the 2008 Beijing Olympic Games. *Atmospheric Environment* 41(3): 480-492.

Zhao, Yu et al. 2008. Primary air pollutant emissions of coal-fired power plants in China: Current status and future prediction. *Atmospheric Environment* 42(36): 8442-8452.

Other Sources

China Daily Online. 2007. China's energy consumption up 8.4% in 2006. *China Daily*, March 7. http://www.chinadaily.com.cn/china/2007-07/03/content_908631.htm.

Energy Information Adminstration (EIA). International energy annual 2006: International emissions data. http://www.eia.doe.gov/environment.html.

JR East Group. Sustainability Report 2008. http://www.jreast.co.jp/e/environment/index.html.

Obama, Barack. 2009. Inaugural address. January 20, Washington, DC.

Pacyna, E.G. and J.M. Pacyna. 2002. Global emission of mercury from anthropogenic sources in 1995. *Water, Air, and Soil Pollution* 137: 149-165.

People's Daily Online. 2009. CNPC to develop Azadegan oilfield. *People's Daily*, January 16. http://english.peopledaily.com.cn/90001/90776/90884/6575282.html.

Seigneur, C. et al. 2004. Global source attribution for mercury deposition in the United States. *Environmental Science & Technology* 38(2): 555–569.

Steding, D.J. and A.R. Flegal. 2002. Mercury concentrations in coastal California precipitation: Evidence of local and trans-Pacific fluxes of mercury to North America. *Journal of Geophysical Research* 107(D24): 4764.

United Nations Development Program. 2005. *Energizing the millennium development goals: A guide to energy's role in reducing poverty*. New York: UNDP.

World Health Organization. 2006. *WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005*. Geneva, Switzerland: WHO Press.

Xinhua News Agency. 2008. Beijing's neighbors report more blue sky days in 2007. Xinhua News Agency and the Official Website of the Beijing Olympic Games, January 9. http://en.beijing2008.cn/news/olympiccities/beijing/n214229614.shtml.

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CHAPTER 8

Pinning Down the Factors: Energy Conservation and Carbon Emission Reduction in China*

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CHAPTER SUMMARY

Now emitting over 6 billion metric tons of carbon dioxide a year, China is an industrial powerhouse whose actions affect the entire world. In this chapter, we examine China's energy and carbon emission patterns and compare these trends with the United States and the European Union. We identify increased economic growth, increased energy intensity, and growth in primary and secondary industries as the major factors behind increased energy consumption, and change in energy consumption as the main contributor to increased carbon dioxide emissions.

After examining these trends in production and services, we focus especially on trends in households, a sector that now accounts for over a third of China's indirect energy consumption. We identify urbanization as the main driver behind increased urban household energy consumption. Technological progress, on the other hand, corresponds to a drop in both indirect and urban household energy consumption.

This chapter concludes with the recommendation that China should transition to market-based policies to induce reductions in energy use, and stresses the importance of global collaboration in tackling this energy and emissions problem.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on October 20, 2008, by Professor Zhao as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Jiaona Zhang, a student in the course, and has been approved by Professor Zhao. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Zhao, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

INTRODUCTION

Energy forms the cornerstone of our economy. Energy commodities provide the fuel that drives our transportation system, heats our homes and offices, and powers our factories. In essence, these commodities are the critical inputs to a wide variety of production processes that drive modern economies. Yet, while energy plays an indispensable role in our daily lives and is the force that drives our society's progress, it also has the potential to slowly degrade the world we live in.

Over the past generation, we have increased our demands for electricity and fuel. Instead of working to rein in our own consumption and emissions, we feel compelled to compete for global resources. This unchecked and self-centered demand for energy has serious consequences for the health of our environment.

The world market for energy consumption—with current laws and policies unchanged—is projected to increase by fifty percent from now to 2030.[1] Ninety percent of the total projected growth in consumption will come from non-OECD countries, and with China ranked only second to the United States in total energy consumption, much of this growth will come from China. The combustion of fossil fuels is the main contributing factor to the release of greenhouse gases into the atmosphere. Therefore, increased energy consumption will inevitably lead to increased greenhouse effects. With China consuming more and more coal—the most carbon-intensive of energy sources—growing energy consumption in China will negatively impact the health of our planet.

[1] Energy Information Administration. Official energy statistics from the U.S. government. http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls.

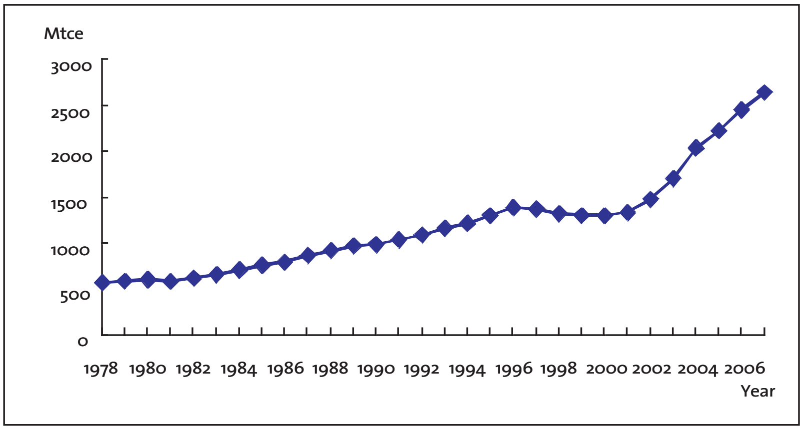
This chapter examines China's energy consumption trends over the past thirty years and breaks that consumption down by sector. Using decomposition analysis, we identify the main factors driving increased energy consumption and carbon dioxide emissions. We then shift our focus to households and energy, identifying the main drivers of increased indirect household energy consumption and urban household energy consumption. Finally, by way of conclusion, we discuss mechanisms to address China's—and the world's—growing energy needs.

ENERGY CONSUMPTION PATTERNS

> *"To understand what is happening and where we want to go, we need to look at the data and the trends they exhibit." – Professor Xu Zhao*

Over the past thirty years, energy consumption in China has risen quickly. From 1978 to 1996, energy consumption increased steadily at an average rate of 42 million TCE (tons of coal equivalent) per year. From 1997 to 2000, energy consumption rose at a slower average rate of 17 million TCE per year. Then, from 2001 to 2007, energy consumption increased dramatically. In 2001, energy consumption was at 1.35 billion TCE, and just six years later, in 2007, energy consumption had almost doubled to 2.65 billion TCE. This translates into an increase of 217 million TCE on average per year, a much faster rate than the previous rate of increase between 1978 and 1996.

Figure 1 Energy consumption in China from 1978 to 2006



Data source: Statistical Yearbook 2007 of China

What has caused this trend of increased energy consumption? In analyzing the forces producing this change, we examine the following five factors: economic growth, energy intensity, industrial structure, sectoral structure, and urbanization. While these factors are not exhaustive, together they form a model that reflects the concerns that people typically have in mind. Usually when analyzing industrial energy consumption, the most common factors that are examined include intensity and structural effect. Thus, it makes sense to include energy intensity, industrial structure, and sectoral structure in our model as relevant factors. Additionally, we are concerned about economic development and population growth and their potential impacts on energy consumption, and therefore we include them in our model as well.

Throughout this chapter, economic growth is measured in GDP per capita, and energy intensity is defined as units of energy per unit of GDP. Using 1978 price levels, we calculated data for real GDP per capita in thousands of yuan and energy consumption per capita in tons of standard coal. In our analysis, "industrial structure" refers to the proportions of total output produced by the country's primary, secondary, and tertiary industries. "Sectoral structure" refers to the proportions of output produced by each individual sector within the primary, secondary, and tertiary industry categories. As defined by Chinese statistical yearbooks, the country's primary industries include the following sectors: farming, fishing, forestry, animal husbandry, fishing, and water conservancy. China's secondary industries include mining and quarrying, manufacturing, construction, and production and supply of electric power, gas, and water. The country's tertiary industries include all service sectors. Finally, we measured urbanization using the rate of population growth in an urban area, which was defined by an increase in the density of manmade structures in comparison to the surrounding area.

Using a co-integrated regression model, we then analyzed these five factors and their relationship with energy consumption. Theoretically, when we regress a time series variable on another time series variable, we obtain spurious results. Behavior would be time dependent, and thus the results we get would be falsely significant and inapplicable in general terms. Co-integration regression, however, allows us to analyze these non-stationary time series variables. Through this method, the linear combination of these variables is stationary, and we can cancel out their non-stationary characteristic.

Using our co-integrated regression model, we determined that increased energy consumption was correlated with economic growth, increased energy intensity, and growth in primary and secondary industries.[2] Out of these three relationships between energy consumption and our other factors, we found that the greatest correlation existed between increased energy consumption and increased energy intensity. Increased economic growth was also highly correlated with energy consumption. On the other hand, our regression test revealed that there was little correlation between China's rising energy consumption and changes in its tertiary industries or level of urbanization.

After identifying the general relationships between energy consumption and its contributing factors, we sought to determine the extent of each factor's contribution through decomposition analysis, a technique that breaks down the changes in one variable into the changes in its determinants. We picked Log Mean Divisia Index (LMDI), a method of structural decomposition that uses a logarithmic mean weight function and gives perfect decomposition by accommodating zero values in the data set.[3]

[2] Wang, Qiong (Juliana). Personal communication.

[3] Ang, B. W. 2005. The LMDI approach to decomposition analysis: A practical guide. *Energy Policy* 33: 867-71.

Figure 2 Results of decomposition analysis of factors contributing to increased energy consumption

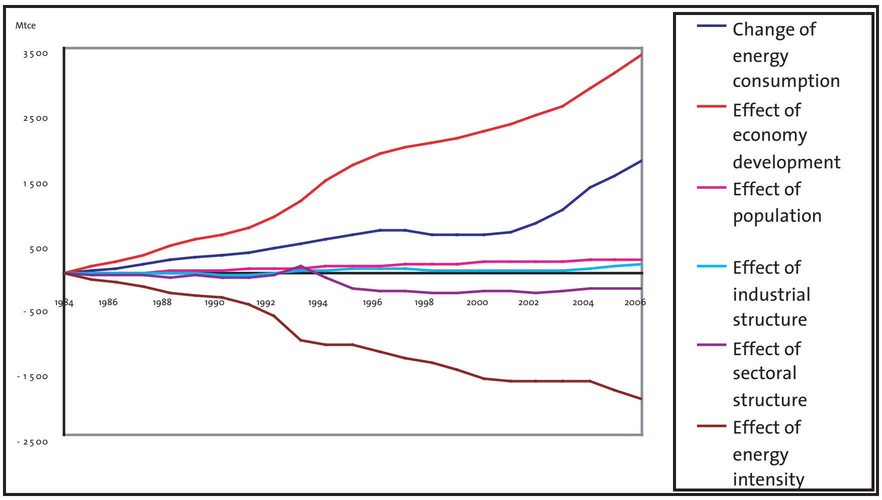


Figure 2 displays the results of our decomposition analysis. It shows that economic growth has the largest positive effect on energy consumption, while declining energy intensity has the largest negative effect on energy consumption. This means that China's energy consumption has primarily increased because of its economic development, and any decrease in overall consumption was largely caused by a decline in energy intensity. The results also show that changes in industrial structure and population contributed to increased energy consumption, although their influence on energy consumption is less than that of economic growth.

Thus, as population has increased, and industrial structure has shifted from primary industry to a greater focus on secondary industry, energy consumption has gone up. Meanwhile, change in sectoral structure has corresponded to a decrease in energy consumption, although its impact on decreasing energy consumption is less than that of declining energy intensity. Thus, China's shift from more energy-intensive sectors to less intensive ones, combined with the country's increased efficiency in production processes has worked to decrease energy consumption.

Knowing that industrial and sectoral structures are large contributors to increased energy consumption, we move on to examine how energy consumption breaks down by sector. This understanding of how consumption in each sector contributes to overall energy consumption gives policy makers an idea of which sectors to target with regulations and incentive schemes.

Figure 3 Breakdown of energy consumption by sector

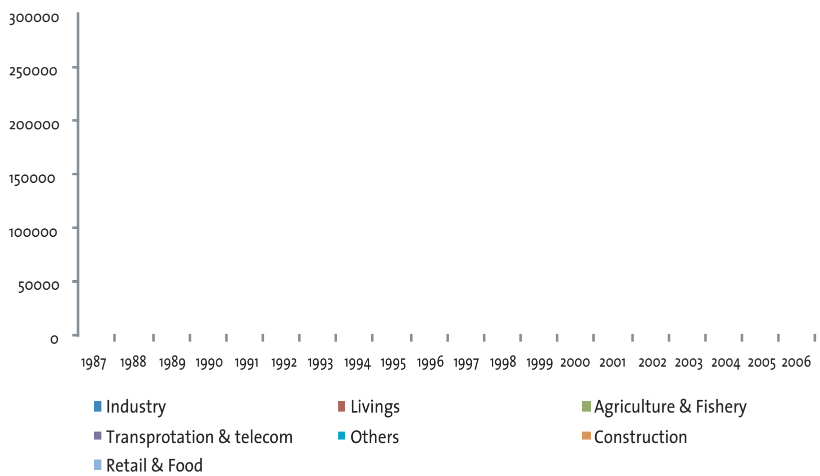


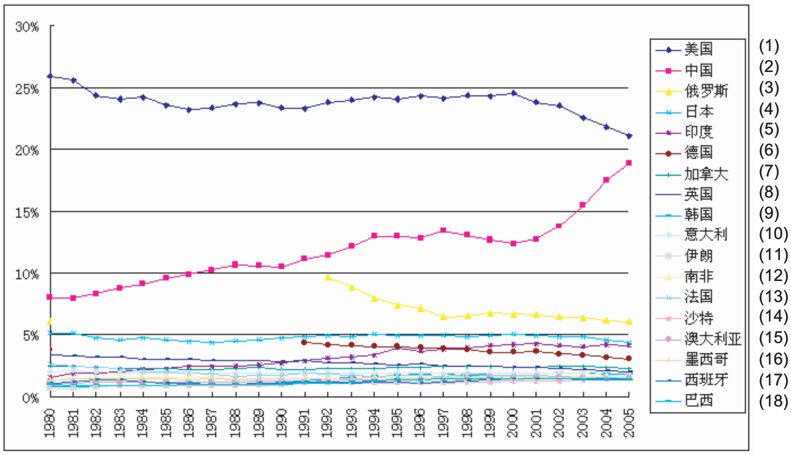
Figure 3 shows the breakdown of energy consumption. Industry has been the dominant consumer of energy over the years, as industrial energy consumption is nearly two-thirds of total energy consumption each year from 1987 to 2006. Looking specifically at 2006, industry occupied 71 percent of all energy consumption. In contrast, household consumption occupied 10 percent of total energy consumption. The transportation and telecom sector occupied about 8 percent, and the final 11 percent was mainly comprised of construction, retail, agriculture, and fishing.

A more detailed look at trends of energy consumption within specific sectors shows that agricultural energy consumption has not changed much over the past twenty years, while energy consumption in transportation and telecom has exhibited more dramatic changes. The agriculture and fishery sector has experienced an average increase of 5 percent per year for the last twenty years. On the other hand, energy consumption from transportation and telecom exhibited an average increase of 20 percent per year over the same period. It is this increase in energy consumption from the transportation and telecom sector that contributed greatly to China's total rise in energy consumption.

CARBON EMISSION PATTERNS

China's rising energy consumption has been accompanied by increased energy-related carbon dioxide emissions. As China's total energy consumption has risen to over 2.5 billion TCE, China's percentage of the world's total carbon dioxide emissions has increased from less than 10 percent in 1990 to 19 percent in 2005. Thus, by 2005 China had exceeded all other countries in emissions, with the exception of the United States, which represented 21 percent of the global total.

Figure 4 Country comparison of energy-related carbon dioxide emissions



(1) US; (2) China; (3) Russia; (4) Japan; (5) India; (6) Germany; (7) Canada; (8) UK; (9) South Korea; (10) Italy: (11) Iran; (12) South Africa; (13) France; (14) Saudi Arabic; (15) Australia; (16) Mexico; (17) Spain; (18) Brazil

Figure 4 shows this marked increase in China's emissions and compares China's trend with seventeen other countries: the United States, Russia, Japan, India, Germany, Canada, the United Kingdom, South Korea, Italy, Iran, South Africa, France, Saudi Arabia, Austria, Mexico, Spain, and Brazil. From Figure 4, we can see that all countries—except for China, the United States, and Russia—have consistently produced 5 percent or less of the world's total carbon emissions since the 1990s. Out of the three countries with emissions of over 5 percent of the global amount, China is the only country whose percentage of global emissions have risen overall from 1990 to 2005. Both the United States and Russia exhibited decreases in total emissions.

The most recent statistics released by the Energy Information Administration (EIA) show that China has overtaken the United States in total carbon emissions. In 2006, China emitted 6.018 billion metric tons of carbon dioxide, while the United States emitted 5.903 billion metric tons. To enhance the comparison, Europe emitted 4.721 billion metric tons, and Russia emitted 1.704 billion metric tons, making China the clear leader in annual carbon dioxide emissions.[4] It is, however, important to keep in mind that while China leads in total carbon dioxide emissions, this total emissions amount is largely an effect of China's immense population. China's per capita carbon dioxide emissions are actually less than the European Union as well as the United States. Per capita carbon dioxide emissions for China, the EU, and the United States were at roughly about 5, 10 and 20 tons of CO_2 per capita in 2004.[5]

What has led to this trend of increased carbon dioxide emissions in China? In analyzing the causes of increased emissions, we examine the following three factors: energy consumption, the fossil energy proportion, and the structure of fossil energy. These factors were chosen because they are known to be linked to carbon dioxide emissions. Energy consumption results in the release of carbon dioxide into the atmosphere, and energy structure also has an impact on emissions, since carbon dioxide is emitted in varying amounts depending on the source. Again, while these factors are not exhaustive, they seem the most relevant according to previous scientific studies and popular concern.

Using co-integrated regression, we found that carbon dioxide emissions were positively correlated with energy consumption. Thus, as we would expect, with increased energy consumption, carbon dioxide emissions also increased. As for fossil energy proportion and the structure of fossil energy, both were negatively correlated with energy consumption. The increase of energy consumption corresponded to a decrease in fossil energy proportion and little change in fossil energy structure.

After identifying the general relationship between increased carbon dioxide emissions and its contributing factors, we sought to determine the extent of each factor's contribution using decomposition analysis. Figure 5 displays the results of our analysis. Out of the three factors, we can see that increased energy consumption was the biggest contributor to increased carbon dioxide emissions from 1984 to 2006. On the other hand, change in fossil energy proportion and structure of fossil energy had a negative impact effect on emissions. Thus, as the amount of fossil fuels China used in proportion to total energy sources decreased, emissions went down. These two factors, however, have had a much smaller impact on carbon dioxide emissions than energy consumption.

Our examination of the factors contributing to increased carbon dioxide emissions showed us that energy structure plays a role in the amount of carbon dioxide we release into the air. Comparing 1978 and 2006, we can see that China's energy structure has remained relatively constant. In 1978, the energy structure was as follows: 71 percent coal, 23 percent petroleum/oil, 3 percent natural gas, and 3 percent hydro, nuclear, and wind. In 2006, the energy structure was notably similar: coal occupied 70 percent, petroleum/oil 20 percent, natural gas 3 percent, and hydro, nuclear, and wind 7 percent. From this comparative breakdown, we can see that the main difference lies in a shift away from fossil fuels and towards nuclear and renewable energy; the percentage of coal and oil in China's overall energy structure has decreased, while hydro, nuclear, and wind have increased.

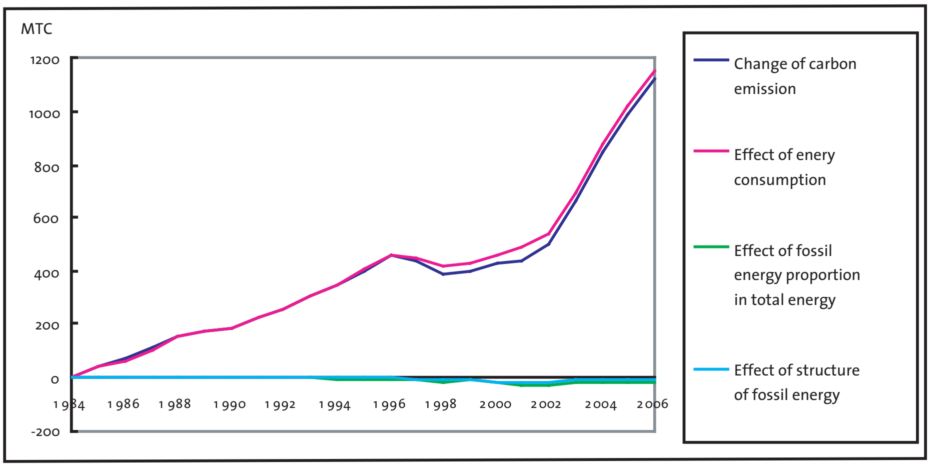
China's energy structure is similar to countries such as the United States and India in that it is highly dependent on coal and oil. In general, energy structure depends on

[4] Energy Information Administration. Official energy statistics from the U.S. government. http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls.

[5] IPCC. 2007. Summary for policymakers. In *Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. B. Metz et al. Cambridge: Cambridge University Press.

resource endowment and policy. Each country has its unique resource endowment, which leads to specific policies and resulting distinctive energy structures across countries. For example, the EU depends heavily on nuclear power as its source of energy. China's change in structure now includes more renewable and nuclear energy. However, China is still far from adopting energy structures similar to European countries.

Figure 5 Results of decomposition analysis of factors contributing to increased carbon dioxide emissions



HOUSEHOLD ENERGY CONSUMPTION

Trends in production and services are not the only patterns of interest. Households—having exhibited an annual growth rate of 10 percent of total consumption since 1999—now account for over a third of China's indirect energy consumption. Therefore, to tackle China's growing energy needs, we must understand the trends within household energy consumption.

Household energy consumption (HEC) includes both direct and indirect energy consumption. Households consume energy either directly through lighting, heating, cooking, electricity use, and petroleum consumption for personal travel, or indirectly by consuming goods and services that require energy input in their production. Over the years, indirect energy consumption has risen in China. Urban households consume most of their energy indirectly, and as the number of urban households has increased, total indirect energy consumption has also gone up.

This growth in indirect energy consumption warrants further examination. Let us first discuss the sources of direct versus indirect energy. Rural households consume more energy directly than indirectly, while urban households consume more energy indirectly than directly. Furthermore, rural households are the main contributors to direct energy consumption, while urban households are the main contributors to overall indirect energy consumption in China. For example, indirect energy consumption of urban households constituted 78–86 percent of total urban HEC, while direct energy consumption of rural households constituted 54–66 percent of total rural HEC in 2006. Two factors related to urban households have resulted in increased indirect energy consumption. First of all, China has undergone growth in its urban centers, and as the number of urban households increases, so does total indirect energy consumption. The other factor is that urban residents are consuming greater amounts of products and services that constitute indirect energy consumption in that they require energy input in their production. Examples of these products include personal vehicles, cell phones, and electronic equipment.

We need, however, a more rigorous analysis of the factors contributing to the trend of increased indirect household energy consumption. Again using decomposition analysis, we analyzed the factors causing change in indirect HEC during the period from 1997 to 2002. Through our analysis, we found that the major contributors to change in indirect HEC were technological progress and increased consumption. Technological progress corresponded to a 37 percent drop in indirect household energy consumption, while increased consumption corresponded to a 42 percent increase in indirect household energy consumption. Additionally, indirect household energy consumption rose with the increased proportion of urban household consumption.

Digging deeper, we use structural decomposition analysis to identify the forces driving the change in urban household energy consumption. Through our analysis, we find that urban HEC was largely caused by urbanization and technological change. Urbanization acted as a positive driving force, while technological change acted as a negative driving force. This analysis is important, because based on expected trends in urbanization we can predict the direction of future changes in urban household energy consumption. We expect urbanization to continue as the income of Chinese residents grows and more people move into the cities. This income growth will also increase the size of the urban elite, a group that currently makes up about 10 percent of the Chinese population but consumes more than 20 percent of total indirect HEC. Thus, with this income growth and rapid urbanization, we expect urban HEC and total indirect HEC to increase in the years to come.

