Economic Benefits of Energy Efficiency in Developing Countries

David Roland-Holst, Fredrich Kahrl, and Ryan Triolo[1]

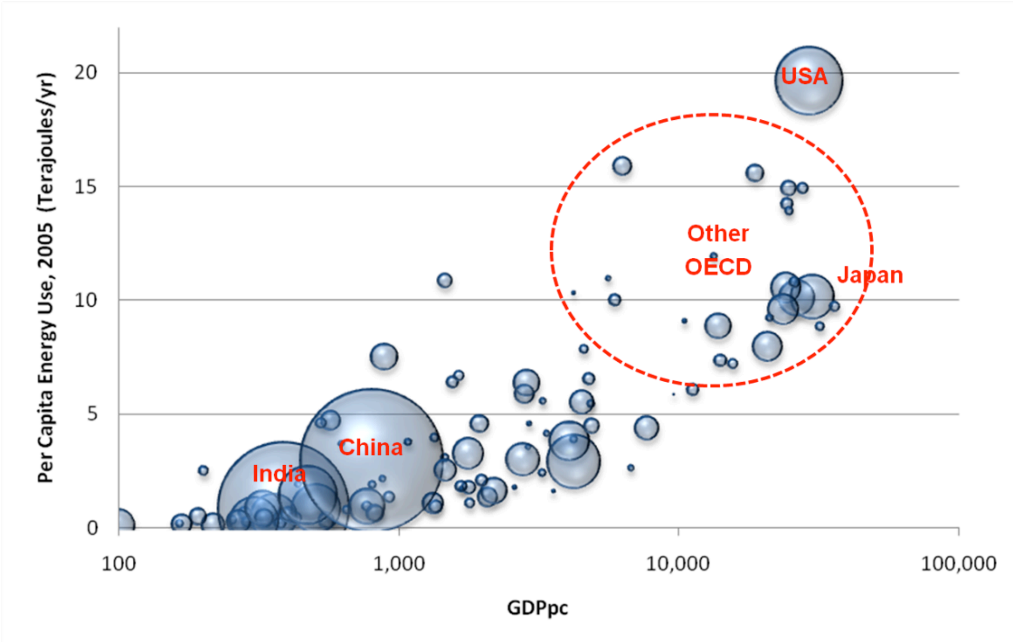
UC Berkeley

1. Introduction

Three centuries since the onset of the industrial revolution have seen carbon fuel energy support living standards unimaginable to earlier generations. Because it is the source of over three quarters of global CO2 emissions, however, the same energy use now poses a serious challenge to economic sustainability and endangers even the modest progress made by the world's poor majority (see Figure 1). Recognition of this has led some to see a necessary trade-off between growth and sustainability, but more dedicated study reveals suggests that innovation and changes in behavior can offer positive approaches. Energy efficiency is such solution, including a rapidly growing variety of enterprise and household technologies that could be widely adopted with the right mix of policy and market conditions.

[1] Department of Agricultural and Resource Economics. Correspondence: dwrh@are.berkeley.edu.

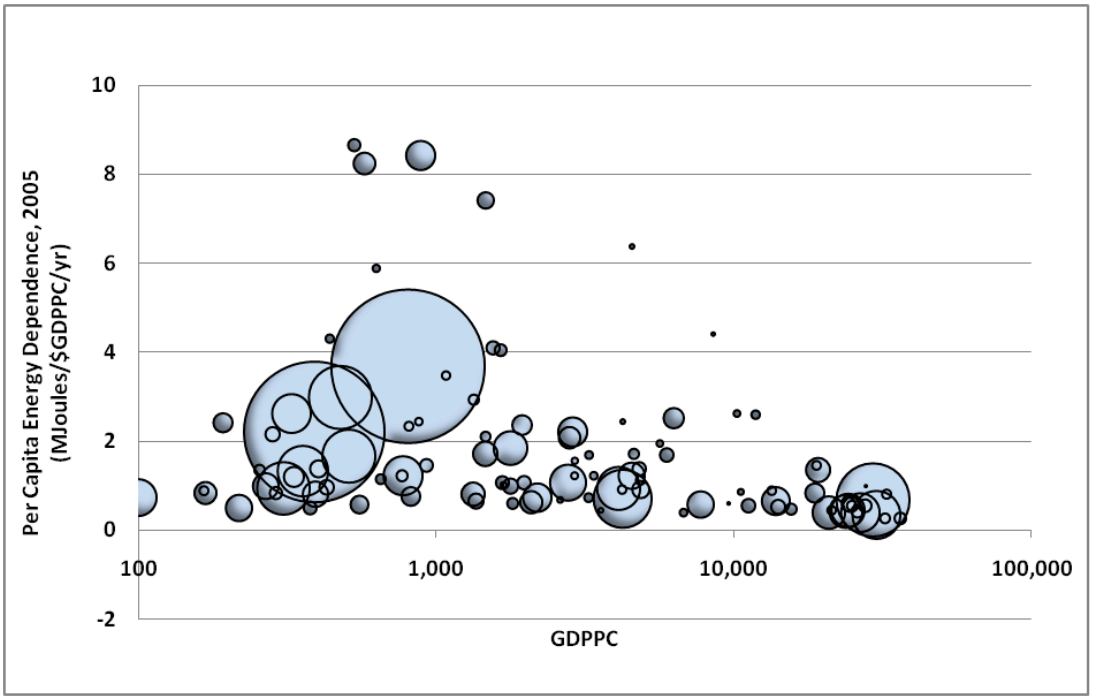
Figure 1: Energy Use per Capita and GDP



Source: Authors estimates from World Bank and IEA data. The horizontal axis is logarithmic, measuring 2005 PPP GDP per capita. Diameter of each bubble is proportional to population.

Energy efficiency offers a direct benefit in the form of carbon mitigation, but many indirect benefits as well. In particular, recent evidence from OECD economies shows how energy efficiency can promote growth as well as sustainability objectives. By saving households and enterprises money, energy efficient technologies can be a potent catalyst for job creation by liberating resources for expenditure outside the carbon fuel supply chain. Expenditure diversion of this kind is likely to be much more employment intensive, and for economies with significant energy import dependence these expenditure chains will have more extended multiplier benefits. For lower income groups, the real income effect of energy savings can also be greater. As the following figure shows, poor countries have higher real energy dependence per dollar of GDP per capita. Whatever domestic energy prices may be, the poor are more vulnerable to these prices in percentage terms.

Figure 2: Energy Dependence and per Capita Income for 113 Countries



Source: Author estimates from World Bank and IEA data. The vertical axis measures average household real energy use in megajoules/yr, divided by 2005 PPP GDP per capita. The horizontal axis is logarithmic, measuring 2005 PPP GDP per capita. Diameter of each bubble is proportional to population.

Because of low incomes and relatively low energy use per capita (Figure 1), developing country governments have historically subsidized energy as part of a larger agenda of economic growth and modernization. While these policies may have been appropriately targeted to improve market access and promote dissemination of energy services like electrification, they have facilitated technology choices, urbanization patterns, and fiscal commitments that increasingly look unsustainable. For this reason, it is important that the Bank—building on the work done for the 2010 World Development Report—support policy research in new directions, including an array of climate mitigation and adaptation measures generally. The temporary demand failure in global energy markets has weakened the resolve of some governments to overcome these long term challenges, making multilateral leadership and policy innovation even more valuable.

As Figure 2 makes clear, energy efficiency should be a high priority for the poor, yet in many countries policies and market failures limit their ability to identify or respond to this. As energy prices rise over the medium and long term, subsidy schemes will be stripped away, yet the poor may still lack the information or financial means they need to adapt. On livelihoods grounds alone, it is important not to wait for the emergence of "energy poverty" before testing and even promoting energy efficiency. Some work of this kind (e.g. alternative energy projects like solar cooking) has been undertaken, but no economywide assessments of long term EE potential have been conducted.

The livelihood and growth dividends of EE suggest it should be evaluated for direct incorporation into national development strategies. This project will examine the economic potential of energy efficiency in four sample countries, Viet Nam, Senegal, Mongolia, and Brazil. If the results are consistent with findings in higher income countries, the policy implications could support a variety of core World Bank development agendas, including GHG mitigation and poverty reduction. It is envisioned that results from the case studies could inform a larger policy research agenda on small scale technology diffusion/adoption in developing countries. Included in this agenda would be individual national assessments, pilot projects for promoting adoption, and policy guidance. The latter would include, but not be limited to, recommendations regarding adoption incentives, micro-credit and other mechanisms to overcome market failures, and coordinated R&D for appropriate technology development.

As has been emphasized, energy efficiency in low income countries advances multiple development objectives. The most direct benefit is enhanced environmental sustainability via higher energy productivity (lower GHG emissions per dollar of real GDP). Secondly, countries with prior commitments to subsidize energy will improve their fiscal conditions and be able to dedicate scarce public resources to other priorities. Energy savings will also advance poverty reduction but increasing real household purchasing power, freeing resources for other essential expenditures in low income households where energy use is high relative to incomes. Efficiency will also have a partial "rebound" effect by making energy services less expensive and improving quality of life (e.g. refrigeration) and productivity (e.g. lighting). This reflects the essential nature of energy services and, judging from evidence elsewhere, will represent a fraction of the savings from efficiency improvements.

Improving energy efficiency offers both carbon mitigation and the possibility of reduced real costs for energy inputs that allows expansion of production possibilities for the economy. The International Energy Agency (IEA) estimates that energy efficiency improvements would contribute 44% of the total emission reductions required to maintain the global CO_2 emissions 50% below 2005 level in 2050 (IEA, 2008). Moreover, many poor countries have higher real energy dependence per dollar of GDP per capita than countries with higher per-capita income, implying a greater direct welfare benefit from reduced energy costs.

Energy efficiency encompasses a variety of supply-side and demand-side technologies and practices that could be adopted in developing countries under favorable policy and market conditions. The debate is not over the existence of energy saving opportunities, but over the circumstances favorable for their adoption. The high energy prices of the 1970s and early 1980s led to energy efficiency improvements all over the world

(Gellings 2000). These included direct responses to price incentives and, in the regulated electricity sector, demand side management (DSM) programs. These investments were not free: in the United States, for example, about US$23 billion was invested for DSM programs between 1989 and 1999 (Laughran and Kulick, 2004).

The next question in assessing the economic benefits of energy efficiency is the extent to which technological potential in energy efficiency can be achieved at a low cost relative to the present value of energy savings realized. To the extent this is the case, in particular because of various market barriers,[2] energy efficiency can reduce GHG emissions while providing an unambiguous economic dividend as well as other potential co-benefits including reduced local air pollution. The literature has been divided on this issue, however, with some analysts claiming the identification of many low-removal-cost barriers while others cast doubt on such findings, arguing that they stem from incomplete analysis that does not capture relevant opportunity costs of switching to greater energy efficiency. In the latter view, energy efficiency improvements may still be very cost-effective for reducing GHG emissions, but they are not necessarily the quintessential “low hanging fruit.”

