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Environmental Impacts of Energy-Efficient Technologies: Potential for Input-Output and Supply-Chain Analyses in Iran

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Abstract

Many analysts investigating environmental and energy issues in developing countries. However Iran as a major producer and exporter of oil is different.

The efforts to contuct industrial analyses to determine energy efficient low-pollution sectors in which to invest is misdirected for two reasions .First,some sectors may,on the surface appear to be very energy-conserving and consequently, create only low levels of pollution because analyst consider only the direct inputs into production process.If analysts consider only energy inputs through use of an input-output table,however they may find that "green" firm,in fact, "brown"firm .Second, The narrow facus of most on evironmental analyeses on firm in a particular location rather than on the entire supply chain serving the firm is misdirected.

In this paper we examine these aspects and present several examples from our research on energy intensity in the Far East,and show how Structural Decomposition Analysis (SDA)of the sectors can help determine the source of the changes in energy intensity.Also we examine the supply chain serving firm which otherwise could lead to misdirected concerns.

Keywords: Environmental Impact,Energy Intensity,Iran Energy Intensity.

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Introduction

Many analysts are investigating environmental and energy issues in developing countries. For Iran, of course, oil is the main focus of attention. I maintain that, in most cases, the efforts to conduct industrial analyses to determine energy-efficient, low-pollution sectors in which to invest are being misdirected for two reasons. First, some sectors may, on the surface, appear to be very energy-conserving and, consequently, create only low levels of pollution, because analysts consider only the direct inputs into the production process. If analysts also consider indirect energy inputs through use of an input-output table, however, they may find that "green" firms, in fact, are "brown" firms. This is not such an unusual finding for those of us immersed in input-output types of analyses. What is surprising is the number of analysts and policy makers who overlook the need to use the input-output framework to conduct systematic analyses concerning energy-conserving sectors. I present several examples from our research on energy intensity (energy consumption per unit of output) in the Far East and show how a Structural Decomposition Analysis (SDA) of the sectors can help determine the source of the changes in energy intensity.

My second reason for believing that some of the current energy and environmental research efforts are misdirected concerns the narrow focus of most environmental analyses on firms in a particular location rather than on the entire supply chain serving the firm. Input-output analysts know many of the most sophisticated input-output models and techniques, but few of them have investigated the supply chains for one or more of the commodities they intend to study. By using input-output and supply-chain techniques in combination, analysts have a robust set of tools to examine socio-economic sustainability issues. I illustrate in this paper some of the ways we have been integrating them to conduct energy and environmental analyses in the People's Republic of China (China) both at the local and the global levels. Some analysts have used one or the other of these techniques, but I show how by combining them, analysts can obtain more detailed and appropriate results than at present.

Comparison of China and Iran

China and Iran are two countries with enormous amounts of fossil-fuel reserves, but they represent almost exact opposites in several ways. First, China has coal, and Iran has mainly oil and gas. China's coal reserves are estimated to be five trillion tonnes, with proven reserves of one trillion tonnes, sufficient to last the country for many years and representing 11 percent of total world reserves of coal, with the United States and the Soviet Union each representing 25 percent [http://www.platts.com/features/ cleancoal/ china.shtml]. The world's known reserves of coal are sufficient to last about 250 years at present rates of production [http://www.eia.doe.gov/ neic/infosheets/coalreserves.htm].

The Iranian fossil-fuel proven reserves include the following: [http://www.eia.doe.gov/ emeu/cabs/iran.html]

1. Proven oil reserves of 99 billion barrels, representing about 9.0% of the world total, 12% of the OPEC (Organization of Petroleum Exporting Countries) total, and over 14% of the Middle East total. (Table 1).
2. Proven natural gas reserves of 24 trillion cubic meters, which are the second largest gas reserves in the world, representing 15% of the world total (Table 2).
3. Only an extremely small amount of proven coal reserves, namely, 13 billion tonnes, compared to China's one trillion tonnes.

A second major difference between China and Iran is what has been happening since the late 1970s in terms of changes in energy intensity. One of the driving forces for my research in China has been to determine the factors behind the rapid decline in energy intensity in the country, especially when compared with other developing countries. Between 1978 and 1997, energy intensity (measured as energy consumption per unit of gross domestic product) has declined by about 50% in China (Figure 1). As we see in the figure, this decline occurred not only in China as a whole, but also in Shanxi Province, which produces over 25 percent of the total coal in China and which has many energy-intensive industries. Although the energy intensity decreased in both from 1978-1997, the index for Shanxi Province is always about twice that of China's, partially reflecting the many energy-intensive industries, such as cokemaking, brick making, and cement making located in the region.

Given the abundance of oil and gas in Iran, I examined how the energy-intensity index in Iran of 1.03, where Syria's index is used as the reference point, compares to that in other major oil-producing countries (Table 3). Only Nigeria, with an intensity of 2.75, has a higher index than Iran. In fact, Iran and Nigeria are the only countries for which the energy-intensity index is higher than in Syria. Iraq (0.99) has an index close to Syria's. Saudi Arabia (0.76) and Venezuela (0.71) have a lower energy-intensity index than Iran, but even their indices are higher than that for Russia (0.57) and Kuwait (0.56). I emphasize that this is an index compared with Syria and not the actual energy intensity of Iran.

Concerning energy intensity itself, according to the case study of Iran, prepared by the World Energy Council (http://www.worldenergy.org/wec-geis /publications/reports/pedc/cases /iran.asp#2.3.2), "Iran is one of the few oil producing and exporting countries in the world to carry out programs for improving the energy efficiency of the different consuming sectors." This effort does not seem to be reflected by the data. In Iran, the energy intensity has increased, rather than decreased, since 1970 (Figure 2). In fact, it has tripled during this time period, which is in sharp contrast to the approximate 50% decrease in energy intensity in China.