There is hope, however, for the expected increase in indirect energy consumption to taper off. As people spend their increased income on more products, indirect energy consumption is expected to increase. However, if people allocate their money to financial markets—abstract entities that consume less direct and indirect energy—urban households will consume less energy overall. Thus, if consumption structure shifts toward products offered in the tertiary industry, we may see trends in energy consumption that ameliorate the expected rise.

DISCUSSION

Economic growth and carbon emission reductions: Mutually exclusive?

> *"So is there a tradeoff between growth and conservation?"* –*Professor Xu Zhao*

When we decomposed the factors contributing to increased energy consumption, we saw that economic growth was the biggest positive force. Then, when we decomposed the factors contributing to carbon dioxide emissions, we saw that increased energy consumption was the most important contributor. Thus, all else equal, economic growth is positively correlated with carbon emissions. Knowing this relationship, it may seem like we face a trade-off between economic growth and energy conservation. Thus emerges the resistance that developing countries such as China exhibit toward potential emission reduction mandates, for they believe that it will come at the cost of hindering their economic growth. However, a trade-off between growth and conservation assumes that we cannot do anything to influence the other determinants of energy consumption and carbon dioxide emissions. Our analyses revealed that increased energy efficiency and sectoral shifts also have an effect on energy consumption. Therefore, by creating policy that shapes the other determinants of carbon emissions, we do not have to slow down growth in order to protect our environment.

Transforming China's energy structure: Expected resistance

> *"Shifting the energy structure in China will be met with resistance."*
> *–Professor Xu Zhao*

A country's energy structure depends on its energy endowment, and China's resource endowment discourages shifting toward sources other than coal and oil—sources that would result in reductions in carbon dioxide emission reductions. Since China has an abundance of coal, shifting the energy structure toward more solar, wind, hydro, and nuclear power—or any other component that is not coal—will face both resource constraints and political resistance. One key to reducing emissions in China is changing attitudes. We need to help people understand that there is not always a one-to-one trade-off between growth and emission reductions, and we also need to think of creative ways to overcome energy endowment constraints, and, most importantly, the political and social attitudes resistant to changing China's energy structure.

Market-based policies

> *"We want to use energy price to adjust industry behavior." —Professor Xu Zhao*

China's current policies induce action through compulsory, rather than incentive-based, measures. Yet, these compulsory policies retain inefficiencies that would otherwise be eliminated by market forces. For example, the Chinese government sets too low a fee for pollution, and only by letting the market determine the fee can we internalize these externalities. Thus, the best way for China to reach its goal of lower energy intensity may be through market-based measures. Potential strategies include price mechanisms, taxes, emission trading, and contracting energy management.

Price mechanisms include releasing current price caps on goods, e.g. oil, and allowing prices to fluctuate to reflect the accurate market price – the price where there is equilibrium between demand and supply. Taxes include carbon taxes and environmental taxes, where polluters must pay a fee for emitting carbon or other pollutants that damage the environment. Emissions trading entails determining standards for emissions, allocating carbon credits, and creating a carbon market. Finally, contracting energy management involves hiring foreign companies that specialize in overseeing and allocating energy resources to work with Chinese companies, or to train the domestic labor force in energy management practices.

As for the first tool, price mechanisms, there exists the risk of social instability. If the central government released its cap on energy prices, the cost of fuel will go up and inputs that rely on fuel will become more expensive. As input prices increase, the price of most goods will go up. Currently, China has price caps on many goods, from electricity to water, medicine, and public transportation. The Chinese central government, which prioritizes maintaining a "harmonious society," is averse to releasing these price caps because of the social instability that will ensue in response to these increased prices. Further research needs to be done on this topic to determine the effects of letting energy prices fluctuate with the market. The hope is that the release of energy price will adjust industry behavior, thus contributing to lower energy consumption and a reduction in carbon emissions.

Taxes can also be an effective tool. In administering a carbon tax, one recommendation is to tax carbon in the coal, oil, and gas extraction and mining sectors. By levying the carbon tax upstream of the industrial production chain, we reduce the administrative cost of imposing such a tax. The cost will automatically carry through in the products of downstream industries, such as chemical and manufacturing industries that use coal or oil. Furthermore, this type of carbon tax would have the added benefit of increasing environmental consciousness in these downstream industries. These industries will learn to factor the carbon content of different fuels into their decisions, and they may shift toward cleaner substitutes.[6]

[6] Wang, Qiong (Juliana). Personal communication.

Finally, as for emissions trading, there have already been some efforts in China to employ this tool. In 1999, China's State Environmental Protection Administration collaborated with the U.S. Environmental Protection Agency and started pilot programs to reduce SO_2 emissions. Two cities were chosen as the first stage: Nantong in Jiangsu Province, and Benxi in Liaoning. Later on, Shandong, Shanxi, Jiangsu, Henan, Shanghai, Tianjin, and more cities also joined the program. The results so far have been mixed. One barrier this program faces is that there is not a national standard in place, even though there are provincial or municipal level legislations and regulations. A second barrier is a lack of enforcement of these regional caps on emissions. Finally, there has been a conflict of interest between the goal of economic growth at the provincial level and the emission reduction target. Under this program, emission reduction is only a "nice" thing to have, whereas "economic growth" is the primary criterion for evaluating provincial governments. As a result, environmental goals are often sacrificed for the sake of economic growth. The shortcomings of these efforts contain important lessons for future emissions trading systems. These pilot programs have demonstrated the importance of setting a national standard, having good enforcement mechanisms, and internalizing environmentalism in incentive schemes.

Moving forward, we face the question of whether a tradable carbon emission permit would be effective, and if so, how to properly design this mechanism. From our examination of the mechanism, we see that the key to effectively designing any market-based mechanism is to have an accurate estimate of the marginal social cost and marginal social benefit. If the price of energy is artificially low, then the cost of using one more unit of energy is going to be lower than the true cost, and people will over-consume energy. Thus, it is imperative to the success of any market-based tool that the price is set such that marginal cost equals marginal benefit.

The global effort

> *"This is a global problem, and collaboration is key."* –*Professor Xu Zhao*

China's energy consumption has reached 19 percent of the world's energy consumption. Environmental issues in China are now more than just a domestic issue – they have become a global problem.

Domestic efforts and goals can be summarized by the Five-Year Plan, which aims to reduce emissions by 20 percent in 2010. Last year, China did not reach its goal to reduce carbon dioxide emissions by 4 percent, and it seems that these plans are more of an aspiration than a manageable reality. The transfer of manufacturing from foreign countries to China may be aggravating this problem, as multinationals pursue cheaper labor costs in the great China region. While we do not know the exact impact of this shift – and it is another topic for further research – it is likely that it has a negative impact on the decline of energy intensity, as it brings high-energy operations to the mainland. Thus, with international actors on and influencing the scene, emissions reduction in China requires a globally coordinated effort.

CONCLUSION

In this chapter, we examined China's energy and carbon emission patterns. We saw that increased economic growth, increased energy intensity, and growth in primary and secondary industries have been major contributors to increased energy consumption, and change in energy consumption has been the biggest driving force behind increased carbon dioxide emissions.

We especially looked at energy consumption trends in households, as this sector now accounts for over a third of China's indirect energy consumption. Similar to trends in the industrial sector, we found that increased indirect household energy consumption (HEC) has been mainly caused by increased consumption. However, households also diverge from industrial sector trends in a couple of ways. For example, urbanization was a key driver behind increased urban HEC, as well as technological progress, which corresponded to a drop in both indirect and urban household energy consumption.

This chapter concludes with the recommendation that China transition to market-based policies to induce reductions, and we wish to stress the importance of global collaboration in tackling this energy and emissions problem that is without borders. Identifying the key factors that have an impact on energy consumption and carbon dioxide emissions in China has pointed out the direction of future efforts to reduce energy consumption and emissions. The best path to fix these problem areas is still an uncertain road ahead, but it is one that we now know must be navigated hand in hand through more research, program trials, and most importantly, with open minds and a greater concern for the well-being of our future world.

Primary References

Ang, B. W. 2005. The LMDI approach to decomposition analysis: A practical guide. *Energy Policy* 33: 867-71.

Wang, C., Jining Chen and Ji Zou. 2005. Decomposition of energy-related CO_2 emission in China: 1957-2000. *Energy* 30: 73-83.

Energy Information Administration. Official energy statistics from the U.S. government. http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls.

IPCC. 2007. Summary for policymakers. In *Climate change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change*, eds. B. Metz et al. Cambridge: Cambridge University Press.

Schipper, L., et al. 2001. Carbon emissions from manufacturing energy use in 13 IEA countries: Long-term trends through 1995. *Energy Policy* 29: 667-688.

Suggested Readings

For further information on air pollution and emissions control, see chapter 7 in this volume, co-written by Professor Jiming Hao.

Ang, B.W., and Na Liu. 2007. Negative-value problems of the logarithmic mean Divisia index decomposition approach. *Energy Policy* 35: 739-42.

Ang, B.W. 2004. Decomposition analysis for policymaking in energy: Which is the preferred method? *Energy Policy* 32: 1131-139.

Berah, N., F. Feng and R. Priddle. 2007. *Sustainable energy in China: The closing window of opportunity*. Chicago: World Bank Publications.

Ebel, R.E. 2005. *China's energy future: The Middle Kingdom seeks its place in the sun.* New York: Center for Strategic and International Studies.

Economy, E. 2005. *The river runs black: The environmental challenge to China's future.* New York: Cornell University Press.

Kambara, T., and C. Howe. 2007. *China and the global energy crisis: Development and prospects for China's oil and natural gas.* Grand Rapids, MI: Edward Elgar.

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CHAPTER 9

Wildlife Conservation in Western China*

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CHAPTER SUMMARY

Eastern and western China have very different climates, population densities, and livelihoods. As a result, distinct conservation models are appropriate in these two regions. Pastoralism (herding and grazing animals) is the primary livelihood in China's west. This extensive land use allows humans and wildlife to coexist. This chapter explores current Chinese views toward wildlife as a basis for understanding Chinese conservation, and then addresses the current state of wildlife management in western China. Finally, it makes recommendations for the future of wildlife conservation.

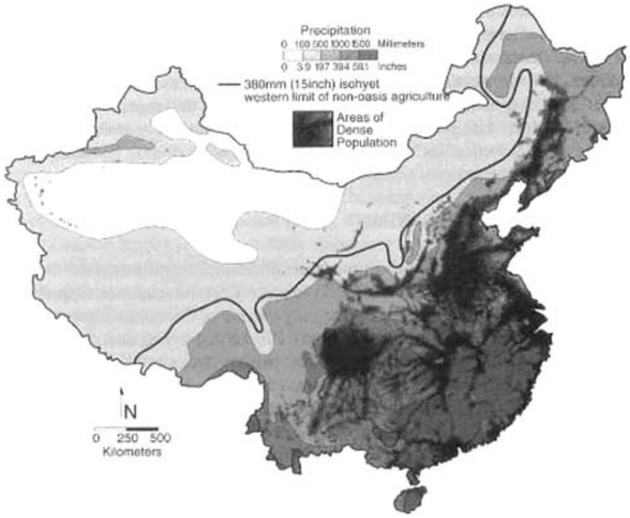
* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on October 6, 2008 by Professor Harris as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Alison Hoyt, a student in the course, and has been approved by Professor Harris. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Harris, as well as background material on the lecture topic prepared by the students. Short biographies of the authors can be found at the end of the chapter.

OVERVIEW OF WESTERN CHINA

Geography, culture, and wildlife vary dramatically from eastern to western China. The two regions are separated by their climates, population densities and livelihoods. To the east, high rainfall and a moist climate make agriculture possible. To the west, arid highlands make agriculture difficult even with intensive irrigation. As a result, pastoralism is the dominant livelihood in the west.

It is appropriate to design and implement distinct conservation models in eastern and western China to reflect the different land usage in the two areas. China's population is densely concentrated in eastern China's agricultural regions. High population densities mean that the only way to protect eastern wildlife, such as pandas, is to set aside clearly delineated reserves. Western China, on the other hand, is characterized by relatively sparse pastoralist populations. Unlike eastern China's intensive agriculture and dense population centers, this form of human land use does not necessarily preclude having wildlife on the land as well. Many wild species are capable of dealing with some level of human involvement. Their survival is not limited to clearly delineated reserves. This has a profound impact on the types of wildlife conservation that are possible in western China.

Figure 1 Map of mainland China, showing precipitation isopleths (shading) and highly concentrated areas of human population. Areas north and west of the solid line cannot support agriculture in the absence of irrigation, and therefore meet Harris's definition of western China.



China is home to a diverse range of biomes and an enormous number of species. It is considered a "mega-diversity" country, ranking second worldwide in its number of mammal species and fourth in its number of reptile species (Harris 2008). China boasts much greater species diversity than North America. Arid western China has less biodiversity than the east, but is still home to an impressive array of terrestrial vertebrates. It has a wealth of bird species, from hawks, falcons, and eagles to upland birds such as the white-eared pheasant and the Himalayan snowcock. Western China has an especially unique wealth of large mammals (Figure 2). Four species of gazelle roam the alpine meadows (Figure 3).

Figure 2 Tibetan wild asses (for Latin names of species in this chapter, refer to Harris 2008)

Photograph courtesy of Milo Burcham of Cordova, Alaska

Figure 3 A young male Przewalski's gazelle

Photo credit: Richard Harris

Figure 4 A wild yak bull

Photograph courtesy of Milo Burcham of Cordova, Alaska

Wild yak (Figure 4) and argali, or wild sheep, are impressive grassland species. The chiru, an antelope-like goat, stands as the emblem of the Tibetan Plateau. Blue sheep, Himalayan tahr, and Asiatic ibex are comfortable along the rocky cliffs. Snow leopards are still present in many mountain chains. Today, this diverse fauna suffers from increasing population and development pressures.

> *"There is, put simply, quite a lot to conserve, and put more darkly, quite a lot at risk." –Richard Harris*

Much like the geography of the two regions, the people of western China are different from the people of eastern China. Han Chinese are a minority in western China, and there are many Tibetans, Mongolians, Kazakhs, and people of other ethnic groups. While Chinese is still the dominant language, many other languages are also spoken. The political system in the area operates just like the rest of China.

The predominance of pastoralism in western China has implications for grassland preservation and species conservation. Traditional practices form a foundation for sustainable use. However, due to increasing market pressures, rangeland degradation has become a growing problem (Figures 5 and 6). Although overgrazing is clearly recognized as the primary cause of rangeland degradation, the drivers of overgrazing behavior are not fully understood. Traditionally, subsistence pastoralists faced with a market economy have been susceptible to overgrazing pressures. While they receive increasingly higher prices for the products they trade, they have no feedback mechanism built into their society to deal with overgrazing. As a result, overgrazing has caused changes to grassland species composition in many areas, and most species whose habitat needs overlap with human needs are generally doing poorly. In contrast, some species whose habitat needs have little overlap with humans continue to thrive.

The "Great Opening of the West," a national strategy to prioritize the development of China's poor rural western regions, also has significant implications for wildlife. This development has focused on building infrastructure such as bridges and highways, although mining has also been encouraged in the area. While some believe this plan was conceived strictly for poverty alleviation, others see it as a government strategy to exert more control on these far-flung regions. This view is based on the concept that those who are currently enjoying a standard of living closer to what is available in eastern China are less likely to rebel or complain about their lifestyles.

Whatever the motivation for the development, the impacts on wildlife are clear. A more crowded, motorized, and industrialized society makes life for wildlife much more difficult. Regions that were previously protected by their remoteness are losing that sense of security. As a result, future wildlife management will need to more actively balance the increasingly overlapping needs of humans and wildlife. Ecological values are emphasized in the Great Opening of the West and highlight the region's pristine waters and open grasslands. However, the development strategy is worrisome for wildlife. Propaganda often addresses wildlife as something to be done away with, promoting an idealized picture of the west that resembles eastern China. However, in order to preserve the unique wildlife of China's west as an asset for the future, alternative models of development will need to be considered.

Figure 5 Jianshe Township in Aksai County, Gansu, shows the effects of excessive livestock use on arid rangelands

Photo credit: Richard Harris

CHINESE PERCEPTIONS OF WILDLIFE

> *"Now is the time for more purposeful management." –Richard Harris*

To best understand the future of wildlife conservation in China, it is important to understand the dominant views of wildlife in Chinese society. Conservation does not exist in a cultural background in China. The dominant view toward wildlife among

Chinese is a utilitarian one. Wildlife has historically been used for food and components of wildlife for traditional Chinese medicine. As Chinese culture continues to change, fewer people are interested in these practices. However, this shift is a gradual one, as evidenced by the Chinese government's supportive policies toward consumption of wildlife products. Demand for wildlife products continues. However, it is illegal to kill or otherwise exploit these animals in the wild. As a result, there has been a shift toward captive breeding to produce animal products. Rather than reducing demand for wildlife products, many originally wild species are now being farmed to meet demand for wildlife products. Wild counterparts can then be left untouched in protected nature reserves.

The utilitarian perspective on wildlife often evokes a negative reaction among North Americans, who have historically prided themselves on eliminating demand for wildlife products. However, use of wildlife products in China is deeply rooted in the culture. Unlike in North America, medicinal uses of wildlife have a strong historical and cultural presence in China. While many North Americans disapprove of the utilitarian approach to wildlife, the utilitarian perspective in itself does not mean that Chinese people view wildlife in a negative light. Rather, it is simply a reflection of the attitude that wildlife products can be put to many human uses. Quite the opposite of a negative view toward wildlife, this utilitarian attitude offers a strong basis for conservation.

There is a subordinate mode of appreciating wildlife among many Chinese which is classified as dominionistic or aesthetic (Harris 2008).[1] This is a positive, but paternalistic attitude toward wildlife. For example, many Chinese view wildlife as something soft and cuddly. This attitude is apparent in propaganda encouraging people to love, learn about, and care for wildlife. One such poster shows a girl holding a tiger cub, an image which resonates among many Chinese. While the idea it represents is unrelated to conservation of wildlife in the wild, it has influenced Chinese wildlife conservation policy. Current policy focuses a large percentage of funds on captive breeding programs to protect wildlife species for future generations within breeding centers (Harris 2008).

[1] Utilitarian, Dominionistic, and Aesthetic views are part of a typology created by Stephen Kellert, a leading scholar of attitudes toward nature.

> *"There is a tendency to view wildlife as something we want to cuddle and take care of as opposed to something we appreciate for its ability to take care of itself in its own natural environment."* –*Richard Harris*

Confucian Optimism and Unity are two concepts prevalent in Chinese society. According to these beliefs, educated citizens can communicate and will eventually come to agreement. Harris views Chinese governance as a reflection of these beliefs. He feels that part of the reason the autocratic system has remained in China is because citizens feel that wise leaders will know what is best for everyone.

These concepts of Confucian Optimism and Unity are also apparent in Chinese wildlife conservation. "Protecting wildlife is really just protecting mankind itself" is a common mantra among wildlife conservationists in China. This reflects the Chinese view that wildlife is beneficial to humans. While this sounds good, it is not necessarily true, except for over very long timescales and very broad geographic areas. Wildlife conservation is fundamentally about compromise between wildlife's needs and humans' demands. In western China, these tensions play out as pastoralists' herds graze on limited grassland resources shared with wildlife and as pastoralists protect their herds from attack by wolves. Wildlife conservation is a balancing act between these two groups. Often their conception of Unity makes Chinese unwilling to admit that wildlife conservation involves allocation of resources to one group at a cost to another.

Pastoralist minority cultures have very different views of nature than Han Chinese. These pastoralist cultures depend on their livestock and the meadows they graze. This direct dependence on natural resources for survival provides a historical and cultural basis for sustainability. Many Americans and Europeans view Tibetan Buddhists as the pristine protectors of nature. While their lifestyle does rely on ecological wisdom, few Tibetan pastoralists are the idealized vegetarians and conservationists that westerners imagine. Quite to the contrary, hunting wildlife, killing of their own herd for food, and use of other natural resources are fundamental aspects of the pastoral livelihood (Huber 1991). There is also a basis for sustainable use among Kazakh and Muslim pastoralists, as the Koran instructs them to use resources wisely and not to overuse.

Figure 6 Grasslands in Gouli, Dulan County, Qinghai

Photo credit: Richard Harris

CHINESE WILDLIFE MANAGEMENT TODAY

The Chinese government has taken many important steps to manage wildlife and its habitat through the implementation of various laws and programs. For instance, the National Wildlife Law of 1988 is the primary law that regulates and provides legal protection to wildlife, and it is popularly quoted in all books on the subject. An extensive network of nature reserves has also been created to protect wildlife habitat, while captive breeding centers have allowed rare species to reproduce in a protected environment. However, these many efforts lack the cohesion and structure which would allow them to function as a unified wildlife management system.

The National Wildlife Law provides two lists of critical species, and killing of these species is strictly prohibited. Scientific use is one exception. However, even in this case it is difficult to obtain a permit. Many have drawn parallels between the two lists of species included in China's National Wildlife Law and those of the U.S. Endangered Species Act. However, Harris sees many differences between the two documents, and believes that any similarities, such as the two lists, are accidental (Harris 2008).

The fact that the law prohibits the killing of any listed species seems to have the best interest of wildlife at heart. However, this uniform ban across all species may in fact have detrimental effects on wildlife. Harris argues that while total prohibition is necessary for species such as a tiger or panda, some species on the lists are abundant enough to tolerate some level of sustainable use. While bans on hunting sound good, they may be a mixed blessing for conservation. By prohibiting use of these relatively abundant species, local people are completely shut off from their traditional use of wildlife and lose their stake in wildlife conservation. The result is a law that tends to disenfranchise local people rather than involve them.

> *"This blanket national ban simply alienates people who have a tradition of using those species." —Richard Harris*

Figure 7 Yeniugou, an important area for Tibetan Plateau wildlife in the Kunlun Mountains

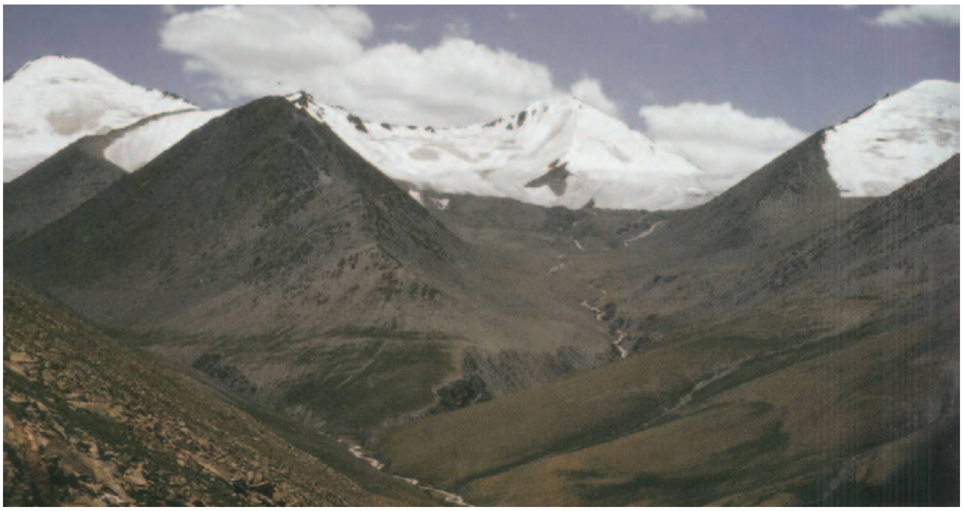


Photo credit: Richard Harris

The National Wildlife Law thus provides some strict regulations. However, it is not accompanied by the resources necessary to create a system of enforcement. For example, the law has no mechanisms to reduce poaching. There is no funding in place for general enforcement, or for a corps of wardens to patrol. Most importantly, the law focuses on protection in the narrow sense and does not have mechanisms for habitat protection.

China's extensive network of nature reserves is another central component of the country's current wildlife management. Currently, an impressive 1.4 million square kilometers of nature reserves account for 15 percent of China's total land area (Harris 2008). However, like the National Wildlife Law of 1988, they lack the structure necessary for management and enforcement of regulations. They have few staff and are severely underfunded. For example, in Qinghai Province, which is twice the size of Montana, there is only a single wildlife biologist (Figures 7 and 8). Others are supposed to address wildlife at the local level, but no funding exists for this work.

While funding is a serious issue for nature reserves today, it is not necessarily the largest impediment to creating a successful management system.