The Bank is pursuing several studies related to the economic and environmental implications of energy efficiency. One area of work requiring further amplification, or fleshing out, is the potential impacts of increased energy efficiency on total GDP, employment, and economic welfare, as well as the composition of goods and services. These impacts will depend on a variety of factors, including:

- The degree of existing energy inefficiency, in particular in industry and power.
- National industrial policies for capital stock modernization, which often provides an energy efficiency co-benefit.
- Potential costs of additional investments in energy efficiency equipment and practices, and their potential benefits.
- Degree to which reduced real costs of energy in the economy (imported or domestically produced) can translate into increased **net** increases in national output and employment.
- The project will address these issues at the national, sectoral and activity levels by combining economic analyses of specific energy efficiency changes with assessment of their economy-wide consequences. [Insert sentence on potential countries.] The research will build on and add to parallel DECRG work on low-carbon growth possibilities focusing on different possibilities for technical

[2] A variety of barriers have been identified including lack of user interest given unfamiliarity with the opportunities and concerns about their performance, high initial capital costs for larger-scale investments in more efficient new capital, and energy price subsidies.

advance in low-carbon energy sources. It also will be synergistic with a project being developed on the economics and political economy of energy subsidy reform.

The challenge is to identify a relevant set of energy efficiency measures for developing countries, their potential energy-saving benefits, the knock-on economic effects; and economic or institutional barriers that may impede their adoption. Various forms of energy efficiency standards are one key component to consider: they are often advocated, yet understanding of potential hidden opportunity costs from their implementation remains limited. Another highly relevant aspect is the possibility for improved technical efficiency in the provision of electricity, reflecting in part past regulatory distortions in the sector and other causes of under-investment. The Bank's consideration of these options will be guided by the availability of economic and engineering information, as well as information on consumer attitudes that can help distinguish "no-regret" possibilities versus measures with more substantial "transactions costs" for implementation.

Relevance to the Bank

The Bank's planned approach for dealing with these micro-level and sectoral issues in its ongoing work will focus strongly on country case studies. This scoping and project development study, accordingly, will focus on identifying which of the economic and institutional factors noted above are especially important for more detailed follow-on work. The relevant information needed is based on a rapid scanning analysis. That analysis based in part on review of relevant published literature and Bank documents, including those related to past and ongoing projects in the study countries.

Among the countries identified as potential targets for the work, China and South Africa are particularly attractive possibilities. Both have energy-and carbon intensive economies and histories of various distortions in energy markets, including a legacy of low energy prices. Both have significant middle class populations whose consumption includes a substantial amount of energy use and purchase of energy-using capital; both also have significant lower-income populations whose needs for both improved and lower-cost basic energy access are acute. Finally, both have active World Bank programs and Country Office staff interested and supportive of work in this area.

2. Overview of Related Policy, Research, and Literature

The World Bank Group has stepped up support of renewable energy (RE) and energy efficiency (EE) programs to record levels. World Bank Group financing for RE/EE projects in the fiscal year 2009 rose to US$3.3 billion, representing an all-time high. New RE/EE commitments far exceeded the expected annual increase of 30 percent rising 88 percent. This level of financing also far exceeds the World Bank obligations under the Bonn Commitment. [3]

Increasing energy efficiency in developing countries is a major priority of the global community due to the vast potential for carbon offsetting. In the International Energy Agency's World Energy Outlook Reference Scenario 90 percent of the increase in global energy demand between 2007 and 2030 comes from non-OECD countries of which China and India account for 39 and 15 percent respectively. In this scenario the non-OECD share of energy consumption grows from 52 to 63 percent due in large part to rapid economic and population growth. The IEA also cites urbanization and industrialization as drivers of increasing demand in the developing world.[4] The large share of global energy demand in the developing world represents an opportunity for carbon emission mitigation through demand side management programs to increase energy efficiency in those markets.

At the Copenhagen conference in December of 2009 developed countries pledged to mobilize US$30 billion by 2012 in "new and additional" resources in support of sustainable energy in developing countries with a planned increase to US$100 billion by 2020 illustrating the commitment that the developed world is prepared to make to assist the developing world in achieving sustainable development.[5] Cooperation between developing and developed countries is imperative to mitigate the effects of accelerating climate change that will affect rich and poor countries alike.

The Strategic Framework for Development and Climate Change (SFDCC) is the acting road map for the various entities of the World Bank Group in effect for the fiscal year 2009-2011. Endorsed by the Development Committee on October 12, 2008 the SFDCC reaffirms the core mandate of the World Bank Group of "supporting growth and overcoming poverty in developing countries while recognizing the added costs and risks of climate change and an evolving global climate policy."[6] The World Bank has facilitated financing and provided technical support for numerous RE/EE projects in order to work toward the objectives articulated in the SFDCC.

---

[3] World Bank Press Release (2010)
[4] International Energy Agency (2009)
[5] World Bank (2010a)
[6] World Bank (2010b)

Projects that aim to introduce energy efficient technology in developing countries require more than mere financing. Despite the potential benefits of energy saving technologies to end users, implementing the use of energy-efficient technologies often encounters difficulty. This difficulty often arises from long established practices and norms, lack of information regarding the benefits of such technology and belief in that information, differing consumer tastes and value systems, and differing or inadequate institutional and organizational arrangements. Due to the difficulties involved, policies and institutions in most countries tend to focus on increasing energy supply rather than demand management.[7]

Improving energy efficiency by expanding CFL markets

Lighting is a significant source of electricity demand. Switching from incandescent bulbs to energy-efficient compact fluorescent lamp (CFL) bulbs reduces lighting energy requirements and holds significant potential for carbon emission mitigation. The principal obstacle to widespread implantation of CFL bulbs is the higher initial cost. For example, in India lighting accounts for approximately 20 percent of electricity demand. Although CFLs are available in the Indian market their use in the country is limited. A CFL bulb in the Indian marketplace costs approximately 10 times as much as an incandescent bulb. If the approximately 400 million light points that exist in India today were replaced with CFLs it is estimated that electricity demand on the over-burdened grid would fall by more than 10,000 MW.[8]

In a study by Martinot and Borg the authors identify nine specific barriers to successful expansion of CFL markets: (1) lack of information for consumers; (2) relatively high initial purchase costs; (3) absence of low transaction cost credit mechanisms in low income countries; (4) lack of manufacturer incentive due to low consumer demand; (5) institutions that lack ability to carry out demand side management programs and market efficient technologies; (6) government agencies' lack of understanding of the benefits of energy efficiency and reluctance to approve investment and regulatory incentives; (7) poor product quality and premature failure; (8) lack of compatibility with existing lighting systems and appliances; and (9) consumer preference factors.[9]

Despite these obstacles there are examples of successful campaigns to introduce CFLs into developing markets. Once barriers to entry are overcome manufacturers and importers have been able to increase the market for CFLs and obtain significant market share. One such project was the ILUMEX project in Mexico (see Box 1).

---

[7] World Bank (2009)
[8] Michaelowa (2009)
[9] Martinot and Borg (2009)

Box 1 – The ILUMEX Project, Mexico

The ILUMEX project was approved by the World Bank in 1994 and was carried out from 1995 to 1998. Co-financed by a grant from the Global Environment Facility (GEF) (US$10 million), the Mexican government (US$10 million), and a grant from Norway (US$3 million). The focus of the project was promotional sales of CFLs and was implemented by the Comisión Federal de Electricidad, the principle electricity utility. The World Bank reported that 2.6 million CFLs were sold by the end of the project.

The impacts of the ILUMEX project included: energy savings, reduced GHG emissions, reduction of other local air pollutants, capacity savings, and financial benefits. The model that included subsidized prices to consumers proved to be successful and deemed to have "great replication value". Although the program was limited geographically, the model was replicated in a nationwide program and has been adapted and adopted in other Efficient Lighting Initiative (ELI) programs in Argentina, Peru, and Costa Rica.

The ILUMEX program was successful in transforming the Mexican lighting market. Before the program CFLs were prohibitively expensive and availability was very limited. Today in Mexico CFLs are affordable, widely available, and have a "significant and growing" share of the market.

Source: World Bank GEF. Post-Implementation Impact Assessment. Mexico-Ilumex Project. 2006.

Air conditioning and refrigeration efficiency

Household and commercial air conditioning and refrigeration systems consume significant amounts of energy. In the residential sector air conditioners and refrigerators are among the highest energy use appliances. Introducing energy efficient cooling appliances in developing countries to replace outdated, energy inefficient models holds great potential for mitigating carbon emissions by reducing electricity demand. In low income countries that are experiencing rapid development (i.e. China and India) these types of appliances will become within reach of an increasing number of consumers. Introducing energy efficient, high energy use household appliances will be a key element in offsetting growth in carbon emissions.

Box 2 – Thailand Promotion of Electrical Energy Efficiency Project

Promotion of energy efficient air conditioning (A/C) units was a part of a broader strategy in a World Bank project in Thailand to improve the country's energy efficiency. This project was approved in 1993 and was put into effect over the 1993-2000 time period. It was co-financed between a GEF grant, the government of Australia, the Electricity Generating Authority of Thailand (EGAT), and a loan from the Overseas Economic Cooperation Fund of Japan/Japan Bank for International Cooperation. $59.3 million was spent on the project which consisted of a 5-year demand-side management plan.

A key component of the energy efficient air conditioning portion of the project was instituting a labeling system to easily identify efficient A/C units and promotions to encourage their purchase and use. Compliant A/C units displayed Label #5 which has become a recognizable insignia of energy efficiency throughout the country.

The process of encouraging widespread use of Label #5 A/C units encountered many obstacles. During the period of the project there were at least 10 manufacturers producing in excess of 200 models of small-size A/C units. Ensuring label compliance and negotiating improvements remained a challenge. Instances of falsely labeled Label #5 units were not uncommon. During a brief period in 2002 the EGAT offered interest-free loans of 10,000 baht for the purchase of Label #5 A/C units. Due to low uptake the program was discontinued after only a few months.

Despite the difficulties facing this project there was significant progress made in the residential sector. Although market transformation is not complete, the energy efficient labeling system gained widespread recognition and has proven to have transformed the behavior of consumers with respect to purchasing of residential appliances.

Source: World Bank GEF. Post-Implementation Impact Assessment. Thailand Promotion of Electrical Energy Efficiency Project. 2006.

There are four distinct factors involved in the successful implementation of energy efficient residential air conditioning and refrigeration appliances: (1) well-defined standardized efficiency test procedures, (2) explicit energy efficiency standards, (3) a standardized labeling system, and (4) an incentive program.[10] A labeling system coupled with an incentive program, if properly implemented, will encourage consumers to pick the most energy efficient appliance that meets his or her particular needs and allow the consumer to evaluate operating energy cost over the product's life cycle while providing incentive for manufacturers, importers, and retailers to supply more energy efficient products.[11]

Successful implementation such systems is a complicated and difficult task, but it is possible. One program that had reasonable success was the Thailand Promotion of Electrical Energy Efficiency Project (see Box 2).

Energy-efficient personal transportation

Transport emissions are a significant source of GHG emissions worldwide. As purchasing power rises in developing countries and motorized personal transportation becomes within reach of a rising number of consumers (China in particular) local air quality is rapidly deteriorating while climate change acceleration is becoming increasingly imminent. Improving infrastructure and public information with regard to public transit is an area of interest in terms of carbon emission mitigation. Alternative fuels for personal transportation vehicles are also of extreme importance in this effort.