The energy intensity in most developing countries has been increasing or remaining constant, while that in the United States and other industrialized countries has been decreasing. The decline in China is dramatic, especially when compared with the energy-intensity trend in India (Figure 3). Although I do not know the detailed factors causing the steady increase in energy intensity in Iran, I will explain what we have determined are leading reasons for the decline in China.

Energy-Intensity in China

For the past ten years, members of my multiregional planning research team and I have been examining the energy-intensity issue in China, both at the national and the provincial levels. We are finding that the decreases in energy intensity are occurring in most provinces and most sectors of the country. As an example, we compared the energy-intensity changes in China and Shanxi Province, the largest coal producer in China (Figure 1). As noted earlier, the energy-intensity in Shanxi is systematically about double the comparable figure for China, but in both cases, it has declined systematically since 1978. Even so, it is still high compared with industrialized countries, indicating that important policy measures for clean-coal technology and other options can be taken to help reduce it further.

We began the examination of factors affecting energy-intensity changes by using a simple shift-share technique and applying it to the changes in energy use in China (Lin and Polenske, 1993). In the early 1990s, most Chinese analysts indicated that the decline was caused by the supposed shift in production from energy-intensive to energy-conserving industries, but our results indicated that technological change was the primary cause. As we will note below, other analysts concurred with our results. We still did not know what would happen over time, nor between provinces. We then used two national input-output tables for China, one for 1981 and one for 1987, and applied the Structural Decomposition Analysis (SDA) technique I describe below (Lin and Polenske, 1995). We again concluded that much of the reduction in energy-intensity in China is due to changes in technology, some of which were encouraged by the opening of the country to outside investments in the late 1970s.

Although results from other analysts verify our findings, until recently they have examined only national energy intensities. One of the most recent studies, however, is by Fisher-Vanden, Jefferson, Liu, and Tao (2002), who have looked at regional energy-intensity effects with an econometric approach. As was expected, they find differences among the regions, but they have looked only at three recent years and have not examined any sector in depth.

Our multiregional research team members seem to be the only ones conducting systematic in-depth analyses of regions. After our 1995 study, our next step was to apply the same technique at the provincial level, using as our first case, Shanxi Province, which produces over 25% of the total coal in China, and coal still represents about 75% of total energy consumption in China. In addition to using the SDA technique to examine the changes between China and Shanxi Province (Shirvani-Mahdavi, 1999), we have also used the technique to examine the changes in Shanxi Province over time (Guo, 2000).

Over the next 10 years, we do not expect petroleum to represent a major portion of the energy consumption in China, although automobiles and other vehicles are being used increasingly. As of 1993, China became a net oil importer, but oil still represents a small amount of China's total energy use. Natural gas production has increased dramatically in China during the past 10 years, and we think the trend will continue, with several major cities, such as Tianjin and Beijing now being almost completely converted from coal to natural gas for household use. We anticipate continued efforts by Chinese policy makers in developing energy-conservation technologies and in proposing many different ways to reduce energy use, while maintaining a rapid growth of 7 percent or more per annum in GDP.

Research Overview

In reviewing energy-intensity studies of other analysts, we have found no published analyses of the regional disparities in energy-intensity reductions and the factors affecting the disparities. Instead, analysts, such as Sinton and Levine (1994), Sinton, Levine, Fridley, Yang, and Lin (1999), Sinton and Fridley (2000), Zhang (1995, 2001), and Jorgenson, Garbaccio, and Ho (1999) focus on the national energy intensity. Those analysts conducting regional studies in China focus on differences in regional per capita income (Fan, 1995; Lin and Ma, 1994; Wei, 2000; Yusuf and Wu, 1999; Zhao and Tong, 2000), rather than on spatial changes and changes in spatial energy and environmental policies that affect energy use. Most important, analysts have not tried to construct integrated tools of analysis, whereas technology issues often affect transportation and other aspects of the economy. Our research is therefore based upon four sets of literature: (1) Extended Input-Output Table Analyses (EIOTA), (2) Geographic-Information-System Transportation Analyses (GISTA), (3) Supply-Chain Analysis Framework (SCAF), (4) Structural-Decomposition Analyses (SDA), and Spatial and Temporal Structural-Decomposition Analyses (SSDA and TSDA).

Extended Input-Output Table Analyses

Professor Chen Xikang, one of my collaborators on our research in China, conducted the first Extended Input-Output Table Analyses (EIOTA) for China in the late 1980s (Chen, 1990). He and his colleagues have collected information on the labor, capital, and land inputs for each sector and have used these extended tables for several important examinations of economic changes in China (Chen, Pan, and Yang, 1999). Two of their most current studies have been used the extended tables to examine the rural economy in China (Chen et al., 1992) and the water-shortage problem in North China (Chen, 2000).