> *"Most people simply view it as a situation that is underfunded or under enforced. I disagree with that. I think there are some fundamental issues that need to be thought about before wildlife conservation, particularly in China's west, will succeed more than it does now." –Richard Harris*

Nature reserves do not form a sufficient foundation for habitat conservation in China's west. This is not because the rules are not sufficiently protective. Paradoxically, it is because they are too protective. This problem stems from the fact that regulations governing nature reserves often fail to take into account on-the-ground realities.

China's nature reserves are structured in a three-tier system. The innermost sanctuaries, called "core zones," do not allow human visitors. While humans are allowed to visit other areas, tourism is only allowed in the outermost "experimental zone." Economic activity that requires extraction of natural resources is forbidden in all nature reserve zones. This restriction effectively forbids people from living within the confines of nature reserves, as the pastoral livelihood is dependent on the land. This mandate becomes a serious problem when taking into account the fact that nature reserves were established only after people had been living in these regions for years. Today, the nature reserve system lacks an effective mechanism for dealing with this clash between strict preservation and existing human inhabitants. To this day, millions of people continue to live within these supposedly strictly protected areas.

Draconian preservation restrictions form a system that is very difficult to enforce. Such extreme regulations confuse managers responsible for enforcement. It is impossible for them to obey regulations without sacrificing the livelihoods of the millions living inside the protected areas. These managers do not have a set of management guidelines to follow that are relevant to their reserves' situations in reality. Harris has observed, "As a result, they ignore the regulations and manage them on an ad hoc basis instead." This leads to complex negotiations between nature reserve authorities and other prevailing systems. On the ground, there is no clear agreement that land inside nature reserves will be managed according to some alternative land management system. Regulations become a continuous compromise. Harris says, "There are two systems. And yet one does not supplant the other, they simply live on top of each other. These two competing mandates, on the one hand limiting human use in favor of nature conservation and on the other economic development, just sit there uncomfortably, one on top of the other." As a result, nature conservation is only a bit better within the reserves than outside of them (Liu et al. 2001). Because the county ultimately has to agree every time a rule is to be enforced, the nature reserve system is fairly weak, despite its enormous size and breadth.

While China's nature reserves protect vast tracts of land, China lacks a comprehensive wildlife protection and management program. Though there are enormous areas that are currently under nature reserve titles, they do not form a true system because there is no common framework among them. This is partly a result of the fact that there is not a comprehensive national nature reserve agency in China, nor is there any other potential analog to the U.S. National Park Service. Thus, there is no national backbone of support for individual reserves. While China's State Environmental Protection Agency plays a nominal role, there is a lack of policy and guidance at the national level. Within individual reserves, there is also no system for drafting a management plan. As a result, most reserves do not have one. Most are the reserves that are in place are underfunded and understaffed with employees who are improperly trained. In many cases, these underpaid staff exploit the resources of the reserves they are supposed to be protecting.

Figure 8 Yeniugou, an important area for Tibetan Plateau wildlife in the Kunlan Mountains, Qinghai. Note Harris' campsite

Photo credit: Richard Harris

THE FUTURE OF WILDLIFE MANAGEMENT IN CHINA

In order to create a successful system of wildlife management in the future, China must recognize and balance the needs of both humans and wildlife. It will need to acknowledge conservation as a way to limit human behavior, which may entail sacrifices for people. Currently, western China views conservation as a biological and technical endeavor, however, much of wildlife conservation is actually about managing humans. To create a successful system of wildlife management, China must increasingly involve local people. There are many ways to do this. For example, allowing subsistence hunts and more local control of trophy hunting would benefit local communities. To take advantage of the potential of China's nature reserve system, regulations should be reformed to allow humans to live within them. Additionally, universities should be encouraged to conduct applied wildlife research. Population studies would allow more knowledgeable management of the reserves. Finally, principles of conservation should be expanded to outside the reserves as well, building a strong foundation for a comprehensive wildlife management system.

> *"While there are biological and technical aspects, I think of wildlife conservation as primarily a human endeavor." –Richard Harris*

Allowing subsistence hunting in China would give local pastoralists a stake in the natural resources of China's west, laying the groundwork for a dialogue about conservation. This would allow local people to continue their traditional lifestyles (Figure 9). It would also lay a foundation for discussing aspects of pastoralist behavior that are hurting certain species, such as argali and wild yaks. At the moment there is no system for sustainable harvests and no hunting is allowed. As a result, there is no one working with wildlife, and local people are not receiving a share in the resources they are being asked to protect. The current system creates unnecessary antagonism, as it is difficult for local people to understand why they should limit themselves in deference to wildlife if they are not receiving anything in return.

Figure 9 Tibetan woman milking a yak

Photo credit: Richard Harris

Figure 10 A small group of blue sheep. An adult female is followed by a lamb, a yearling, and a subadult male

Photograph courtesy of Milo Burcham of Cordova, Alaska

Limited subsistence hunts would allow people to make use of certain species. Blue sheep (Figure 10), for example, are abundant enough to sustain a limited subsistence hunt. Currently there is a fear in China that allowing any hunting at all will lead to complete decimation of all wildlife. Pastoralists would be able to successfully limit themselves if they had a vested interest in wildlife populations. Subsistence hunts would only be allowed for specific species and would be managed within relatively small areas. Within these areas, a biologist could collect information on population sizes and communities would be in communication about how many animals had been taken each year. This would only be possible by a common agreement, under which some communities would have to make sacrifices each year. Harris believes this could be successful because most local people would be happy to have some and to limit themselves.

> *"Of late, the problem is not so much under-regulation as overregulation. Many wildlife species have been put off limits to people for consumptive use to the point where people are alienated. People are seen as the enemy, and they see government as the enemy. There is very little opportunity for community management under the current system." –Richard Harris*

Many factors influence a species' ability to be hunted sustainably. Population density, renewal rate, strength of the indigenous conservation system of limiting resource use, and degree of integration with the market economy all factor into the probability of the hunt leading to sustainability or overharvesting. It is important to consider the multiple dimensions of the problem. For example, chiru now number in the thousands. Some people believe that if poaching were controlled, Tibetans could take some for sustainable use. However, chiru is a migratory species. This means that their range is so large that no single population area can take responsibility for their habitat. Thus, their migratory nature disqualifies them from sustainable use. Musk deer, on the other hand, are a sedentary species. They could be harvested sustainably if a community would take responsibility for their habitat in return for the rights to harvest a few individuals each season.

Figure 11 A group of adult male argali in Yeniugou

Photograph courtesy of Milo Burcham of Cordova, Alaska

Trophy hunting, in which wealthy foreigners come in to kill a large male and take its head home, is another scheme that has the potential to increase local involvement with wildlife. The revenue generated from hunting would be an incentive for communities to protect populations of that single species. In order to save these populations, communities would need to protect wildlife habitat. This would have cascading benefits for other species. In this way, trophy hunting provides indirect incentives for wildlife habitat conservation.

Currently some trophy hunting is allowed in western China, and an international hunter may pay $21,500 for a single argali (Figure 11). However, little of this money makes it to local communities, and as a result the incentive structure is not operating as hoped (Harris and Pletscher 2002). Money is paid to foreign outfitters, import/export taxes, and forestry bureaucracy at the national, provincial, prefecture, and county levels. The only money left for the local hunting authority covers the cost of outfitting the hunt, and very little money is left to compensate people for limiting their behavior.

In the future, trophy hunting systems should be restructured to provide stronger incentives for local people. However, even in its current state, trophy hunting offers the benefit of providing employment that is actively involved with wildlife. People managing hunts tend to love their jobs and become interested in animal preservation.

Harris believes, "At this stage, it is a huge asset to have anyone on the ground whose job is something related to wildlife."

China should be proud of its extensive nature reserves. These areas offer extremely high potential for habitat protection. However, in their current state, the nature reserves do not offer the comprehensive wildlife protection that they might. Currently regulations are unrealistically strict. As a result, enforcement is impossible. If regulations were actually implemented, a large portion of western China would be dispossessed. Thus, reform of nature reserve policies is necessary to make them more reasonable and to provide provisions for humans to live within them. Two different reform scenarios might be effective. One possibility is to adapt regulations to be more realistic and not completely limit humans from living in the areas in which they are already present. The other possibility is to retract boundaries in order to focus on the natural areas where humans are not currently present.

There are several smaller changes that would significantly benefit nature reserves as well. First, it is important to get more people involved with wildlife, both through hunting programs and by working as reserve staff. More people working with wildlife will increase knowledge of and concern for wildlife. Second, greater value should be placed on keeping wildlife wild. A smaller percentage of conservation budgets should be spent on captive breeding centers, and increased emphasis should be placed on protecting habitat and monitoring wild populations. Third, universities should be asked to help with this monitoring task. Currently there is a focus on theoretical research in China. When people begin to ask questions about wildlife populations, applied wildlife research in China will grow.

> *"These changes would build a foundation for consideration of wildlife outside of the nature reserves as well, which ultimately is where we need to go."*
> *–Richard Harris*

In the long run, China's west should aim to make conservation a priority even outside nature reserves. In eastern China, population pressure demands a sharp delineation between what is inside and outside of nature reserves. However, in western China land use is much more extensive, allowing both wildlife and pastoralism to coexist. The ideal wildlife conservation system in western China would place value on wildlife both inside and outside of nature reserves. It would also have strong mechanisms for habitat preservation. This would be possible with a network of core protected areas linked by a matrix of secondary zones, where management plans could be designed to balance human and wildlife needs. With a few key changes, western China has the potential for a highly effective conservation system in which compromises from both humans and wildlife allow them to coexist.

References

Harris, Richard B. 2008. *Wildlife conservation in China: Preserving the habitat of China's wild west.* London: East Gate Books.

Harris, Richard B. and Daniel H. Pletscher. 2002. Incentives toward conservation of argali *Ovis ammon*: A case of trophy hunting in western China. Oryx 36(4): 373-81.

Huber, Toni. 1991. Traditional environmental protectionism in Tibet reconsidered. *Tibet Journal* 16(3): 63-77.

Liu, Jianguo et al. 2001. Ecological degradation in protected areas: The case of Wolong Nature Reserve for giant pandas. Science 292(5514): 98-101.

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Richard Harris is an adjunct associate professor of wildlife conservation at the University of Montana's College of Forestry and Conservation. He also serves as editor-in-chief of *Ursus*, the international scientific journal of bear biology and management. Before beginning his work in western China, Harris worked as a classically trained musician, a computer modeler of wildlife populations, and a caribou biologist in the Alaskan arctic.

Alison Hoyt is a senior at Yale University, pursuing a Bachelor of Science degree in physics and environmental engineering with a concentration in water resources. She hopes to apply her skills to a career in the developing world. At Yale, Engineers Without Borders has allowed her to explore this passion. Along with a team of students and faculty, she designed a water system that is currently being built in rural Cameroon. This year she is studying elementary Chinese. She looks forward to living in China in the future, where full immersion will speed her learning process.

CHAPTER 10

Impact of Increasing Feed and Meat Demand on China's Agriculture and Environment*

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CHAPTER SUMMARY

Chinese agriculture produces a significant amount of food. To address the future challenges that the Chinese agriculture sector may face, a state-of-the-art decision support tool, the Chinagro simulation model, was developed by two EU-funded projects. This chapter applies this model to simulate the supply and demand dynamics of agriculture products and their impacts under several scenarios of farmland and population change, non-agricultural growth, and world food prices. The results of the baseline scenario indicate that China will be able to feed itself with grain, but will need to import meat and livestock feed from the world market to satisfy its new demand for protein. Under this scenario, income disparity between rural and urban people will continue to grow, raising the possibility of social instability. Under an alternative scenario in which China becomes more self-sufficient in meat, China will need to import a higher amount of livestock feed, and farmers will get paid for raising more livestock. The concern for both scenarios is the increasing environmental risks from excessive fertilizer use and possible mishandling of manure. A third scenario shows a choice between economic efficiency and environmental concerns: moving the livestock production from highly populated areas to relatively remote areas will reduce environmental risk but increase the cost of production.

* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on November 10, 2008 by Professor Sun as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Yi Luo, a graduate student in the course, and has been approved by Professor Sun. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Sun, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

BACKGROUND

About ten years ago, when the Chinese population broke the 1 billion mark, the world started to worry about how to feed the Chinese people. It was a reasonable concern, since such a huge population could have created unbearable pressure on the country's agriculture sector, as well as a mammoth amount of demand in the international food market. Fortunately, with good planning and improved technology, starvation did not become an issue.

However, while the rest of the world starts to feel less concerned about food security in China, the Chinese are still worrying. This is because the population is no longer satisfied with being fed by carbohydrates alone. They want protein, or in other words, meat. This creates a new concern: Who will feed Chinese livestock, and how?

In this chapter, we will first provide an overview of the status of the Chinese agricultural sector. Next, we will evaluate scenarios in which China would be able to provide sufficient meat, either domestically or by import, to meet the demand. The tradeoff between producing livestock domestically and importing meat or livestock feed from the international market will be discussed. An objective of this exercise is to quantify the environmental impact of different meat production scenarios. The agricultural sector is labor intensive. Its future changes will have far-reaching impacts on farmers' living standards, and its massive fertilizer use and manure waste production are major environmental concerns.

The assessment provided in this chapter is based on the results of two research projects. The first one is Chinagro, which aimed to provide policy decision support for sustainable adaptation of China's agricultural to globalization. Chinagro was an EU Fifth Framework Program International Scientific Cooperation (INCO) project and ran from October 2001 to January 2005. Team members came from six institutions in China and Europe.

The second project is Catsei (Chinese Agricultural Transition: Trade, Social and Environmental Impacts). This project is supported by the EU Sixth Framework Special Targeted Research Project (STRP) program. It began in January 2007 and will continue through December 2009 (Fischer et al. 2007). Professor Laixiang Sun has served as a leading scientist on both projects. The fact that the same team received back-to-back support from the EU highlights the importance of China's agricultural sector to the global community.

CHINESE AGRICULTURE THEN AND NOW

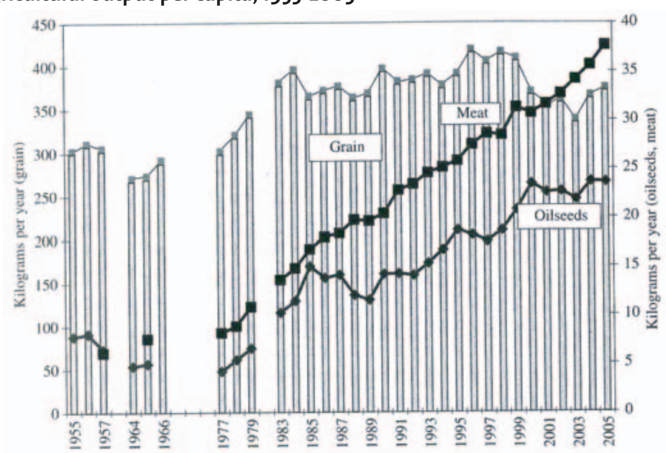
> *Chinese agriculture follows a high input, high output pattern. While its production per hectare is among the highest in the world, its fertilizer and human power input are also among the highest. Therefore, it raises concerns about farmer's income, sustainability of food supply when food prices fluctuate, and the environmental impacts of food production—mainly fertilizer use and manure disposal. –Professor Laixiang Sun*

In China, more than twenty kinds of food crops are cultivated on large scales. The dominant species are rice, wheat, corn, sorghum, soybean, millet, and potato. Of these, rice, wheat, and corn are the three most widely cultivated crops, yielding 86 percent of the whole country's grain production. In 2007, China's grain production was 501.5 million metric tons, equaling about 25 percent of the world's total production (China Statistical Yearbook 2008; Wei 2008).

Except for a few purely pastoral areas, almost all counties in China cultivate cereal crops. However, the different food production portfolios are variable, since soil and climate conditions vary from county to county. The area to the south of the Qinghai-Tibet Plateau (青藏高原), Wulate (内蒙古乌拉特中旗), and Wushen (内蒙古乌审旗) produces 96 percent of China's grain. Each grain species also has its major production regions. In the area to the south of the Qinghai-Tibet Plateau, Qinling Mountain (秦岭), and the Huaihe River (淮河), rice is the major crop. Wheat, rapeseed, soybeans, and peas are also cultivated as winter rotation crops. The multi-cropping index (MCI, a measure of number of crops grown in one year) can reach two or three on a yearly average base in this area. North of the line between the Qinghai-Tibet Plateau, Qinling Mountain, and the Huaihe River, and south of Liaoning Province, winter wheat is the major crop. Corn, millet, potato, peas, and beans are cultivated as secondary crops during the summer. The MCI is 1.0 or 1.5 in this region. In Heilongjiang, Jilin, and Liaoning (黑龙江，吉林，辽宁) provinces, corn, soybean, sorghum, millet and wheat are cultivated in rotation. The MCI is 1.0 in these areas. On the Qinghai-Tibet Plateau itself, the major crops are barley, peas, and spring wheat. The MCI is less than one on the plateau.[1]

Livestock production is another element of the agricultural sector. Historically, both industrialized intensive livestock production and small-scale household backyard livestock production exist in China. In recent years, more and more large-scale production sites have emerged. In 2005, China's official statistics put the total meat production at 69 million metric tons, equal to 25 percent of the world total (China Statistical Yearbook 2008).

Figure 1 Agricultural output per capita, 1955-2005



Source: Naughton 2007[2]

[1] http://www.hudong.com/wiki/中国粮食作物地理

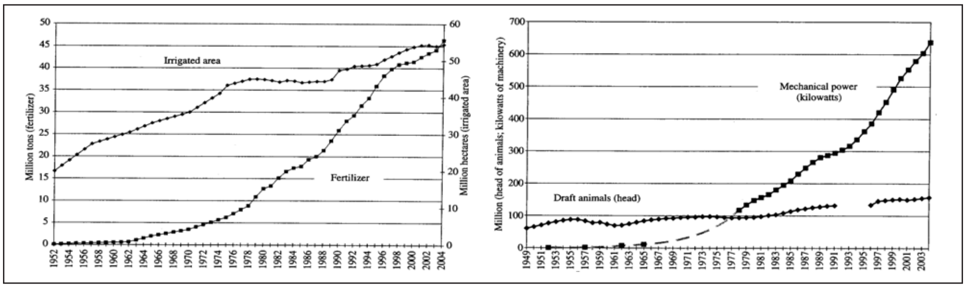
[2] Note: Meat production is measured by carcass weight and represents total production of pork, mutton, and beef. Official meat production data are adjusted downward in accordance with the procedure in Ma et al. (2004).

Figure 1 shows the time trends of agricultural production per capita. Food production, which includes grain and meat, has greatly increased over the past fifty years. Although the increase of China's per capita grain production was not significant and often fluctuated between 300kg/year to 400kg/year, the total amount of grain produced tripled over this period due to the near tripling of the Chinese population from 500 million to 1.3 billion.

Unlike the grain figures, per capita meat production and consumption climbed rapidly during this period. The production was around 6 kg/year in 1955 and rose steadily to 38 kg/year in 2005. Considering the significant population growth from 500 million to 1.3 billion people, the growth of total production and consumption is remarkable. The production of edible oil also shows an impressive growth trend: per capita production grew more than four times, and the total amount produced in 2005 was six times that of 1978 (China Statistical Yearbook 2008).

The growth in China's agricultural productivity was supported by increased use of resources (Figure 2). China's fertilizer use increased rapidly from 1952 to 2004. The national total fertilizer use climbed from virtually zero in the 1950s to 46 million tons in 2004. The amount of irrigated area followed this trend, growing from about 20 million hectares in 1952 to 54.5 million hectares in 2004. Growth in both of these areas led to a significant increase in yield. Additionally, Chinese scientists succeeded in creating high-yield crop varieties by cross-breeding, further enhancing the land's productivity.

Figure 2 Fertilizer use, irrigation, and mechanical power



Source: Naughton 2007

Power input in the Chinese agriculture sector also increased rapidly over the years. Machine power use grew from almost zero in 1949 to 640 million kilowatts of machinery in 2004. Farmers traditionally use machines mainly for irrigation and transportation. However, recently some have started to use them for cultivation, contributing to the improvement in productivity. Use of draft animals grew at a modest rate, from 50 million heads in 1949 to 150 million heads in 2004.

Table 1 shows a comparison of the agricultural input and output among China, the United States, and global averages. China's per hectare crop yield is disproportional to its fertilizer and manpower input, even though it is above the world average. For example, China's rice yield averages 6.2 metric tons per hectare, higher than the world average of 3.9 metric tons per hectare. China's wheat and corn yields are also higher than the world averages. However, these high yields are largely a result of China's huge fertilizer and manpower inputs to farmland. Chinese farmers lead the world in fertilizer application, using 271 kg chemical fertilizers per hectare—three times the amount of the world average, and 2.5 times the U.S. amount. Similarly, China's labor input, as measured in the number of farm workers per 100 hectare, is also very high, at more than 150 times the U.S. level and 4 times the world average. This number is only matched by India, which is also a highly labor-intensive country. China's percentage of irrigation area, a measure of water consumption, is also higher than the world average and the U.S. level. With these numbers, it is reasonable to conclude that the total factor productivity (TFP) of Chinese agriculture is low, that farmers' profit margin is small, and that the pressure on the environment is inevitably greater than in other countries.

Table 1 Comparison of yields and inputs, 1997

	Unit	China	World	US
Production per hectare				
Rice, paddy	Tons	6.2	3.9	7.0
Wheat	Tons	3.7	2.7	2.8
Corn	Tons	4.6	4.3	8.6
Soybeans	Tons	1.7	2.2	2.6
Fertilizer use per hectare	Kilograms	271	94	111
Farm worker per 100 hectare	Number	310	82	2
Land irrigated	Percent	40	18	13
Tractor per 1,000 hectare	Number	7	18	27

Source: Gale 2002

THE CHINAGRO MODEL

Overview

Chinagro is a spatially explicit general equilibrium model that comprehensively depicts China's farm sector in 2,433 counties, while connecting them through trade and transportation flows. The model was first developed in 2002-2005 as a part of an EU-funded Fifth Framework Program project. It was then refined in 2006-2007 under a bridging project funded by the Netherlands Ministry of Agriculture, Nature Management, and Food Quality, and further developed in 2007-09 under a follow-up project funded by the EU in its Sixth Framework Program. Eight institutes have contributed to the development of the model: the International Institute for Applied Systems Analysis, Laxenburg, Austria; the Centre for World Food Studies, Vrije Universiteit, Amsterdam, The Netherlands; the Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing; the Institute for Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing; the China Agricultural University, Beijing; the School of Oriental and African Studies of the University of London, UK; the International Food Policy Research Institute, Washington D.C., USA; and the Agricultural Economics Research Institute, The Hague (Fischer et al. 2007).

The model simulates the interactions between farmers and consumers of agricultural products based on the most plausible assumptions of current and future social, economic, and political situations. It seeks to answer the questions of how farmers allocate labor and other inputs according to changes in food price and how consumers behave in response to a given market situation. On the supply side of the model, parameters for 2,433 counties, or all counties with agricultural production in China, are defined, including land use type, cereal crop cultivated, and livestock production system. On the demand side, consumers are grouped by whether they are from urban or rural areas, as well as by income levels (Van Veen et al. 2005). The model structure is discussed in Keyzer and van Veen (2005). The year 1997, for which a complete data collection is available, is used as the baseline year. The year 2003 is used for validation of the model performance. Scenario simulations are conducted for three selected years (2010, 2020, 2030).

Baseline scenario

In the baseline scenario, the following assumptions are made: First, there will be sustained high economic growth in the non-agricultural sector—in other words, the industry and service sectors—over the next twenty years. The growth is assumed at 6-7.5 percent per year. Second, there will be moderate population growth to a total of 1,460 million in year 2030. Third, urbanization will continue so that 60 percent of the population will live in urban areas in 2030, which will create further land use demands, cause environmental pressures in areas of high population density, and most importantly, move a huge number of people from rural to urban areas. Fourth, there will be a 7 million ha loss of cropland, primarily in regions of rain-fed agriculture, in response to the "Grain to Green" policy. Fifth, technical progress will continue and contribute to a yield increase of 0.5-1.0 percent per year. An increasing number of large livestock farms are anticipated, since the capacity of backyard feeding is anticipated to decline as a large proportion of the rural population moves into cities. Sixth, trade liberalization will continue, including a reduction over time of tariffs and non-tariff barriers, farm taxes will be abolished, and an average subsidy rate of 5 percent to support grain production will be introduced. Finally, the model assumes that world agricultural prices will follow the FAO-OECD projections.

