Total Energy Use and Related CO_2 Emissions of American Household Consumption, 1997-2007

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ABSTRACT

The energy and carbon quantification of U.S. household consumption is an important research subject of the human dimension of global change. This paper studies how U.S. household consumption contributed to national and global energy use and related carbon emissions from 1997 to 2007. The results clearly reveal that (1) U.S. household consumption was a dominant driving force of energy use and related carbon emissions at both national and global scales during the study period; and (2) annual growth rates of energy use and carbon emissions of U.S. household consumption were much higher than official statistics indicated. This paper suggests that a consumption-based accounting framework, in an open consumption-oriented economy, could serve as an important alternative to the existing production-based energy and carbon accounting framework for better reporting, analyzing, and helping mitigate national and regional energy use and related carbon emissions.

Introduction

The energy and carbon quantification of U.S. household consumption is an important research subject of the human dimension of global change, considering that (1) the United States contributes significantly to global economic development, energy use and related carbon emissions; (2) the U.S. household lifestyle, with its admirers, followers and critics worldwide, has long been a subject for sustainability; and (3) the well-documented data provide unique information support for data analysis, methodology development and policy studies. Quantification of total energy use and related carbon emissions of U.S. households will not only inform U.S. households of their role in resource management and climate change, but also help policy decision makers better target key consumption activities and consumer segments.

Quantification studies of U.S. household consumption can be traced back to the late 1970s and 1980s, when there was an increasing research and policy interest in household energy use in the wake of the oil crisis. Herendeens and Tankaka (1976) studied the Consumer Expenditure Survey (CES) 1960-1961, and "evaluated empirically the relationship between household expenditures and total resulting energy requirements." Schipper et. al. (1989) discussed the role of consumer lifestyles in energy use, and concluded that: ''about 45–55% of total energy use is influenced by consumers' activities for personal transportation, personal services, and homes.''

In the late 1990s and 2000s, there was a series of country studies on energy and carbon quantification of household consumption activities in developed economies, such as Australia (Lenzen 1998; Lenzen et al. 2004), Germany and other European countries (Weber and Perrels 2000; Reinders et al. 2003; Druckman and Jackson 2009). Shui and Dowlatabadi (2005) quantified energy and carbon profiles of U.S. household consumption in 1997 and suggested that "more than 80% of the energy used and the CO_2 emitted in the U.S. are a consequence of consumer demands and the economic activities to support these demands."

Recently, the research community has extended these discussions to include the role of international trade and the development of quantification methodologies. Ghertner and Fripp (2007) studied the amount of environmental impacts from U.S. consumption that "leaked from the current, production-based accounting" during 1998 to 2004." Their study revealed that in 2004 "this leakage[1] exceed[ed] 10% for all studied impacts, exceed[ed] 20% for GWP, energy, and most criteria air pollutants, and exceed[ed] 80% for lead emissions and toxics." Weber and Matthews (2008) conducted a thorough account of the significance of international trade in "quantifying the global and distributional aspects of U.S. household carbon footprint." Their study indicated that about "30% of total U.S. household CO_2 impact in 2004 occurred outside the U.S." They also pointed out that the carbon footprints of U.S. household consumption vary significantly by household income.

This paper, based on an earlier paper which introduced total consumer impacts (TCI) assessment methodology, provides an updated TCI assessment on energy use and related carbon emissions from U.S. household consumption from 1997 to 2007. Section 2 revisits key concepts and methodology of the TCI approach, followed by a time-series quantification analysis in Section 3. Policy implications and conclusions are presented in Sections 4 and 5, respectively.

Key Concepts and Methodology

Key Concepts

The TCI approach was developed in recognition of the relative magnitude of direct energy use classified under residential consumption compared to the indirect impacts of household consumption. This approach uses the existing statistics of household consumption activities to develop a more complete picture of household level impacts on energy use and its externalities (Shui and Dowlatabadi 2005).