Geographic-Information System Transportation Analyses

In our Alliance for Global Sustainability (AGS) research, we initially developed a simple Net-Flow Model to examine the flows of coal to the coke plant and of coke to the final consumer (Kraines, Akatsuka, Crissman, Polenske, and Komiyama, forthcoming). This model, however, is not based on a Geographic Information System (GIS) framework. Previous transportation analysts have constructed GIS models for developing countries. Examples include (1) the GIS based planning support system for transportation planning and infrastructure and management in Bolivia (GAF mbH Company for Applied Remote Sensing, 1998), (2) An integrated planning support system model (Mejia-Navarro and Garcia, 1996), and (3) an environmental planning-support-system model (MCNC, 2000).By extending the net-flow model and incorporating a GIS model, Chen Yan (2003) conducted a Geographic-Information System Transportation Analyses (GISTA)

Supply-Chain Analysis Framework

Also relevant is our work on a Supply-Chain Analysis Framework (SCAF), which is especially pertinent in today's global economy for the examination of investment decision-making, transportation options, industrial and regional restructuring, and regulatory planning (Polenske, 2001). Only a few analysts have studied supply chains from an explicit regional perspective, i.e., to determine the effect of the chain on a particular region. Supply chains are considered to be one way for an industry/region to compete in an increasingly globalized market place (Ellram, 1991; Glasmeier and Kibler, 1996). Depending upon the study objectives, analysts have used four types of models to design and analyze supply chains: (1) deterministic analytical, (2) stochastic analytical, (3) economic, and (4) simulation. Many of the analysts focus primarily on minimizing production and transportation costs for a single product; others have developed a more complicated global supply-chain model with multiple facilities, products, stages, time periods, and transportation modes. They use this to minimize not only production and transportation costs, but also inventory, materials handling, overhead, and activity days.

For industrial and regional planning, analysts need to expand the scope of supply-chain issues by conducting case studies. Polenske, McCormick, Pereira, and Rockler (1996) are among the first to apply supply chains at a regional level with a case-study approach. They conducted a case study of the Chicago metalworking sector. Polenske (2001) has also started to use the SCAF for her study of the cokemaking sector in Shanxi Province, China. She and her students have completed a comprehensive case study of three alternative cokemaking plants in Shanxi Province (Chen, 2000; Polenske, ed., forthcoming), and she and McMichael (2002) constructed a hypothetical process-flow model for an individual plant that had an option of using any of three types of coke ovens.

Structural-Decomposition-Analysis (SDA) Models

The antecedents of Structural Decomposition Analysis (SDA) are the various analyses of changes in technologies, such as that by Leontief (1941), using some of the early U.S. input-output tables. The first formal identity-splitting derivation is the three-part decomposition of sources of change in air-pollution emissions performed by Leontief and Ford (1972). Rose and Chen (1991) extended the derivation to 14 estimating equations, comparable analytically with that of a neoclassical, two-tier KLEM (capital, labor, energy, and materials) production function. Overall, SDA has been used in many applications, including an examination of the sources of change in international trade (e.g., Kanemitsu and Ohnishi, 1989; Chen and Wu, 1995), technological change (e.g., Zhang, 2001; Oosterhaven and van der Linden, 1994), energy use (e.g., Office of Technology Assessment (OTA), 1990; Lin and Polenske, 1995; Shirvani-Mahdavi, 1999), workforce requirements (e.g., Wolff, 1985; Han, 1995), and development planning (e.g., Siegel, Alwang, and Johnson, 1996). These empirical studies have yielded valuable findings about the success of energy-conservation measures; limitations of import substitutions; prevalence of changing tastes; pervasiveness of factor productivity; and importance of skill attainment (Rose and Casler, 1996).

The basic rationale for SDA is to split an identity into its components (Rose and Casler, 1996; Casler and Rose, 1998). SDA is an effective tool of analysis for several reasons. First, it overcomes many of the static features of input-output models and can be used to examine changes over time and space in technical coefficients and industrial mix. Second, SDA is a practical alternative to econometric estimation, requiring only two input-output tables, one for the initial year and one for the terminal year. Third, its input-output base provides a comprehensive accounting of all inputs in production.

Energy is one of the areas where different types of SDA have been used extensively. Proops (1984) decomposed changes in the energy-output ratio into three factors: (1) changes in energy intensities, (2) changes in final demand, and (3) changes in the structure of interindustry trading. Ploger (1985) assessed the effects of changes in output mix and energy coefficients on energy consumption in the Danish manufacturing industries. The Office of Technology Assessment (OTA, 1990) staff performed an SDA on US energy-use changes between 1972 and 1988. After the shift-share analysis by Polenske and Lin (1993), Lin and Polenske (1995) and Lin (1996) developed and used the SDA to explore factors behind the drop in China's energy intensity between 1981 and 1987. Students working with Polenske developed the Spatial Structural Decomposition Analysis (SSDA), e.g. Shirvani-Mahdavi (1999), and the temporal structural decomposition analysis (TSDA), e.g., Guo (2000), and Pereira (1997) and Polenske, McCormick, Pereira, and Rockler (1996) on SCAF.

In our review of the literature, we found no published work other than that of our research team on incorporating labor, capital, and land inputs into the input-output tables, so that they could be used as EIO models for energy analyses, and we have found only limited work on integrating supply chain, GIS, and process-flow analyses. We therefore expect the results of our research to fill an important gap in the spatial-analysis literature. Given that Iran has nine input-output tables, the SDA technique is a logical one for analysts to use, along with case studies, to determine the factors affecting the rapid increases in energy-intensity in Iran.

Spatial Structural-Decomposition Analyses

Analysts can use the Spatial Structural-Decomposition Analysis (SSDA) tool to compare the technology and demand structures of a nation, province, or some other regional unit. For example, in our work in China, we are using it to compare changes in energy intensities over time and between the nation and Shanxi and Liaoning provinces. Through our analyses in China, we will be able to determine the amount of the changes in energy use that are attributable to technology changes versus changes due to shifts in the mix of output and final-demand shifts. We are focusing on the cokemaking and steelmaking sector, because they are among the heaviest energy users. Before providing a brief review of the results of that analysis, I explain the SSDA system of equations.

Structural decomposition analysis is a practical tool that makes it possible to quantify fundamental factors of change in a wide range of variables, including economic growth, energy use, employment, trade, and material intensity of use, employing input-output economics. Because input-output analysis is well known to this audience, I will only give some brief comments concerning it.