According to the baseline simulation, China will be able to feed itself with grain, vegetables, and fruit, and even export part of its grain production. However, China will have to import feed for its fast-growing livestock production, and eventually import meat. This is because the demand for meat will rise rapidly when people's incomes rise. Furthermore, this increase in income will result in an increase in the cost of labor, which will raise the cost of domestic meat production.

The simulation indicates that in 2030 China will be able to export 3.5 million tons of rice (2.6 percent of its production), 3.9 million tons of wheat (4.5 percent), 12.7 million tons of vegetables (4.6 percent), and 3.0 million tons of fruit (3.9 percent). At the same time, it will need to import 7.3 million tons of pork (12 percent of its demand) and 3.6 million tons of poultry meat (20 percent). It will also need to import 5.8 million tons of maize feed (5 percent), 15.7 million tons of other carbohydrate feed (16 percent), and 30.2 million tons of protein feed (29 percent).

The baseline simulation also calculates an increase in farmers' earnings at 4.0 percent per year for cropping, 5.5 percent per year for livestock, or a combined 4.6 percent per year for all farming activities. These numbers look impressive by the world standard. However, Chinese farmers' incomes will still be below non-agricultural income, which is projected to increase at 6–7 percent per year. Therefore, agricultural income will lag significantly behind non-agricultural income, leading to extended income disparity between farming and non-farming activities. As a result, concerns about the urban-rural income distribution will continue.

Table 2 provides detailed information on projected income changes by land use type. The most noticeable feature is that the value added per person is higher for the livestock sector than for the cropping sector, especially for intensive livestock production.

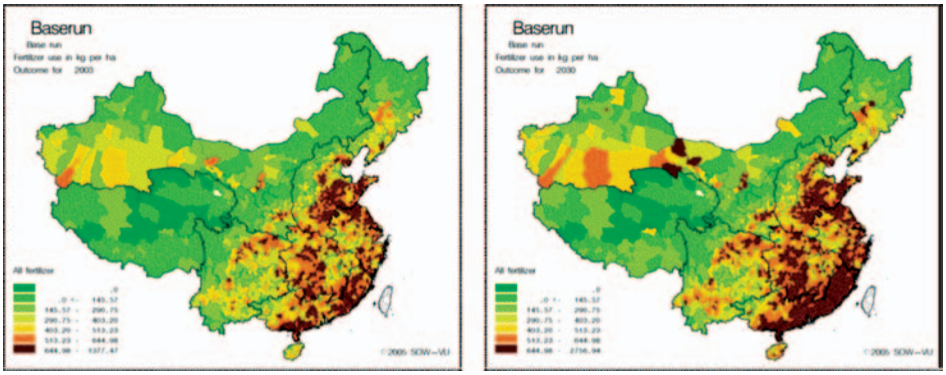
Table 2 Value added per farm worker (in 1997 prices in RMB) by land use type

	1997	2003	2010	2020	2030
Cropping Sector	3820	4127	6552	8632	10584
Irrigated cropping	4135	3863	6893	9157	11237
Rainfed cropping	3244	4231	5997	8041	10040
Tree cropping	5148	6173	7545	8197	9013
Livestock Sector	4028	8578	12841	20968	29800
Draught animal system	-6605	-4939	-5778	-6323	-5813
Grazing ruminant farm	8715	12415	14585	18319	25969
Trad. ruminant farm	544	5462	6104	8621	13924
Intens. dairy farm	24800	25730	24509	25183	26821
Trad. nonruminant farm	5438	8898	12512	18950	24829
Intens. nonruminant farm	14315	21344	28946	42830	56000
Average	3852	4908	7736	11288	15153

Source: Fischer et al. 2007

Another important issue concerns the environmental pressures of the agriculture sector, especially related to intensive fertilizer use and the disposal of manure from livestock production. Since 1981, China has been the largest consumer of fertilizer in the world and has accounted for more than 90 percent of the growth in global fertilizer use (Liu and Diamond 2005). Although it is possible to increase the efficiency of fertilizer use, the demand for fertilizer will be significant in the coming years (Figure 3). In 2003, fertilizer application was already quite high, at an average of 330 kg chemicals and 70 kg organic nutrients per ha. In 2030, it is estimated that China will use 376 kg chemicals and 74 kg organic nutrients per ha. The manure generated from livestock production amounted to approximately 114 kg nutrients per ha of cultivated land in 2003 and will increase to 136 kg in 2030. Figure 3 indicates that areas with high fertilizer use density are usually those with high population density. Similar spatial patterns exist for manure production. The disposal of unused manure and unabsorbed fertilizer will be serious environmental concerns, as they add nutrient pressure in water bodies and increase health risks. In 2003, for example, only 47 percent of the manure was applied to cropland.

Figure 3 Fertilizer use in kg/ha, 2003 and 2030



Alternative scenario

In an alternative scenario, more livestock would be produced domestically than in the baseline scenario. This scenario seeks to address the following question: Would it be better to produce more meat inside China than to import it? In order to answer this question, it is assumed that from 2020 onward, pork and poultry production from large-scale intensive farms will be 30 percent higher than the baseline, specialized dairy production will be 20 percent higher than baseline, and meat ruminant (beef and mutton) sector production will be 10 percent higher than the baseline due to further intensification.

Table 3 summarizes meat and feed imports projected for 2030. According to this alternative scenario, to reduce meat imports, China would need to increase feed imports by a large amount. For example, maize feed imports would rise to 24.6 million tons, or four times the baseline prediction. Other carbohydrate and protein feed imports would be 60 percent higher than the baseline predictions. In order to transport such huge amounts of feed at a reasonable cost, China would need to locate livestock production near the harbor.

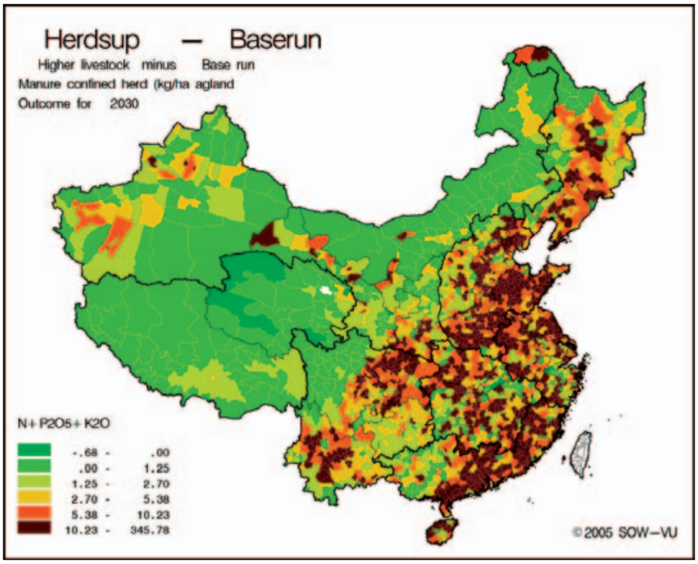
As a result of the enhanced domestic production capacity, meat prices in 2030 would go down somewhat in comparison to the baseline projection and consumers would gain 5 kg more meat per year. However, the average farm value added would stay virtually the same. Income discrepancy between urban and rural areas would still be a critical social problem.

In this alternative scenario, the national average of manure generated per ha would be 3 kg lower than the baseline prediction. This is because the most intensive livestock production would be concentrated in areas close to harbors, and the production would be more efficient due to economies of scale. However, since harbor areas are also highly populated, mishandling of manure can lead to disease and pollution, imposing risks to human health on a larger population. In Figure 4, the red and dark red areas show where manure discharge is more than 10 kg pure nutrition per ha of agricultural land.

Table 3 Meat and feed imports in millions of tons, year 2030

	Baseline scenario	Alternative scenario
Beef, mutton	0.0	0.0
Pork	7.3	2.3
Poultry meat	3.6	1.2
Maize feed	5.8	24.6
Other carbohydrate feed	15.7	23.8
Protein feed	30.2	47.1

Figure 4 Manure discharge in kg/ha, 2030



China faces a tough choice. Importing meat that meets China's demand for protein appears to be more environmentally friendly than importing feed because it leaves the environmental pressures associated with production outside the country. However, it may be risky to rely heavily on the world market when demand would be so high. If China imports feed to raise more livestock domestically, it will improve its self-sufficiency with respect to meat but will increase its dependence upon the world feed market. It will also create livestock "hotspots" near the harbor areas, which would cause health concerns.

SPATIAL LIVESTOCK PRODUCTION PLANNING UNDER RISKS AND UNCERTAINTIES

The tradeoff between the two scenarios prompts us to look more closely at how livestock production should be spatially planned. One important question is whether there are alternatives for locating the livestock production away from harbors. In order to address this issue, new scenarios have been developed to estimate the probabilities. Specifically, we are interested in two scenarios. The first represents a "business as usual" approach of intensification driven by easy access to consumers, and the second is a plausible alternative that may give attention to both economic efficiency and environmental sustainability (Fischer et al. 2009).

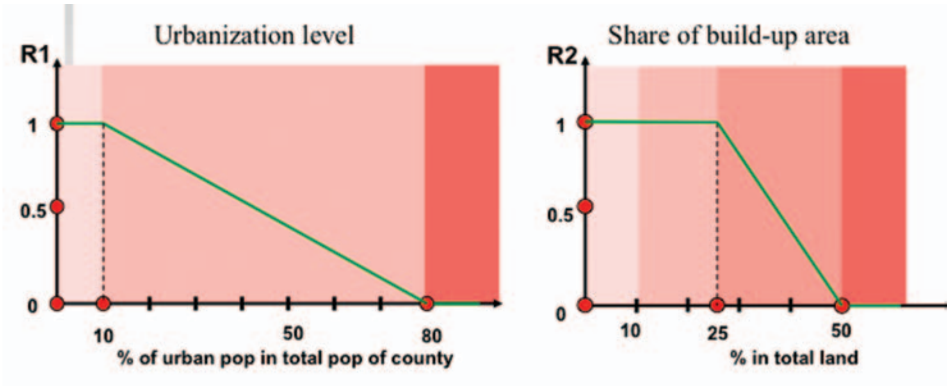
S1. Demand-Driving Scenario: The "business as usual" practice is to allocate intensive livestock production in areas with convenient access to consumers, high demand, and high population density.

S2. Sustainable Scenario: In this scenario, a trade-off is made between pure economic efficiency and environmental risk aversion. The goal is to find a balancing point. To achieve this, socioeconomic, demographic, sustainability, and environmental risk indicators are specified. Location-specific conditions and limitations, such as water and land scarcity, livestock density, and urbanization level are specified as constraints on livestock production. The amount of livestock production in a region is allocated based on the individual "weight" of each indicator of the area. Allocation of livestock beyond the specified constraints may lead to disastrous consequences related to water and air pollution, increasing the chance of either livestock disease outbreak or threats to human health, both of which would incur high costs.

The degree of urbanization and population density are considered critical constraints in this model. For example, it is considered excessively risky to build up intensive livestock sites if more than 80 percent of the county's population is urban, but safe if less then 10 percent of the population is urban. Similarly, if more than 50 percent of the area is built up, meaning that more than half of the land area is already occupied by buildings and roads, it would be excessively risky to practice intensive livestock farming there. However, it would be safe to do so if only 25 percent of the area was already built up. If an area is in between what would typically be considered "safe" and "unsafe," the area's suitability of livestock operation is measured by compromise curves as shown in Figure 5.

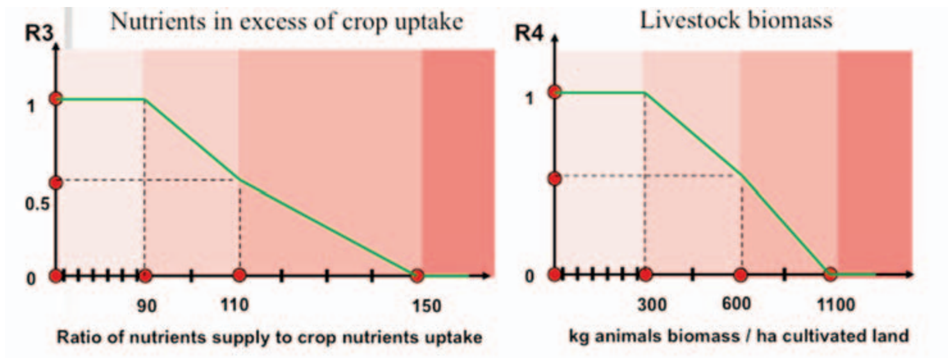
Nutrient level is another critical constraint. Similar to urbanization level, if nutrient supply—mainly fertilizer use—is more than 150 percent of the crop's nutrient uptake, it is considered highly risky. However, if only 90 percent of the needed amount is supplied, it is considered perfectly safe. If 110 percent of the nutrient uptake is applied, the risk is considered moderate, since the soil can also digest some nutrients. Between those numbers, there is a compromise curve as shown in the left panel of Figure 6.

Figure 5 Constraints on intensive livestock production (urbanization). Here R1 and R2 indicate the level of risks for counties with different degrees of urbanization.



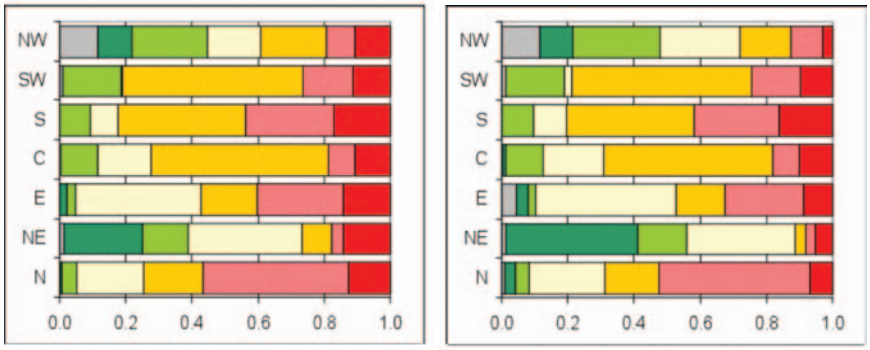
The compromise curve for livestock biomass, the fourth constraint, is shown in the right panel of Figure 6. If more than 1.1 tons of animal biomass is produced per hectare of cultivated land, the model considers the production to be risky. However, 0.3 tons of livestock biomass to per hectare land is considered safe.

Figure 6 Constraints on intensive livestock production (nutrients)



Using the constraint functions defined above, the model generates a comparison between the two scenarios (S1 and S2) with regard to the number of people exposed to different categories of environmental risk. The results are summarized in Figure 7. On the left side is S1, the business as usual scenario. On the right side is S2, the more sustainable scenario, where livestock production plants are moved away from highly populated areas. In the figure, the color scheme is such that the degree of risk increases in the order from grey, dark green, bright green, white, yellow, pink, to red. As demonstrated by Figure 7, in most regions it is not surprising that moving intensive livestock production to remote areas helps reduce the environmental risk. However, in the south, where farmland parcels are populated with nearly equal density, there are fewer choices for livestock production locations. Therefore, moving livestock production sites would not help relieve environmental pressures in all regions.

Figure 7 **Relative distribution of population according to classes of severity of environmental pressure from livestock production in 2030. In color scheme, degree of risk increases in order from grey, dark green, bright green, white, yellow, pink to red.**



CONCLUDING REMARKS

Intensified livestock systems will play a critical role in meeting China's increasing demand for meat in the future. Pig, broiler, and layer stock in intensified systems are expected to increase by at least 2.5 times between 2000 and 2030. The "business as usual" scenario suggests a high correlation between the geographic distribution of animals and population density. Unused animal manure and leaching of chemical fertilizers will imply serious environmental and health hazards. To reduce these hazards, this chapter reports a method for spatially explicit planning of production levels in given locations. The method is based on a rebalancing algorithm and takes into account "weighted" combinations of criteria for sustainable livestock production and intensification.

This research highlights an urgent need for a technological breakthrough in manure management. It calls for a new third generation of biofuel technology. The first generation of biofuel technology relied on maize, beans, and sugar. The second generation uses non-food crops. We hope that the third generation will start to use manure. If manure can be directly converted into biofuel on a large scale, it would be a blessing for China.[3]

[3] Cow and horse manure have been in use by farmers in northern China as a heating source in the winter for many years, but not on a large scale.

REFERENCES

Fischer, G., J. Huang, M. Keyzer, H. Qiu, L. Sun, and W. van Veen. 2007. China's agricultural prospects and challenges: Report on scenario simulations until 2030 with the Chinagro welfare model covering national, regional and county level. Amsterdam, The Netherlands: Centre for World Food Studies, Vrije Universiteit.

Fischer, G., T. Ermolieva, Y. Ermoliev and L. Sun. 2008. Risk-adjusted approaches for planning sustainable agricultural development. *Stochastic Environmental Research and Risk Assessment* 23(4): 441-50.

Gale, F. 2002. China at a glance: A statistical overview of China's food and agriculture. In *China's Food and Agriculture: Issues for the 21st Century*, ed. F. Gale, Washington, DC: USDA Economic Research Service: 5-9.

Keyzer, M. and W. van Veen. 2005. Towards a spatially explicit agricultural policy analysis for China: Specification of the Chinagro models. Working Paper 05-02, SOW-VU. Amsterdam, The Netherlands: Vrije Universiteit.

Liu, J. and J. Diamond. 2005. China's environment in a globalizing world. *Nature* 435: 1179-1186.

Ma, H.Y., J. K. Huang, and S. Rozelle. 2004. Reassessing China's livestock statistics: an analysis of discrepancies and the creation of new data series. *Economic Development and Cultural Change* 52: 445-473.

Naughton, B. 2007. *The Chinese economy: Transitions and growth*. Cambridge, MA: MIT Press.

Van Veen, W., P. Albersen, G. Fischer and L. Sun. 2005. Dataset for the Chinagro welfare model: Structure and composition. Working Paper 05-03, SOW-VU. Amsterdam, The Netherlands: Vrije Universiteit.

Wei, S. 2008. Strengthen sense of responsibility and do a good job in this year's summer harvest credit work. *Grain and Oil Market Report*, May 21.

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CHAPTER 11

Air Pollution Status and Challenges Ahead in the Greater Pearl River Delta Region*

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* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on September 22, 2008 by Professor Chan as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Xin Zhang, a graduate student in the course, and has been approved by Professor Chan. The paper incorporates material from the lecture, the discussion session after the lecture with Professor Chan, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

CHAPTER SUMMARY

This chapter describes current air pollution conditions in the Greater Pearl River Delta (GPRD) region and illustrates how urbanization and industrialization have led to dramatic air quality degradation. In addition, it shows how the long-distance transportation of ozone precursors along the East Asian coast and from the Southeast Asian subcontinent contributes to ozone enhancement in the GPRD. Limited air quality data in the GPRD has become the main obstacle for scientists addressing air pollution problems there. Also, the unclear interpretation of the Air Pollution Index in the Chinese mainland conceals the urgency of these problems from the public.

INTRODUCTION

The Greater Pearl River Delta (GPRD) is located on the southeast coast of China and includes nine cities in Guangdong province (Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Dongguan, Zhongshan, Huizhou, Zhaoqing), Hong Kong, and Macau.[1] The GPRD is one of the most developed regions in China. These nine cities in Guangdong have been recognized as the Pearl River Delta (PRD) economic zone since 1978, and it is now one of the most important manufacturing centers in the

[1] Department of Foreign Trade and Economic Cooperation of Guangdong Province. http://www.thegprd.com/index.asp.

world. From 1980 to 2004, the annual GDP (gross domestic product) growth rate in the PRD was 16.24 percent, which was about 70 percent more than the growth rate of the rest of China.[2] Since the 1970s,[3] Hong Kong has surpassed Shanghai as an international financial center. It now has the second-largest stock market in Asia and ranks eleventh among the world's trading economies.[4] Relying on tourism, Macau's GDP per capita reached $28,436 in 2006, ranking first in the GPRD.[5]

[2] http://www.investhk.gov.hk/pages/1/67.html

[3] http://www.chinavalue.net/Media/Article.aspx?ArticleId=16086

[4] http://www.hketo.ca/abouthk/international.html

[5] http://www.investhk.gov.hk/pages/1/67.html

Along with the growth of GDP, the GPRD has seen substantial increases in population, energy consumption, and the number of vehicles on the road. Within only 42,648 km^2, four major cities—Guangzhou, Shenzhen, Hong Kong, and Macau—coexist with more than 54 million permanent residents and a huge influx of migrants. With the dramatic industrialization and urbanization of the past thirty years, environment degradation in the region is significant. Air pollution, as the most observable and crucial environmental problem in the GPRD region, is a concern for local people, government officials, entrepreneurs, and even the global community. High pollutant concentration and low visibility have been affecting local people's living conditions and health.

These challenges are even more difficult to address because three different governments with separate institutions coexist in the GPRD region: the People's Government of Guangdong Province; the Government of the Macau Special Administrative Region; and the Government of the Hong Kong Special Administrative Region (HKSAR). This unique situation makes the allocation of responsibilities and cooperative policy-making more complex. In addition, increasing emissions in the GPRD are possibly affecting downwind areas over the Pacific Ocean, including the West Coast of the United States, so the GPRD's emissions are a concern for countries far beyond China's borders.

This paper will address the current air pollution status in the GPRD and explore its affiliation with regional and global pollutant emissions. The aim is to provide a comprehensive scientific background for policymakers to address air quality degradation in the GPRD.

AIR POLLUTION STATUS IN GPRD REGION

The air pollution status in the GPRD region is quite complex and very different from most U.S. and European cities. Because the GPRD region has had a relatively short but intensive developmental history, London-type smog problems, mainly caused by coal combustion, and photochemical smog problems, mainly caused by vehicle emissions, coexist in this region (Wang et al. 2005). In addition, industrial emissions, biomass burning, and biogenic emissions in rural areas add more complexity to air pollution control. These conditions make it necessary to research the many reactions among different pollutants while exploring emissions of each pollutant individually.

Particulate matter

Particulate matter is considered to be the most crucial air pollution problem in the GPRD region because of its high concentration and great impact on human health.

Particulate matter has very broad health effects for all populations, but the respiratory and cardiovascular systems are predominantly affected. Finer particles tend to have a stronger impact on health. Particles with diameters less than 10 μm (PM_{10}) can enter the respiratory tract and increase respiratory symptoms and disease, while particles with diameters less than 2.5 μm ($PM_{2.5}$) can more easily penetrate the lungs, decrease lung function, alter lung tissue and structure, and even lead to premature death (Zheng et al. 2000). In the GPRD, $PM_{2.5}$ accounts for a very high percentage of particulate matter, up to 70.4 percent of PM_{10} (Cao et al. 2003).

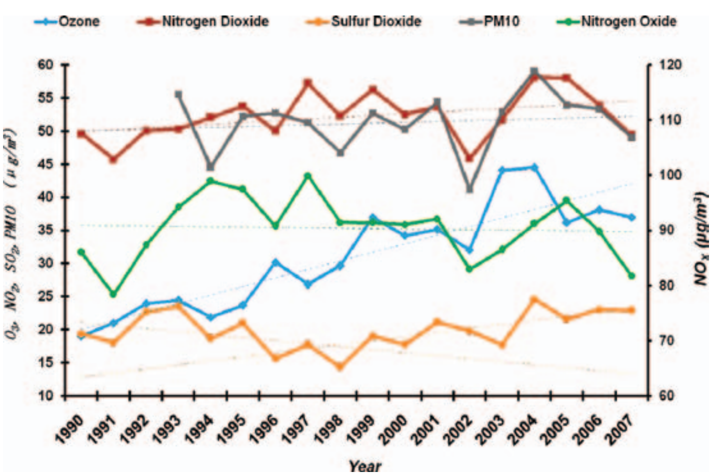
Guangzhou has the one of the highest annual average PM_{10} concentrations in this region, ranging from 73 to 99 μg m^{-3}. Even though this range is below the Chinese National Ambient Air Quality Standard of 100 μg m^{-3} for urban and residential areas, it is still much higher than the standard of 20 μg m^{-3} that is suggested by the World Health Organization's air quality guidelines (AQGs) (WHO 2006). Shenzhen and Hong Kong have lower annual average PM_{10} concentrations—around 50 μg m^{-3}—which are still more than double the concentration suggested by AQGs.

Some components of particulate matter, such as toxic metals, can have great health impacts on humans, but this data is generally not available for the GPRD beyond Hong Kong. While Hong Kong's annual average of toxic metals in PM_{10} was under the safety limits (Lee et al. 1999), more research should be done for the rest of the GPRD region.