The TCI categorizes household consumption activities into two groups: direct vs. indirect impacts. ***Direct impacts*** refer to fossil fuel use and related CO_2 emissions during the use of a product or a service by the consumer(s). ***Indirect impacts*** refer to the energy being used and CO_2 being emitted before the use of a product or service. The indirect impacts are embodied in the process of the resource exploitation, production, and delivery process. Household consumption activities which lead to direct impacts include home energy use and personal travel. Household consumption activities which lead to indirect impacts include housing operation (e.g., shelter and furniture), transportation operation (e.g., vehicles), food, apparel, health care, entertainment and others. Table 1 presents the categorization of household consumption activities and a simple comparison to the existing, production-based sectoral approach.

[1] Carbon leakage refers to amount of carbon emissions embodied in imported products and services which are not accounted by the existing carbon accounting framework for the import country.

Table 1 Categorization of Direct and Indirect Impacts

The Categorization of TCI			Comparisons with the Production-based Sectoral Approach
Direct Impacts	Home Energy Use	space heating	Residential sector
		air conditioning	
		water heating	
		energy use by appliances	
	Personal Travel	cars	A subset of the transportation sector
		personal trucks	
		air travel	
		others (water, public, on demand)	
Indirect Impacts	Housing Operation	housing construction, production and transportation of appliances, household furnishing, etc.	A subset of commercial, industrial and transportation sectors.
	Transportation Operation	production of vehicle purchase (net), production of gasoline and motor oil, other vehicle expenses, etc.	
	Food and Beverage	food at home, food away from home	
	Apparel	men and boys clothes, women and girls clothes, footwear, etc.	
	Health Care	health insurance, prescriptions, etc.	
	Entertainment and Reading	fees and admissions, magazines, etc.	
	Others	education, tobacco, etc.	

Methodology

Home energy use of direct impacts. The Residential Energy Consumption Survey (RECS), a national household energy survey conducted by the U.S. Energy Information Administration (EIA) every three years, provided home end use data (space heating, air conditioning, water heating, lighting and appliances) in the years of 1997, 2001 and 2005. EIA also provided statistics of home energy use by total and fuel type from 1997 to 2007. The TCI estimates on home energy use and related carbon emissions were based on the statistics above, with interpolation and extrapolation for the years not provided.

Personal travel of direct impacts. The Transportation Energy Data Book (TEDB), developed by Oak Ridge National Laboratory, provided aggregated energy estimates by personal transportation means, such as car, personal trucks, air travel, water, tax, public transportation, and taxi (Davis et al. 2010).The TCI estimates of personal travel were based on the statistics above.

Indirect impacts. The estimates of indirect impacts of household consumption are based on the annual CES provided by the U.S. Census Bureau, and the Environmental Input-Output Lifecycle Analysis (EIO-LCA) model developed by the Green Design Institute at Carnegie Mellon University (Carnegie Mellon University Green Design Institute 2009). The indirect impacts of this study employed the 1997 EIOLCA input-output industrial benchmark model. Notice that the consumption expenditure categories of the CES are not a one-to-one match to the 480 commodity categories in the EIO-LCA. Data mapping has been conducted by translating each of the consumer expenditure categories to appropriate commodity categories defined by the input-output tables.

$$X_{p,i} = \sum_j CES_{j,i} \frac{CPI1997_j}{CPI_{j,i}} \times T_{j,p}$$

$$IndirectEnergy_i = \sum_p (EI_p \times X_{p,i})$$

$$IndirectCO2_i = \sum_p (CI_p \times X_{p,i})$$

Where:

- $X_{p,i}$ *($)* is a household's expenditure in a year *i* on products or services *p* in the EIO-LCA;
- $CES_{j,i}$ *($)* is the consumer expenditure on product *j* in a year *i*;
- $CPI1997_j$ and $CPI_{j,i}$ are the consumer price indices in 1997 in year *i* for a product or service *j;*
- T_{jp} is the transformation matrix of consumer expenditure category *j* to an industrial product or a service category *p;*
- *IndirectEnergy*(EJ) is annual energy consumption of indirect influences in the United States;
- *IndirectCO2*(Mt) is the annual CO_2 emissions of indirect influences in United States;
- *p* refers to an industrial product or a service in a year *i,* where *i* = 1997 to 2007;
- *j* refers to a CES expenditure category;
- EI_p (thousand J/$) is the energy intensity of industrial output or a service *p.*
- CI_p (thousand J/$) is the carbon intensity of industrial output or a service *p.*