The empirical basis of input-output analysis is the transactions table, which provides a detailed statistical account of the flows of goods and services among all the producing and consuming sectors of a given economy, that is, among all the various branches of business, households, and government. The table displays not only complete details of the income and product accounts, but also all intermediate transactions among producers and purchasers within a consistent accounting framework (Polenske and Fournier 1993).

Using the input-output tables in China, we decompose the final-demand shifts into three components: the energy-use differences associated with changes in the (1) level, (2) distribution, and (3) pattern of final demand. The level of final demand refers to the overall level of total demand, which equals the sum of all final output or expenditures. The distribution of demand refers to the allocation of total demand among the individual final-demand sectors. The pattern of demand refers to the mix of goods and services within an individual final-demand sector (Lin, 1996). Table 4 shows the decomposition of the difference in the energy consumption in China and in a province that an analyst can make.

I show here only the most important SSDA equations that we use in China. Using a hybrid energy input-output model (Miller and Blair, 1985), we are able to identify two parts of the energy consumption: intermediate and direct. Intermediate energy consumption is the energy used or sold directly to final users, such as households and government agencies.

Table–4. Spatial Structural Decomposition of Energy–Use–Changes

Factor	*Equation*
Final-Demand Difference	$F[Y - Y_R] + e[Y - Y_R]n$
Level Effect	$F_R M_R D_R(L - L_R) + eM_R D_R(L - L_R)n$
Distribution Effect	$F_R M_R(D - D_R)L + eM_R(D - D_R)Ln$
Pattern Effect	$F_R(M - M_R)DL + e(M - M_R)DLn$
Production-Technology Difference	$[F - F_R]Y$
Energy Inputs	$eG(A^E - A_R{}^E]G_R Y$
Nonenergy Inputs	$eG(A^N - A_R{}^N]G_R Y$

Where $F = e[(I-A)^{-1} - I]$;

e = matrix, consisting of ones and zeroes, with ones in the row locations corresponding to energy sectors and zeroes in all other elements of the matrix, which is used to select the energy rows from the input-output table;

I = identity matrix;

A = matrix of technical coefficients;

Y = vector of final demand (i.e., gross domestic product);

R = subscript that indexes the variable under analysis (in this case the provinces, or the TVE sector during a given time period);

n = matrix consisting of ones and zeroes, with ones in the diagonal locations corresponding to those columns that are not imports, exports, and inventory changes and zeroes in all other elements of the matrix. It excludes energy imports, exports, and inventory changes from calculation of direct energy consumption;

$G = (I-A)^{-1}$;

M = matrix of spending mix of individual final demand sectors;

D = diagonal matrix with the sectoral distribution of total final demand on the diagonal;

L = diagonal matrix with the overall total final demand level on the diagonal;

E = superscript that indexes the direct use of energy inputs like coal, oil, and electricity; and

N = superscript that indexes the non-energy sectors.

Source: The Multiregional Planning Team at MIT.

we determine whether energy use in the different regions (or time periods) and sectors are different because of variations in final demand and/or because of differences in production technology.

We are asking what would happen to the target variable's energy consumption, if it possessed the same production technology as the reference variable? However, we could have also used another reference point, by asking what would have happened to the reference variable's energy consumption, if it used the same production technology as the target variable? We asked the first question for three reasons. First, China is a very heterogeneous country with provinces that have extremely disparate energy-intensity levels. As such, asking the second question would be contradictory, because one of our primary aims in this research is to understand how much of this disparity is due to technological variations among the provinces. The second reason is that there have not been many studies showing how technology transfer within China could reduce energy intensity, thus overall energy consumption. Finally, we want to analyze the changes in energy consumption as Township and Village Enterprises (TVEs) grow in number and play a larger role in the total output of China.

SDA is a powerful analytical tool because both the final-demand differences and production-technology changes in energy consumption can be decomposed further. First, the final-demand difference can be separated into the three components (level, distribution, and pattern). Second, we can calculate the differences in the amounts of energy-use changes originating in individual final-demand sectors, such as personal consumption, investment, exports, and imports. Third, we can determine how changes in the purchase of an individual product or product group affect energy consumption. Then, we can calculate how much of the energy-use change due to final-demand differences comes directly from purchases of energy products and how much comes indirectly from purchases of nonenergy products.

In addition, we can split the production technology into two portions. The energy portion represents the direct use of energy inputs, like coal, natural gas, oil, and electricity, by sector. It measures the energy requirement per unit of output. The nonenergy portion contains all the other inputs by production sectors, such as plastics, steel, and chemical fertilizers. Thus, we have an extremely comprehensive analysis of changes in energy use, and, if we have data and funding, we can do these by province and over time.

We are integrating the SDA technique just discussed with other spatial analytical techniques, such as a supply-chain model, for our own use as well as by scholars and by local and national policy makers interested in energy, environmental, and transportation issues in China. Analysts can also use such an integrated toolkit for analyses of many diverse issues as well in China, Iran, or in other countries.

Two Important Reseaerch Issues

Many analysts are investigating environmental and energy issues in developing countries. For Iran, of course, oil is the main focus of attention. Energy intensity in China, Iran, and other developing countries can be reduced. To determine which industries to target for those reductions, analysts need tools of analysis like input-output. Investment funds are too scarce to invest in all available energy-saving technologies. I maintain that, in most cases, the efforts to conduct industrial analyses to determine energy-efficient, low-pollution sectors in which to invest may be misdirected for two reasons.