Ozone

Since 1990, ozone concentration in Hong Kong has continued to increase (Figure 1), while little data is available for the rest of the GPRD region. In October 1995, daily average ozone concentration exceeded 80 ppbv (parts per billion by volume) for at least five days (Zhang et al. 2008b). The highest hourly ozone average in the GPRD increased from 142 ppbv between October and December 2001 to 179 ppbv between October and November 2004 (Zhang et al. 2008a). In the downwind southern PRD, the 8-hour mean ozone concentration reached 116±16 ppbv in 2004, which is higher than 100 ppvb suggested by the WHO AQGs (WHO 2006).

Figure 1 Trends in major air pollutant concentrations in urban Hong Kong (central/western, 1990-2007)



The year-to-year change in ozone concentration also depends on weather patterns. For example, when rainfall was very low in 2004, ozone concentration soared dramatically. Ozone concentration also has obvious seasonal patterns: fall and spring always have higher ozone concentrations (Wang et al. 1998). Anthropogenic VOCs (volatile organic compounds) and NO_x are also important control factors (Huang et al. 2005), and on-road vehicles and power plants are reported to be the main sources (Chan et al. 2002; Lee et al. 2002).

VOCs

As the precursors of ozone on the ground level, VOCs are critical air pollutants, especially in urban areas (Liu et al. 2008). From 2001 to 2006, the composition of VOCs in the GPRD region changed dramatically: propane concentration increased to nearly 50 percent in both urban (Guangzhou) and rural (Dinghu) areas; isoprene and ethyne decreased by 47 percent and 78 percent, respectively; and benzene concentrations in cities (Guangzhou) reached 20 ppb due to industrial emissions, compared to 16.25 μg m^{-3} (about 5 ppb) by the UK Air Quality Objectives.[6]

[6] http://www.airquality.co.uk/archive/standards.php

The change in VOC composition at different sites provides vital insight into the sources of pollutants. For example, the similar changes in VOC spectrum for urban and roadside atmospheres indicate that VOC emissions in the city are mainly due to fuel combustion in vehicles. VOC composition can further indicate the fuel structure of vehicles: ethylene, acetylene, and other light alkenes are attributed to local emissions from gasoline-powered vehicles, while propane is mainly contributed by Liquefied Petroleum Gas (LPG) fuel (Box 1).

SO_2 and acid rain

Since 1999, few trends could be observed for acid rain in most of the GPRD region. Guangzhou, which is located at the center of the second largest acid rain region of China, has been suffering from frequent and intense acid rain for several decades. From 1999 to 2005, acid rain accounted for 63 to 91 percent of rain days every year, with the annual average pH values ranging from 4.4 to 4.8. The occurrence of acid rain in Hong Kong remains steady, with the annual average pH around 4.6. Acid rain occurrences in Shenzhen have increased from 33 percent in 1999 to 81 percent in 2005, while the annual average pH values have decreased from 5.1 to 4.6 (Chan and Yao 2008). These acid rain events are mainly caused by the oxidation of SO_2, though the ratio of another acidic species, NO_{3-}, has been increasing.

To deal with the acid rain problem, the government of Guangdong province has taken efforts to reduce SO_2 emissions, especially emissions from power plants, which account for 32.9 percent of SO_2 emissions (Wang et al. 2005). An execution plan for de-sulfurizing power plants in Guangdong Province was promoted in 2003, and a slight decrease of SO_2 concentration in Guangdong and Shenzhen was observed in 2005 (Chan and Yao 2008). However, the SO_2 concentration in Guangzhou, 77 μg m^{-3}, was still higher than the Chinese National Ambient Air Quality Standards for urban and residential areas. SO_2 concentration in Shenzhen and Hong Kong are around 27 μg m^{-3}, much lower than the standard.

Box 1: A Lesson from LPG Fuel

In 2003, in order to reduce dust emissions from vehicles and improve urban air quality, the Guangdong government started to encourage replacing diesel light buses and taxis with LPG versions by offering incentives.[a]

With 2 billion RMB invested by the government, LPG was quickly adopted by switching the engines of existing vehicles. By the end of 2007, about 6,400 buses and 16,000 taxis had been changed to use LPG, which accounted for 80% of buses and 100% of taxis in Guangzhou.[b] However, the many problems that came to light during this dramatic change have revealed that LPG is not necessarily an economical, environmental, and safe way to improve urban air quality.[c]

LPG in Guangzhou faces the dual challenge of high economic costs and limited fuel resources. Even though the government has spent a lot on the transition to LPG vehicles and subsidized the LPG fuel price, most of the bus corporations have been suffering from debts since they adopted LPG. In addition, LPG fuel in Guangdong is highly dependent on imports. With the drastic increase of LPG in the vehicle fuel structure from nearly zero percent to 14.2 percent within only five years,[d] pressure will increase on the limited LPG resources, as well as the price.

In addition, without careful design, new engines are not efficient enough to burn all of the LPG. Sometimes the fuel can be seen leaking out of the vehicles. As a result, even though on-street dust has been reduced, propane—one of the reactive VOC species—has been found in increasing amounts, which could potentially lead to even more serious O_3 problems in the region.

[a] Key points of the Pearl River Delta Regional Air Quality Management Plan. www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/files/plan_english.pdf.
[b] http://www.ycwb.com/2008-01/16/content_1757848.htm
[c] http://house.people.com.cn/GB/6779543.html
[d] 2000-2006 Almanac of Guangzhou

Visibility deterioration

Deterioration of visibility in the whole GPRD region is the most observable air pollution problem among the general public. The number of hazy days—visibility less than 10 km and relative humidity less than 80 percent—in Shenzhen has soared from 6 in the 1980s to 164 in 2006. In Hong Kong, the percentage of hours with low visibility—visibility less than 8 km and relative humidity less than 80 percent—has increased from about 4 percent in the 1990s to about 15 percent in 2006. Although the number of hazy days in Guangzhou decreased from 1997 to 2001, the number increased significantly from 65 in 2001 to 144 in 2004 (Wu et al. 2007).

This deterioration is caused by the coexistence of multiple pollutants, which also makes it difficult to determine the key control elements. Extremely hazy days are associated with high concentrations of aerosols, which are the solid or liquid form of particles suspended in the atmosphere (Wu et al. 2007). However, a multiple linear regression analysis, which was conducted to determine the relations between pollutant concentrations and monthly reduced visibility in Hong Kong, shows different results: monthly reduced visibility has little relation with PM_{10}, which is supposed to be the main cause of visibility degradation. Meanwhile, monthly reduced visibility is highly correlated with SO_2 and O_3. Thus, the complex chemical composition of the atmosphere in the GPRD region requires further research to understand the internal mechanisms and determine a control strategy.

EMISSIONS AND AIR POLLUTION: REGIONAL AND GLOBAL

As the variety and emission intensity of air pollutants increase continuously, the impact of emissions is no longer limited to a local area. The long-distance transportation of pollutants and precursors has enlarged the impact radius of local emissions to a regional and even global scale. Consequently, in order to improve air quality in the GPRD effectively, it is not enough to just understand the association between local emissions and pollution conditions. Rather, more attention should be paid to the regional transportation of essential pollutants and precursors.

The Hong Kong paradox

The Hong Kong government has been putting a great deal of effort into controlling regional smog and street-level air pollution, and local emissions of sulfur dioxide, nitrogen dioxide, and PM_{10} have been dramatically reduced (Figure 2). In 1990, annual emissions of SO_2, NO_x, and PM_{10} were about 140,000 tons, 180,000 tons, and 12,200 tons respectively. After sixteen years, the emissions have been reduced to 70,000 tons, 100,000 tons, and 6,000 tons, respectively.

After cutting local emissions almost in half, better air quality should be expected. However, the impact of these drastic reductions was rarely reflected by the local air pollutants concentration (Figure 1). On the contrary, the percentage of poor visibility days even actually increased dramatically since the 1990s (Figure 3). If not local emissions, what is dominating the continuous degradation of air quality in Hong Kong?

Could it be attributed to emissions from Guangdong Province? Though many researchers and Hong Kong citizens complain about this, it is not necessarily true. The GPRD region is dominated by East Asian monsoons, and about 70 percent of the winds in Hong Kong are from the ocean or the northeast part of Guangdong, which is less industrial than the PRD. In fact, the wind blew directly from Guangzhou/Shenzhen—a highly developed region in Guangdong—to Hong Kong for less than ten days out of the year. Thus, even though the airmass from Guangzhou/Shenzhen is full of pollutants, the direct transportation of this dirty airmass to Hong Kong is infrequent.

Figure 2 Trends in pollutant emissions in Hong Kong (1990-2006)

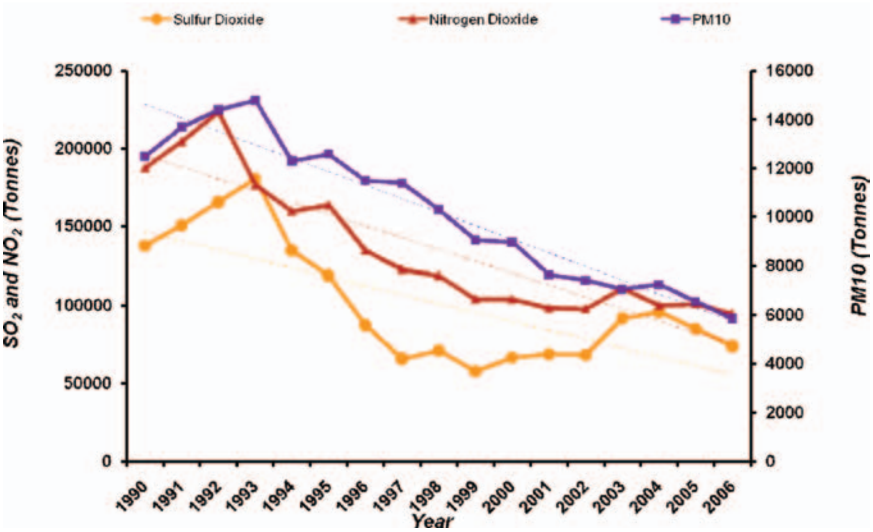
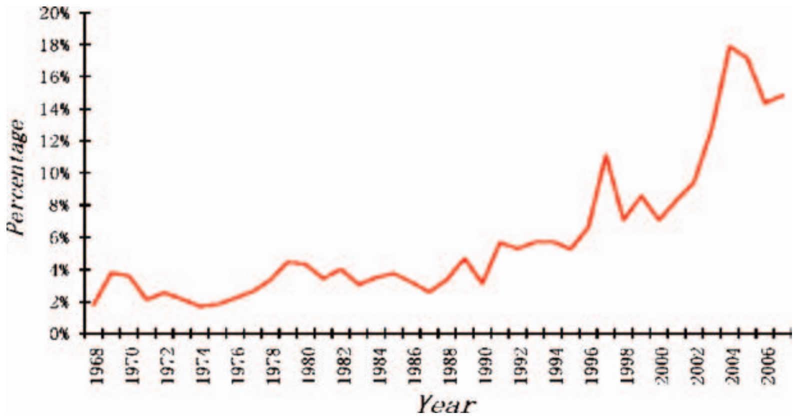


Figure 3 Trends in reduced visibility at the Hong Kong Observatory (1968-2007)



Source: Chan and Yao 2008

> *"In terms of air pollution, if you just conduct local control you will not be successful."*
>
> –John C.Y. Chan

Even if the impact from Guangdong Province is included, the dominant factor for air degradation in Hong Kong is still missing. To identify it, air mass transportation on a continental scale should be considered. With this reasoning, the increasing ozone concentration along the East Asian coast indicates that the impact of emissions from continental scale may be a crucial factor.

Ozone increases along East Asian coast

If the landmass upwind of Hong Kong is considered, all of the East Asian coast could be included in the source area. According to backward trajectory calculations, about 21 percent of the airmass is from the east coast pathway. Correspondingly, obvious increases of ozone concentration along the East Asian coast, such as Taiwan and Japan, have been reported (Chou et al. 2006; Lee et al. 1998). The annual average of daily maximum 1h ozone concentration increased about 2.6 percent yr^{-1} in Taiwan for the period of 1994-2003 and increased 2.5±0.6 percent yr^{-1} at Okinawa, Japan, for the period of 1989-1997 (Chou et al. 2006).

A possible hypothesis is that ozone precursors are transported and accumulate from north to south along the East Asian coast. Under this hypothesis, two factors could be explained: (1) the fastest rate of ozone increase was observed upwind of the GPRD region. This may be caused by the transportation of ozone precursors from the north. (2) when the airmass is transported from north to south, the higher ozone concentration tends to be formed in Hong Kong than that in Taiwan and Japan because of the higher temperature and radiation in Hong Kong.

Biomass burning in Southeast Asia

In Hong Kong, most ozone enhancement cases occur from February to early May, which corresponds to the period when biomass burning is most intensive in Southeast Asia. Biomass burning includes forest fires, grassland fires, agricultural waste burning in the field, and domestic biofuel use for cooking and heating. These fires are often initiated by humans, such as burning vegetation for land clearing, but biomass burning may also start naturally, such as the case of fires induced by lightning.[7]

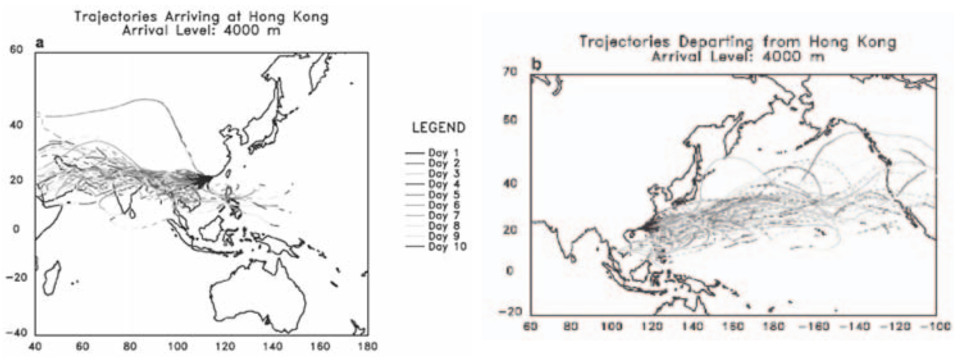
The amount of burning is highly related to the location, season, and human activities. The severity of forest and grassland fires initiated by natural causes is determined by lightning, precipitation, and temperature. Crop residue burning, on the other hand, is determined by agricultural practices (Streets et al. 2003). India, Thailand, Laos, Cambodia and Vietnam are the major contributors of biomass burning in Southeast Asia, and these burning activities show obvious seasonal patterns. For example, in 1998 and 1999, the number of fires gradually increased starting in January, reached a peak in March, and then dropped dramatically in May. This period accounts more than 80 percent of the total fires annually.

During the same period, huge enhancement of ozone and aerosols could be observed in South China, even in the Tengchong, a remote mountain site in Yunnan. In addition, the enrichment of a biomass burning tracer, CH_3Cl, could be observed in the ozone-rich airmass (Chan et al. 2003). The results from a ten-day backward trajectory model show that before reaching the GPRD region, the airmass traveled across Southeast Asia from west to east, passing through regions with intensive biomass burning activities, such as India, Myanmar, and southwest China (Figure 4). Therefore it is believed that ozone enhancement in the GPRD in spring results from the intensive biomass burning activities in the Southeast Asia subcontinent.

[7] http://earthobservatory.nasa.gov/Features/BiomassBurning/

Forward trajectories (Figure 5) also suggest that the emission of air pollutants in GPRD could affect the air quality on the other side of the world in a short time. In fact, pollutants from biomass burning in Southeast Asia, enhanced by local emissions from the GPRD region, can make the journey across the Pacific Ocean and reach North America within ten days. Thus, the transcontinental transportation of air pollutants makes it possible for local emissions to have a drastic impact around the world.

Figure 4 Ten-day (a) backward air trajectories reaching Hong Kong and (b) forward trajectories departing from Hong Kong at 4 km during ozone enhancement events from October 1993 to September 1999



Source: Chan et al. 2003

DATA AVAILABILITY, DATA QUALITY, AND INTERPRETATION

Even though the world has been paying close attention to China's air pollution issues, few people can get access to detailed air quality data. Data availability, as well as data quality, has become the biggest barrier for scientists and the public to understand China's air pollution problems.

The Chinese government has tried to be more open with information on the condition of China's environment, especially since the "Regulation on Government Information Openness" was approved in 2007. Daily air quality forecast data for sixty-nine important cities has been available online since 2005. These forecasts include the maximum and minimum Air Pollution Index (API), primary pollutants, air quality levels according to China's Ambient Air Quality Standards, and descriptions of the "Air Quality Situation."[8] In addition to the data published online, citizens can request more information by submitting application forms to the environmental protection agency within the local or central government, and the agency should respond within fifteen workdays.[9]

Some provincial governments have also launched initiatives to establish regional monitoring networks and publish the results online. In the case of the GPRD, the Guangdong Provincial Environmental Protection Monitoring Centre (GDEMC) and

[8] http://www.sepa.gov.cn/quality/airforecast/air_forecast.php

[9] http://www.gov.cn/flfg/2007-04/20/content_589673.htm

the Environmental Protection Department of the Hong Kong Special Administrative Region (HKEPD) have been working together to establish a PRD Regional Air Quality Monitoring Network since 2003. In this network, sixteen automatic air quality monitoring stations, including three regional stations, measure SO_2, NO_2, O_3, and PM_{10} continuously. The measurements are controlled by a set of quality assurance and quality control (QA/QC) operating procedures developed by the two governments. Monthly maximum and minimum hourly averages for all of the network's monitored pollutants have been reported to the public since 2005.[10]

[10] http://www.gdepb.gov.cn/gsgg/200710/t20071026_49978.html

Box 2: Manufacturers: Move or Stay?

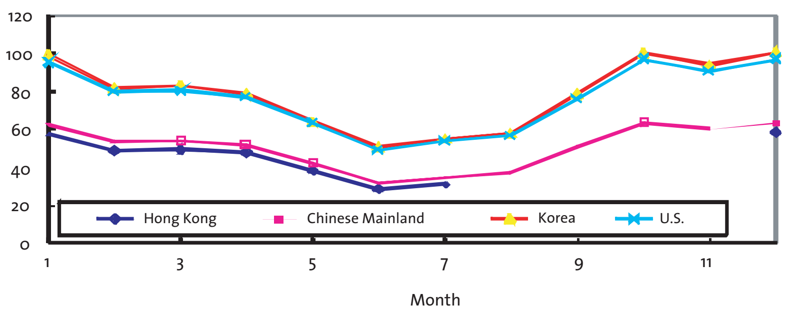
In order to improve air quality in the GPRD, emissions regulations in the region became much tougher than in most parts of China, especially more remote areas such as southwest China. Thus, many heavily polluting manufacturers could not afford to survive in the GPRD and moved to southwest China, where they have been welcomed in order to help with the development of the local economy.

By moving some of the most heavily polluting manufacturers to southwest China, local pollutant emissions within the GPRD could ideally be better controlled. However, the impact of the pollution from those manufactures is far from being eliminated. Through the same pathway demonstrated in Figure 4(a), emissions from southwest China can still affect the air quality in the GPRD. As a result, the situation in the GPRD may actually get worse, since southwest China has a strong desire for a booming economy and little incentive to control pollution, and thus emissions there tend to be much more severe. In addition, as manufacturers are scattered in remote areas, it is becoming more difficult to impose regulations on them.

However, detailed air quality monitoring data is still difficult to access in most parts of China, especially less developed areas. Without the permission of the local and central governments, data related to air pollution cannot be accessed, used, or published. Most of the local governments still treat air quality data as confidential and regulate it strictly. Thus, although more observation sites have be established nationwide, data from these sites still cannot be easily accessed by citizens, scientists, or even the other governments in the region. These restrictions might quell public blame temporarily, but they have killed initiatives and regional cooperation on the air pollution problem. Lack of information makes it very difficult for researchers to find an effective air pollution control strategy, especially in the context of increasing impacts from regional emissions.

Figure 5 Spatial distribution of the PRD Regional Air Quality Monitoring Stations

Figure 6 The monthly variations of PM-API in four different API systems in a general station of Hong Kong (2005-2007)



Most data published online is rough and veils the severity of the air pollution situation in China. For example, API values that are reported are usually not bad at all. Why does China's API provide a better image of China's air quality than what is happening in reality? Two facts are usually overlooked: (1) China has a very different API calculation system from those used in Korea and the United States. With the same air pollutant concentration, the PM-API numbers from different calculation systems do not match (Figure 6). The results from the Chinese mainland and Hong Kong systems are much lower than the results from the American and Korean systems (Figure 6); (2) The interpretation methods of API values in the Chinese mainland are different from those used in Hong Kong and the United States. The interpretation of the API number in the Chinese mainland is called the "Air Quality Situation," with categories such as Excellent, Good, Light Pollution, Low-level Pollution, Severe Pollution, etc. Hong Kong interprets API as "Air Pollution Level," while the United

States interprets it as "Levels of Health Concern." Hence, with an API number between 50-100, the interpretation in the Chinese mainland is that the Air Quality Situation is "good," while the rating would be a "high air pollution level" in Hong Kong and "moderate health concern" in the United States.

Table 1 Interpretations of the API in Hong Kong, the Chinese mainland, and the United States

API system of HK		**API system of Chinese mainland**		**API system of U.S**	
API	Air Pollution Level		Air Quality Situation		Levels of Health Concern
0-25	Low	0-50	Excellent（优）	0-50	Good
26-50	Medium				
51-100	High	51-100	Good（良）	51-100	Moderate
101-200	Very High	101-150	Light pollution（轻微污染）	101-150	Unhealthy for Sensitive Groups
		151-200	Low-level Pollution（轻度污染）	151-200	Unhealthy
201-500	Severe	201-250	Medium-level Pollution（中度污染）	201-300	Very Unhealthy
		251-300	Medium Level-severe Pollution（中度重污		
		301-500	Severe Pollution（重度污染）	301-500	Hazardous

Even if all the air quality data could be accessed freely, the quality of the data is another crucial concern. Because air pollution has not been included in the top issues on most local governments' agendas, and most of the detailed data is concealed from the public, there is little incentive for monitoring stations to stick to or improve quality assurance and quality control operating procedures. In addition to the absence of public oversight, financial support for more advanced equipment and experienced technicians is also urgently needed. In short, the Chinese government still has a long way to go to improve the quality and availability of data for the general public.

> *Technicians are considered "blue collar" workers. Few well-educated people are willing to become a technician for their permanent job.*
>
> –John C.Y. Chan

In closing, though many measures have been taken to tackle air quality degradation, the GPRD region still faces great challenges. How can they provide enough energy for ongoing industrialization and urbanization while preventing the public from exposure to toxic air pollutants? How can they evaluate the impact of local and upwind emissions? How can they collaborate with upwind provinces and countries to limit emissions of ozone precursors? These tough problems still remain in this region.

In order to tackle these challenges, scientists must work closely with governments to build a high-quality, long-term monitoring network, determine the critical areas and pollutants for a cohesive control strategy, and evaluate the appropriateness of control measures proposed by the government. Meanwhile, entrepreneurs, NGOs (non-governmental organizations), and citizens should be encouraged to participate in these efforts. Increasing air quality information transparency should be the first step for the government to move forward.

DISCUSSION

In the lecture, current scientific findings on the air pollution situation in the GPRD were summarized, and some lessons and experiences from previous and current pollution control practices were discussed. The questions of how to make good use of current knowledge and how to move forward to improve air quality in the GPRD region became the key points in the discussion session.

In order to tackle these questions, scientists and policy makers should work together. This cooperation requires efforts from both sides. On one hand, scientists should state the scientific facts clearly and comprehensively to draw the attention of policymakers, while applicable scientific research should be conducted to develop and evaluate solutions. On the other hand, policymakers should learn to live with both the findings and occasional uncertainties of science. Uncertainties are inherent to science and can make science difficult for policymakers to utilize. However, that should not be used as an excuse for denying suggestions for vital policymaking. Strategies with a long-term vision should be made based on risk analysis. Strategies without vision and careful analysis may lead to another situation like the LPG fuel dilemma in Guangzhou. One of the practical ways to encourage cooperation is to have more scientists involved in policymaking procedures.

