Re-estimation and Reflection: The Role of Consumer Demand In U.S. Energy Use and CO_2 Emissions

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ABSTRACT

A conventional sectoral approach, based on the industrial, transportation, commercial, and residential sectors, has shaped the way we frame and analyze issues of human dimension of energy conservation and CO_2 mitigation. This sectoral categorization, however, is limited in its capacity to reveal the total impacts of consumer activities on energy use and the related environmental impacts. In this paper, the author explores the relationship between consumer activities, energy use and related CO_2 emissions from both top-down and bottom-up approaches. A top-down study, the re-estimation of U.S. energy use and CO_2 emissions from consumer perspective, reveals that about 65% of the energy used and 75% of the CO_2 emitted in the U.S. for the year of 2001 are a result of direct and indirect consequences of American consumer demands. A bottom-up study, the development of an individual CO_2 emissions estimator, is a preliminary effort helping the public gain knowledge of their lifestyles-related CO_2 emissions, and aiding researchers understand how people respond once informed. Initial findings of this paper suggest that 1) consumer demand is the driving force for the U.S. energy use and CO_2 emissions, 2) people are interested in knowing their CO_2 emissions profiles. However, not all of informed people seem to intend to take active actions, and people who are interested in mitigation may not know how to act effectively.

Introduction

Historically, a sector-based approach (i.e., industrial, transportation, commercial and residential) has shaped the way we frame and analyze issues of human dimensions of energy use and the related CO_2 emissions. For example, in the U.S. for 2001, the industrial and transportation sectors were the most energy-intensive (34% and 27% of US total) and CO_2 – intensive (29% and 33%), while the residential sector ranked third, taking 21% and 20% of U.S. total energy use and CO_2 emissions, respectively (EIA 2004). In the sector-based approach, the residential sector is the only sector to directly reflect consumer activities which merely refer to end uses of home energy, such as space heating, water heating, and appliance use. The existing sectoral research and data sources do not provide ready information to describe the total energy use and the related carbon emissions from the production and consumption of consumer products (such as the production of automobiles) and services (such as health insurance) meeting consumer demand.

In order to understand the impact of household consumption patterns on energy use and related carbon emissions, several quantitative analyses have been carried out by researchers of different countries. Vringer and Blok estimated energy requirement of households in the Netherlands (Vringer and Blok 1995), Lenzen assessed the energy use and greenhouse gases attributable to consumer activities in Australia (Lenzen 1998), Weber and Perrels quantified the impact of lifestyle factors on the 1990's and 2010's energy demand and related emissions in West Germany, France and the Netherlands (Weber and Perrels 2000), Pachauri and Spreng

studied energy requirement of households in India (Pachauri and Spreng 2002), and Reinders, Vringer and Blok conducted a study to estimate direct and indirect energy requirement of households in 11 European countries (Reinders, Vringer et al. 2003).

Studies on estimating environmental impacts from American consumer activities started in the 1980s. Lee Schipper *et al.* concluded that: "about 45%-55% of total energy use is influenced by consumers' activities for personal transportation, personal services, and homes."(Schipper, Bartlett et al. 1989) Brower and Leon (1999) assessed the total environmental impacts caused by American consumer activities (Brower, Leon et al. 1999) However, Schipper's paper provides few clues on its methodology, and the "total" environmental impacts defined in Brower and Leon's book refer to greenhouse gases in general, air pollution, water pollution, and habitat alteration but excludes the estimation of energy use and the related CO_2 emissions in particular.

This paper aims to shed light on the relationship between U.S. consumer activities, energy use and the related CO_2 emissions with both top-down and bottom-up approaches. The top-down study refers to the re-estimation of U.S. energy use and the related CO_2 emissions from consumer perspective by using official statistical data. Its methodology and corresponding results are introduced in the Section 2. The bottom-up study, documented in the Section 3, briefly presents the development of the individual CO_2 emissions estimator, called ICEE, and introduce the results of three pilot studies using ICEE. The objectives of this bottom-up study are to build a "mirror" to reflect a user's annual CO_2 emissions profiles resulting from his/her consumption activities, and preliminarily investigate how people respond once they are informed their annual CO_2 emission profiles. The derived discussions from both studies are reported in the Section 2 and Section 3, respectively. Final remarks are drawn in the Section 4.