First, some sectors may, on the surface, appear to be extremely energy conserving and, consequently, create only low levels of pollution, because analysts consider only the direct inputs into the production process. If analysts also consider indirect energy inputs through use of an input-output table, however, they may find that "green" firms, in fact, are "brown" firms. I use input-output data from Taiwan to illustrate my point. In comparing the petroleum and electricity inputs into different sectors in Taiwan, Yang (1999) discovered 10 petroleum-using and 9 electricity-using sectors with below-average direct petroleum/electricity input coefficients but above-average direct-and-indirect petroleum input coefficients in 1981 and 1991 (Tables 4 and 5). This is not such an unusual finding for those of us immersed in input-output types of analyses. What is surprising is the number of analysts and policy makers who overlook the need to use the input-output framework to conduct systematic analyses concerning energy-conserving sectors. If an analyst examines most input-output tables, similar points can be derived prior even to conducting the modeling and analysis of results.

My second reason for believing that some of the current energy and environmental research efforts are misdirected concerns the narrow focus of most environmental analyses on firms in a particular location rather than on the entire supply chain serving the firm. Input-output analysts know many of the most sophisticated input-output models and techniques, but few have investigated the supply chains for one or more of the commodities they intend to study. By using input-output and supply-chain techniques in combination, analysts have a robust set of tools to examine socio-economic sustainability issues. We are in the midst of a major investigation in China of the supply chains for coke and steel in Shanxi and Liaoning Province. I do not have time to discuss the specifics of this combined tool in this paper, but I give one example of some of our findings to date.

Some of the team members working with us are physicists who measure the particulate pollution in plants and households, using battery-operated monitors. On our first field mission to Shanxi Province in 1998 to study the energy use and pollution from coke ovens, we visited a large number of cokemaking sites along about 150 kilometers of the Fen River from Taiyuan to Hongtong. At the coke ovens, we recorded relatively high levels of Polycyclic Aromatic Hydrocarbons (PAHs), which are ultra fine particulates of smaller than 1 micrometer. Our measurements at the plant ranged from 200 to 1,000 or higher nanograms of particulates per cubic meter. We recorded the highest levels at the quenching car after water had been poured over the hot coke to cool it.

As we traveled in an air-conditioned car of the provincial Environmental Protection Bureau (EPB) from one plant to another, I was surprised that my mobile monitor also was registering even higher levels of PAHs than at the plant. The provincial EPB official said that my monitor must be broken. I knew it was not, and finally discovered that the highest levels always occurred as we followed or passed a diesel truck, which happened in that part of the province to be hauling coal or coke. Our team discussed our findings and decided that in order to develop appropriate environmental policies, the national and local officials should consider the entire cokemaking supply chain from the coal mine to the coke plant and to the iron and steel mills, which are the major consumers of coke, and finally to automobile plants and other steel consumers, including exporters. Thus, we have a need to study the pollution associated with the technologies of alternative transport modes used to haul coal and coke, as well as the coke-oven technologies, and we are beginning to study the iron and steelmaking plants as well.

By conducting such a supply-chain analysis, we can use the pollution data we are collecting to compare the state of the air quality in China with the air quality in other locations around the globe. As soon as we find additional funding, we will be able to connect the fine-particle properties with more confidence to the air-pollution health effects observed or quoted in different locations.

Conclusion

We believe that the information from our analyses in China will provide the managers in smaller Township and Village Enterprise (TVE) coke and steel plants with much-needed information that the bigger plants and State-Owned

Enterprises (SOEs) usually already have at their disposal. This information would give the nonstate-owned plants a better opportunity to compete effectively against the SOEs in the global market place, especially as environmental regulations become more stringent.

In the present phase of our research, we are proceeding along the coke supply chain to study the major users of Shanxi coke, which are the iron and steel plants in Liaoning Province. Northeastern China is the base of national heavy industries. In Liaoning Province, cities like Benxi and Anshan have had very bad air quality for a long time, partly due to the iron- and steel-making plants in these cities. Particulate pollution is one of the key pollutants, and passenger and truck vehicles as well as the plants are emitting particles that are harmful to human health. This particulate pollution is increasing dramatically in the last several years and will continue in the near future.

From our summer 2003 field mission to the major iron- and steel-making plants in that region, we already know that particulate air pollution, for example PM_{10}, is very heavy in most of the plants that use BOF (basic oxygen furnace) technology without dust-cleaning equipment. The PM_{10} value is normally several times higher than the national standard. Particularly important is that most of these plants are located in the city or very near the city, so that large amounts of dust and smoke are emitted in these heavily populated areas. We also know that the PAH emissions from diesel trucks or other motor vehicles are extremely high. Until now, the particulate pollution from transportation has not been given the necessary attention by local plants and planning officials.

We could use our process-flow (Polenske and McMichael, 2002) or input-output models to determine the most energy-efficient technology for coke, but we may not solve many of the energy and pollution issues unless we investigate the entire supply chain. Chen Yan (2003) has just completed an initial design of a combined Geographic Information System (GIS) process-flow model that we can use for Shanxi Province to examine alternative cokemaking technologies and the road and rail transport options.

Based upon our current and past research, I propose therefore that input-output and supply-chain techniques need to be used together to study energy use and pollution for different sectors and regions in a country. They are a powerful and meaningful way of conducting energy and environmental analyses in China, Iran, and other countries both at the local and the global levels.