Uncertainties

EIOLCA. EIO-LCA analyses are based on surveys of expenditure in the economy. These reflect the price paid by each industry for inputs to its production process. This approach is excellent in providing an economy-wide measure of energy, material and labor inputs and externalities from economic activity. However, the specifics of any particular product are subject to significant uncertainty. These uncertainties arise from two factors: (1) the data have been collected at an aggregate level of economic activity – rarely processed at a finer scale than 500 identifiers; (2) the models are based on average expenditures on inputs. There can be significant variation in prices for products (depending on their attributes) within most particular product category. For example, shoes can be $15/pr or $1500/pr. Within the EIOLCA framework, the analyses are based on the average cost of products and the average of inputs to and externalities associated with their production. This makes EIOLCA an excellent tool for an economy-wide assessment of resource inputs and externalities, even capable of tracking technological and relative price changes at the aggregate scale. However, EIOLCAs are not suited to analysis of a specific product's mix of inputs and environmental impacts – if it uses inputs that are very different in price to the average or a product whose price is atypical of that sector.

International trade. This TCI study does not explicitly quantify the contribution of international trade to U.S. household consumption. This simplification, however, seems to produce a similar result as Weber and Matthews' 2008 paper, which calculated the contribution of exports from the top seven trade partners (Canada, China, Germany, Japan, Mexico, United Kingdom. and Korea) to the U.S. household carbon footprint (HCF) through the input-output tables of these seven trade partners. Their HCF paper presented two estimates of U.S. household carbon footprints in 2004, 4,693 Mt using weighted CES data and 6,694 Mt using input-output expenditure data. The estimated CO_2 emissions presented in this TCI study for the same study year was 4,876 Mt, 3.9% higher than the CES estimates of the HCF paper.

It may be explained that offset of energy and carbon embodiment may be incurred between the United States and its top trade partners. China, with more carbon-intensive fuel structure than the United States, holds the largest trade deficit with the United States. However, the total exports of Canada, Germany, Japan and Mexico have higher aggregated exports to the United States compared to China over the study period[2], and these countries have cleaner fuel structures than the United States.

This study does not account for air, sea, and rail transportation outside of the United States.

Others. The TCI estimates inherit all uncertainties from the aggregated data provided by different data sources such as RECS, TEDB, and CES. Besides EIOLCA, there are uncertainties associated with an input-output analysis, such as (1) the aggregation of household consumption categories based on the household consumption categories defined by CES and the corresponding match to the industrial categories defined by the production categorization of input-output tables, and (2) assumptions on homogeneity and temporal discrepancies (Wiedmann 2009)

Results and Discussion

A Significant Driving Force at the National Level

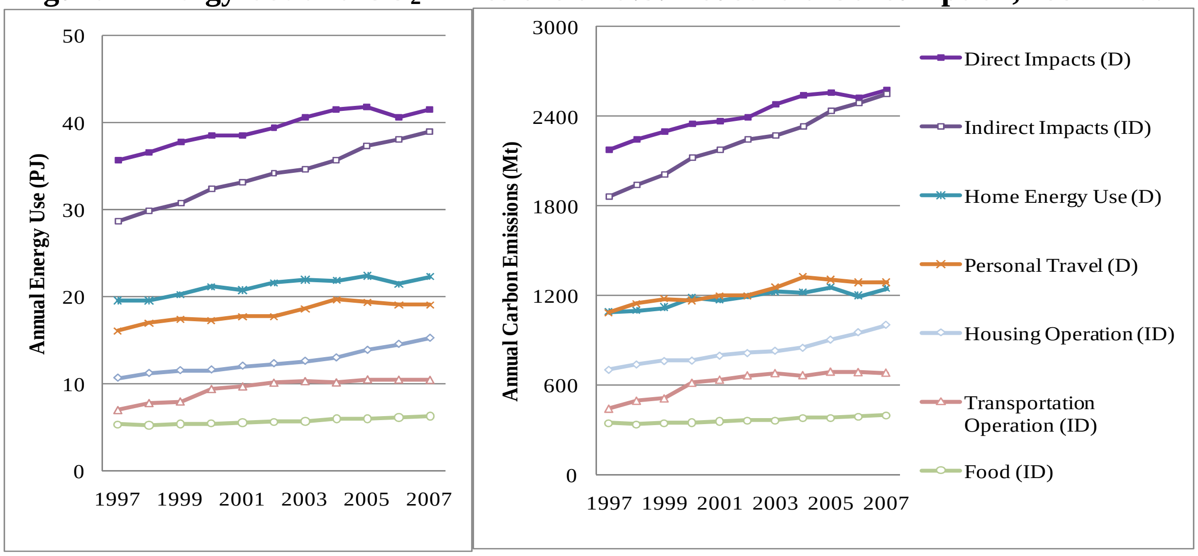
Total energy use and related CO_2 emissions from U.S. household consumption had increased from 64.3 EJ and 4,039 Mt in 1997 to 80.4 EJ and 5,084 Mt in 2007, respectively, with an annual growth rate of 2.3%.