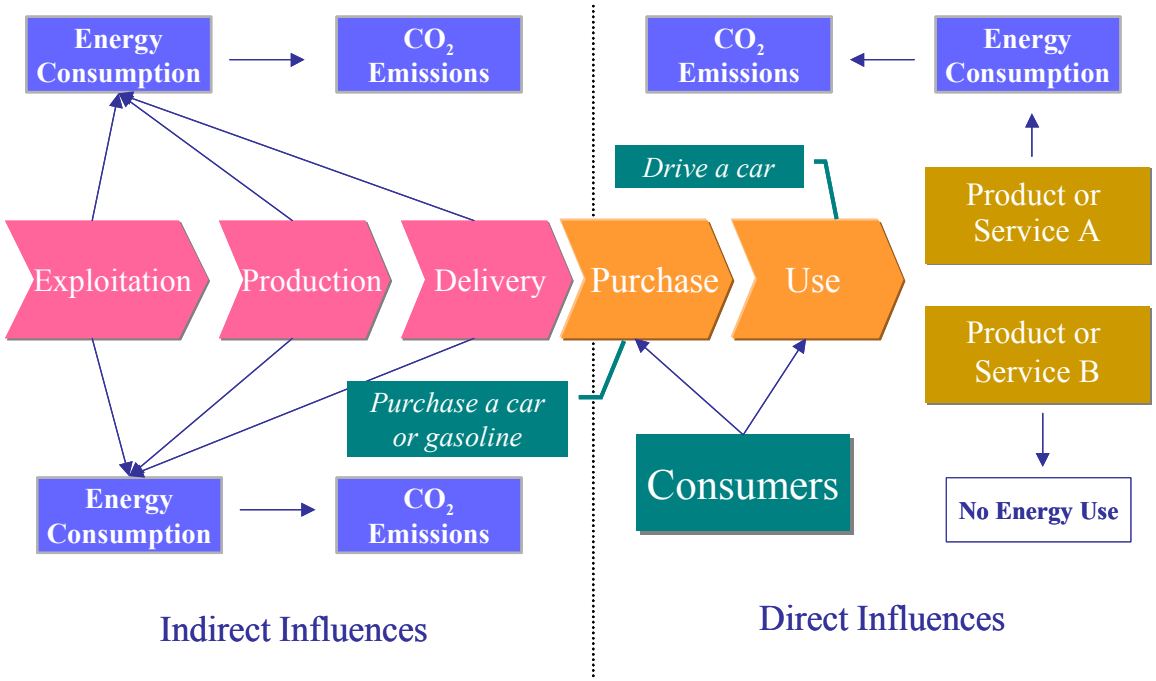
A Top-down Study: Re-estimation

Key Concepts

The term **consumer** in this paper refers to the entity that purchases and uses products and services for the purpose of individual or household consumption.

Environmental impacts of a consumer activity can be categorized as direct or indirect influences. If a consumer's activity leads to energy consumption and CO_2 emissions while the product or service is in use, these are called **direct (on-site) influences**, where energy consumption and CO_2 emissions occur in the preparation (production and delivery) of a product or service and before its use are called **indirect (embodied) influences**. See Figure 1. The terms of "direct" and "indirect" in this paper are defined from a consumer's perspective. To distinguish a consumer activity causing to direct or indirect influences is to see if the energy is being used and the related CO_2 is emitted at the same time of using or before (or after) a consumer uses a product or service. For example, driving a car leads to direct influences as gasoline is used and CO_2 is emitted while a consumer operates the car. In addition, there are indirect impacts related to the manufacturing of cars, their maintenance and insurance, provision of a road infrastructure, and discovery, production, transport and sale of gasoline to consumers taking a ride in their car (Shui and Dowlatabadi in press).