One example of government regulation that resulted in private sector adaptation occurred in several urban areas in China where gasoline-powered motorbikes were banned in 2004. Combined with rapid urbanization, rising purchasing power, and improved electric motor and battery technology, conditions were optimal for a rapid expansion of the electric bicycle market. The regulation imposed by government provided E-bike manufacturers the opportunity to enter the market which rose from 40,000 bikes in 1998 to 21 million in 2008. E-bikes are cheaper and cleaner than other forms of transportation (buses included) and now China is exporting E-bikes all over the world.[12]

Because of the rapid increase in carbon emissions in China, the country is an area of particular focus in increasing energy efficiency of personal transportation. One major project currently underway to improve public transformation is the China-GEF-World Bank Urban Transport Partnership Program Project (see Box 3).

---

[10] Mahlia and Saidur (2010)
[11] Mahlia and Saidur (2010)
[12] World Bank (2009)

Box 3 – China-GEF-World Bank Urban Transport Partnership Program Project

Rapidly increasing car ownership in China has resulted in rapid increases in GHG emissions in the urban transport sector and deteriorating air quality. This project approved by the World Bank in June 2008 is an attempt to achieve a paradigm shift in urban transport and land use strategies in favor of public and non-motorized transit use in the country. In order to achieve this goal the project will at the national level develop and promote a National Sustainable Urban Transport Strategy and detailed planning guidelines while encouraging sustainable urban transport development and improving the quality of training and research in this area. On a local level the project will encourage through technical support and investment incentives at least 14 major, sustainable urban transport model sub-projects, at least 4 of which will be World Bank co-financed. The objective will be to illustrate the benefits of public transport investments and is projected to be replicated in at least 25 other urban areas.

The projects that will receive World Bank co-financing are Xian Urban Transport Project (US$73.5 million), Guangzhou City Center Project (US$4 million), Liaoning Medium Cities Infrastructure Project (US$71.5 million), and the Urumqi Urban Improvement Project (US$11 million). By implementing this program the partnership between the Chinese government, the GEF, and the World Bank will aim to slow the trajectory of deteriorating air quality in these Chinese cities, mitigate overall GHG emissions, while encouraging similar investment programs in other urban areas.

Source: World Bank. Project Information Document: China: GEF-World Bank Urban Transport Partnership Program Project. Report No.: AB3762.

Cooking in rural areas of developing countries

An estimated 2 billion people in developing countries rely on the burning of biomass for heating and cooking. Cookstoves used widely in rural areas in many countries release CO_2, black carbon, and hazardous products of incomplete combustion. It is estimated that indoor smoke from the burning of biomass contributes to 1.6 million deaths (1 million of which children under 5) every year. Black carbon is also a very significant contributor to global climate change. Approximately 18 percent of black carbon in the atmosphere is generated by the burning of solid fuel in cookstoves in developing countries. Therefore there is great incentive for both health reasons and climate change mitigation to improve cookstove technologies in the developing world.[13]

Significant funding has been directed toward promoting the use of liquefied petroleum gas stoves to replace biomass cookstoves but even with heavy subsidies the cost has been prohibitive in poor, rural communities. In China and India there have been attempts to subsidize improved stoves and tailor improved cookstoves to the needs of rural residents but achieving widespread use has been elusive. Currently a pilot evaluation program, project Surya, is the largest cookstove research project of its kind. It will support the distribution of 15,000 newly designed energy efficient cookstoves in three different areas in India and monitor the pollutants with “cutting edge sensor technologies”.

Improving cookstove technology in rural communities in developing countries holds great potential for GHG mitigation. In order for improved cookstove technology to become more widespread such stoves need to be accessible and affordable while at the same time adaptable to the specific needs of the local community. A project in Cambodia illustrates an example of successful cookstove introduction into a developing market (see Box 4).

---

[13] World Bank (2009)

Box 4 – Improved Cookstove Sector Market Development, Cambodia

In 2008 and 2009 the World Bank-Asia Sustainable and Alternative Energy Program (ASTAE) provided US$43,900 and US$86,912 respectively toward a program to improve efficiency of cookstoves in targeted regions of Cambodia. This project was a small part of the broader ASTAE but was effective in transforming the Cambodian cookstove sector. The program provided technical assistance to scale up the development of market-oriented, improved, more efficient cookstoves in the targeted regions. Technical assistance was provided to GERES Cambodia to develop a model production facility in Banh Chhkoul village, Kampong Chhnang Province to produce improved Neang Kongrey stoves designed to replace the use of the energy inefficient "three stone stoves" and "traditional Lao stove". The facility offers improved technology to manufacture the ceramic stoves including mechanical clay mixing, improved molding techniques, and kiln firing. Improved cookstoves are based on the traditional models so as to be suitable for local use but certain modifications greatly improve their efficiency. The three principal improvements in cookstove design are: (1) a reduction in the space between the pot and pot-rest, (2) smaller holes in the grate, and (3) a smaller combustion chamber. The modifications result in better combustion with less heat loss, more complete burning of wood fuel, and reduced smoke.

More than 90 percent of energy consumed in rural Cambodia households is derived from wood and charcoal. Improved cookstoves can save over 60 percent on fuel as compared to the traditional "three stone stove". Improved cookstoves have been successfully introduced in approximately 40 percent of the population. Neang Kongrey stoves cost about US$1.25 and last approximately 1-2 years but this can be unaffordable to the poorest Cambodians in the absence of subsidies or installment plans. However, once a new stove is purchased, the savings due to less fuel use rapidly pays for the amount of the purchase. For those who use coking coal, less fuel is required resulting in monetary savings. For Cambodians who chop their own firewood the reduction in fuel use means less time spent cutting and gathering wood.

In addition to the economic benefits of the improved cookstoves, lower emissions will have beneficial impacts on respiratory health of rural Cambodians and on Cambodia's aggregate GHG emission output.

Sources: Michael Wild. Improved Energy Technologies for Rural Cambodia. IBRD/World Bank, Dec 2009.; World Bank. Asia Sustainable and Alternative Energy Program. Annual Status Report 17. Fiscal year 2009.

Improving energy efficiency of public sector buildings

Making buildings and businesses more energy efficient is a potential opportunity for GHG emission mitigation. It is estimated that buildings are responsible for more than a third of energy-related CO_2 emissions worldwide. Improving the efficiency of buildings is a key low-cost measure toward climate change mitigation. In the developing world in particular the potential for reducing building-related emissions is large with "cost-effective" CO_2 mitigation potential at approximately 52 percent.[14] Implementing energy-efficient lighting has been identified as the most attractive energy saving measure due to energy use reduction potential, cost-effectiveness, and ease of implementation.

Box 5 – Montenegro Energy Efficiency Project

Montenegro is relatively energy-intensive with respect to other countries in the region. The level of energy-intensity is two times the European average. The country imports about one-third of its power needs and the antiquated electricity production network that suffers from lack of investment is not capable of keeping up with rising electricity demand. The state-owned electricity company, Electric Power Company of Montenegro (EPCM), has reported annual losses equivalent to one percent of GDP annually since 2002. However, the EPCM is currently embarking on an ambitious investment program to ramp up power production capability and improve transmission capability.

The development objective of the Montenegro Energy Efficiency Project will be to improve energy efficiency in "targeted public sector buildings" including mostly education and health centers managed by the Ministry of Education and Science and the Ministry of Health, Labor and Social Welfare. This will provide a basis upon which to model energy efficiency in public sector buildings throughout the country. Energy efficiency improvements will include "retrofitting for improvement of heating systems, insulation, thermostatic valves and other installations . . . as well as heat substations and networks." Financing for this project will include US$9.4 million from the International Bank for Reconstruction and Development. This project was approved by the World Bank in December of 2008 and is projected to be completed in December of 2012.

Source: World Bank. Project Information Document: Montenegro Energy Efficiency Project. Report No.: AB3954.

[14] Ürge-Vorsatz and Novikova (2008)

Certain programs initiated by the World Bank have focused on making public sector buildings (i.e. schools, hospitals, government offices, etc.) more energy efficient. Although these buildings may represent a small proportion of energy consumption in the broader landscape, by beginning with public sector buildings structural energy efficiency knowledge and technology then becomes more accessible to residential and private sector applications. Once such project is the Montenegro Energy Efficiency Project (see Box 5).

Box 6 - Karnataka Municipal Water Energy Efficiency Project, India

Although water supply and sanitation has been steadily improving in India regular supply to consumers remains a challenge. With a population of 53 million Karnataka is one the most urbanized states in India. Approximately 94 percent of the population of Karnataka has access to water supply (roughly on par with the average in the country) although the access is usually limited to less than four hours a day. It is estimated that only 35 percent of cities in the state have access to water seven days a week.

The water pumping system in Karnataka is plagued by inefficiencies that prevent the delivery of water to end-users. Inefficiencies in the pumping system include poor engineering and maintenance, outdated systems, improper equipment size, redundant and inefficient water pipe routing, and outdated equipment that is in need of replacement. The pumping system is powered by the national electricity grid which relies principally on the burning of fossil fuels for power generation. Increasing the efficiency of this system would not only improve the regularity of the water system increasing water accessibility in the region, but also reduce the amount of energy used in the pumping system mitigating unnecessary GHG emissions.

The Karnataka project was recently approved by the World Bank in November of 2009. The activities undertaken in the course of this project will include: (1) installation of new pumps and components; (2) proper sizing of pumps and components; (3) improvement of electrical efficiency in the system (power factors correction and stand-by transformers); (4) improved metering and monitoring systems; and (5) reduction of water leakage in main pipes. The following six cities will participate and serve as pilot locations in this project: Belgaum, Gulbarga, Hubli/Dharwad, Mangalore, Bellary, and Mysore.

Source: World Bank. Project Information Document: India: Karnataka Municipal Water Energy Efficiency Project. Report No.: 44018.

Efficiency in water distribution

In many developing communities access to water is limited and irregular. In many instances this is due to lack of investment in water delivery systems that use outdated equipment and poor engineering and waste significant amounts of energy in moving water to end users. Pumping systems require a significant amount of energy while energy efficiency in water distribution systems remains very limited. In addition to inadequate and improper pumping systems, leakage, redundant piping, and inefficient engineering contribute to energy waste in such systems.

There is significant potential in this area for energy efficiency improvements. Improvement of water supply systems in developing communities improves the community's access to water, lessens the burden on the local electricity grid, and reduces overall GHG emissions. One such project that is currently underway is the Karnataka Municipal Water Energy Efficiency Project in India (see Box 6).

Energy efficiency in industry

Heavy industry is a contributor to GHG emissions around the world. The problem is particularly acute in China, the world's largest GHG emitter, where the extremely high levels of heavy industry have pushed up energy demand and resulting emissions. Although steps have been taken to improve efficiency, heavy industry plants in China, as in other developing countries, are often outdated and grossly inefficient which presents a significant opportunity for offsetting carbon emissions.

The extremely high level of energy input requirement and the energy inefficient character of heavy industry in many developing countries presents opportunities for carbon emission mitigation. Many technologies and practices are available that could potentially increase energy efficiency of heavy industry in the developing world the challenge will be successful implementation of such technologies. Often such technologies have high initial costs which can in many instances be offset by the selling of Carbon Emissions Reductions (CERs) under the Clean Development Mechanism of the Kyoto Protocol. One such example is the China Luojing COREX Carbon Finance Project (see Box 7).