Public participation should also be encouraged to help with environmental protection. Environmental protection used to be the obligation of the government, but that is no longer the case today. Citizens and corporations have been increasingly affected by environmental degradation. For instance, children's health has been threatened, and real estate corporations have lost customers. In other words, there are many stakeholders besides the government who have an incentive to support and work for environmental protection. They should be used more effectively. Government should gradually increase the transparency of air quality data and policy making procedures to build up public confidence and encourage public participation in decision making.

Finally, regional cooperation is vital because the impact of transboundary transportation has become increasingly important. It is no longer possible to control the degradation of air quality in Hong Kong by restricting local emissions. Although Hong Kong and Guangdong Province have initiated cooperation on air pollution monitoring, there are more challenges ahead for this process in other fields and on a larger scale: (1) For most governments, the priority of air pollution control is still very low, so the incentive for intergovernmental cooperation is not strong enough, unless economic benefits are provided. (2) The obligations of pollution control are difficult to determine. Research on transboundary transportation is still preliminary; reliable and quantitative analysis is expected. At this point, although people are drawing attention to the impact of transboundary pollution, few effective rules have been established. More actions should be taken to foster a more constructive conversation between governments, allowing them to tackle their air pollution issues together.

References

Cao, J.J. et al. 2003. Characteristics of carbonaceous aerosol in Pearl River Delta Region, China during 2001 winter period. *Atmospheric Environment* 37(11): 1451-1460.

Chan, C.K. and X. Yao. 2008. Air pollution in mega cities in China. *Atmospheric Environment* 42(1): 1-42.

Chan, C.Y. et al. 2003. Characteristics of biomass burning emission sources, transport, and chemical speciation in enhanced springtime tropospheric ozone profile over Hong Kong. *Journal of Geophysical Research–Atmospheres* 108(D1)

Chan, C.Y. et al. 2002. Volatile organic compounds in roadside microenvironments of metropolitan Hong Kong. *Atmospheric Environment* 36(12): 2039-2047.

Chou, C.C.K., S.C. Liu, C.Y. Lin, C.J. Shiu, and K.H. Chang. 2006. The trend of surface ozone in Taipei, Taiwan, and its causes: Implications for ozone control strategies. *Atmospheric Environment* 40(21): 3898-3908.

Huang, J.P., J.C.H. Fung, A.K.H. Lau, and Y. Qin. 2005. Numerical simulation and process analysis of typhoon-related ozone episodes in Hong Kong. *Journal of Geophysical Research–Atmospheres* 110(D5).

Lee, E., C.K. Chan, and P. Paatero. 1999. Application of positive matrix factorization in source apportionment of particulate pollutants in Hong Kong. *Atmospheric Environment* 33(19): 3201-3212.

Lee, S., H. Akimoto, H. Nakane, S. Kurnosenko, and Y. Kinjo. 1998. Lower tropospheric ozone trend observed in 1989-1997 at Okinawa, Japan. Geophysical Research Letters 25(10): 1637-1640.

Lee, S.C., M.Y. Chiu, K.F. Ho, S.C. Zou, and X.M. Wang. 2002. Volatile organic compounds (VOCs) in urban atmosphere of Hong Kong. *Chemosphere* 48(3): 375-382.

Liu, Y. et al. 2008. Volatile organic compound (VOC) measurements in the Pearl River Delta (PRD) region, China. *Atmospheric Chemistry and Physics* 8(6): 1531-1545.

Streets, D.G., K.F. Yarber, J.H. Woo, and G.R. Carmichael. 2003. Biomass burning in Asia: Annual and seasonal estimates and atmospheric emissions. *Global Biogeochemical Cycles* 17(4): 20.

Wang, T., K.S. Lam, A.S.Y. Lee, S.W. Pang, and W.S. Tsui. 1998. Meteorological and chemical characteristics of the photochemical ozone episodes observed at Cape D'Aguilar in Hong Kong. Presented at the Fifth International Conference on Atmospheric Science and Applications to Air Quality, American Meteorological Society, Seattle, WA, pp. 1167-1178.

Wang, X.M., G. Carmichael, D.L. Chen, Y.H. Tang, and T.J. Wang. 2005. Impacts of different emission sources on air quality during March 2001 in the Pearl River Delta (PRD) region. *Atmospheric Environment* 39(29): 5227-5241.

World Health Organization. 2006. World Health Organization (WHO) air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Geneva, Switzerland: WHO Press.

Wu, D. et al. 2007. Effect of atmospheric haze on the deterioration of visibility over the Pearl River Delta. *Acta Meteorologica Sinica* 21(2): 215-223.

Zhang, Y.H. et al. 2008a. Regional integrated experiments on air quality over Pearl River Delta 2004 (PRIDE-PRD2004): Overview. *Atmospheric Environment* 42(25): 6157-6173.

Zhang, Y.H. et al. 2008b. Regional ozone pollution and observation-based approach for analyzing ozone-precursor relationship during the PRIDE-PRD2004 campaign. *Atmospheric Environment* 42(25): 6203-6218.

Zheng, M., M. Fang, F. Wang, and K.L. To. 2000. Characterization of the solvent extractable organic compounds in $PM_{2.5}$ aerosols in Hong Kong. *Atmospheric Environment* 34(17): 2691-2702.

Suggested Reading

Andrews, S.Q. 2008. Inconsistencies in air quality metrics: ‘Blue Sky’ days and PM_{10} concentrations in Beijing. *Environmental Research Letters* 3:1-14.

Cai, H., and S.D. Xie. 2007. Estimation of vehicular emission inventories in China from 1980 to 2005. *Atmospheric Environment* 41(39): 8963-8979.

Civic Exchange. Hong Kong and Pearl River Delta Pilot Air Monitoring Project. http://people.ce.gatech.edu/~mhbergin/hk_prd_public/index.htm.

He, L.Y., M. Hu, Y.H. Zhang, X.F. Huang, and T.T. Yao. 2008. Fine particle emissions from on-road vehicles in the Zhujiang Tunnel, China. *Environmental Science & Technology* 42(12): 4461-4466.

Louie, P.K.K. et al. 2005. Seasonal characteristics and regional transport of PM2.5 in Hong Kong. *Atmospheric Environment* 39(9): 1695-1710.

Shan, W.P., Y.Q. Yin, J.D. Zhang, and Y.P. Ding. 2008. Observational study of surface ozone at an urban site in East China. *Atmospheric Research* 89(3): 252-261.

Song, Y. et al. 2008. Identifying dominant sources of respirable suspended particulates in Guangzhou, China. *Environmental Engineering Science* 25(7): 959-968.

Wang, T., C.N. Poon, Y.H. Kwok, and Y.S. Li. 2003. Characterizing the temporal variability and emission patterns of pollution plumes in the Pearl River Delta of China. *Atmospheric Environment* 37(25): 3539-3550.

Wong, C.S.C., X.D. Li, G. Zhang, S.H. Qi, and X.Z. Peng. 2003. Atmospheric deposition of heavy metals in the Pearl River Delta, China. *Atmospheric Environment* 37(6): 767-776.

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CHAPTER 12

Human-induced Drivers of the Development of Lake Taihu*

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CHAPTER SUMMARY

"Shocked" is the best word to describe the reaction of people who come back to Lake Taihu today after visiting years ago. The lake's previous reputation for glorious beauty has been ruined by frequent algal blooms in the summer. Human activities are widely recognized as the most important forces driving this change.

This chapter gives an overview of the main human-induced causes of Lake Taihu's decline. The most radical changes in the lake have occurred during the period from the 1950s to the present. Flood control projects, wetland reclamation and pollution inputs are the three primary causes of the lake's degradation, all resulting from human development. Major management efforts to restore the lake to its pre-1950s condition include algae cleanup, discharge regulations, Yangtze River water transfer, wetland protection and restoration, and demonstration farming zone construction. Thanks to these restoration efforts, recent years have seen some signs of recovery, such as temporary water clarification and reduced risk of flooding. However, scientific understanding of the human and biotic drivers of the lake's eutrophication status is far from comprehensive, and more research needs to be done.

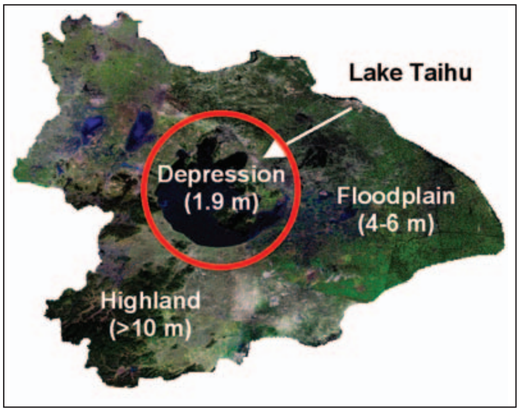
* This paper is based on a lecture presented at the Yale School of Forestry & Environmental Studies on December 1, 2008 by Professor An as part of a graduate course taught by Professor Xuhui Lee entitled "China's Environment." The paper was written by Ranran Wang, a graduate student in the course, and has been approved by Professor An. The paper incorporates material from the lecture, the discussion session after the lecture with Professor An, as well as background material on the lecture topic prepared by the students. For short biographies of the authors, please go to the end of the chapter.

INTRODUCTION

Lake Taihu receives enormous public attention in China. Located in a depression in the center of the Lake Taihu catchment, it is the third largest freshwater lake in China

(Figure 1). The lake is 1.9 m deep on average and has a total surface area as large as 2,425 km^2. The lake catchment is 36,900 km^2 in size, located at the middle to lower reaches of the Yangtze River basin. With a high drainage density (>3 km/km^2), the lake basin produces the huge volume of 16.3×10^8 km^3 water every year. At a distance of 60-100 km from the East China Sea, the catchment is dominated by a subtropical monsoon climate, resulting in a relatively high temperature (annual average 15-17°C) and abundant precipitation (1,180 mm/yr). The basin is made up of highlands (16 percent) in the southwest, floodplains (68 percent) in the northeast and intermittent water areas (16 percent) distributed around the lake.

Figure 1 Topography of Lake Taihu



The Lake Taihu catchment holds a unique place in China's political economy. The basin contains administrative divisions that belong to Jiangsu Province (52.6 percent), Zhejiang Province (32.8 percent), Anhui Province (0.6 percent) and Shanghai City (14 percent) (Figure 2). Accounting for only 0.4 percent of China's land area, the catchment contains 3.7 percent of the country's population and 11.6 percent of its gross domestic product (GDP). GDP per capita in this area exceeded US$8,000 in 2007, over three times the country's average level. Additionally, the catchment's economic yield per unit of land is 57 times the national average.[1] In 2005, the urbanization rate in the lake basin exceeded 70 percent. In the past, the lake has provided multiple services, such as municipal water supplies, fish stocks, irrigation, and tourism. These uses demonstrate that Lake Taihu plays a crucial role in the social and economic development of China.

[1] Taihu Basin Authority, 2007. Taihu Basin & Southeast Rivers Water Resources Bulletin 2007, Ministry of Water Resources

Recent years have seen increased stress on the quantity and quality of water in Lake Taihu. The notorious blue-green algal bloom in the summer of 2008 resulted in serious drinking water shortages in Wuxi City, the most economically developed city in Jiangsu Province, and sounded a loud alarm bell for the government, scientists, and citizens. Two principal natural factors are thought to be responsible for the problem. First, as a result of global warming, the winter of 2007 was unusually warm, failing to kill most of the residual algae left from the preceding summer. In the summer of 2008, the extremely hot weather was ideal for algal growth and hastened the algae's decomposition, the product of which was the direct source of water pollution.

Second, since Lake Taihu is an adlittoral lake (or a shallow water body near the shore), its shallow depth makes the pollution very difficult to diffuse. However, human development, which has resulted in a large amount of agricultural, industrial, and municipal waste discharge, as well as construction that disturbs biochemical cycles in the basin, is an equally important cause of the problem.

Figure 2 Location of Lake Taihu in China

Source: Wikipedia. Revised by Ranran Wang

In this chapter, we will focus on the principal human-induced drivers of Lake Taihu's development. First, in a historical overview, we will briefly discuss the development of human impacts and synchronous conditions at Lake Taihu. This is followed by an examination of the major actions designed to aid in the lake's recovery. In the third part, we will discuss several new problems uncovered in the course of recent lake restoration efforts. Finally, we will propose some suggestions for future improvement.

HUMAN-INDUCED DRIVERS OF THE DEVELOPMENT OF LAKE TAIHU

Before 1 AD

The origin of Lake Taihu is a subject of debate. There are four main hypotheses about the lake's formation and evolution. Inspired by the lake's unique circular basin structure (Figure 1), one hypothesis suggests that the lake was formed by a meteor impact dating back to more than 70,000 years ago (Wang 2002). The second hypothesis holds that Lake Taihu was once a lagoon created by sea-land interactions 6,000 to 3,500 years ago and was then desalinated by freshwater from mountain rivers (Wang et al. 2001). A third hypothesis, based on plate tectonics, proposes that, just like many other great lakes in the world, the basin of Lake Taihu was a result of land subsidence associated with tectonic movement (Sun and Mao 2008). The fourth hypothesis is that the lake was a gathering of three rivers that were blocked at the basin, perhaps due to sea level receding (Sun and Wu 1989).

During this long historical period, several remarkable ancient civilizations emerged in the basin: the Majiabang (马家浜)Culture (7000 BP), the Songzhe (淞泽)Culture (6000-5300 BP) and the Liangzhu (良渚) Culture (5250-4150 BP), followed by an unexplained cultural gap until the Song Dynasty(宋朝)Culture (1048 AD). Characterized by low social productivity, human disturbance in the lake area was negligible during this period. Rather, the lake formation and the subsequent expansion were mainly caused by natural forces.

From 1 AD to the 1950s

Development in this period can be divided into three phases: before the East Han (唐) Dynasty, from the East Han Dynasty to the Tang (唐)Dynasty, and from the Tang Dynasty to the 1950s. These three phases are distinguished by different levels of human development.

Before the East Han Dynasty

During this phase, the Lake Taihu catchment was much less developed than the Yellow River Valley to the north. The primary human activities included primitive reclamation, crude fishery and crude organic agriculture. Towns in the lake area developed at a slow rate. Anthropogenic impacts on Lake Taihu were insignificant.

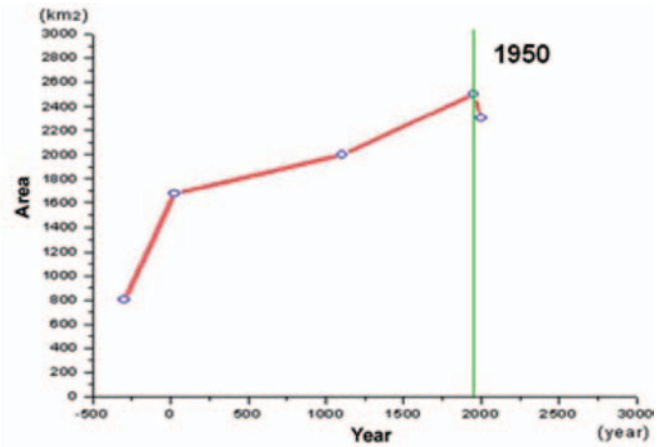
From the East Han to the Tang Dynasty

The first southern migration in the history of China, caused by civil wars, happened at the end of the East Han Dynasty. This big population movement brought both labor forces and advanced technology to the Lake Taihu catchment, and stimulated unprecedented economic development. Numerous towns were built throughout the following 400 years. By the end of the Tang Dynasty, this area had become an important national economic region. In this period, human activities expanded to include extensive land reclamation, organic agriculture, crude fishing and early urbanization. Human influences started to play a role in the lake's development.

From the Tang Dynasty (618 AD) to the 1950s

As national economic development gradually transferred to the south, development in the Lake Taihu catchment experienced rapid growth. Political disorder in the north resulted in China's second and third southern migrations, which further enriched the labor resources in the catchment. Relying on natural advantages (e.g. sufficient water supply) and social advancement, industries like textiles and breweries began to flourish. This period was marked by intensified human activities. Population growth, agricultural reclamation and industrial construction exerted measurable pressure on the lake's development. From the South Song (南宋)Dynasty (1127-1279 AD) onward, the central government prohibited all reclamation for fear of aggravated flood disasters brought on by river blockage, but the burden of an ever-growing population was hard on the land. Thanks to the lake's great natural buffering capacity, however, there was still no record of major environmental havoc caused by humans. Strong wind-driven currents in the lake may have overcome the lake shrinkage due to human reclamation by facilitating shoreline erosion and sedimentation transformation (Pu 1987; Su and Wu 1989). The lake area kept expanding and peaked at 2,550 km2 in 1950 (Figure 3).

Figure 3 Area change of Lake Taihu in the past 2,000 years



Since the 1950s

The abrupt decline of the lake area in the last 50 years occurred in parallel with the degradation of water quality. The local sayings in Table 1 present a lively description of water quality degradation in Lake Taihu. These profound transformations were driven by anthropogenic impacts from three main categories: (1) flood control projects; (2) wetland reclamation; and (3) pollution inputs.

Table 1 Local sayings about water quality degradation in Lake Taihu

Era	Local Saying
1950s	Cleaning rice and vegetables
1960s	Washing clothes
1970s	Becoming dirty
1980s	Losing fish and shrimp
1990s	Causing human injury

Flood control

Flood threats in the Lake Taihu catchment come from two main sources: "plum" rain in June and July, controlled by the Pacific subtropical high pressure system, and hurricanes from August to October originating in the Pacific. Prolonged and intense precipitation can cause waterlogging in the catchment's flat topography. The intrusion of sea tides makes water drainage difficult. Flooding will result in high social and economic costs in this wealthiest area of China. In order to control flood damage over the years, local people have built 20 medium to large reservoirs, 540 km of sea walls and river banks, 270 km of embankment around the lake, 25 dredged riverways, and 28,000 km of polder dikes. Indeed, some benefits have been achieved. For the three largest floods since the 1950s (1954, 1991, and 1999), although the absolute economic cost increased with each flood, the ratio of the economic cost of the floods to GDP actually decreased (Mao 2000). However, these human interventions will eventually disturb the biochemical cycle in the aquatic ecosystem. For example, by blocking the transport of nutrients, dams will result in nutrient accumulation in the lake basin and lead to lake eutrophication, reducing dissolved oxygen (DO) levels and disrupting the fishery. With the waterways blocked by the flood-control structures, populations of migratory fish species such as *Coilia ectenes* and *Anguilla japonica*, as well as semi-migratory fish species such as *Mylopharyngodon piceus* and *Ctenopharyngodon idellus*, will inevitably be reduced.

Wetland reclamation

Wetland reclamation is another contributor to the degraded ecosystem health of Lake Taihu. Known as the kidneys of the earth, wetlands play an important part in ecosystem functioning. Wetlands in the Lake Taihu basin consist of lakes, reservoirs, ponds, rice paddies, and bogs, and account for 65.9 percent of the basin's territory. They serve as habitat for a large number of animal species, including zooplankton (79 species), zoobenthos (59), fish (106), amphibians (9), reptiles (25), mammals (36), birds (173), and hydrophytes (75). They also provide ecological benefits in the form of flood diversion and storage, water clarification, eutrophication prevention, regional climate adjustment, and ecotourism. Since the 1950s, the ever-increasing demand for land, owing to continuous population growth, has led to a large amount of wetland reclamation for farming and building construction. From 1950 to 1985, a total of 160 km^2 lake area was reclaimed. East of Taihu Lake, an area of 3,200 km^2 was utilized for fish breeding even though the quota set by the central government was only 1,000 km^2. These disturbances have resulted in a dramatic species decline. From the 1960s to the 1990s, the number of fish species in Lake Taihu declined from 106 to 60. Additionally, when the wetlands suffered from human reclamation, the lake's capacity for water purification and eutrophication prevention was greatly weakened. The combined effects of flood control projects and wetland reclamation have radically changed the trophic status and fish populations in Lake Taihu over the last 60 years.

Pollution input

Along with the booming human population, which has led to rapid industrialization and urbanization, pollution discharge to the lake has been increasing since the 1950s. During the 1960s and 1970s, the pollution mainly came from farmland fertilizer use and household sewage, in fairly low amounts. Vigorous water circulation provided by strong currents in the lake helped maintain a reasonably high DO level (>7 mg O_2/L) even at the bottom of the lake as measured in the 1970s (Chang 1996). The high DO was able to oxidize much of the organic matter that had entered the lake and keep the lake generally oligotrophic or mesotrophic. It was not until the 1980s that the rate of pollution discharge was considered to be detrimental.

Pollutants emitted by agriculture, industrial facilities, and households in the lake basin have increased substantially since the 1980s. In 2000, 80 percent of the water had been polluted by emissions containing 491,500 t (metric tons) COD (chemical oxidation demand), 14,400 t TP (total phosphorus) and 130,000 t TN (total nitrogen). These effluents are responsible for the lake's drastic change in eutrophication status and the sharp decrease in water quality. Table 2 shows the changes of several biochemical indices for water quality (COD_{Mn}, TN, TP, Chl a, TSI), the water quality index, and trophic states from 1960 to 2005.

Table 2 Water quality and trophic state changes in Lake Taihu

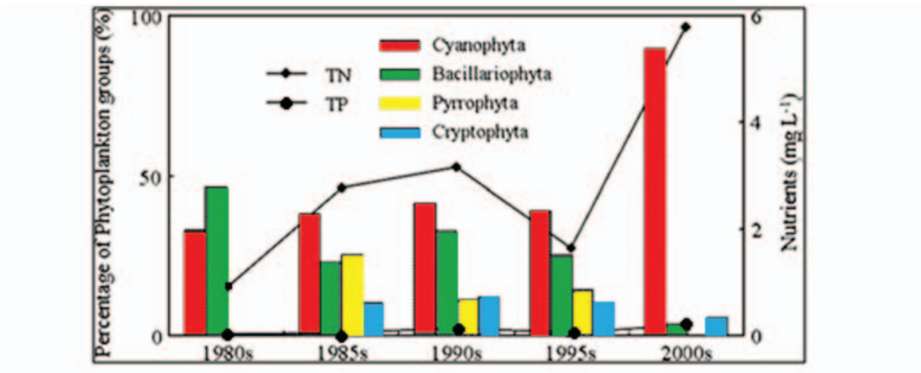
Year	COD_{Mn} mg/L	TN mg/L	TP mg/L	Chl a mg/L	TSI	Water Quality Index	Trophic States
1960	1.90	0.05	0.020	ND	34.97	I-II	Oligotrophic
1981	2.83	0.900	0.020	0.4	43.60	II	Oligotrophic
1987	3.30	1.543	0.029	7.0	54.08	II-III	Mesotrophic
1988	4.20	2.772	0.032	12.0	63.69	II-III	Mesotrophic
1990	3.90	2.349	0.058	43.0	69.05	II-III	Mesotrophic
1992	3.70	2.870	0.080	12.0	66.50	II-III	Mesotrophic
1993	4.05	2.350	0.080	30.0	68.70	III	Eutrophic
1994	4.12	1.730	0.130	13.0	65.13	III	Eutrophic
1995	4.48	3.140	0.133	19.0	71.01	III-IV	Eutrophic
1999	4.99	2.570	0.105	ND	69.61	IV	Eutrophic
2000	5.28	2.540	0.100	23.0	70.01	IV	Eutrophic
2003	4.59	2.850	0.078	14.4	67.60	IV	Eutrophic
2005	4.99	2.950	0.074	10.2	66.92	IV	Eutrophic

1. COD_{Mn}: A measure of the oxygen demand for oxidation of all the organics in solution through the strong oxidizing agent potassium permanganate ($KMnO_4$).
2. TN: A measure of all the forms of nitrogen found in water solution.
3. TP: A measure of all the forms of phosphorus found in water solution.
4. Chl a: C55H72O5N4Mg, an essential molecule in algae for photosynthesis; it is a good indicator of lake primary productivity.
5. TSI: Trophic state index, a measure of water trophic states.
6. Water quality index: Based on the national standard for surface water in China, surface water quality is categorized into 5 classes. With the index running from Class I to V, water quality decreases.

From 1981 to 2005, COD increased from 2.83 to 4.99 mg/L. TN and TP increased to more than three times the original values. Water quality deteriorated from Class II to IV. The trophic state transformed from oligotrophic, meaning relatively low concentrations of plant nutrients and high concentrations of DO, to eutrophic, meaning relatively high concentrations of plant nutrients and low concentrations of DO. All other variables in Table 2 also indicate chemical deteorioration of Lake Taihu in this period.