Figure 1. Direct and Indirect Influences of Consumer Activities



In this study, consumer activities are aggregated into three levels. At the highest level, all consumer activities are categorized into two groups: direct influences and indirect influences. At the second level, direct influences include *home energy use* and *personal travel*, while indirect influences include *housing operation*, *transportation operation*, *food consumption*, etc. Table 1 shows the three levels of consumer activities[1].

Methodology

Information of residential sector or *home energy use* is well documented in the Energy Information Administration (EIA). For example, EIA provides residential energy consumption data on five end-uses (space heating, water heating, air conditioning, refrigeration, other appliances and lighting) by four fuel types (electricity, natural gas, fuel oil, and liquid petroleum gas) (EIA 2003). The CO_2 emissions of home energy use are estimated by the multiplication of fuel use of five end-uses and the corresponding CO_2 coefficients for each fuel type.

The estimation of energy use from *personal travel* is based on Transportation Energy Data Book (TEDB). TEDB provides each vehicle's (automobiles, motorcycles, trucks, buses, air, rail-passenger, and water-recreational) energy consumption by fuel type (gasoline, diesel fuel, LPG, jet fuel, and electricity)(Oak Ridge National Laboratory 2003). The related CO_2 emissions are calculated as the product of the fuel consumed and its corresponding CO_2 coefficient.

Input-output analysis has been widely recognized as a popular tool to estimate energy use and greenhouse gas emissions embodied in consumer goods and services on a macro scale. The Environmental Input-output Lifecycle Analysis (EIO-LCA) model developed at Carnegie Mellon

[1]Because of space limitation, detailed third levels of each second level under indirect influence are not presented in Table 1.

University is a suitable and convenient tool to estimate energy use and related greenhouse gas emissions embodied in U.S. domestic goods and services. It has adjunct tables that represent various environmental effluents from each industry and economic activity associated with dollar value of output (Chris Henderickson, Arpad Horvath et al. 1998; Carnegie Mellon University Green Design Initiative 2004). In this study, an average annual consumer expenditure, containing 70 different categories(Bureau of Labor Statistics 2004), is used as inputs to one of the EIO-LCA model which is based on 1997 U.S. input-output tables. Since these consumption expenditure categories 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 EIO-LCA. This effort allows the use of EIO-LCA to estimate indirect energy use and CO_2 emissions from existing consumer expenditures (Shui and Dowlatabadi in press).

Results

The total direct and indirect influences of consumer demand occupy 65% and 75% of US energy use (96.3 QBTU) and CO_2 emissions (5,715 MMTCO2) in 2001. The re-estimation results are summarized in Table 1.

Since the electric system energy losses from providing useful thermal outputs to *home energy use* and *personal travel* are allocated to these two sectors, direct energy use (36.9 QBTU) and the related CO_2 emissions (2,384 Mt CO_2-e) are 38% and 25% higher than indirect energy use (26.8 QBTU) and the related CO_2 emissions (1,901 Mt CO_2-e), respectively.

For direct influences, "automobiles" in *personal travel* consumes most energy and emits most CO_2 (9.1 QBTU and 648 Mt CO_2 –e), followed by "other appliances and lighting" in *home energy use* (7.4 QBTU and 438 Mt CO_2 – e). Other important direct end-uses include "space heating" (5.5 QBTU and 321 Mt CO_2 – e) and "light truck use" (4.7 QBTU and 336 Mt CO_2 – e).

For indirect influences, *housing operation* and *transportation operation* rank the top two, accounting to 7.7 QBTU and 572 Mt CO_2 –e, as well as 7.6 QBTU and 510 Mt CO_2-e, respectively. Most of these indirect influences are from their subcategories of "shelter" and "vehicle purchases (net outlay)". *Food, beverages & tobacco* is the third, which is mainly contributed by one of its subcategories, "meats, poultry and fish", with a share of nearly 30%.