Box 7 – China Luojing COREX Carbon Finance Project

Heavy industry in China is a principal source of CO_2 emissions in the country. Approved by the World Bank in July of 2008, the purpose of this project is to reduce the CO_2 emissions of a large iron and steel company by instituting energy efficient technology. The project sponsor, Baosteel Group Pudong Iron and Steel Co. Ltd. (Pusteel), was founded in 1913 with a plant in the Pudong area of Shanghai. The original plant site occupied 40 percent of the area upon which the Shanghai World Expo was to be held. In order to make way for the World Expo it was decided that a site in Luojing town, northern Shanghai, would be the new site for the plant. The relocating process began in 2005.

The new site in Luojing will use "COREX technology and energy recovery facilities including combined cycle power plants (CCPPs) in two phases instead of conventional blast furnaces". Using COREX technology rather than conventional blast furnaces in steel production enables the use of non-coking coal as a reducing agent and energy source and enables iron ore to be directly "charged to the process in the form of lump ore and/or pellets." The direct reduction process lowers requisite energy consumption and reduces CO_2 emissions. Further efficiency can be achieved at the CCPPs by using the gas by-product for power generation.

China approved the Kyoto Protocol in August 2002. China also agreed to cooperate with the World Bank in the market for Certified Emissions Reductions (CERs) under the Protocol's Clean Development Mechanism. The Luojing project is a Carbon Finance Operation (CFO) which will facilitate the purchase of the CERs in accordance with an Emissions Reduction Purchase Agreement (ERPA). Pusteel will achieve CERs by the reduction of GHG emissions, the exact amount of which will be determined by the ERPA. The World Bank is not financing the COREX installation but rather will purchase the CERs from Pusteel on behalf of the Spanish Carbon Fund.

Four other plants using COREX technology were already operational before this project: one in South Korea, one in South Africa, and two units at a location in India. Pusteel will have two units and be the largest existing COREX facility.

Source: World Bank. Project Information Document: China Luojing COREX Carbon Finance Project. Report No.: 43230.

Box 8 - Mexico Sustainable Rural Development

In Mexico agriculture remains a significant source of carbon emissions. According to Mexico's National Climate Change Strategy the agriculture sector accounts for 7 percent of total emissions. Primary causes of carbon emissions are recognized as land-use change, tillage, synthetic fertilizers, and anaerobic decomposition of organic materials. The Government of Mexico has made increasing efficiency in agriculture and agribusiness a priority, both to increase competitiveness and environmental sustainability. The government plans to pursue the following measures to achieve this objective: "(i) the provision of technical and financial incentives in improved productivity, (ii) sustainable utilization of natural resources, (iii) mechanisms to improve market access, (iv) extended use of energy efficiency practices, and (v) development of renewable energy sources."

This project was approved by the World Bank in October of 2008. Implemented over a five year period this project will have a projected total cost of US$168 million. Financing will be supplied by an IBRD loan of US$60 million, a GEF grant of US$10.5 million, government counterpart funds of US$18 million, and beneficiaries contribution of US$79.5 million. In addition to this funding it is estimated that selling of carbon credits achieved by the implementation of this program under the Kyoto Protocol's Clean Development Mechanism will amount to approximately US$24 million that can be made available to project beneficiaries.

The financing of this project would be directed at improving energy efficiency using various technologies. Increasing energy efficiency of small- and medium-sized agribusinesses will be achieved through improving efficiency of production technologies, promoting more efficient milking equipment and cooling equipment for dairy products, and improving efficiency of drying and packaging facilities for fruits and vegetables and meat processing plants. There will also be a particular focus on the development of energy production from biomass. GEF support will be largely directed toward initial capital investment and the removal of technological barriers. Other components of this project will focus on investment and production support services, institutional strengthening, and project management, monitoring, and evaluation.

Source: World Bank. Project Information Document: Mexico Sustainable Rural Development. Report No.: AB4026.

Agribusiness and potential energy efficiency improvements

Agriculture provides a livelihood for a large part of the population in the developing world. In many countries the agriculture sector contributes significantly to aggregate carbon emissions and steps can be taken to help agriculture and agribusiness take advantage of improved agricultural technology to improve productivity and energy efficiency to increase yields while reducing GHG output. It is estimated that agriculture accounts for 14 percent of total global anthropogenic emissions of GHGs with N_2O emissions from soils and CH_4 from enteric fermentation being the largest contributors. Rice production, manure management, and biomass burning also contribute significantly to agricultural GHG emissions.[15]

Improving the energy efficiency of agriculture in developing countries will help to mitigate emissions from the agricultural sector. Energy efficiency in agriculture is defined as energy use per tonne of crop produced while lower energy use per tonne represents improving energy efficiency. Energy savings can be achieved by decreasing the energy for ‘inputs’ such as tillage operations, fertilizer, herbicides, etc. or by increasing ‘outputs’ with less than proportional increase in energy expenditure.[16] A coordinated effort to promote energy efficiency in agriculture is the Mexico Sustainable Rural Development project (see Box 8).

Summary Comments

The projects discussed here by no means represent an exhaustive list of all possible technologies that can improve energy efficiency in developing countries. These examples illustrate the means by which barriers to entry can be overcome through cooperative financing and regulation. Effective, long-term energy saving technologies will utilize government policy and financing to spur private sector innovation. Such technologies will be financially beneficial to end-users, will create opportunity for private enterprise, and will benefit the country as a whole. Citizens all over the world also benefit from lowered GHG emissions. As model projects are developed the spillover effect will be powerful as improved energy efficiency technology becomes more widespread and more affordable.

---

[15] Smith et al. (2007)
[16] Swanton et al. (1996)

In order to achieve a model of “long term climate smart development” it is necessary to involve the private sector.[17] The private sector can be an engine of innovation and adaptation under appropriate conditions. Carbon pricing and other regulation can be an effective means by which to spur such innovation and market-driven solutions to carbon emission problems. By increasing the cost of high carbon emitting technologies firms will innovate to reduce the use of such technologies. As energy efficient technologies overcome barriers to entry assisted by carbon pricing and regulation the production of such technology can achieve increasing market share and economies of scale enabling competitive pricing which will be enjoyed by end users. The end result is a paradigm shift encouraged by regulation and financing but ultimately powered by innovation and adaptation in the private sector.

[17] World Bank (2010a)

3. Conceptual Framework and Application to China and South Africa

This section provides an overall conceptual framework for a more comprehensive program to support energy efficiency improvements in developing countries. To begin, we examine the established legacy of EE in the OECD. This provides not only legacy experience but a concrete empirical framework for understanding realistic goals and resource commitments. We then examine the state of understanding regarding micro-macro effects and linkages between them, an essential issue for understanding the broader implications of bottom-up efforts to conserve energy. Finally, we use two potential case countries to illustrate

Drivers of Energy Efficiency in OECD and Emerging Economies

In many OECD countries, policies to promote energy efficiency began in the 1970s in the wake of the 1973 oil crisis, increased concerns over the environmental impacts of fossil fuel energy use, and rising energy costs. In tandem, these forces led to a paradigm shift in energy policy and a greater emphasis on energy efficiency in energy planning and investment.

Emerging economies, and particularly China, are now facing many of these same pressures. China became a net oil importer in 1992 and a net coal importer in 2007. With scarce natural gas or uranium resources, energy security has become a paramount concern for China's leadership. Environmental issues have become increasingly important for China's foreign domestic and policy, both as China became the world's largest emitter of greenhouse gases (GHGs) in 2009 and as regulations to control criteria air pollutions (PM, SO_2, NO_x) have raised the cost of energy supply. A number of factors have driven energy prices in China to levels comparable with those in OECD countries. For instance, by 2005 electricity prices in many provinces in China were on par with those in U.S. states (Williams et al., 2010).

Although macroeconomic considerations have not figured prominently in energy efficiency policy discourse in either OECD or non-OECD countries, in principle there are important links between the benefits and costs of energy efficiency at a micro level and the broader macroeconomy. These links are poorly understood and could be an important consideration for energy efficiency policy going forward, particularly in emerging economies where energy efficiency planning has yet to be more rigorously institutionalized.

A Conceptual Framework for Energy Efficiency

Energy policies around the world today, while generally embodying a well-intentioned strategy for protecting living standards and promoting modernization, are an artifact of a long era of carbon-intensive industrialization and low energy prices. High-income industrialized countries, now that they recognize the challenge, can begin to change their approach to this legacy because they have the purchasing power to include higher cost mitigation options in their policies. Developing countries, however, lack the latter flexibility so their attention is best focused on so-called negative cost mitigation. Energy efficiency is the primary example of this, adopting technologies whose costs are exceeded by the long term energy savings they confer.

The research challenge in this context is then to identify such technologies, their potential benefits, and any barriers that may impede their adoption. The research literature on technology adoption suggests there are many uncertainties in such an exercise, and this project will only attempt to answer salient questions in a limited but diverse set of cases. At the present time, the conventional economic framework for energy efficiency is incomplete. This section extends more conventional notions of energy efficiency, and we use the framework developed here to organize the remaining sections.

Energy Efficiency Taxonomy

There are four primary channels for improvements in economy-wide energy efficiency:

- **Replacing or Upgrading Equipment and Optimizing Performance (Equipment).** Improvements to the average efficiency of energy using equipment in a sector can be made through:
  - replacing inefficient equipment with more efficient equipment before the end of its expected lifetime (early retirement);
  - replacing obsolete equipment with equipment that is more efficient than the industry average (natural retirement);
  - purchasing new equipment that is more efficient than the industry average; and/or
  - optimizing equipment or process performance.
- **Changing Industry Technology Structure (Technology Structure).** In addition to equipment-based efficiency, improvements to the average energy efficiency of a given sector can be made through broader changes in the technology mix of a given sector. For instance, in many countries (with the notable exception of China) replacing coal gasification with steam reforming in the 1970s and 1980s led to significant improvements in the energy efficiency of ammonia production.
- **Changing Structure of Production (Production Structure).** Increases in the average efficiency of an entire economy can occur through shifts in the structure

of production. For instance, shifts away from heavy industries and toward less energy-intensive goods and services can reduce an economy's energy needs per unit GDP.

- **Changing Structure of Final Consumption (Consumption Structure).** Similarly, improvements in macroeconomic efficiency can emerge through changes in the structure of consumption, either through a declining share of energy in final expenditures or through shifts to less intensive sources of final demand (e.g., government to household consumption).

The first two types of energy efficiency improvements can be categorized as micro level; the second two types can be categorized as macro level.

More formally, these four changes in efficiency can be represented by the simple decomposition

$$E = \sum_i \sum_j \frac{NE_{ij}}{VA_{ij}} \times VA_{ij} + \sum_k \frac{FE_k}{\sum_l C_{kl} + \sum_e C_{ke}} \times C_k \quad (1)$$

where

- E is total economy-wide energy use
- NE_{ij} is energy consumed by technology j in intermediate sector i
- VA_{ij} is value added produced by technology j in sector i
- FE_k is energy consumed by final demand k
- C_{kl} is total expenditure on non-energy good or service l by final demand k
- C_{ke} is total expenditure on energy good e by final demand k

Within this framework, reductions in energy use — without reducing value added or consumption — can be made by:

- Reducing NE_{ij}/VA_{ij} or FE_k/C_k (Replacing or Upgrading Equipment)
- Reducing the share of technology type j, if $NE_j/VA_j < NE/VA$, either through directly phasing it out or through dilution (Technology Structure)
- Reducing the share of sector i in total value added (Production Structure)
- Increasing consumption of non-energy goods and services (C_{kl}) or reducing the share of final demand C_k in C if $FE_k/C_k < FE/C$ (Consumption Structure)

Micro and macro level energy efficiency may be interlinked. For instance, improvements in equipment energy efficiency can reduce enterprise expenditures on energy, and, if there are net savings and depending on how these savings are spent, can lead to shifts in economic structure.