During the same period, direct impacts (the purple lines with solid squares in Figure 1) had higher energy use and related carbon emissions than indirect impacts (the purple lines with empty squares), but the gap between them decreased over years. In 2007, direct impacts were associated with 41.3 EJ energy use (compared to 38.9 EJ from indirect impacts) and 2,580 Mt CO_2 emissions (compared to 2,546 Mt from indirect impacts). Indirect impacts, however, grew much faster than direct impacts, with annual growth rates of 3.1 vs. 1.5% for energy use, and 3.2 vs. 2.3% for carbon emissions.

[2] For example, in 2007, exports from China to the U.S. were 321.5 billion U.S. dollars, while the total of Canada (313.1), Mexico (210.8), Japan (145.5), and Germany (94.4) was nearly 763.8 billion U.S. dollars.

Direct impacts. Home energy use (22.3 EJ and 1,249 Mt in 2007) and personal travel (19.1 EJ and 1,289 Mt in 2007), two direct impacts, had higher total energy use and related CO_2 emissions than the top three household activities of indirect impacts (housing operation, transportation operation and food) in Figure 1.

Figure 1 Energy Use and CO_2 Emissions of U.S. Household Consumption, 1997 - 2007

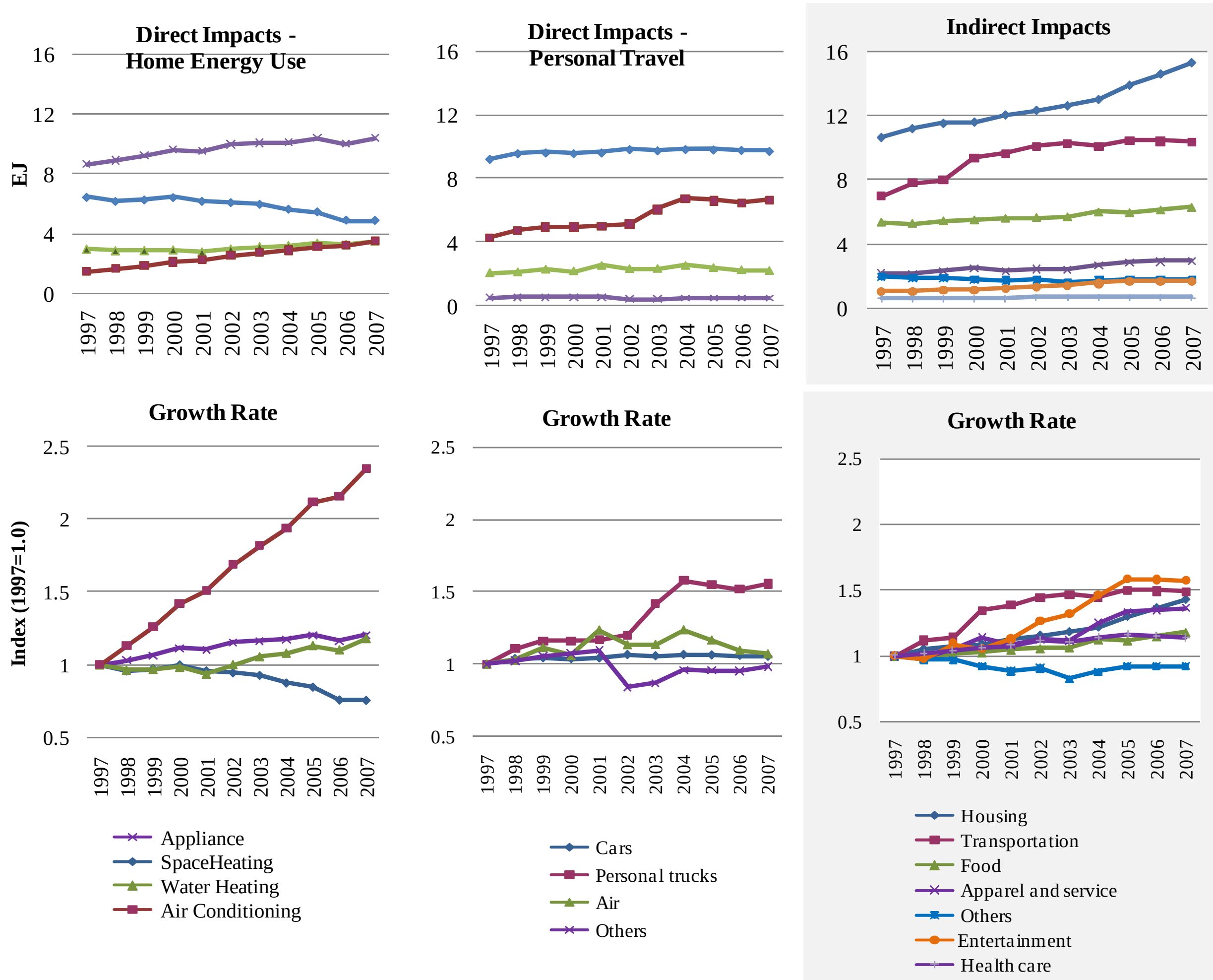