Figure –

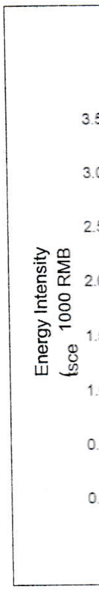

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Figure-

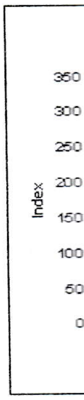

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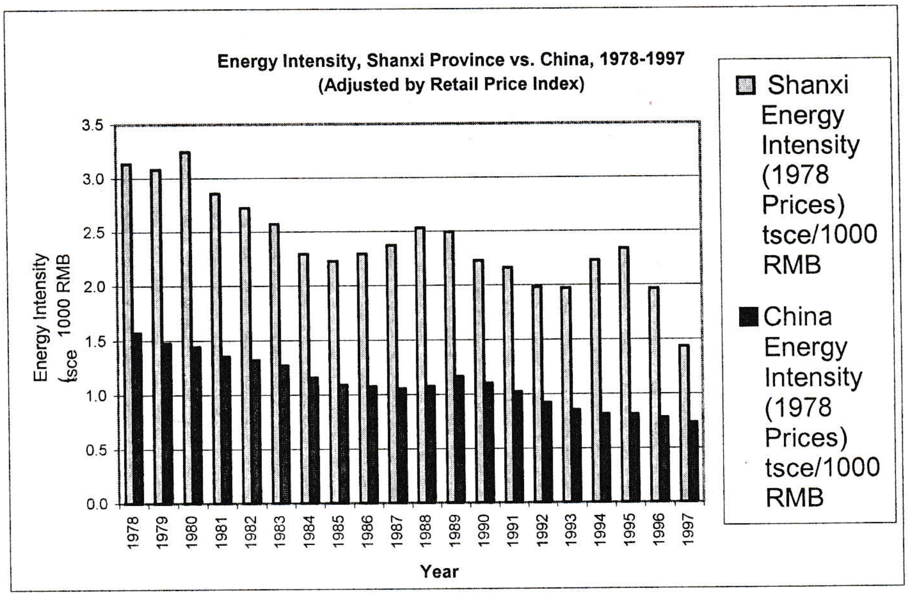
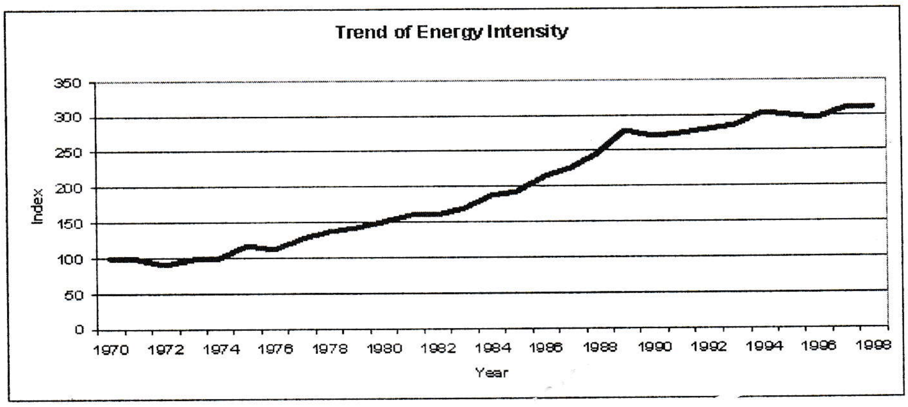
Figure –1. China and Shanxi Energy Intensity 1978-1998



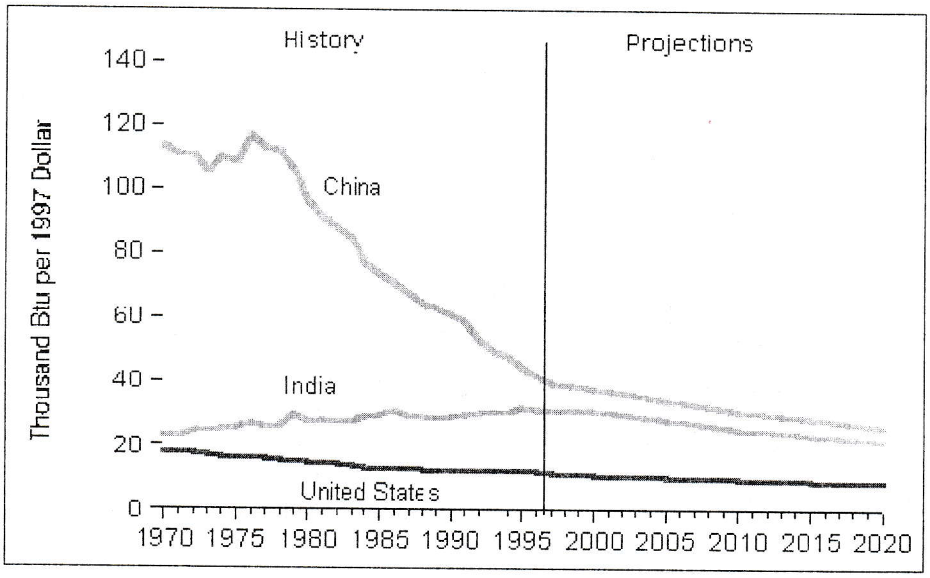
Source: MIT Multiregional Planning Research Team, 1999.

Figure-2. The Energy-Intensity Trend in IRAN 1970-1998



Source: The Internet.
(http://www.worldenergy.org/wec-geis/publications/reports/pedc/cases/iran.asp#2.3.2).

Figure- 3. Energy Intensity in Selected Countries, 1970-2020



Source: International Energy Outlook, 2002.