Energy Efficiency Micro-level and Macro-level Benefits and Costs

The benefits and costs of energy efficiency can be separated into micro- and macro-level benefits and costs. Micro-level economics are more applicable to Equipment and Technology Structure, whereas all four categories of energy efficiency (Equipment, Technology Structure, Production Structure, Consumption Structure) are relevant to the macroeconomic dimension of energy efficiency.

Micro-level Benefits and Costs

Cost-benefit analysis has often focused on equipment-based energy efficiency. The costs and benefits of policies that induce shifts in industry technology are much less well understood, particularly in transition economies where a significant portion of the capital stock was often inherited from the planned economy.

Equipment-based energy efficiency projects typically involve some incrementally higher upfront cost that is accompanied by energy savings that accrue over time

$$NPVES = \sum_{t} (-\Delta C \tau + [(\Delta L \times h_t) P_t]) \delta_t \quad (2)$$

where

- NPVES is the net present value of energy savings
- ΔC is the incremental increase in cost
- τ is a capital recovery factor, $r/[1-(1+r)]^{-t}$, where r is an interest rate and t is the lifetime of the loan
- ΔL is the reduction in average load
- h_t is the annual operating hours of the equipment at time t, and could increase if energy costs fall (commonly referred to as the "rebound effect")
- P_t is the price of energy at time t
- δ_t is a present value discount factor $(1+r)^{-t}$, where r is a discount rate and t is the lifetime of the equipment

If the result of Equation 2 is negative, energy efficiency is a net cost to the end user; if positive, energy efficiency provides net savings.[18] Because initial costs are often

[18] More sophisticated discounting is needed when comparing projects that have different lifetimes. Equation 2 assumes there is only one measure or several measures with the same lifetimes.

financed and because energy savings occur throughout the lifetime of the device (e.g., for an HVAC system, 10-15 years), discount rates play an important role in cost-benefit analysis and much of the academic debate over the cost-effectiveness of energy efficiency to individual end users has focused on discount rates and the opportunity cost of energy efficiency investments. A general consensus across the literature is that, public policy interventions to promote energy efficiency can be cost-effective to the extent that information, financial, and incentive barriers to energy efficiency exist, but what the “right” level of societal investment in energy efficiency is remains a matter of debate.[19]

From a supply-side perspective, if the marginal cost of energy efficiency is cheaper than the marginal cost of energy supply, energy efficiency may be cost-effective from a societal standpoint because it can mean lower costs for energy services. Because many energy utilities in OECD and non-OECD countries are heavily regulated, whether energy efficiency is cheaper on the margin than the cost of supplying conventional energy depends on institutions and incentives.

For instance, utilities are typically averse to energy efficiency programs because their profits are, in most cases, tied to energy sales. As Equation 3 shows, if utilities have a fixed revenue requirement, decreasing total energy sales leads to an increase in retail prices to maintain required revenue levels

$$\frac{\$}{MJ} = \frac{Total\ Revenues}{Total\ Energy\ Sales}$$

Decoupling, essentially separating utility profits from sales through the ratemaking process, has emerged as one solution to overcome utility disincentives for energy efficiency. In addition, regulators in many OECD countries apply metrics to evaluate the cost-effectiveness of energy efficiency investments. For instance, in the U.S. commonly used cost test metrics include the participant cost (PC), utility cost (UC), total resource cost (TRC), and ratepayer impact measure (RIM) tests.

Determining the broader benefits of energy efficiency can be complex because the benefits are often time dependent. For instance, on the demand side, customers may be on time-of-use (TOU) pricing, in which case the value of energy efficiency to the end use is higher in periods where TOU prices are higher. On the supply side, the avoided cost of energy efficiency includes both the marginal cost of converting and distributing energy and the marginal cost of capacity in periods where capacity is constrained.

[19] For a review of these debates see Blumstein et al. (1980), Sutherland (1991), DeCanio (1993), and Jaffe and Stavins (1994).

Environmental considerations, such as GHG emissions, may also be time dependent, being higher in periods where less efficient or more polluting equipment is being used.

Developing the data and methods to institutionalize more sophisticated assessments of the value of energy efficiency is difficult for non-OECD countries. In China, as we describe below, these kinds of cost-benefit tools for assessing the cost-effectiveness of energy efficiency investments are not in widespread use.

Although comparatively little research has been done on the benefits and costs of energy efficiency through changes in technology structure, particularly in transition economies this is an important area of research. For instance, governments' use of mandates or incentives to close down inefficient production capacity does have benefits (e.g., lower energy and pollution intensity) but may also impose costs (e.g., higher costs and prices through lower capacity utilization). We describe more China-specific examples in the text below.

Macro-level Benefits and Costs

Micro-macro cost-benefit linkages can occur through two channels:

- energy efficiency net costs and savings at the level of the end user, which are then transmitted into the broader economy;
- changes in baseline energy prices that result from energy efficiency investments, which decrease or increase total energy bills, which in turn affect expenditure patterns, which in turn are transmitted through the rest of the economy.

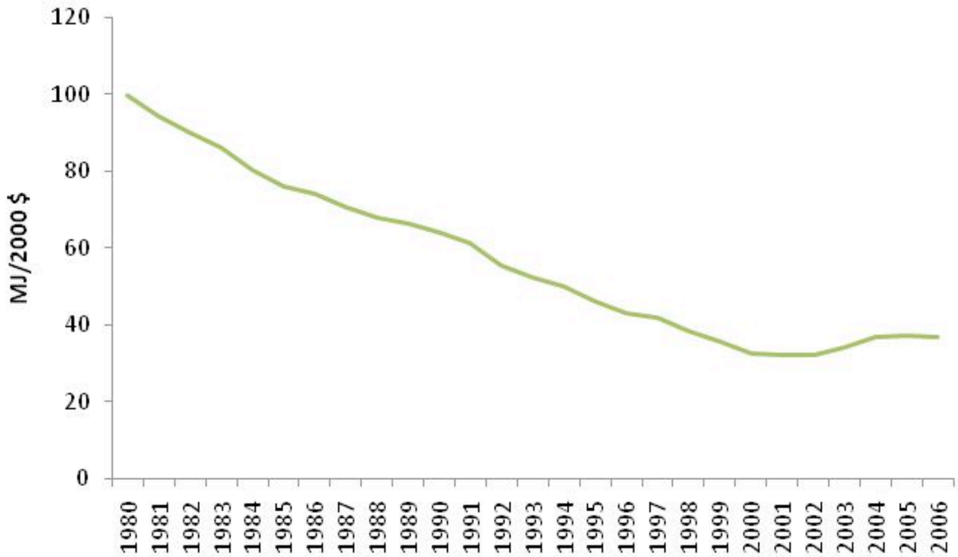
Results from computable general equilibrium (CGE) models suggest that the effects of expenditure shifting that accompany energy efficiency investments can be significant at an aggregate level (Roland-Holst, 2006). However, these results appear to be economy specific, depending on a range of factors, such as economic structure, employment levels, household and enterprise savings levels, and consumption patterns. More analytical and empirical work is needed on this topic.

At a macro-level, changes in economic structure can have important macroeconomic effects, particularly policy efforts to induce changes in macroeconomic structure such as are currently under deliberation in China. The effectiveness of these policies, their impacts on energy use, and their impacts on longer-term growth paths are uncertain.

Energy Efficiency in China

China's central government has had strong energy efficiency standards and incentive programs in place since the 1980s (Lin, 2005), which contributed to a dramatic fall in energy intensity (energy consumption per unit GDP) from 1980 until around 2000 (Figure 3).

Figure 3. Energy Intensity of GDP, 1980-2006, China



Source: Data are from EIA website.

After 2000, rapid economic growth and an abrupt reversal in energy intensity declines led to a surge in energy demand in China, and the Chinese central government responded with an aggressive package of energy efficiency programs, policies, and incentives combined with a target to reduce the energy intensity of GDP by 20% below 2005 levels by the end of the 10th Five-Year Plan (2006-2010).

Energy Efficiency Trends in China

China's energy efficiency trends run counter to one another:

- New equipment energy efficiency is increasingly close to OECD country levels
- In many industrial sectors, the share of old technologies has been reduced through a combination of direct measures, but in some sectors the share of older, less efficient technologies remains substantial
- Higher share of heavy industry has led to rising energy intensity
- Growing energy consumption by households has led to a growing energy per consumption ratio.

Micro: Equipment and Technology Structure

Industry is by far the largest energy consumer in China, accounting for 75% of total energy consumption in 2007. Four heavy industrial sectors — building materials, chemicals, ferrous metals smelting, and non-ferrous metals smelting — accounted for 40% of total energy consumption, highlighting the dominant role that heavy industry continues to play in the Chinese economy. The commercial sector and households, by comparison, accounted for only 16% of total energy consumption in 2007 (NBS, 2009). These demand patterns will play an important role in shaping China's energy future, and in defining the opportunities for energy efficiency. For instance, China has been able to operate an electricity system based largely on a baseload resource (i.e., coal, coal accounted for an estimated 81% of generation in 2007 [IEA, 2009]) because of the high share of industry in total load. Declines in the share of industrial load will lead to a "peakier" system (i.e., lower system-wide load factors), which in turn will reshape the economics of the Chinese power sector and the opportunities for demand-side energy efficiency in that sector.

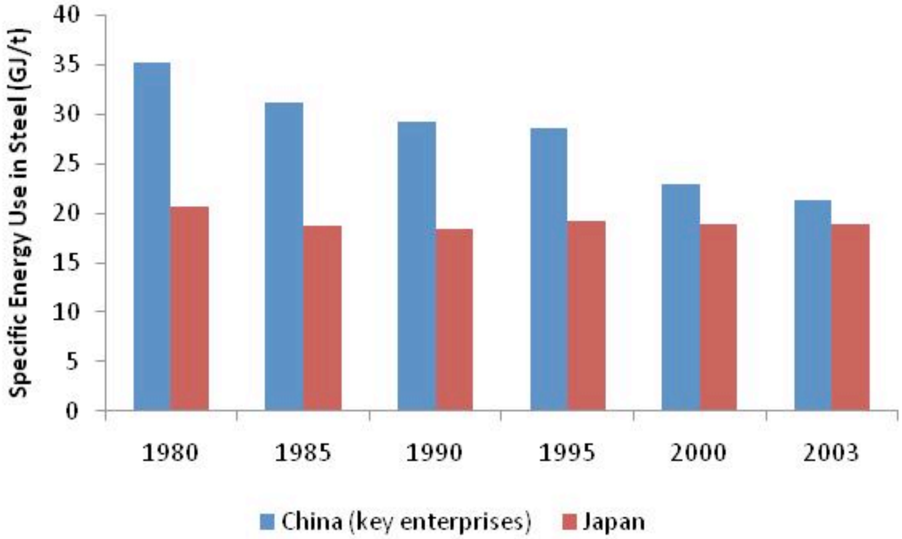
Over the past three decades, specific energy consumption (SEC, in units of energy consumed per unit output) in China's industrial sectors has converged to levels comparable with OECD countries. In some sectors, new production capacity in China is often more energy efficient than typical technologies found in OECD countries. However, in many industries in China a significant percentage of total production capacity consists of facilities that are much less energy efficient (i.e., higher SEC) than the industry average. This large variation in technology levels defines the energy efficiency problem in China, and makes the analytics of energy efficiency in China somewhat different from those in OECD countries, where such large variation is comparatively rare.