Table 1. Energy Use and related CO_2 Emissions From Consumer Activities in US, 2001

Consumer Activities	National Picture		Per Capita	
	Energy	$C0_2$ Emissions	Energy	$C0_2$ Emissions
	QBTU	MMTCO2	Mmbtu	Tonne
Total	64	4285	223	15.0
Direct Influences	36.9	2384	129.4	8.4
Home Energy Use (1)	19.8	1161	69	4.1
Other Appliances and Lighting	7.4	438	25.9	1.5
Space Heating	5.5	321	19.4	1.1
Water Heating	2.7	153	9.3	0.5
Air Conditioning	2.2	132	7.8	0.5
Refrigerators	2.0	117	6.9	0.4
Personal Travel	17.1	1223	60.0	4.3
Automobiles	9.1	648	32.0	2.3
Trucks	4.7	336	16.6	1.2
Air	2.4	171	8.5	0.6
Buses	0.2	15	0.7	0.1
Others (rail, motorcycles, demand purpose, water etc.)	0.6	53	2.2	0.2
Indirect Influences	26.8	1901	93.9	6.7
Housing Operation	7.7	572	26.9	2.0
Transportation Operation	7.6	510	26.5	1.8
Food, Beverages & Tobacco	5.5	383	19.3	1.3
Others (personal care, education, etc.)	2.1	155	7.2	0.5
Apparel and service	2.1	145	7.5	0.5
Recreation & Reading	1.1	80	3.8	0.3
Health care	0.8	56	2.8	0.2

Discussion: Target Activities

Table 1 presents the estimated total energy use and CO_2 emissions resulted from direct and indirect influences of consumer activities. It also identifies target consumer activities which are more energy and carbon intensive than others.

This identification may help policy makers and researchers employ scarce resources in the most efficient way. The findings suggest that financial investment, technology development, capability building and research focus should be addressed to services and products related to home (*home energy use* and *housing operation*) and personal transportation (*personal travel* and *transportation operation*) for energy conservation and carbon mitigation. The reduction potential of energy use and carbon emissions from *food* and *clothing* consumption is relatively limited to be worthy of efforts.

The identification also helps lay people become aware of the level of impacts associated with each of their consumption activities. Most lay people, even when motivated to become more environmentally responsible, are not equipped with such knowledge. Some think that turning off lights, recycling cans, and becoming vegetarians are the most significant behavioral choices they can make. Although these behaviors often reduce energy use and CO_2 emissions, their overall effect is minimal. Meanwhile, unwitting persistence in other activities, such as frequent air-travel and using electricity as a source for heat can lead to significant primary energy use and CO_2 emissions (Shui and Dowlatabadi in press). It is suggested that well-designed and credible

information dissemination programs which aim at target consumption activities may help consumers better make informed and effective choices.

A Bottom-up Study: Reflection

Although the above top-down study can provide a big picture at national level, the "down" level of the study, or energy use and carbon emissions per capita, can not "descend" further to help a consumer know his/her own profile of CO_2 emissions. A tool is needed to help consumers acquire such knowledge about the energy use and the related environmental impacts from their consumption activities. In addition, this tool may help researchers and policy makers explore issues like how people respond once they are informed. This section illustrates a preliminary effort and initial results.

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Several tools are available to help people acquire such knowledge. Home Energy Saver (http://hes.lbl.gov/hes/vh.shtml), developed by Lawrence Berkeley National Laboratory, is an on-line tool to demonstrate energy use and expense by home end-uses in the U.S.. An on-line personal CO_2 calculator (http://www3.iclei.org/co2/co2calc.htm), developed by the International Council for Local Environmental Initiatives, demonstrates the CO_2 emissions from home energy use and personal travel. The Climate Change Calculator (http://www.climcalc.net) is an interactive on-line tool designed to raise Canadians' awareness of the greenhouse gases they produce through their lifestyle choices.

The developed Individual CO_2 Emissions Estimator, or called ICEE, is a standing-alone software. One of the major differences between the ICEE and the above-mentioned tools is that the ICEE reflects CO_2 emissions from both direct and indirect influences from consumer activities, while all other tools estimate the direct influences. The direct influences in the current version of ICEE include *home energy use* and *personal travel*, and indirect influences cover food consumption, car purchase and recreation activities.

During the design of ICEE, special attention is paid to model CO_2 emissions by employing enough behavior variables to express consumers' purchase and use behaviors. It is assumed that 1) the more personalized a tool can be, the more likely that the users would accept it as a reflection of "their reality", and 2) the larger the number of behavior variables, the higher the chances of developing a good experimental tool for the study of individual choices (Shui 2002).