Table-
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Region

North Am
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Table-1. Proven Petroleum Reserves for Selected Countries, 1997-2001 (million barrels)

Region/Country	1997	1998	1999	2000	2001	Percent*
North America	30,652.1	31,272.3	30,146.9	33,065.7	33,345.7	0.8
Canada	8,635.1	8,726.3	9,112.9	11,300.7	11,300.7	-
United States	22,017.0	22,546.0	21,034.0	21,765.0	22,045.0	1.3
Latin America	140,342.1	141,909.2	123,103.5	123,779.8	123,896.1	0.1
Mexico	47,822.0	47,822.0	28,399.0	28,260.0	26,941.0	-4.7
Venezuela	74,930.8	76,108.4	76,848.1	76,848.1	77,685.0	1.1
Eastern Europe	67,373.9	67,281.4	67,259.7	67,159.7	66,790.4	-0.5
Former USSR	65,405.0	65,405.0	65,405.0	65,305.0	65,405.0	0.2
Middle East	676,755.3	677,806.2	678,736.9	694,753.9	696,261.3	0.2
IR Iran	**92,600.0**	**93,700.0**	**93,100.0**	**99,530.0**	**99,080.0**	**-0.5**
Iraq	112,500.0	112,500.0	112,500.0	112,500.0	112,500.0	-
Kuwait	96,500.0	96,500.0	96,500.0	96,500.0	96,500.0	-
Saudi Arabia	261,541.0	261,542.0	262,784.0	262,766.0	262,697.0	-
Africa	75,194.7	76,980.5	83,504.0	90,003.9	92,797.1	3.1
SP Libyan AJ	29,500.0	29,500.0	29,500.0	36,000.0	36,000.0	-
Nigeria	20,828.0	22,500.0	29,000.0	29,000.0	31,506.0	8.6
Asia and Pacific	43,438.2	44,255.1	44,386.8	44,390.5	44,980.0	1.3
China	**24,000.0**	**24,000.0**	**24,000.0**	**24,000.0**	**24,000.0**	-
Total World	1,052,507.7	1,057,853.0	1,045,980.9	1,070,686.1	1,074,850.2	0.4
OPEC	806,079.5	810,144.1	818,247.0	840,537.7	845,411.6	0.6
OPEC (%)	*76.6*	*76.6*	*78.2*	*78.5*	*78.7*	

Proven Oil Reserves 1997-2001, with percentage change for 2000-2001 in the last column.
Source: OPEC Annual Statistical Bulletin, 2001, p. 34 [http://www.opec.org/]

Table–2. Proven Natural Gas Reserves for Selected Countries, 1997-2001 (billion standard cubic meters)

Region/Country Percent*	1997	1998	1999	2000		2001
North America	6,576.0	6,454.0	6,487.5	6,741.0	7,041.7	4.5
Canada	1,841.0	1,809.0	1,747.5	1,718.0	1,691.7	-1.5
United States	4,735.0	4,645.0	4,740.0	5,023.0	5,350.0	6.5
Latin America	8,080.3	8,172.6	7,762.7	8,038.7	8,082.2	0.5
Mexico	1,796.9	1,760.0	861	835	797	-4.6
Venezuela	4,120.8	4,147.5	4,152.4	4,152.4	4,163.0	0.3
Eastern Europe	57,740.8	57,301.8	56,626.8	56,524.7	56,376.7	-0.3
Former USSR	57,100.0	56,682.0	56,023.7	55,928.6	55,793.6	-0.2
Middle East	49,794.6	53,406.0	52,053.0	59,807.0	71,355.6	19.3
IR Iran	23,000.0	24,100.0	22,370.0	26,600.0	26,600.0	-
Iraq	3,188.0	3,188.0	3,285.0	3,109.0	3,109.0	-
Kuwait	1,490.0	1,482.0	1,482.0	1,557.0	1,557.0	-
Qatar	8,500.0	10,900.0	11,157.0	14,443.0	25,768.0	78.4
Saudi Arabia	5,882.0	6,068.0	6,146.0	6,301.0	6,455.6	2.5
United Arab Emirates	6,063.0	5,996.0	5,936.0	6,060.0	6,060.0	-
Africa	10,634.1	10,791.0	11,501.0	11,969.3	13,107.3	9.5
Algeria	4,077.0	4,077.0	4,523.0	4,523.0	4,523.0	-
SP Libyan AJ	1,314.0	1,315.0	1,315.0	1,314.0	1,314.0	-
Nigeria	3,483.0	3,510.0	3,568.0	3,610.0	4,503.0	24.7
Asia and Pacific	14,332.0	14,198.0	14,757.0	14,910.0	15,225.0	2.1
Australia	3,280.0	3,310.0	3,500.0	3,530.0	3,550.0	0.6
China	1,199.0	1,200.0	1,375.0	1,515.0	1,560.0	3
Indonesia	3,902.0	3,650.0	3,770.0	3,790.0	3,800.0	0.3
Malaysia	2,464.0	2,410.0	2,476.0	2,314.0	2,390.0	3.3
Total World	154,314.1	157,470.6	156,314.7	165,066.8	178,216.3	8
OPEC	65,019.8	68,433.5	67,704.4	75,459.4	87,852.6	16.4
OPEC (%)	*42.1*	*43.5*	*43.3*	*45.7*	*49.3*	

Proven Natural Gas Reserves 1997-2001, with percentage change for 2000-2001 in the last column.
Source: *OPEC Annual Statistical Bulletin*, 2001, p. 36 [http://www.opec.org/]

tries, 1997-2001

	2001
7,041.7	4.5
1,691.7	-1.5
5,350.0	6.5
8,082.2	0.5
797	-4.6
4,163.0	0.3
56,376.7	-0.3
55,793.6	-0.2
71,355.6	19.3
26,600.0	-
3,109.0	-
1,557.0	-
25,768.0	78.4
6,455.6	2.5
6,060.0	-
13,107.3	9.5
4,523.0	-
1,314.0	-
4,503.0	24.7
15,225.0	2.1
3,550.0	0.6
1,560.0	3
3,800.0	0.3
2,390.0	3.3
178,216.3	8
87,852.6	16.4
49.3	

the last column.