Steel, cement, ammonia, and power generation provide illustrative examples of this tension marked by the co-existence of advanced and older technologies. As

Figure 4 shows, by 2003 average SEC in “key enterprises” (重点企业) in China’s steel sector had reportedly fallen to levels (21.3 GJ/t) only 12% higher than those in Japan. However, average SCE estimates for larger firms can be misleading. The National Development and Reform Commission (NDRC), China’s chief planning agency, estimates average SEC for the steel sector at 26.7 GJ/t (784 tce/t) in 2000 (NDRC, 2004), which just under 20% higher than the 2000 SEC estimate for key enterprises (22.9 GJ/t) shown in the figure below.[20]

[20] Neither of these sources is transparent about methods used in calculating SCE estimates, and it is unclear how comparable these two estimates are. More generally, although a significant amount of progress has been made in developing methods that allow for greater comparability between SCE estimates within China and between China and other countries (Price et al., 2000), direct comparisons remain difficult and estimates should be viewed with caution.

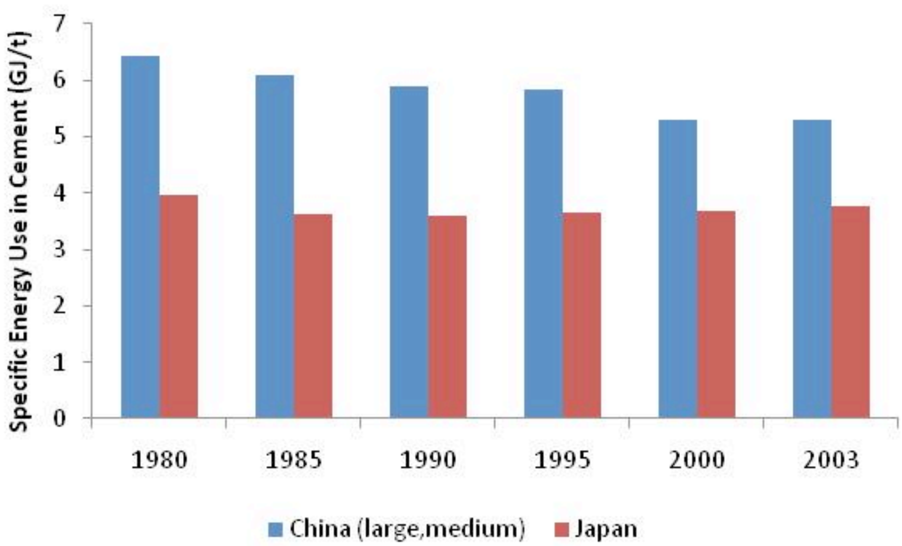
Figure 4. Specific Energy Consumption in Steel Production, China and Japan, 1980-2003



Source: NBS, 2008.

Average SEC in the cement sector (大中型企业) was still significantly (41%) higher than that in Japan in 2003 (Figure 5), in part because of the substantial portion (~40%) of total cement production that still uses inefficient vertical shaft kilns (Price et al., 2009). The NDRC (2004) estimates SCE in cement at 6.9 GJ/t in 2000, which would have been 86% higher than in Japan in 2000.

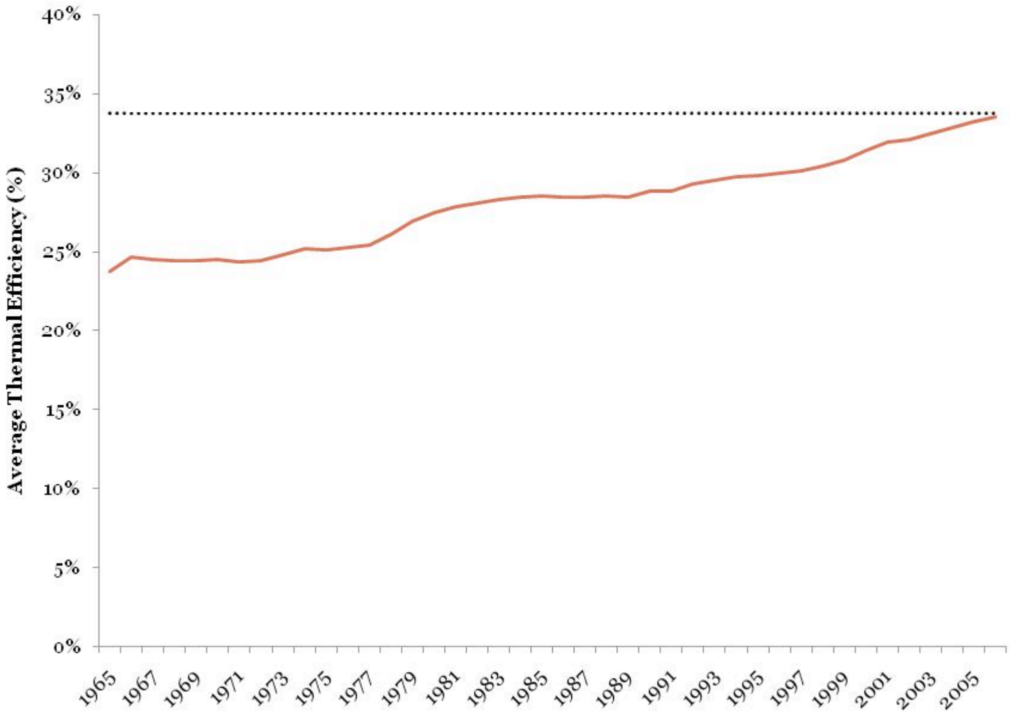
Figure 5. Specific Energy Consumption in Cement Production, China and Japan, 1980-2003



Source: NBS, 2008.

U.S. Average Thermal Efficiency (2007)

Figure 6. Thermal Efficiency for Coal-Fired Power Plants in China, 1965-2007, vis-à-vis U.S. in 2007



Sources: China data are from CEG, 2007; U.S. data are from the EIA website

The NDRC (2004) estimates average SEC for “large-scale” (大型) ammonia facilities of 46.8 GJ/t (1,372 kgce/t) in 2000, and set a target of 41.3 GJ/t (1,210 kgce/t) for large-scale facilities in 2005. However, a significant portion of China’s ammonia producers are small- to medium-scale facilities that have upgraded their facilities but are still significantly lower efficiency than a large, new facility. Yu (2006) estimates average SCE for the entire ammonia industry (both large and small facilities) at 48.7 GJ/t in 2005. This estimate does not include losses (conversion, line) in electricity, which would raise SEC in ammonia production to 59.3 GJ/t in 2005 (Kahrl et al., forthcoming), compared with an international average of 36.6 GJ/t in 2008 (IFA, 2009).

China has made significant strides in improving the thermal efficiency of coal-fired generation over the past three decades. According to official estimates, the average efficiency in coal-fired generation in China exceeded that in the U.S. in 2007 (Figure 6). In the past five years, increases in heat rates for coal-fired power plants have been driven by the significant amount of advanced coal capacity that has come online. By 2009, supercritical and ultrasupercritical coal reportedly accounted for around 30% of China’s total installed coal generation capacity,[21] up from roughly zero a decade before.

[21] Based on 电力统计资料汇编和文献 and 电力统计资料汇编.

Rated heat rates for these technologies can reach, and potentially exceed, 300 gce/kWh (~40% total thermal efficiency). In some provinces, advanced coal penetration has been driven by fiat. However, at least anecdotally sustained increases in coal prices are also thought to be a main driver of advanced coal.

However, despite dramatic improvements in generation technology, significant potential inefficiencies in the power system remain. Because coal-fired generation in China is often used for load following and, in some cases, peaking generation, power plants are often run at partial load, which decreases both their actual heat rates and the lifetime of their equipment. In addition, many provinces still operate system dispatch based on an “equal shares” principle, where generators of a given category are allocated the same number of hours regardless of efficiency and cost (in most OECD countries, dispatch is based on marginal cost). Improving power system operations could improve system efficiency (Hu et al., 2005; Mercados, 2009), but the economic changes (e.g., incentives, prices) resulting from improved operations are still uncertain.

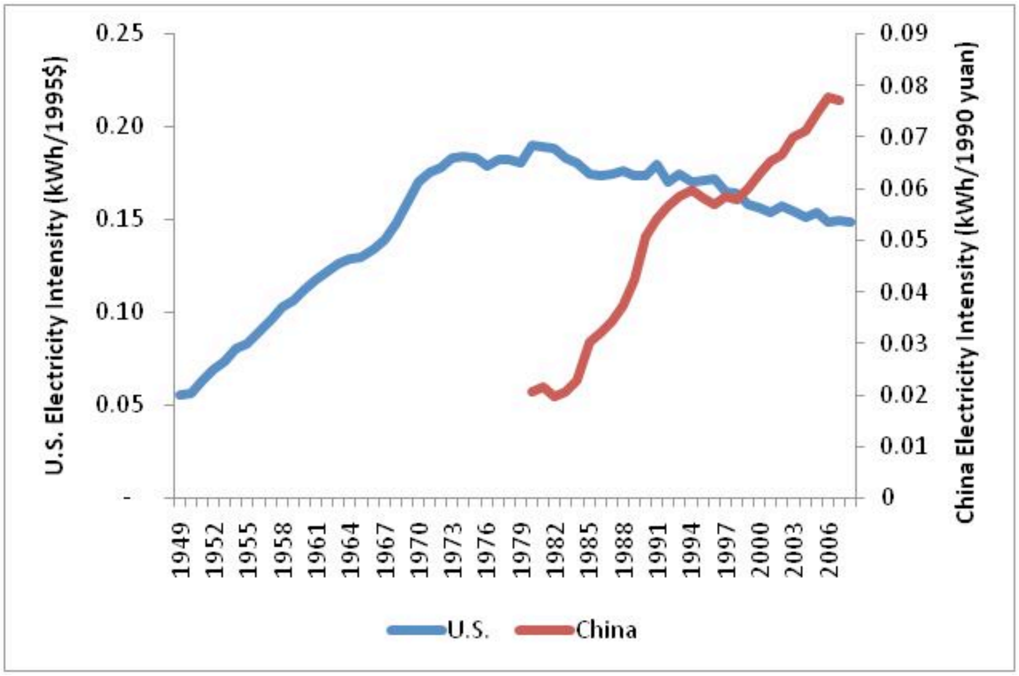
All of the above examples suggest that, while new industrial facilities can be as or even more advanced than in OECD countries, there is still room for significant improvements in energy efficiency that would bring average SEC in Chinese industries closer to OECD levels. However, China’s efficiency problem is somewhat different than that in many OECD countries, in that larger-scale improvements in average sector energy efficiency are often a matter of forcing entire, outdated production technologies out of the market, rather than just replacing or installing new equipment at existing facilities. Whether this process of weeding out technologies is part of China’s economic transition is an open question, as we discuss below.