Pilot Studies

Few people have exact sense on how much CO_2 he or she emitted a year. It would be interesting to know 1) once they are informed these information, how people would respond, and 2) if an informed consumer could make effective choices. Pilot studies with two stages are conducted to explore these questions. Three users from Pittsburgh participated in pilot studies. User 1 is a white male, a UniMart clerk. He is in his-mid-twenties and lives alone. His annual income is estimated below $15,000. User 2 is a late-20-something African-American woman, with a graduate degree. She lives with her mother. Both mother and daughter are employed in white-collar jobs. The User 2's household annual income is about $65,000. User 3 is a 40-

something white female. She and her husband have three children. The household annual income is below $50,000.

The design of pilot studies and corresponding results are introduced below.

Pilot study design. Stage 1: A user is first asked to input his household demographic information such as number of household members, then he is asked to fill in a questionnaire based on his household consumption information related to home energy, personal travel, food and entertainment. Estimated results can be reviewed in the format of charts demonstrating the CO_2 emission distribution by consumption activities. In addition, ICEE provides the average American CO_2 emissions of the same consumer category for comparison.

Stage 2: After learning about their CO_2 profile, the user enters the second stage of inquiry in which he is asked what choices the household is willing to make in order to change their current CO_2 emission profile. The user's choices are translated into calculated emissions presented by green bars in ICEE.

Results. Stage 1: User 1 lives in a small row house, without cooling. Natural gas is the main fuel for his space heating, water heating, and cooking. His dryer is powered by electricity. He usually takes a bus to work, about 5,200 miles per year. He has no car. His food expenditure is about $20 per week. He spends $500 on magazines and books a year. His annual CO_2 emissions are 2.8 tonne, only 30% of the average U.S. individual. About half of it is from his home energy use[2].

User 2 lives in a large single-detached house. Natural gas is the space heating fuel. Room temperature during heating seasons is kept at 76°F, and it is 72°F during cooling seasons. Their water heater, dryer and cooking appliances are fueled by electricity. They watch TV 25 hours per week. The household has more than 20 incandescent lighting bulbs (each is 100 W, using less than 4 hours a day). The household travels 14,000 miles annually, 85% is used for commuting. Their annual air travel is about 7,200 miles, all for leisure purposes. Their weekly food expenditure is $100. The household's expenditure on books, magazines and newspaper is about $200 per year. The annual CO_2 emissions per household member are 12.4 tonne, 33% higher than the average. Personal travel (6.8 tonne) and home energy (5.2 tonne) are the main contributors.

User 3 is a large household in a medium-sized single-detached house, with no cooling in the summer. The indoor temperature is kept 68 °F during heating seasons. They have an automatic defrost side-by-side refrigerator, which was bought after 1995. Their weekly TV watching is about 45 hours. They have 14 incandescent light bulbs (100 W) which are on 4-8 hours a day. They have two cars. The total annual mileage traveled by the two cars is about 24,000 miles. Half is for the purpose of commuting. Their weekly food expenditure is about $220. They spend $900 on pet products and services, $250 on recreational books, magazines and newspapers. The annual CO_2 emissions per capita are 7.7 tonne, about 83% of the average level.

[2]Notice that 1) during the development of ICEE, the electric system energy losses from providing useful thermal outputs to *home energy use* and *personal travel* are allocated to *housing operation* and *transportation operation* in indirect influences. The information of energy use and CO_2 emissions per capita used in ICEE is not simply comparable to Table 1. 2) Some carbon coefficiencies of ICEE is derived from EIOLCA model based on 1992 U.S. input-output tables. 3) The three pilot studies documented in this paper were conducted in the year of 1999.

For Stage 2, User 1 claims that he has no reason to make changes because his is well below the average. He believes his current level of emissions is the minimal level for an American.