Table–3. International Comparison of Energy Intensities 1997

	Energy Intensity (TOE/US$1000)	GDP (billion US$)	GDP/Capita US$	Area (1000 sq. km)	Population (thousands)	Population Density (people/sq. km)
Iran	**1.03 ****	**114.1**	**1,767**	**1,648**	**64,583**	**39**
Kuwait	0.56 *	32.8	14,420	18	2,275	126
Iraq	0.99 **	27.8	1,178	438	23,600	54
Saudi Arabia	0.76 *	186.5	8,962	2,150	20,810	10
Venezuela	0.71 *	124.9	5,078	916	24,600	27
Nigeria	2.85 *	41.1	315	924	130,296	141
Russia	0.57 *	388.2	2,290	17,075	144,979	8

GDP = gross domestic product
Sq. km. = square kilometers
TOE = tonnes of oil equivalent

Source: www.opec.org/Publications/AB/pdf/AB002001.pdf)
***Source**:http://earthtrends.wri.org/country_profiles/index.cfm?theme=6&rcode=3
****Source:**Derived from http://pdf.wri.org/middle_east_2000_energy.pdf.

Table–4. 1981 and 1991 Petroleum Direct and Direct and Indirect Input Coefficients, Taiwan (29 Sectors) (direct input per unit of output; direct and indirect input per unit of final demand)

Year	Food	Apparel	Synthetic Fibers and Plastic and Plastic Products	Machinery	Household Electrical Appliances	Electronic Components and Parts	Transport Equipment	Other Manufactures	Construction	National Average
Output (1981)	278,727	213,742	263,878	88,061	33,975	178,468	153,968	122,959	346,683	*4,991,354
Direct Petroleum Input Coefficient (1981)	0.006	0.010	0.012	0.009	0.005	0.002	0.005	0.005	0.009	0.025
Direct and Indirect Petroleum Input Coefficient (1981)	0.030	0.048	0.032	0.035	0.050	0.032	0.037	0.043	0.057	0.027
Output (1991)	401,035	307,584	578,103	270,768	110,103	648,109	378,882	217,186	616,571	*10,738,293
Direct Petroleum Input Coefficient (1991)	0.005	0.008	0.007	0.007	0.002	0.002	0.003	0.004	0.011	0.019
Direct and Indirect Petroleum Input Coefficient (1991)	0.028	0.041	0.032	0.040	0.041	0.024	0.028	0.040	0.057	0.017

Gross Output: 1 million 1991 New Taiwan Dollars (NT$)
Direct Input Coefficients: one NT$ of petroleum direct Input per NT$ of gross output.
Direct and Indirect Input Coefficients: one NT$ of petroleum direct and indirect Input per NT$ of gross output.
Note: I list all sectors with below-average direct petroleum input coefficients but above-average direct-and-indirect petroleum input coefficients.
Source: Chi-Jen Yang. 1999. "Taiwan's Industrial Structural Chang and Its Implications for Energy Intensity." Master's thesis, Technology and Policy Program, Massachusetts Institute of Technology.
Original Data Source: the Directorate General of Budget, Accounting, and Statistics (DGBAS), Taiwan.

Table–5. 1981 and 1991 Electricity Direct and Direct and Indirect Input Coefficients, Taiwan (29 Sectors) (direct input per unit of output; direct and indirect input per unit of final demand)

Direct and Indirect Input Coefficients: one NT$ of petroleum direct and indirect Input per NT$ of gross output.
Note: I list all sectors with below-average direct petroleum input coefficients but above-average direct-and-indirect petroleum input coefficients.

Source: Chi-Jen Yang. 1999. "Taiwan's Industrial Structural Chang and Its Implications for Energy Intensity." Master's thesis, Technology and Policy Program, Massachusetts Institute of Technology.

Original Data Source: the Directorate General of Budget, Accounting, and Statistics (DGBAS), Taiwan.

Table–5. 1981 and 1991 Electricity Direct and Direct and Indirect Input Coefficients, Taiwan (29 Sectors) (direct input per unit of output; direct and indirect input per unit of final demand)

Year	Food	Apparel	Machinery	Household Electrical Appliances	Electronic Components and Parts	Transport Equipment	Other Manufactures	Construction	National Average
Output (1981)	278,727	213,742	88,061	33,975	178,468	153,968	122,959	346,683	*4,991,354
Direct Electricity Input Coefficient (1981)	0.010	0.012	0.015	0.010	0.010	0.008	0.016	0.004	0.017
Direct and Indirect Electricity Input Coefficient (1981)	0.021	0.051	0.034	0.051	0.034	0.035	0.046	0.039	0.020
Output (1991)	401,035	307,584	270,768	110,103	648,109	378,882	217,186	616,571	*10,738,293
Direct Electricity Input Coefficient (1991)	0.013	0.013	0.013	0.009	0.009	0.008	0.013	0.003	0.017
Direct and Indirect Electricity Input Coefficient (1991)	0.026	0.050	0.039	0.044	0.027	0.029	0.045	0.040	0.021

Gross Output: 1 million 1991 New Taiwan Dollars (NT$)
Direct Input Coefficients: one NT$ of petroleum direct Input per NT$ of gross output.
Direct and Indirect Input Coefficients: one NT$ of petroleum direct and indirect Input per NT$ of gross output.
Note: These are all sectors with below-average direct petroleum input coefficients but above-average direct-and-indirect petroleum input coefficients.

Source: Chi-Jen Yang. 1999. "Taiwan's Industrial Structural Chang and Its Implications for Energy Intensity." Master's thesis, Technology and Policy Program, Massachusetts Institute of Technology.

Original Data Source: the Directorate General of Budget, Accounting, and Statistics (DGBAS), Taiwan.

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