For residential and commercial sectors, China’s energy efficiency issues are more similar to those in OECD countries: How much to do, how much does it cost, what are the benefits, how can costs and benefits be fairly allocated, and how to design incentives to ensure cost-effective levels of energy efficiency are achieved. In both appliances and buildings, China has made significant progress in encouraging energy efficiency over the past three decades but there is still considerable potential for energy efficiency improvements (Lin, 2006; Zhou and Lin, 2007). The buildings sector, in particular, is and will continue to be an important driver of energy use in China, but building energy use in China is still poorly understood (Fridley et al., 2007; Zhou and Lin, 2007).

Both production and consumption in China have grown more energy intensive over the past decade. On the production side, increases in energy intensity have been driven by a rising share of heavy industry. On the expenditure side, increases in energy intensity appear to have been driven by a rising share of investment and an increase in the energy intensity of consumption (Kahrl and Roland-Holst, 2009). U.S. experience shows that the energy intensity of household consumption saturates at a certain level (Figure

7), but it is unclear when China will reach such a saturation point. These trends, and the policies than can influence them, are not well understood.Energy Efficiency in China: Benefits and Costs

Figure 7. Energy Intensity of Household Consumption, U.S. and China



Sources: U.S. data are from EIA and BEA websites. China data are from the China Statistical Yearbooks

Macro: Production and Consumption Structure

Despite the large and growing interest in energy efficiency in Chinese policy circles, there are still major gaps in information on the physical potential, benefits, and costs of energy efficiency projects-programs-portfolios in China. In part, these gaps exist because large-scale, central government energy efficiency programs have not been explicitly driven or constrained by cost considerations, which has limited the amount of publicly available information or analysis generated as part of these programs.

For equipment- and process-based efficiency projects, at a minimum the following data on energy efficiency measures is needed:

- incremental cost
- annual energy savings
- lifetime

For more sophisticated analysis, 24-hour load reduction shapes and estimates of demand and peak demand reductions are needed.

In China, measure data (cost, energy and demand savings, lifetime) is not widely available. The China Energy Group (CEG) at Lawrence Berkeley National Laboratory has assembled some industrial measure data for China as part of its *Energy Efficiency Guidebooks* series,[22] but more detailed measure data for China has not been collected, has not been made public, and/or has not been aggregated. Load reduction shape data, while in theory existent at the utilities, is not made available outside of the utilities. This lack of publicly available data is a major impediment to assessing the costs and benefits of energy efficiency in China. By contrast, the state of California has a detailed database of energy efficiency measures (DEER, Database for Energy Efficiency Resources)[23] and a detailed database of load shapes (CEUS, California Commercial End-Use Survey),[24] both of which were funded through ratepayers.

Table 1. Industry and Commercial Electricity Prices for Beijing, 2006

	Ordinary Industry (普通工业)			**Commercial (商业)**			**Residential (商业)**		
	< 1 kW	1-10 kW	> 35 kW	< 1 kW	1-10 kW	> 35 kW	< 1 kW	1-10 kW	> 35 kW
Peak (高峰)	1.0295	1.0195	1.0085	1.1515	1.1395	1.1385			
Normal (平段)	0.6895	0.6795	0.6695	0.7625	0.7525	0.7525	0.4883	0.4783	0.4783
Trough (低谷)	0.3705	0.3595	0.3495	0.3965	0.3875	0.3875			

Source: Data are from http://www.bjdsm.com/newweb/article/article_show.asp?id=1866.

In China, a few general themes shaping energy efficiency economics are more apparent, particularly for electric equipment. Retail electricity prices in China tend to be relatively high. In Beijing, for instance, normal (non-peak and non-trough) retail prices range from 0.67-0.75 yuan/kWh (US$0.10-0.11/kWh) for commercial and industrial users, which is higher than commercial and industrial electricity prices in the majority of U.S. states.[25] Peak prices are roughly 50% higher than normal rates for industrial and commercial customers, but Beijing does not yet have TOU prices for residential customers. There is no evidence that TOU rates are actually tied to costs, and, like China's retail electricity prices more generally, may be based more on ability to pay than cost per se. For political reasons, China's rate structure is different than in most OECD countries. In the former, residential customers pay, at normal rates, roughly two-thirds of what industrial and commercial customers pay. In most OECD countries, residential

[22] See "Energy Efficiency Guidebooks for Industry," http://china.lbl.gov/energy.efficiency.guidebooks.
[23] See http://www.energy.ca.gov/deer/.
[24] See http://www.energy.ca.gov/ceus/.
[25] See http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html for average retail prices by customer class in U.S. states.

customers pay higher prices than residential or industrial customers. Regional variation in retail electricity prices is significant, as Figure 6 shows.

High prices, the large difference between peak and normal prices, and rate structure shape incentives for energy efficiency in the electricity sector. In principle, energy efficiency should be very cost-effective for commercial and industrial customers, particularly for measures that reduce load in peak periods. In practice, however, these customers appear to have simple payback periods that are on the order of a few months.[26] Much more research is needed to understand facility-level energy efficiency investment behavior for in China, in order to better set incentive levels as part of energy efficiency programs. Provincial DSM Centers, for instance, often provide a flat, percentage-based incentive for all efficiency projects.

Figure 8. Average Retail Electricity Prices by Region in China, 2008

Source: Data are from SERC, 2008.

The disjuncture between electricity supply costs and retail prices in China means that incentives on the supply and demand sides may be quite different. Low cost coal accounts for around 80% of total generation in China — wholesale rates for new coal

[26] Based on comments at a recent RAP/NRDC workshop on "Building an Energy Efficiency Powerplant" in Beijing. Maximum payback periods for businesses in the U.S. tend to be around three years, by contrast.

were 0.31 yuan/MWh (US$0.046/kWh) in 2009[27] — which means that energy values (marginal cost of generation) are low. Capacity values are more difficult to assess in China because of the lack of data and a more standardized methodology specific to China. However, because of the lack of non-hydro peaking generation in China and the cost of running power plants at partial load factor, capacity values may be substantial. In general, though, benefits on the customer side may be higher than benefits on the utility side.

By most estimates, the lack of more robust institutions is still a significant barrier to energy efficiency in China (Taylor et al., 2008; Williams and Kahrl, 2009), and institutional innovations are necessary for both improving the effectiveness of current energy efficiency investments and for scaling those investments up. For instance, at the level of industrial organizations, energy service companies (ESCOs) are a growing presence in China's energy efficiency marketplace but have found their contracts difficult to enforce. How ESCOs can effectively operate in China without a stronger system for enforcing contracts is an open question. At a regulatory level, among energy-relevant regulatory agencies China currently lacks a ratepayer advocate, and without an explicit agency tasked with assessing prices it is unclear whether creating a level playing field for demand- and supply-side resources is possible. At an even broader level is the question of how energy efficiency might be integrated into China's ongoing electricity reform process (IEA, 2006), which, after years of being stalled, is set to continue. All of these institutional questions, and a host of others, are in need of research.

Although the NDRC has put significant effort into forcibly retiring obsolete production technologies, either through mandates or incentives, little research has been done on either the costs or benefits of these strategies. In addition to a more detailed inventory of costs and benefits associated with a given policy, two questions are particularly salient: Was the policy necessary, and was it cost-effective relative to another approach. Providing satisfactory answers to these questions is often difficult. For instance, the NDRC's strategy over the last decades has been to wait until industries are at overcapacity to force restructuring. In 2009, for example, the NDRC revised its long-standing energy price subsidy policy for the ammonia industry, in the hopes that inefficient ammonia producers will go bankrupt. If ammonia cost increases are passed through to fertilizer costs and then to farmers, the benefits of higher efficiency would need to be compared against the opportunity costs of original subsidies and losses to farmers. Alternatively, there is evidence that fertilizer use is currently not socially optimal (Kahrl et al., Forthcoming), in which case an assessment of an efficiency intervention becomes significantly more complicated.

---

[27] Personal communication, former director of Huaneng Energy Research Center.

Another interesting and particularly relevant example is the NDRC's policy of differential electricity prices. The NDRC created a four-tier pricing system for certain industries in 2004-2005, with higher prices for more energy inefficient producers and lower prices for more efficient producers, in an effort to force less efficient producers out of the market. The Center for Research on Chinese Public Policy (CRCPP), in tandem with the State Electricity Regulatory Commission (SERC), is sponsoring ongoing analysis of this and other similar policies. However, data and methods remain an issue, and continued attention to both is necessary.

To the authors' knowledge, there have not been any analyses of the macro-level benefits and costs of energy efficiency policies in China. Similarly, the effects of policy on macroeconomic structure in China are understudied.

Greater analysis of these issues is important for energy efficiency planning in China going forward. Funding for energy efficiency programs in China is already substantial. Price et al. (2010) report that central government funding for energy efficiency and pollution abatement was 23.5 billion yuan (US$3.4 billion) in 2007. However, scaling up energy efficiency to levels comparable to supply-wide investments would require a significant increase over current levels. Total supply-side investment in generation and T&D capacity was 756 billion yuan in 2009 (49% generation, 51% T&D) (SERC, 2010). Achieving a level of 20% of total power sector investment from energy efficiency, at this level, would require 189 billion yuan *per year* in investment. There are talks of requiring grid companies to meet 3% of demand with energy efficiency. Assuming, for illustrative purposes, that the costs of energy efficiency are at parity with the costs of supply, 3% of total grid company revenues in 2009 would be 110 billion yuan.[28] Significant changes would be required to China's institutional and analysis capacity to manage this level of investment.

4. Energy Efficiency in South Africa

South Africa is Africa's largest economy where strong growth in the economy has improved per capita GDP to just under US$6,000 in 2008 putting the country on par with countries such as Brazil, Argentina, and Malaysia establishing its position in the world's Upper Middle-Income Countries. Despite its strong performance the South African economy was hit hard by the financial crisis and has one of the highest inequality rates in the world. [29]

---

[28] Total implied grid company revenues were 3.66 trillion yuan in 2009 (SERC, 2010)
[29] World Bank. Project Information Document: Eskom Power Investment Support Project. Report No.: AB5486.

Demand for power in South Africa has been exceeding supply. The state energy company Eskom has embarked on a major program to modernize and expand the country's electricity infrastructure.[30] Power shortages became a national crisis by 2008 when power cuts of up to 20 percent were imposed on large industrial customers presenting difficulties for the country's mining sector as large enterprises were forced to factor in self-generation of electricity into the development of new projects.[31]

South Africa holds great potential for energy efficiency improvements. The economy revolves largely around energy intensive, large-scale mining and other activities in the minerals sector. Energy intensity in the country is well above average with only 10 other countries having higher levels. Such high levels of energy intensity leaves the economy with much room for improvement. South Africa is a prime location for energy efficiency improvements and large strides in carbon mitigation.[32]

As of May 2010 South African unemployment stands at over 25 percent.[33] With high levels of unemployment in the country, ideal programs will focus on a comprehensive approach that encourages local private sector innovation and domestically produced technologies to answer energy use challenges. Decreasing energy demand will lessen the burden on the South African electricity grid thereby enabling companies to have improved confidence in regular electricity supply and less reluctance to embark on developing new projects which will improve levels of employment in the country.