Within home energy use, appliances (10.4 EJ and 590 Mt in 2007) and space heating (4.9 EJ and 269 Mt in 2007) were the top two end uses, followed by water heating and air conditioning. Between 1997 and 2007, air conditioning and space heating had the fastest growth (8.9%) and decline (-2.8%) rates, respectively, among all household activities under both direct and indirect impacts (Figure 2).

Cars (9.7 EJ and 654 Mt in 2007) and personal trucks (6.7 EJ and 448 Mt in 2007) were the top two end uses in personal travel. The growth rate of personal trucks (e.g., SUV) took off in 2002 and then leveled off beginning in 2004, with an overall 4.5% annual growth rate, the second highest among all categories. Energy use and related carbon emissions from air travel and other travel modes (categorized as “Others” in Figure 2) plunged in 2001, reflecting the sharp reduction in travel following the September 11 attack. Although air travel slowly bounced back in 2002, it began decreasing again in 2003, largely due to the rising price of fuel.

Indirect impacts. Housing operation (15.3 EJ and 1,005 Mt in 2007), transportation operation (10.4 EJ and 681 Mt in 2007) and food consumption (6.3 EJ and 654 Mt in 2007) were the top three categories of indirect energy use and related carbon emissions (Figure 2). Transportation operation and entertainment were the fastest growing categories of indirect impacts during the study period, with 4.1 and 4.6% respectively.

Figure 2 Energy Use and Related CO_2 Emissions by Household Consumption Category and Annual Growth Rate, 1997 - 2007