Biological changes in terms of species composition were also alarming (Figure 4). In the 1980s, when the lake was still oligotrophic, bacillariophyta was the dominant phytoplankton species. Cyanophyta, which has an exceptional capacity for N assimilation, was the second largest group. From 1985 to 1995, when the concentrations of TN and TP greatly increased, the lake's trophic states changed from mesotrophic to eutrophic and cyanophyta replaced bacillariophyta as the principal species.

Figure 4 Variations of phytoplankton species composition with TN and TP increase in the water column of Lake Taihu since the 1980s



Source: Fan, 1996; Li et al. 2006, revised by Ranran Wang

During this period, the population of *cyanophyta* was relatively stable while those of the other three species (*bacillariophyta*, *pyrrophyta*, and *cryptophyta*) fluctuated. So far in the 2000s, the role of *cyanophyta* has been so overwhelming that the other species have almost gone extinct. Now *cyanophyta* is known to be the prime culprit in the eutrophication in Lake Taihu.

Fertilizer overuse in farmland is a major force driving the water quality degradation. In recent years, fertilizer use intensity in the Lake Taihu basin has been 578 kg/km^2, 41 percent higher than the national average. While fertilizer use continues to go up, crop yields only show a moderate increase that is not proportional to the increase in fertilizer use. The excess fertilizer will be carried by runoff into the lake, contributing to the lake eutrophication problem. However, given the importance of agriculture, the pollution impacts of fertilizer use have been ignored by the government.

The water degradation in Lake Taihu also results from mounting releases of industrial and municipal wastes. In the mid-1990s, 0.54 billion m^3 of industrial effluents and 0.32 billion m^3 of municipal effluents were discharged to the basin every year. In 2000, industrial effluents rose to 5.33 billion m^3 and municipal effluents to 3.24 billion m^3. While the decreasing trends of TN, TP, Chl a and TSI since 2000 are a positive sign from restoration efforts (Table 2), the clockwork-like boom of cyanophyta in recent summers reminds us that we are still a long way from fully restoring the health of the lake.

RESTORATION AND MANAGEMENT

Since the establishment of the Taihu Lake Basin Administrative Bureau in 1984, multiple actions have been taken with regard to the lake's management, restoration, and protection. Some of them are more effective than others. In the following section, we will provide a brief summary of these actions.

Action 1: Algae cleanup

Algae cleanup is the most direct way to limit algae spread. In the early years, this was done manually by employing professional salvage crews. Because of the high algae propogation rate, dozens of workers were needed for continuous work every day. In recent years, mechanical salvage boats have replaced the traditional manual labor and thus have sped up the cleanup in some lake areas. Several large-scale mechanical removal methods are in the development stage, which will integrate physical separation with purification by special detergents based on biochemical technologies. If successfully put into use, the removal efficiency will be greatly enhanced. However, it is a challenge to find good places to dispose of the massive amount of algal residue salvaged from the water without causing more pollution in the future. Obviously, algae cleanup cannot cure the root of the problem.

Action 2: Discharge regulation

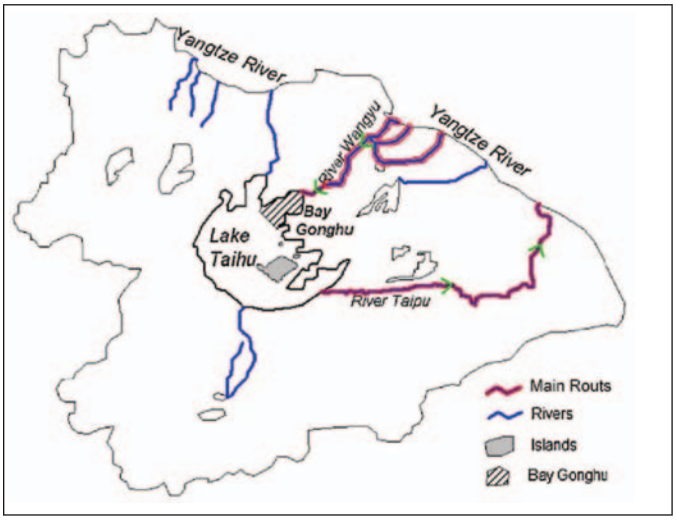
Since the mid-1990s, the State Council and local governments have launched a series of discharge regulations for Lake Taihu. The "Zero o'clock Pass" action called for chemical industries, livestock farmers, hotels, and restaurants along the lake to achieve the national emission standards before midnight on January 1, 1999. Subsequently, local governments launched movements like "Turning the Lake Clean in 2000" and "Shutting Pollution off before the 21st Century." Unfortunately, despite these efforts, the water continues to deteriorate. In 2005, 84.4 percent of water resources in the basin were listed as Category III or worse, and 34 percent of drinking water sources were polluted to varing degrees. In January 2008, the provincial government of Jiangsu put a new set of sewage discharge standards into effect, the toughest ever in China, for sewage treatment plants in the Lake Taihu basin. For plants built before 2008, the regulatory release limit for COD in effluents was changed from 60-120 mg/L to 50-60 mg/L, NH_3-N from 15 mg/L to 5-8 mg/L, and TP from 1 mg/L to 0.5 mg/L. TN was added as a new index, with the regulatory limit of 15-20 mg/L. Sewage treatment plants constructed after 2008 must meet the lower limits of these emission ranges. Once the 169 sewage treatment plants along Lake Taihu have achieved the upgraded standards, it is possible that the COD emission will be reduced by 50 percent, TN by 60 percent and TP by 50 percent.

Action 3: Yangtze River water transfer

This operation uses the existing river channels and flood gates to flush the lake with water from the Yangtze River. It is based on the idea of "conquering the unmoving with the moving, diluting the polluted with the clean, supplementing low flow with ample flow" to improve water quality. Two experimental trials were conducted. In the first trial in 2002, 784.38 million m^3 of water was transferred through five experimental diversions (January 1 to April 3, August 7 to 12, September 26 to October

11, October 19 to 31, and December 5 to 9). In the second trial, 1.109 billion m^3 of water was transferred between August 6 and December 17, 2003 (Hu et al. 2008; Figure 5). Six days after the water transfer in both experiments, notable abatement was seen in the density of phytoplankton and the concentrations of TN and chlorophyll a. However, ten days after the transfer, water conditions returned to their original state. No reduction was ever observed in TP, which is a key determinant of the lake's eutrophication. The limited success of the water transfer operation is a result of sediment re-suspension by scouring and pollutant accumulation in the sediment.

Figure 5 Main routes of water transfer



Source: Hu et al. 2008. Revised by Ranran Wang.

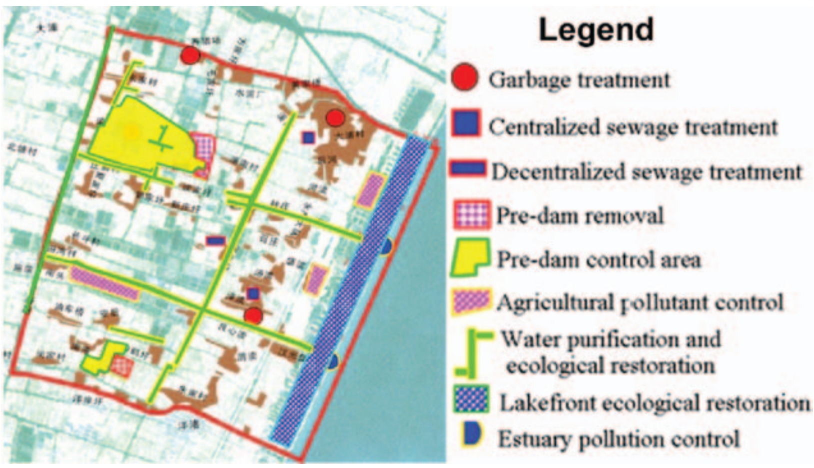
Action 4: Wetland protection and restoration

Natural wetlands, while accounting for only 3.8 percent of land area in China, contribute 54 percent of the total services provided by all natural ecosystems (An et al. 2007). The natural wetlands lost in the past fifty years would have provided the capacity to purify 150 percent of the TN and 60 percent of the TP discharges in China in the year of 2000 (An et al. 2007). In order to improve water quality and rebuild the ecological functions of Lake Taihu, great efforts have been invested in wetland protection, restoration, and construction. According to one scenario constructed by the government for improving Taihu water quality, 14.79 billion RMB will be invested in ecological renovation by the Ministry of Water Resources, a big part of which will be spent directly on wetland protection. The local government also plans to provide funds for wetland construction. In Jiangsu Province, a wetland park in Suzhou City has been built, and a project to build lakefront wetlands is underway around Wuxi City. With a growing awareness of the importance of wetlands, restoration and protection are likely to receive more attention.

Action 5: Demonstration farming zones to control agricultural pollution

Non-point pollution from agricultural activities is a major cause of eutrophication in Lake Taihu. To improve water conditions in the lake, these non-point sources must be carefully controlled. Demonstration farming zones are proving to be an effective way to control this kind of pollution (Figure 6). In these zones, any effluents flowing into the village must go through the "pre-dam control area" and be treated in the "pre-dam removal" facility. Pollutants from agricultural activities, such as fertilizers and pesticides, are treated by the "agricultural pollutant control" facilities around the farmland. Household sewage is delivered into the "decentralized sewage treatment" facility for pre-treatment and then to the "centralized sewage treatment" facility for further treatment. "Garbage treatment" facilities are designed for collection of other domestic wastes. Riverways in the village are protected by the "water purification and ecological restoration" facilities. "Lakefront ecological restoration" and "estuary pollution control" are achieved through physical barriers that prevent pollution from flowing into the lake. These demonstration zones can be found in Jiangsu, Zhejiang, and Anhui Provinces. At present, they are receiving a great deal of attention and support from the government, the scientific community, and the public. Their fate is unclear in the future.

Figure 6 An illustrative map of a demonstration farming zone for controlling non-point agricultural pollution



SUMMARY

The Lake Taihu Basin is one of the most important economic and cultural centers in China. Formed thousands of years ago, the lake has provided for shipping, fisheries, irrigation, drinking water, and tourism for a long period of time (Figure 7). Since the 1950s, human activities have placed a growing stress on the lake's development. Flood control projects, wetland reclamation, and pollution input are the three major human drivers responsible for the lake's degradation. Although huge restoration efforts have been made toward restoring the basin, no obvious recovery has been noticed so far. More research is needed for a complete understanding of the biogeochemical cycles in the basin. Environmental regulations and engineering projects should focus more on the root of the problem by controlling pollution sources rather than focusing on cleanup operations.

Figure 7 The traditional Chinese character "Su" appears in the name of Jiangsu Province where Lake Taihu is located. It depicts a landscape of fish, rice paddy and natural vegetation. Professor Shuqing An hopes that the Taihu Catchment will be restored to this harmonious coexistence of humans and nature.

Calligraphy by Xin Zhang

Primary References

An, S. et al. 2007. China's natural wetlands: Past problems, current status, and future challenges. *Ambio* 36(4): 335-342.

Chang, W.Y. 1996. Major environmental changes since 1950 and the onset of accelerated eutrophication in Taihu Lake, China. *Acta Palaeontologica Sinica* 35(2): 155-174.

Chen, Z., and D.J. Stanley. 1998. Rising sea level on Eastern China's Yangtze Delta. *Journal of Coastal Research* 14(1): 360–366.

Chen, Z., and Z.H. Wang. 1999. Yangtze Delta, China: Taihu lake level variation since 1950s, response to sea-level and human impact. *Environmental Geology* 37(4): 333–339.

Hu, W. et al. 2008. Impacts of the Yangtze River water transfer on the restoration of Lake Taihu. *Ecological Engineering* 34: 10-49.

Mao, R. 2000. Comparison of three heavy floods since 1949 in Taihu Lake Basin and some suggestions on flood control in future. *Journal of Lake Sciences* 12(1): 12-18.

Nanjing Institute of Geography. 1982. *Lakes in Jiangsu Province*. Nanjing, China: Jiangsu Scientific and Technical Publisher.

Pu, P. et al. 1987. Diagnostic analysis of the local wind system over Taihu Lake and its influences on lake current. International Symposium on Lake Taihu and Lake Biwa, Nanjing.

Sun, S. and Y. Huang. 1993. *Taihu Lake*. Beijing: Ocean Publisher Inc.

Sun, S. and R. Mao. 2008. Hydrology and drainage basin. In Boqiang Qin ed. *Lake Taihu, China: Dynamics and Environmental Change*. Springer, New York.

Wang, E. 2002. Discovery and implication of shock metamorphic unloading microfractures in Devonian bedrock of Taihu Lake. Science in China Series D. *Earth Sciences* 45(5): 459-467.

Wang, J. et al. 2001. Taihu Lake, lower Yangtze drainage basin: Evolution, sedimentation rate and the sea level. *Geomorphology* 41: 183-193.

Suggested Sources

Chen, J. 1989. A preliminary research on the regularity and factors of changes of flood and drought in Taihu Lake Basin since the southern Song Dynasty. *Scientia Geographica Sinica* 9(1): 25-33.

Dong, X. et al. 2008. Tracking eutrophication in Taihu Lake using the diatom record: Potential and problems. *Journal of Paleolimnology*, 40: 413-429.

Fan, C. 1996. Historical evolution of water ecological setting in Taihu Lake. *Journal of Lake Sciences* 8(4): 297-304.

Guo, L. 2007. Doing battle with the green monster of Taihu Lake. *Science* 317: 1166.

Huang, Y. 1992. Dynamic cluster analysis and distributions. *Journal of Lake Sciences* 4(2): 73-78.

Huang, W. et al. 2002. Environmental effects of "zero" actions in Taihu Basin. *Journal of Lake Sciences* 14(1): 67-71.

Lai, G. and G. Yu. 2007. A modeling-based assessment study on nutrient transport in Taihu basin during 1960s. *Journal of the Graduate School of the Chinese Academy of Science* 24(6): 756-764.

Le, C. et al. 2008. Spatio-temporal distribution of chlorophyll a concentration and its estimation in Taihu Lake. *Environmental Science* 29(3): 619-626.

Li, J. et al. 2008. Historical eutrophication in Lake Taihu: Evidence from biogenic silica and total phosphorus accumulation in sediments from northern part of Lake Taihu. *Environmental Geology* 55: 1493-1500.

Liu, J. et al. 2007. Complexity of coupled human and natural systems. *Science* 317: 1513-1516.

Liu, Y. et al. 2008. Calculation of contribution value of non-point source pollution of rural refuse in Tai Lake Region. *Journal of Agro-Environment Science* 27(4): 1442-1445.

Lu, Y. and P. Dong. 2005. Central place system of Taihu Basin during the Ming and Qing dynasties. *Acta Geographica Sinica* 60(4): 587-596.

Qin, B. et al. 2002. Water environmental issues in Taihu Lake of China: Problems, causes and management. *Journal of Natural Resources* 17(2): 221-228.

Qin, B. et al. 2006. Estimation of internal nutrient release in large shallow Lake Taihu, China. Science in China Series D. *Earth Sciences* 49 (Supp.): 38-50.

Qu, W. et al. 1997. Record of paleoenvironmental evolution of Taihu Lake in the past 14,000 years. *Journal of Geomechanics* 3(4): 53-61.

Shen, M. et al. 2007. Long-term effects of fertilizer management on crop yields and organic carbon storage of a typical rice-wheat agroecosystem of China. *Biology of Fertile Soils* 44: 187-200.

Yang, M. 2008. Taihu Lake not to blame for Wuxi's woes. *Science* 319: 158.

Yin, L. 2004. The fishery economy of Su-Song-Chang area in the Ming and Qing dynasties. *Agriculture Today and Tomorrow* 2:28-35.

Zhang, H. and B. Wang. 2006. A study of ancient towns in Jiangnan from the perspective of historical geography – six ancient towns in Taihu River basin. *Journal of Hangzhou Teachers College* (Natural Science Edition) 5(1): 61-64.

Zhang, W. et al. 2001. Effect of emission control on water quality of the Taihu Lake. *Rural Eco-Environment* 17(1): 44-47.

Zhao, B. et al. 2007. Climate, vegetation and geomorphology evolution since 8 ka BP recorded by sediments from dish-like depression of Taihu Lake Plain. *Journal of Paleogeography* 9(3): 321-330.

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CHAPTER 13

Synthesis: Ways to Move Forward*

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In this chapter, we wish to synthesize the most important aspects of the semester-long seminar course on China's environment that forms the basis for this book. The course was offered in the fall semester of 2008 at the Yale School of Forestry & Environmental Studies and included public lectures by eleven invited experts as well as discussion sessions with the guest lecturers and Yale students and faculty.

* This chapter was written by Professor Lee with contributions from the student authors of chapters 2-12.

In the course, we discussed a set of diverse and seemingly unconnected topics. Our speakers were asked to deliver their perspectives on the topic of their choice, and not to focus too much on cross-cutting issues. Listening to their lectures, reading their background papers, and interacting with them during reception events, we have gained a tremendous appreciation for the complexity of China's environmental challenges. At the same time, a number of coherent themes have emerged out of the complexity. The purpose of this synthesis exercise is to distill these themes into constructive recommendations, in the hope that they may help policymakers to move forward with China's environmental reform.

POLLUTION DISPERSION: LOCAL INTEREST VERSUS REGIONAL COORDINATION

Protection of local interests occurs in response to various political and regulatory pressures. During the 2008 Olympics, "yellow cars" – cars that were built before 1999 and did not meet the EU1 emissions standards – were kept outside Ring Road 6, in an effort to improve air quality in Beijing. In Guangdong Province, policies that promote the change of its industrial structure toward the service and high tech sectors have caused polluting textile factories to relocate to the less-developed neighboring provinces such as Guangxi. For some factories, relocation to regions with cheaper labor is also a matter of survival as the new labor contract law[1] increases their costs of operation. In the wake of the 2008 Lake Taihu algal boom, the central government shut down thousands of chemical factories in the lake catchment, only

[1] The labor contract law, which went into effect in January 2008, makes it difficult for an employer to terminate employment contracts.

to find that many of them re-opened elsewhere. Because of the lack of national and regional coordination, such instances of pollution dispersion appear widespread.

Pollution dispersion also occurs in subtle ways. The Olympics cleanup efforts involved importing clean natural gas from southwest China. As a result, people in that region were left with dirtier fuels for domestic and industrial use. Clean air in Beijing came at the cost of deteriorated air quality elsewhere.

Pollution dispersion matters because a pollution footprint is not confined to any political boundary. In principle, the performance of government officials is evaluated against not only GDP growth but also emission reductions and energy savings targets, but attention to these environmental goals varies across the country. In the less-developed interior regions, GDP growth still dominates the social and economic agenda, so much so that some county and provincial officials would disregard environmental regulations in order to recruit polluting enterprises. Yet locations that see polluters moving away may not actually enjoy improved environmental quality. For example, relocating textile factories from Guangdong to Guangxi could even degrade the water quality of the Pearl River in Guangdong. This is because with less stringent regulations, these factories can discharge more waste water into the West River, a large tributary of the Pearl River. In the case of air quality management, consideration of the pollution footprint is equally important. Only by shutting down factory operations and tightening road traffic in its neighboring provinces did Beijing see improved air quality during the Olympics (Chapter 7).

Clearly, regional coordination is necessary in order to improve environmental quality. One recommendation we discussed is to utilize industrial parks as an effective solution to the dispersion problem. In these parks, pollution regulation is more stringent, environmental monitoring more comprehensive, and enforcement capacity stronger than if pollution sources were dispersed to remote locations. By confining industries in a small area, recycling of solid waste, heat, and waste water becomes cost-effective (Chapter 6). One downside is that most of the industrial parks in China are located in population centers, so that special attention must be given to human exposure to air pollution.

A second idea we discussed is ranking ecological service zones according to their carrying capacity. Some zones must be protected for water quality and others for wildlife conservation. These ecological attributes determine where pollution sources should be placed. Practicing ecological principles, however, requires holistic thinking beyond one single performance measure. The "Grain-to-Green" program is a successful example of national coordination to protect marginal land in China's west (Chapter 4). The burden of food production is now shifted to more fertile lands in the east, sometimes with unintended consequences. In the Lake Taihu catchment, the pressure to maintain high crop yields means that curbing fertilizer use, which degrades the lake's water quality, becomes difficult (Chapter 12).

SPECIAL EXPERIMENTAL ENVIRONMENTAL ZONE

Progress toward environmental objectives is hampered, in our view, by the mismatch between the simplicity of environmental policies and the complex reality on the ground. Environmental laws in China often lack enforceable details. Policy directives, such as the 11th Five-Year Plan, contain goals that are more aspirational than binding. In the case of wildlife conservation, the blanket ban against hunting may actually hurt conservation objectives because it removes incentives for local people to participate (Chapter 9). As one student puts it, prohibition is easy to legislate, though not necessarily easy to enforce.

One way to move forward is to create special environmental experimental zones (SEEZs). Like the special economic zones that spurred the economic reform in the 1980s, the SEEZs are designed for experimenting with bold, forward-thinking environmental measures. They are test grounds for trying out concrete methods being used in the developed countries for regulation, monitoring, and capacity building. The mindset of learning from experimentation also provides real hope for breaking the ideological gridlock that otherwise would be insurmountable at the national scale. The lessons learned would then propagate from these zones to the rest of the country, much like the way the economic reform policy did in the 1990s. To paraphrase Deng Xiaoping, China would be practicing environmental regulation with Chinese characteristics.

Some environmental experiments are already happening. In ecocities, new technology and concepts are being tested that will minimize resource consumption and waste output (Chapter 6). The trial SO_2 emissions trading program is an attempt to learn from the success of acid rain abatement in the U.S. (Chapter 5). In Shanghai, a new land credit system allows real estate developers to gain development rights if they restore enough degraded wetland elsewhere (Professor Shuqing An, personal communication). One feature that distinguishes the SEEZ from these ongoing experiments is the necessity to think big geographically. Without coordination over a large enough geographic area, ecocities cannot improve the quality of life because they are merely green dots in a landscape inundated with brown smog and fouled by polluted water.

In the spirit of experimentation, we should challenge the widely-held view that it is publicizing the damage of pollution, not the pollution problem itself, that may trigger social unrest. In the SEEZ, efforts should be made to ensure that not only data on environmental quality, but also data on human health, are easily accessible to the general public. Even simple maps of morbidity and mortality, when analyzed together with air and water pollution maps (Chapter 5), can send powerful messages to policymakers and entrepreneurs about the real cost of economic development.

Another experiment for consideration in the SEEZ is to privatize the work related to environmental monitoring. An obstacle in China's environmental reform is the lack of manpower in the State Environmental Protection Agency (SEPA; now Ministry of Environmental Protection, or MEP). As noted by Prof Jianguo Liu[2], SEPA employed only one-eighth the number of workers of the U.S. Environmental Protection Agency even though China's population was three times that of the U.S. The elevation of SEPA to a full ministry has changed the power dynamics, as MEP leaders can now participate in cabinet-level meetings. However, the size of the MEP workforce remains essentially unchanged. Because the government uses a rigid quota system for hiring public servants, a drastic increase in the MEP size is not going to

[2] Jianquo Liu and Jared Diamond (2008). Revolutionizing China's environmental protection. *Science* 319:37-38.

happen anytime soon. In recognition of this reality, private firms should be allowed to shoulder some of the workload. Environmental monitoring is a technical field, with well-defined parameters and technology. It is a good candidate for the privatization experiment.

Forward-thinking should be an important hallmark of the SEEZ. So far, air quality management has focused on sulfur compounds and particulate matter. Ozone and mercury, two other pollutants at the center of regulatory activity in the developed countries, have received little attention. Rather than handling one set of pollutants at a time, policymakers should be encouraged to think beyond the present time frame and anticipate the harm ozone and mercury will continue to cause in the future. Similarly, the SEEZ should lead the way in experimenting with effective strategies for reducing the carbon footprint of economic development (Chapter 8). Experiments of this type could be an impetus for transforming China into a society in true harmony with nature.

ENVIRONMENTAL EDUCATION AND HUMAN RESOURCE DEVELOPMENT

The need to build environmental capacity, especially human resource development, was an issue repeatedly brought up by our guest speakers. Professor Richard Harris offered a sobering example: only one wildlife biologist was engaged in the management of a wildlife reserve in China that is twice the size of Montana (Chapter 9). The reasons for the low capacity are manifold. Wildlife education and research in China are very theoretical and are not well connected to managing wild species in open habitats. More generally, environmental monitoring is a blue-collar, technician's job with low social status and little prospect for career advancement (Chapter 11). In universities and government laboratories, SCI publication[3] counts are an overriding factor in job performance evaluation. People are not rewarded for painstaking work on data collection and on the solution of practical problems.