Solar water heaters may present a substantial opportunity for such a project. Relatively low technology is required for manufacturing and installation of these rooftop contraptions. Acceptance of solar water heaters in developing markets is particularly apparent in China where in some cities they are found on nearly every rooftop. In South Africa, where weather conditions are such that solar water heaters could be a very feasible option, a program to encourage their manufacturing and use holds great potential to achieve progress toward the twin objectives of increasing employment while reducing energy demand. The manufacturing and sales of water heaters would provide opportunity in the private sector while additional needs for installation and repair service could potentially provide further employment opportunity. The externalities of more employment opportunities will also carry over into other sectors of the economy.

The government of South Africa is focusing on a program to increase the use of solar water heaters and CFL bulbs as part of a near-term DSM strategy but more research

---

[30] South Africa's Energy Supply. Available at: <http://www.southafrica.info/business/economy/infrastructure/energy.htm>.

[31] G. Heffner, L. Maurer, A. Sarkar, X. Wang. Minding the gap: World Bank's assistance to power shortage mitigation in the developing world. Energy 35 (2010): 1584–1591.

[32] South Africa's Energy Supply. Available at: <http://www.southafrica.info/business/economy/infrastructure/energy.htm>.

1. [33] Robb M. Stewart. South Africa Unemployment Hits 25.2%. Wall Street Jounal. 4 May 2010.

and funding will be needed to achieve scaled up domestic manufacturing and widespread use.[34] Other possibilities for energy efficiency improvement include the encouragement of energy efficient home appliances such as air conditioners and refrigerators, energy efficiency improvement of public sector buildings, modernization of water delivery systems to avoid unnecessary waste, improvement of energy efficiency in industry, and increased attention to energy consumption in the transportation sector focusing on public transport, non-motorized transport, and electric bike manufacturing.

5. Priorities for Research

The next decade will be a defining period in the economic and environmental future of emerging economies. Energy efficiency could be an important part of energy and climate policy in these countries in the near- and medium-term future, but important questions remain on both the level of cost-effective investments in energy efficiency and how to improve the effectiveness of existing energy efficiency programs. Macroeconomic effects of energy efficiency could be an important policy consideration, but need further study.

As described in greater detail above, research priorities in this area should include, but not be limited to, developing:

- A database of publicly available energy efficiency measures and load shapes, including incremental costs, annual energy savings, demand savings, peak demand savings, and 24-hour load reduction shapes;
- A standardized economic framework for cost-benefit analysis for energy efficiency projects and portfolios that is appropriate to China, including consensus cost test metrics;
- An analytical framework for understanding benefits and costs of policies to induce and adapt technological change (Technology Structure, from above), and empirical work to inform specific policies;
- An analytical framework for understanding the macroeconomic effects of energy efficiency policies in emerging economies, and empirical work to inform energy efficiency planning;
- Empirical work to understand the kinds of policies that can induce changes in economic structure, and to understand their shorter- and longer-term implications.

---

[34] World Bank. Project Information Document: Eskom Power Investment Support Project. Report No.: AB5486.

6. References

Besley, T., A. Case. 1993. "Modeling Technology Adoption in Developing Countries." The American Economic Review 83(2): 396-402.

Blumstein, Carl, Betsy Krieg, Lee Schipper, and Carl York. 1980. "Overcoming Social and Institutional Barriers to Energy Conservation." Energy 5: 355-371.

China Energy Group (CEG). 2007. China Energy Databook Version 7.0. Lawrence Berkeley National Lab China Energy Group Database.

DeCanio, Stephen J. "Barriers within Firms to Energy-efficient Investments." Energy Policy 21: 906-915.

Feder, G., R.E. Just, D. Zilberman. 1985. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change* 32(2): 255-298.

Fridley, David G., Nathaniel Aden, Zhou Nan. 2007. "China's Building Energy Use." Lawrence Berkeley National Laboratory Report LBNL-506E.

Hassett, Kevin, and Gilbert Metcalf. 1992. "Energy Conservation Investment: Do Consumers Discount the Future Correctly?" Energy Policy 21(6): 710-716.

Howat, J., & Oppenheim, J. (1999). Analysis of low-income benefits in determining cost-effectiveness of energy efficiency programs. Washington, DC. National Consumer Law Center

http://are.berkeley.edu/~dwrh/CERES_Web/Docs/California%20Climate%20Risk%20and%20Response.pdf

Hu, Zhaoguang, David Moskovitz, Zhao Jianping. 2005. Demand-Side Management in China's Restructured Power Industry: How Regulation and Policy Can Deliver Demand-Side Management Benefits to a Growing Economy and a Changing Power System. Washington, DC: World Bank.

International Energy Agency (IEA). 2006. China's Power Sector Reforms: Where to Next? Paris: IEA/OECD.

International Energy Agency (IEA). 2009. World Energy Outlook 2009. Paris: IEA/OECD.

International Energy Agency. World Energy Outlook: 2009. Paris, France: IEA Publications: 76.

International Fertilizer Industry Association (IFA), 2009. Energy Efficiency and CO2 Emissions in Ammonia Production: 2008-2009 Summary Report. IFA, Paris.

Jaffe, Adam B. and Robert N. Stavins. 1994. "The Energy-efficiency Gap. What Does it Mean?" Energy Policy 22(10): 804-811.

Kahrl, Fredrich, David Roland-Holst. 2009. "Growth and Structural Change in China's Energy Economy." Energy 34(7): 894-903.

Kahrl, Fredrich, Li Yunju, Su Yufang, Timm Tennigkeit, Andreas Wilkes, Xu Jianchu. Forthcoming. "Greenhouse Gas Emissions from Nitrogen Fertilizer Use in China." Environmental Science & Policy.

Lin, Jiang. 2006. "Mitigating Carbon Emissions: the Potential of Improving Efficiency of Household Appliances in China." Lawrence Berkeley Lab Report LBNL-60973.

Mahajan, V., E. Muller, F.M. Bass. 1990. "New Product Diffusion Models in Marketing: A Review and Directions for Research." *Journal of Marketing* 54: 1-26.

Mahlia, T.M.I. and R. Saidur. A review on test procedure, energy efficiency standards and energy labels for room air conditioners and refrigerator–freezers. Renewable and Sustainable Energy Reviews 14 (2010): 1889, 1896.

Martinot, Eric and Nils Borg. Energy-efficient lighting programs: Experience and lessons from eight countries. Energy Policy. Vol. 26, No. 14, 1998: 1074.

Mercados – Energy Markets International. 2009. "China Power Dispatch Efficiency Improvement." Task III Report Prepared for the World Bank.

Michaelowa, Axel, Daisuke Hayashi, and Marc Marr. Challenges for energy efficiency improvement under the CDM—the case of energy-efficient lighting. Energy Efficiency (2009) 2:361.

National Bureau of Statistics (NBS). 2009. China Statistical Yearbook 2009. Beijing: China Statistics Press.

National Bureau of Statistics. 2007. China Energy Statistical Yearbook 2007.

National Development and Reform Commission (NDRC), 2004. Medium- and Longer-term Energy Efficiency Plan [节能中长期专项规划]. NDRC Policy Document.

Pachuri, S., Jiang L.W. 2008. "The household energy transition in India and China." *Energy Policy* 36(11): 4022-4035.

Price, L., Worrell, E., Martin, N., Lehman, B., Sinton, J., 2000. "China's Industrial Sector in an International Context." Lawrence Berkeley National Lab Report 46273.

Price, Lynn, Wang Xuejun, Yun Jiang. 2010. "The Challenge of Reducing Energy Consumption of the Top-1000 Largest Industrial Enterprises in China." Energy Policy 38(11).

Ravallion, Martin, 2008a, "On the Welfarist Rationale for Relative Poverty Lines," in Kaushik Basu and Ravi Kanbur (eds) The Oxford Handbook of Arguments for a Better World: Essays in Honor of Amartya Sen. Volume I: Ethics, Welfare and Measurement, Oxford: Oxford University Press, 2008., Oxford: Oxford University Press.

Ravallion, Martin, 2008b, "Mixing Surveys and National Accounts in Measuring Global Poverty," Policy Research Working Paper @@, World Bank, Washington DC.

Roland-Holst, David (2008), "Climate Action, Energy Efficiency, and Job Creation in California," Working Paper, Department of Agriculture and Resource Economics, University of California, Berkeley—see http://are.berkeley.edu/~dwrh/CERES_Web/Docs/California%20Climate%20Risk%20and%20Response.pdf and http://are.berkeley.edu/~dwrh/CERES_Web/Docs/CCRR_Supplement.pdf

Smith, Pete et al. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agriculture, Ecosystems and Environment 118 (2007): 12.

State Electricity Regulatory Commission (SERC). 2009. Electricity Regulation Annual Report 2008 [电力监管年度报告]. Beijing: SERC.

State Electricity Regulatory Commission (SERC). 2010. Electricity Regulation Annual Report 2009 [电力监管年度报告]. Beijing: SERC.

Swanton, Clarence J., Stephen D. Murphy, David J. Humea, and David R. Clement. Recent Improvements in the Energy Efficiency of Agriculture: Case Studies from Ontario, Canada Agriculturul Systems, 52 (1996): 399.

Taylor, Robert P., Chandrasekar Govindarajalu, Jeremy Levin, Anke S. Meyer, William

A. Ward. 2008. Financing Energy Efficiency: Lessons from Brazil, China, India, and Beyond. Washington, DC: World Bank.

Ürge-Vorsatz, Diana and Aleksandra Novikova. Potentials and costs of carbon dioxide mitigation in the world's buildings. Energy Policy 36 (2008): 642.

Vine E, Rhee C.H, Lee K.D. 2006. "Measurement and Evaluation of Energy Efficiency Programs: California and South Korea". Energy 31:1100-1113.

Williams, James H. and Fredrich Kahrl. 2008. "Sustainable Development and China's Electricity Sector Reforms." Environmental Research Letters 3: 1-14.

Williams, Jim, Fritz Kahrl, Ding Jianhua, Snuller Price. 2010. "Electricity with Chinese Characteristics: The Complexities of Decarbonizing China's Electricity Sector." Presentation at the Woodrow Wilson Center, China Environment Forum, 24 June 2010.

World Bank Press Release. Developing Countries Stepping up Action Against Climate Change. 11 May 2010. Available at: < http://beta.worldbank.org/climatechange/node/5614>. Accessed 25 June 2010.

World Bank. Developing Countries Ratcheting up Action on Climate Change. 2010a. Available at: <http://beta.worldbank.org/climatechange/content/developing-countries-ratcheting-up-action>. Accessed 25 June 2010.

World Bank. Development and Climate Change: A Strategic Framework for the World Bank Group, Interim Progress Report. 20 Apr 2010b. Washington, DC.

World Bank. World Development Report: 2010. Washington, DC. Sep 2009: 312, 321.

Yu, Z., 2009. Energy Use and Energy Efficiency Pathways in the Ammonia Industry [合成氨行业能耗现状与主要节能途径]. Nitrogen Fertilizer [小氮肥] 37 (2), 1-3.

Zhou, Nan and Lin Jiang. 2007. "The Reality and Future Scenarios of Commercial Building Energy Consumption in China." Lawrence Berkeley National Lab Report LBNL-1036E.