After learning of that her CO_2 emissions are well above the U.S. average, User 2 appears eager to bring her emissions down to the average level. She attempts to reduce CO_2 emissions by decreasing weekly bathing frequency, dishwashing frequency, and hours of TV watching. She considers reducing weekly expenditure on food away from home and on entertainment. However these choices have a limited effect on her overall emissions, reducing them only by 2.5%. Her emissions are still above the average level. This realization was upsetting to User 2.

User 3 said their household is planning to increase the frequency of clothes washing from 8 times to 11 times per week.

Discussion: Engagement

Considering people may have limited patience to focus on playing ICEE, a simple version of ICEE was developed except for the full version. The simple version contains only one page of questionnaire and takes about 20 minutes to complete, while the full version have four pages of questionnaire and takes about 45 minutes. To our surprise, the majority of people (6 out of 8) are interested in the full version because they think the longer version may reflect more accurate results. It was also noticed that all users, including people who played the simple ICEE only, seemed very interested in knowing their CO_2 emissions profiles and methods to reduce their CO_2 emissions.

Although almost all participants showed great interests triggered by playing with the ICEE, not every one expressed intention for mitigation. For example, User 1 said clearly that he had no intention to reduce more, and User 3 claimed the increase of household activities on cloth washing. These results may confirm Bittle, Valesano, and Thaler's earlier research in which they found that feedback was effective in reducing consumption for high consumers but may have the opposite effect for medium and low consumers (Bittle, Valesano et al. 1979-1980).

For people, like User 2, who like to devote for mitigation seems to lack of information on effective action. As the pilot study shows, all of her strategies for “being environmentally responsible” involved lifestyle sacrifices. Few of these sacrifices (e.g., cutting down on showers, watching less TV, eating less food, etc.) had a significant impact. She was unaware that she had access to both electricity and natural gas but used electric water heating and cooking. Actually, she can dramatically reduce her emission level by switching to gas-fired water heating and cooking without “hard sacrifice”. Studies conducted by Kempton, and colleagues (Kempton, Harris et al. 1982; Kempton and Neiman 1987) suggest that people usually think of energy conservation in terms of behavior conservation or curtailment actions, such as turning off lights, watching less TV, and using less hot water. They proposed that one possible answer involves "visibility": People can directly perceive the operation of lights, TVs, stoves, dishwashers, and so on. They know that energy could be saved if these devices were used less intensively.

Notice that, the reported pretests and pilot studies attempt to give a favor on what kind of mean may be used to better engage the public and how to study people response once they are informed about their annual CO_2 emissions. However, the results and conclusions presented here should be interpreted cautiously and should not be generalized due to the extremely small size of samples investigated. For example, there is no conclusion on the relationship between household income, household carbon emissions, and intention of mitigation, although a plausible positive

correlation provide by the reported limited pilot studies seem to exist. The hypothesis that higher household income induce to higher CO_2 emissions and stronger intention for mitigation should be testified by conducting large sample size and refining experiment procedures.

Conclusions

This paper integrate both direct and indirect influences of consumer activities to estimate the role of U.S. consumer demand in energy use and CO_2 emissions which has not been reflected by using the conventional sectoral approach.

The top-down study, the re-estimation of U.S. energy use and CO_2 emissions from the perspective of consumer demand, illustrates that consumer demand is the driving force for the U.S. energy use and CO_2 emissions. It reveals that about 65% of the energy used and 75% of the CO_2 emitted in the U.S. for the year of 2001 are resulted from direct and indirect consequences of American consumer activities. This study also identifies target energy-intensive and CO_2 – intensive consumer activities at aggregated levels.

The bottom-up study, the ICEE development, is to help the public gain knowledge of their lifestyles-related CO_2 emissions, and help researchers understand how people respond once informed. Although limited to its small size of pilot studies, the initial results may suggest that the development of a carbon calculator may be a useful mean to engage the public into the human-induced environmental issues which are often discussed by researchers and policy makers. These initial results also suggest that, although people may be interested in knowing their environmental impacts, not every one shows intention to mitigation. For people who would like to mitigate, they may lack of information on effective actions. It is concluded that further studies should be conducted to test the robustness of preliminary pilot studies, as well as the relationship between household income, energy use and carbon emissions level, and their intention for change.

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