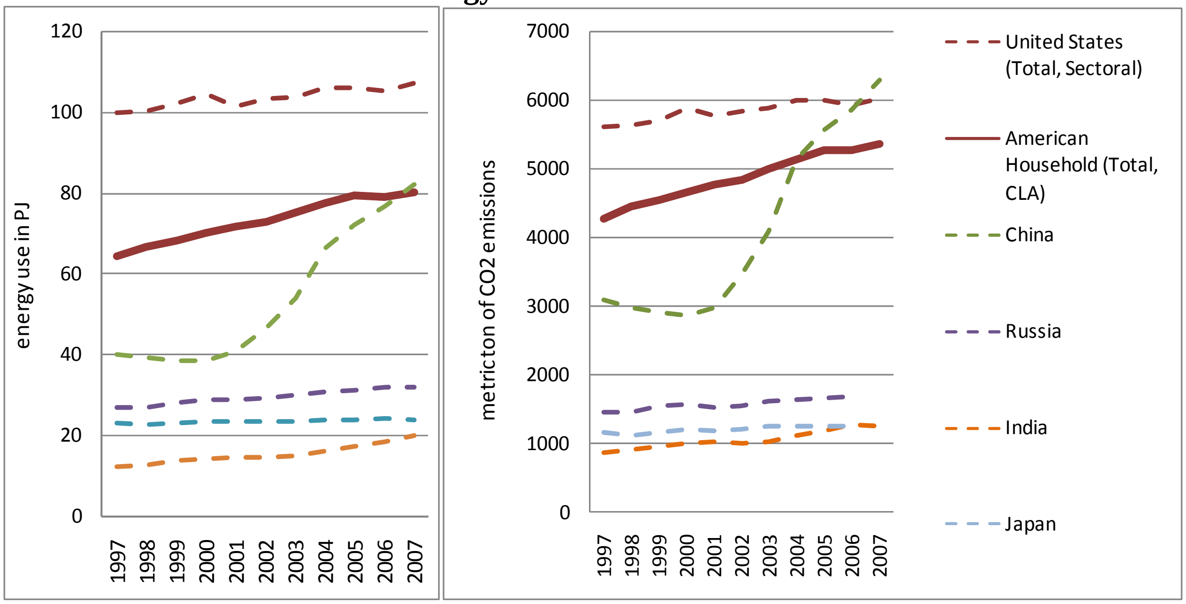


The Significance of U.S. Household Consumption at the Global Level

During the study period, U.S. household consumption was a dominant driving force not only at the national level but also at the global level. Our estimates suggest that U.S. household consumption contributed 16-17% of global energy use and 18-20% of global CO_2 emissions, respectively.

According to the existing production-based accounting framework, the United States, China, Russia, India and Japan were the top five countries with the highest national energy consumption and related carbon emissions between 1997 and 2007, represented by the dotted lines in Figure 3 (U.S. Energy Information Administration 2010). The energy use and related carbon emissions from U.S. household consumption, TCI estimates, are represented by the red solid lines. In terms of contribution magnitude, energy use and related CO_2 emissions from U.S. household consumption was a consistently significant driving force at the global level, outpacing the other four top countries until it was surpassed by China in 2004 in terms of CO_2 emissions and in 2007 for final energy use.

Figure 3 Energy Use and Related CO_2 Emissions of U.S. Household Consumption and Top Five Global Energy Consumers and Carbon Emitters



Policy Implications

U.S. Household Consumption as an Important Policy and Research Subject

The significant contribution of U.S. household consumption to national and global energy use and related CO_2 emissions suggests that U.S. household consumption is a relevant and significant target for policy and research at both scales, with the ability to inform serious actions to improve energy efficiency and mitigate carbon emissions. Related policy implications and discussions could include the following:

Direct impacts. Home energy use and personal travel are target consumption activities for U.S. households in terms of their shares of total household energy use and related CO_2 emissions. These two consumption activities are where households have more direct control (such as use frequencies, purchase of energy-efficient appliances and cars, and fuel choices) compared to household activities with indirect impacts.

Energy and fuel efficiency standards. Energy use of air conditioning and personal trucks (e.g., SUV) had the highest annual growth rates among all categories, 8.9 vs. 4.9% (see Appendix 1). This highlights the importance of developing stronger energy efficiency standards for air conditioning and fuel efficiency standards for personal trucks.

Land-use policy and urban design. According to the TCI estimates, household daily mobility (cars and personal trucks) accounted for 86% of energy use for personal travel and 40% of direct energy use in 2007. Besides the development and promotion of advanced fuel standards is not the only solution, an integrated consideration of land-use policy and urban design (a compact city regarding locations between office buildings, residences, schools, and shopping malls), and the development of a public transportation system could be considered as an integrated urban plan to reduce energy use of personal travel.