[3] Publication that appears in the journals cataloged by the science citation index system of ISI Web of Knowledge.

New incentives generated by the privatization experiment discussed above can operate in parallel to the academic performance matrix. They allow market mechanisms to value the service technical people provide to the society.

University education plays a vital role in capacity building. Environmental degree programs in Chinese universities have a relatively short history of ten years or less. They place a strong emphasis on technical training related to some focused aspects of the environment. In comparison, the U.S. environmental programs emphasize rounded education, with a mode of training akin to that of the MBA degree. Students study not only technical skills, but also environmental law and policy, environmental economics, and statistical analysis of environmental data. At graduation, they are knowledgeable about the critical issues concerning pollution, resources, conservation, and environmental regulation, the four pillars of effective environmental management. Such a model of environmental training could be of value for China.

A related, but broader question is whether people with more advanced education will have a smaller environmental footprint. Professor Jianguo Liu made a convincing case that investment in education is a viable solution to making the Wolong Panda

Reserve a better system. This is because with good education, young people in the reserve can find employment elsewhere, thus reducing the pressure on local ecosystems. On larger scales, how education shapes personal consumption habits is poorly known. Quantitative studies are needed to establish evidence that links better education to greener consumption choices.

Several speakers emphasized the increasing role of executive training in capacity building. Tsinghua University, Professor Jimin Hao's home institute, has been collaborating with the Yale School of Forestry & Environmental Studies on an environmental education program targeted at city mayors. Professor Zunyu Chen's university has launched a training program for the municipal government of Shenzhen, to which mandatory attendance is required of its top officials. These speakers believe that executive training is much more effective if social, economic and technical lessons are brought to bear on the analysis of specific cases rather than theoretical lectures on environment 101.

Lake Taihu, the third largest freshwater lake in China, is an excellent candidate for such a case analysis. According to Professor Shuqing An, there are 103 lakes with a size greater than 1 km^2 in the Yangtze River Basin. All but three are now isolated from the Yangtze for flood control, land reclamation, and fish horticulture. By the end of 2009, Lake Puoyang, China's biggest freshwater lake, will likely be blocked by dams. (Lake Dongting, the second largest lake, seems safe at the moment because the nature of the surrounding geography requires that the river water runs though it.) There is an urgent need for local officials and business leaders to learn lessons from Lake Taihu's management so that the ecological problems that have occurred in its catchment are not repeated elsewhere.

INTERNATIONAL COLLABORATION

China's environmental woes are also those of the world. The developed countries are partially responsible for environmental degradation in China: They import factory products from China but leave behind hazardous wastes (Chapter 4). It is also important to note that some of the pollutants are dispersed globally so that their damages are not confined to China's national boundaries. It is imperative that the international community play an active role in helping China meet its environmental challenges.

Mr. Ma Jun's lecture emphasized the unique role of business leaders of multinational companies (Chapter 5). By forming partnership with domestic NGOs, these companies can influence business practice in China. Some of them mandate that their suppliers adhere to stringent international pollution standards. Domestic companies on their own pay less attention to being black-listed on Ma Jun's pollution map, but are more likely to clean up if their polluting behavior is hurting the brand name of the multinational that purchases their products. Over time, this bottom-up pressure should lead to positive changes in Chinese corporate culture.

In our discussion with the speakers, we have identified several barriers to international collaboration that deserve further attention. The first one concerns intellectual property rights. Technology transfer, especially the transfer of green technology, has the potential to produce tempting low-hanging fruit. Although Chinese laws on intellectual property have been streamlined since China joined the WTO, enforcement of these laws is still weak. Strengthened protection will remove the fear of some entrepreneurs that their intellectual property rights may be infringed upon should they use their latest invention in China. It will also stimulate the emergence of new technology that can cope with China's unique situations. For example, there is an urgent need to find ways to dispose of the massive amounts of manure waste being produced by livestock farming. Scientists are challenged to convert the manure to either chemically balanced fertilizer or a new generation of biofuel (Chapter 10). Foreign talents are likely to take on these challenges if they are assured that their research results will be strictly protected.

A second barrier is the lack of transparency in bilateral collaborations. Many government agencies and universities have environmental programs that engage partners in China, but they are not fully informed of what others are doing. The lack of multi-lateral dialogues may stem from the desire to protect trade secrets, or more likely from different incentive structures for their work with China (Chapter 2). We believe that programs that target a specific problem can induce nations to work together. For example, South Korea, Japan and the U.S. all feel the impact of mercury emissions in China. Having this problem orientation should help streamline the incentive structure toward a common goal for these countries.

A shortage of bilingual professionals is identified as the third barrier that hinders international collaboration. In Dr. Gary Waxmonsky's division at the U.S. EPA, fewer than a handful of people are proficient in Chinese. According to Professor Alice Newton, language difficulty is a big obstacle that plagues the direct dialog between small businesses in the EU countries and their Chinese counterparts. She also notes that EU's capacity building efforts bear the legacy of its colonial past: Spanish researchers prefer to work in Mexico and Portuguese scientists in Brazil, in large part because of convenience of communication. Language immersion programs, such as the two-way Erasmus-Mundus where western students receive intensive language training in China, could facilitate better collaboration in the future (Chapter 3).

CHECKS AND BALANCES

The power balance in China's environmental regulation is played out vertically between the central government and those at the provincial and county levels. In western democracies, environmental regulations are negotiated among elected government officials (who represent citizens' concerns), industrial groups, and environmental NGOs[4]. In China, the interests of various actors are intertwined. For example, enterprises in the energy, auto and construction sectors are the backbone of the booming economy and also the main culprit in the smog problem. A majority of these enterprises are state-owned. Some government entities serve the dual role of polluter and pollution regulator. There is little oversight from NGOs and private citizens of how these regulators regulate themselves. Only their superiors in the vertical chain of command have the real power to hold them accountable.

[4] Revesz RL (1997) *Foundations of Environmental Law and Policy*. Foundation Press.

The central government, with good intentions and policies, often relies on environmental incidents as leverage for action. Immediately after the chemical spill in the Songhua River in 2005, the Minister of Environmental Protection was removed from power. The Lake Taihu algal boom cut off water supply to millions of residents in the Wuxi municipality, and more than 3000 chemical plants were shut down. In response to the severe water shortage in the lower reach of the Yellow River, a strict water quota system was enforced in provinces in the upper reach of the river basin[5]. The governmental response is decisive when people's lives are threatened or conditions are causing social unrest.

Environmental degradation differs by degree. If the situation does not reach the point of crisis, it usually does not get attention at the top. Even if it does, the shortage of enforcement manpower does not guarantee prompt action. This is a gap that non-governmental actors can fill. Through streamlining the accessibility of environmental pollution data, NGOs can generate pressure on polluting enterprises and even on local governments (Chapter 5). With the backing of the central government, professional societies, such as the Ecological Society of China, are now taking on the added responsibility of environmental monitoring, auditing and eco-labeling. Scientists, especially prominent ones such as members of the People's Congress and the Science Academy, are playing an important role in the power balance. We have seen good examples: Professor Xu Zhao is a consultant to the government of Shanghai; Professor Jiming Hao played a critical role in shaping the air quality regulations for the Olympics; Professor Zunyu Chen has been organizing environmental training for the government of Shenzhen.

The relationship between NGOs and the government is unique in China. In the opinion of some guest speakers, for these actors to be effective, it is essential that they do not have a hidden agenda, that their motives are in line with the social and economic goals of the central government, and that their actions support rather than undermine the socialist state of governance.

[5] The quota system, together with the "Grain-to-Green" program, produced a successful solution to the trans-boundary water problem. The river stopped running dry about 5 years ago. Jinan, the capital of Shangdong Province located at the end of the river, no longer needs groundwater to meet its water needs. Natural spring fountains – the "spirit of the city" – have returned to numerous tourist attractions in the city.

BIOSKETCH OF AUTHOR

Professor Xuhui Lee 李旭辉 received his undergraduate training at the Nanjing Institute of Meteorology, China (now renamed the Nanjing University of Information, Science and Technology) and his Ph.D. from the University of British Columbia, Canada. He joined the faculty of the Yale School of Forestry & Environmental Studies (F&ES) as an assistant professor in 1994 and was promoted in 2002 to the rank of full professor with tenure. Professor Lee has been the recipient of several awards, including the U. S. National Science Foundation CAREER award, an award for excellence in teaching at the Yale School of Forestry & Environmental Studies, and an award for outstanding young scientist from the Chinese National Science Foundation. In addition to his teaching and research, he serves as the F&ES faculty coordinator for global change science and policy and editor-in-chief of an international journal, *Agricultural and Forest Meteorology*.

第13章 关于中国环境改革的几点思考

Xuhui Lee (李旭辉)[1]

我们就中国环境问题开展了为期一学期的研讨。十一名环境专家应邀到耶鲁大学与师生交流讨论，讨论的一系列问题从表面看来似乎不相关联。专家们自己选择题目，发表观点，而不是过分强调相互交叉的问题。通过他们的演讲、阅读背景文章、并在招待会上与他们进行交流，我们认识到中国环境挑战的复杂性。同时，一些条理分明的主题从这一复杂性中突显出来。本章的目的是将这些主题提炼成建设性意见，希望能对决策者推进中国环境改革有所帮助。

污染扩散：地方利益与区域协调

造成地方利益保护的根源是各种政治和制度的压力：2008年奥运会期间，为了改善北京空气质量，“黄标车”——即1999年前生产没有达到EU1排放标准的车辆——被禁止在六环以内行驶。广东省推出了促进工业向服务业和高新技术产业转变的政策，使得污染较重的纺织业向欠发达的邻近省区（如广西区）转移。由于新劳动合同法提高了运营成本，一些工厂为了生存而向劳动力较便宜的地区转移。[2] 随着2008年太湖蓝藻爆发，政府关闭了流域内几千家化工厂，但是其中很多化工厂又在其它地方重新开工。由于缺乏全国和地区的协调，这类污染扩散的事件普遍发生。

污染扩散还以隐蔽的方式发生。奥运会减排措施之一是从中国西南部引入天然气。结果是，那里的居民和厂家只能用排污重的燃料。有人认为，北京的蓝天是以部分牺牲其它地区的空气质量换来的。

污染扩散之所以重要，是因为污染的影响范围(footprint)并不局限于任何行政边界。原则上，政府官员政绩的评价标准不应只是GDP的增长，还应该包括节能减排目标的实现。但是全国各地对环境保护的关注程度不尽相同。在欠发达的内陆地区，GDP在社会和经济发展的议程中仍占主导地位，这种主导性是如此之强，以致于一些市县和省级官员为了吸引污染企

[1] 肖薇译

[2] 劳动合同法，2008年 1月生效，使得雇主很难终止雇佣合同。

业宁愿忽视环境条例。而那些将污染源移走的地区也不见得能真正享受到环境质量的改善。例如，将纺织厂从广东转移到广西，可能使广东境内的珠江水质更加恶化。这是因为环境管理变得没有那么严格，这些工厂可能会向珠江的一大支流西江排放更多污水。而对于空气质量管理的问题，考虑污染影响范围同样很重要：奥运会期间是因为在邻近省部分关闭工厂和限制车辆的运行，才使北京的空气质量有了很大的改善（第 7章）。

显然，为改善环境质量，区域合作是十分必要的。有一种观点提倡利用工业园区来有效解决污染扩散问题。相对于将污染源分散到边远地区而言，这些园区的污染政策更加严格，环境监测更加全面，执政能力更加强大。将各种工业限制在小范围内，使得固体废物、废热和废水能低成本地回收再利用（第6章）。但不利的方面是中国的大部分工业园区都位于人口中心，所以需要特别关注空气污染对居民健康的影响。

我们讨论的第二个观点是根据生态服务区的承载力将其分级。为了水质要保护一些区域，而为了野生动物要保护另外一些区。这些生态特征决定污染源的安放位置。不过，生态学原则的实施需要超越单一性能的度量，进行整体思考。"退耕还林"计划是国家范围协调的成功范例，对保护西部土地贫瘠的生态系统起了决定性作用（第4章）。但粮食生产的重担被转移到土地肥沃的东部地区，有时会造成出乎意料的结果。在太湖流域，化肥是湖水水质恶化的原因之一，但作物高产的压力使得控制化肥使用变得十分困难（第12章)。

环境试验特区

环境政策的简单性与实际情况的复杂性不匹配，从而阻碍了环境改革的进程。中国的环境法律通常缺乏可执行的细节。政策规划，如"十一五"规划，涵盖的目标号召性强但约束力弱。关于野生动物保护，100%禁猎可能实际上破坏了保护的目标，因为它打消了当地群众参与的积极性（第9章）。正如一位学生所讲的，禁止容易立法，但不见得容易实施。

创建环境试验特区可以打破这种不匹配局面。就像20世纪80年代刺激了经济改革的经济特区一样，环境特区是一个做试验的舞台，旨在对有魄力、前瞻性的环境政策进行试验。在环境特区内，可以引进那些发达国家在环境法规、监测和能力建设中已经采用过的具体方法。做试验就不怕走弯路，也敢于冲破根深蒂固的政治观念和条条框框。这种实验精神在国家范围难以做到，但在小范围可以实现。在特区学习到的经验可推广到其他地区，就像20世纪90年代的经济改革政策从经济特区向外推广一样。按邓小平的说法，中国将进行有中国特色的环境管理。

目前有一些环境试验正在进行中。生态城市正在对一些新技术和新概念进行试验，以达到减少资源利用和污染输出的目的（第6章）。试行SO_2排放交易项目，试图吸取美国控制酸雨的成功经验（第7章）。上海市建立了一个新的土地信用制度，如果房地产开发商在其他地区恢复足够多的退化湿地，他们就可以获得土地开

发的权利（安树青教授，个人交流）。但特区与这些正在进行的试验的区别是必须考虑较大的地理范围。没有足够大的地理区域上的协调，生态城市仅仅是淹没在棕色烟雾中的景观中的绿点而已。

目前被广泛接受的观点是，引起社会不安的因素是对污染危害的曝光，而非污染问题本身。我们应从试验的角度对这一观点提出挑战。在特区内，需要确保公众不仅容易获得环境质量资料，而且还能获得公共健康资料。一张简单的发病率和死亡率的地图，在与空气和水污染地图一起分析时（第5章），就能为决策者和企业家提供强效的信息，使他们认识到经济发展的真正代价。

另外一个特区试验是将环境监测工作私有化。中国环境改革的一大障碍就是国家环保总局（SEPA，现名环境保护部或MEP）的人力资源不足。如刘建国 教授指出的，虽然中国人口是美国的三倍，但是SEPA职员数量仅为美国国家环保局的八分之一。[3] SEPA提升为部级单位使得权利动态有所改变，因为MEP领导可以参加部级会议。但是MEP工作的规模基本没变。由于政府雇佣公务员受名额限制，所以短期内MEP规模不会剧增。面对这一现实，就应该允许私人企业分担一些工作量。环境监测是属于技术领域，监测参数和技术都很规范，很适合进行私有化试验。

超前思维应 该是特区的重要特点。迄今为止，空气质量管理的重点是硫化物和颗粒物。而目前发达国家重点治理的另外两种污染物——臭氧和汞——并没有受到应有的关注。环境治理不应局限于影响API最大的一两种污染物，而应超越当前时间框架进行思考，预先考虑臭氧和汞长久的危害性。另外，在特区内应该率先对减少碳排放的有效策略进行试验。通过这类大胆的尝试，才可能推动中国转型为真正与自然和谐的社会。

环境教育和人力资源发展

应邀的专家反复提到一个问题，就是环境管理能力建设特别是发展人力资源的必要性。Rich Harris教授列举了一个值得深思的例子：在西部一个相当于Montana面积两倍的野生动物保护区，只有一个野生动物学家在从事管理工作（第9章）。人力资源不足的原因很多。中国的野生动物教育和科研还局限于理论上，与野外野生动物管理的实际联系不密切。更普遍的情况是，环境监测是蓝领技术工作，社会地位低，没有升职前景 (第11章)。在大学和政府的实验室中，SCI论文[4]发表数量是工作评估的最重要的指标。数据采集和解决实际问题的辛苦劳动并不能使工作者们获得应有的回报。

上文讨论的私有化试验将产生的新奖励方法，可以弥补与学术绩效评估的不

[3] Jianguo Liu and Jared Diamond (2008) Revolutionizing China's environmental protection. Science 319: 37-38.

[4] ISI Web of Knowledge 科学索引系统收录期刊的论文。

足，用市场机制来评估技术人员对社会的贡献。

大学教育在人力资源建设中起着重要的作用。中国大学的环境学位课程开设的历史相对较短，一般不超过10年。这些课程着重强调专业技术培训。相对而言，美国的环境课程强调全面教育，培养模式类似工商管理(MBA)学位。学生不仅学习技能，还学习环境法律政策、环境经济和环境数据的统计分析等。毕业后，他们对环境管理的四大支柱——污染、资源、生物保护、环境政策——的关键性问题有足够的了解。这种环境管理教育模式对中国是有参考价值的。

有人提出一个与教育有关的问题：是否受教育程度越高的人环境脚印就越小？刘建国教授列举了一个有说服力的例子，表明投资教育是改善卧龙熊猫保护区的切实可行的方法。原因是有了良好的教育，保护区里的年轻人就可以在外地就职，这样就减小了对当地生态系统的压力。在更大的空间尺度上，教育模式如何塑造个人消费习惯还知之甚少。受教育程度是如何影响个人绿色消费行为的问题还需要进行定量化研究。

几位报告人提到了领导培训学习 (executive training) 在能力建设中的重要作用。郝吉明教授所在的清华大学已经与耶鲁大学森林与环境学院合作，面向市长进行环境管理教育。陈尊裕教授所在的中山大学对深圳市政府开展了环境工作培训项目。这些专家认为，更有效的培训方法是通过案例分析社会、经济和技术方面的经验教训，而不是单纯讲授环境科学理论。

太湖就是案例分析的优秀范例。安树青教授指出，长江流域中面积超过1 km^2的湖泊有103个。为了防洪、土地开垦和养鱼业的需要，目前除了3个湖以外，其他所有湖泊都已与长江隔离。2009年末，中国最大的淡水湖鄱阳湖可能会被大坝围堵。（受地理条件的影响，第二大湖洞庭湖目前似乎不会隔离）。迫切需要地方政府和企业领导学习太湖管理的经验，从而避免在太湖流域已经发生的生态问题在其他地方再次发生。

国际合作

中国的环境问题也是世界的问题。发达国家对中国的环境恶化应负部分责任：他们从中国进口工业产品，却把有害垃圾留在中国 (第4章)。另外，一些污染物会在全球扩散，所以其危害并非局限于中国境内。国际社会有义务和必要帮助中国克服环境的挑战。

马军先生强调了跨国公司的独特作用（第5章）。其中一些公司与国内NGO形成合作伙伴关系，在影响中国的商业运作。它们要求其供应商遵守严格的国际污染标准。国内企业自身并不在乎被马军列入污染地图的“黑名单”，但是如果他们的污染行为危害到购买他们产品的跨国公司的品牌，他们就很可能会进行清理改造。长此以往，这种自下而上的压力会引导中国商业文化向积极的方向转变。

在与专家们的讨论中，我们发现几个阻碍国际合作的因素，值得进一步关注。

第一个是知识产权。技术转让，特别是绿色技术转让，可以很快见效。尽管自中国加入WTO以来，中国的知识产权法律已经逐渐完善，但是执法力度仍旧薄弱。一些企业家担心如果将最新的发明转到中国使用，知识产权会受到侵害。如果能加强对知识产权的保护，就可以消除这一顾虑。知识产权的保护也可以激发那些能应对中国特殊情况的新技术开发。例如，目前迫切需要找到方法处理畜牧业产生的大量粪便。能否将粪便转化成成份均衡化肥或新一代生物燃料是一个技术难题（第10章）。如果能确保外国科学家的研究结果被严密保护，他们很可能会迎接这一难题的挑战。

第二个障碍是双边合作缺乏透明度。很多政府机构和大学都有与中国建立合作伙伴关系，但是他们并不完全了解其他人在做什么。缺乏多边对话的原因可能是因为要保护商业机密，但是更可能是因为他们在中国工作的出发点不尽相同。我们认为，以具体问题为中心的合作可以促进多边交流。例如，韩国、日本和美国都受到中国汞排放的影响，这一问题定位可能有助于这些国家互相合作。

阻碍国际合作的第三个因素是缺少精通两种语言的专业人员。在美国环保局Gary Waxmonsky博士工作的部门，只有极少几个人精通汉语。Alice Newton教授指出，语言是个很大的障碍，阻碍了欧盟国家和中国中小企业之间的直接对话。她也指出欧盟的能力建设工作受到其殖民历史的影响：西班牙研究者倾向于在墨西哥工作，葡萄牙研究者倾向于在巴西工作，这很大程度上是为了语言交流的方便。全浸式语言培训可能会推动未来更好的合作。如双向Erasmus-Mundus交流项目中，西方学生可以在中国接受强化语言培训（第3章）。

权利的制约与平衡

中国环境治理中的权利制衡主要是一种中央与地方政府的垂直关系。在西方民主国家，环境法规是由选举产生的政府官员（代表民意）、工业团体和环境NGO互相制约“三位一体”的结果。[5]在中国，权利平衡的参与者们的利益是很难分离的。例如能源、汽车和建筑部门是经济增长的主力，同时也是空气质量恶化的主犯。这些部门的大部分企业属政府所有。一些政府实体扮演着双重角色，既是污染者，又是污染治理者。NGO和老百姓对这些治理者是如何治理他们自己的监控程度有限。只有他们的上级领导才有真正的实权控制他们的行为。

中央政府具有良好的意图和政策，通常将环境事件作为行动的杠杆。2005年松花江化学品溢漏事故后，环境保护部长被立即免职。太湖藻类爆发导致无锡市几百万居民的水供应被切断，超过3000个化工厂被关闭。为了解决黄河下游严重缺水的问题，黄河流域上游的省市被强制执行一套严格的水配额制度。[6]当人民的生

[5] Revesz RL (1997) Foundations of Environmental Law and Policy. Foundation Press.

[6] 与“退耕还林”计划一起，定额制度成功地解决了跨界水问题。几年前黄河不再干涸。位于黄河末端的山东省省会济南市，不再需要地下水来满足用水需求。作为“城市灵魂”的天然泉涌重新出现在很多旅游景点内。

命受到威胁，或问题开始引起社会不安时，政府的反应是十分果断的。

环境退化的程度各有不同。如果情况不够危急，通常很难获得高层的关注。即便得到上层的关注，由于执政人员不足，也很难确保迅速处理。而非政府人员可以填补这一空缺。通过收集公布环境污染资料和促进污染信息交流，NGO可以向污染企业甚至地方政府施压(第5章)。以中央政府为后盾，目前一些专业学会（如中国生态学会）正在负责环境监测、审核和生态标识等工作。科学家们，特别是人大代表和科学院院士等突出科学家，在权利制衡中起着重要作用。我们看到了一些很好的范例：赵旭教授是上海市政府顾问，郝吉明教授在奥运会空气质量治理中起到了关键作用，陈尊裕教授组织了深圳市政府的环境培训课程。

在中国，NGO与政府的关系是很特别的。一些专家认为，NGO要想起到真正的作用，必须满足一些基本条件：他们不应有隐藏行为，动机必须与中央政府的社会经济发展目标一致，他们的工作必须是支持而不是暗中破坏社会主义制度。

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李旭辉 Xuhui Lee本科和硕士毕业于南京气象学院（现更名为南京信息工程大学），1992年获加拿大University of British Columbia大学土壤学博士，1994年进美国耶鲁大学任教，2002年被批准为耶鲁大学终身教授。现任耶鲁大学森林环境学院全球变化事务主任，中国环境问题讲座系列负责人，是国际专业杂志《Agricultural and Forest Meteorology》主编。曾任美国气象学会农林气象学分会主席，耶鲁大学森林环境学院博士学部负责人。获耶鲁大学优秀教师奖，美国自然科学基金CAREER奖，中国自然科学基金海外杰出青年科学家奖，是中国科学院海外评审专家。教学和科研领域包括全球气候变化科学与政策，温室气体循环，空气污染，中国环境政策。

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