Many of the policy topics mentioned above have been analyzed and discussed. The TCI analysis helps to identify the target activities that not only have higher impacts on energy use and related carbon emissions, but also in which households are the key stakeholders and decision makers in the policy and project development related to energy efficiency, technology development, land use and urban design (Shui and Dowlatabadi 2005).

An Alternative Perspective from the Consumption-based Approach to the Sectoral Approach

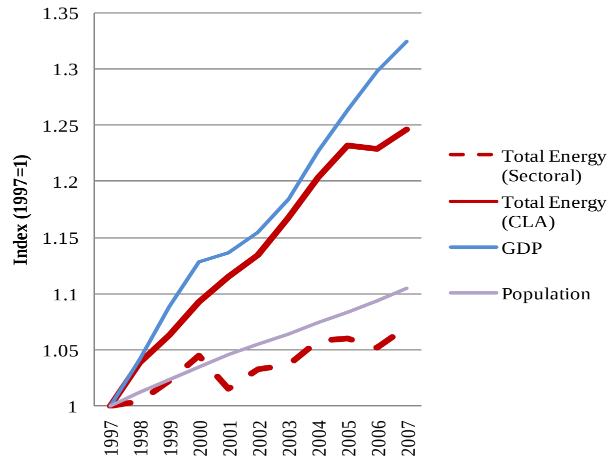
The current sectoral and production-based approach is widely employed as the standard national reporting framework to account energy consumption and carbon emissions (Eggleston et al. 2006). This approach often groups human consumption activities into administrative sectors such as industrial, transportation, commercial and residential (U.S. Energy Information Administration 2010). As the default energy and carbon accounting system at the regional and national levels, the sectoral approach is given substantial administrative support for data collection and policy research, in order to better serve national and regional policy makers.

Emerging consumption-based approaches often are composed of a wide range of household consumption categories and reflect energy use and related carbon emissions from the perspective of household consumption. The differences between the consumption-based and production-based accounting frameworks provide different perspectives when evaluating national and regional energy consumption and carbon emissions.

For example, the energy and carbon estimates based on the sectoral approach indicated that industrial and transportation sectors are the largest two energy user and carbon emitters in the United States while residential sector (or home energy use) only ranks the third. The TCI estimates, based on a consumption-based accounting approach, clearly suggested that the household sector is the largest energy user and carbon emitter in the United States.

Another example, the production-based annual growth of total energy consumption in the United States. (the dashed red line in Figure 4) grew far more slowly than the annual growth of GDP and population during the same period (the solid blue and purple lines, respectively). However, the consumption-based estimate (the solid red line) shows a much higher growth rate for U.S. household consumption than total U.S. energy use and population growth. This indicates that the growth of U.S. households' contribution to global energy consumption is not only higher than the country's population growth but also much faster than the growth level often claimed and widely perceived.

Figure 4 Annual Growth Rate of Energy Use of U.S. Household Consumption: The TCI vs. the Sectoral Approach, 1997-2007



The two examples above suggest that a consumption-based accounting framework could serve as an important alternative to the existing production-based accounting framework.

Conclusion

U.S. household consumption is a significant driving force behind energy use and related carbon emissions at both the national and global scales. This study reveals that total energy use and related CO_2 emissions of U.S. household consumption ranged from 64.4 EJ to 80.2 EJ and 4,266 Mt to 5,369 Mt from 1997 to 2007, which accounted for 16-17% of global energy use and 18-20% of global CO_2 emissions during the same period, with much higher annual growth rates than the official, production-based statistics indicated.

Quantifying household consumption is an important research subject of human dimensions of global change. It helps reveal critical information on energy consumption and related carbon emissions of human consumption activities, which have been overlooked or cannot be fully reflected by the existing production-based sectoral accounting approach. Quantification of total energy use and related carbon emissions of U.S. households will not only inform U.S. households of their roles in resources management and climate change, but also help policy decision makers better target key consumption activities.

In an open consumption-oriented economy, a consumption-based accounting framework, such as TCI, can serve as an important alternative to quantify, analyze, and mitigate national and regional energy use and carbon emissions.

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