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Energy requirements of consumption: Urban form, climatic and socio-economic factors, rebounds and their policy implications

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HIGHLIGHTS

- We statistically analyze the energy requirements of consumption in Australia.
- Contrasting urban/suburban/rural consumption patterns and spatial inequality.
- Energy requirements are influenced by urban form, income and demographics.
- Urban households require less direct energy, but their total consumption is higher.
- Significant rebound effects can be expected when direct energy use is decreased.

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ABSTRACT

Household consumption requires energy to be used at all stages of the economic process, thereby directly and indirectly leading to environmental impacts across the entire production chain. The levels, structure and determinants of energy requirements of household consumption therefore constitute an important avenue of research. Incorporating the full upstream requirements into the analysis helps to avoid simplistic conclusions which would actually only imply shifts between consumption categories without taking the economy wide effects into account. This paper presents the investigation of the direct and indirect primary energy requirements of Australian households, contrasting urban, suburban and rural consumption patterns as well as inter- and intra-regional levels of inequality in energy requirements. Furthermore the spatial and socio-economic drivers of energy consumption for different categories of energy requirements are identified and quantified. Conclusions regarding the relationships between energy requirements, household characteristics, urban form and urbanization processes are drawn and the respective policy implications are explored.

1. Introduction

The high levels of consumption and large dependence on fossil fuels in industrialized countries is one of the principal challenges for global sustainability. The changes which have been induced by the expansion of the fossil fueled economic system at all scales and in all the regions of the world are unparalleled in human history (McNeill, 2000). Serious concerns have furthermore been raised about the global production of conventional oil peaking sometime between now and in the next 10–30 years (Aleklett et al., 2009; Sorrell et al., 2010a, 2010b; Hirsch, 2008). Furthermore climate change can ultimately be expected to have direct socio-economic and ecological consequences if the long term trend of increasing fossil fuel use does not change dramatically (Lynas, 2008). Some even argue that these outcomes cannot be avoided anymore, because of the inertia of political systems, individual consumer psychology and identity and strong time lags between cause and effect (Hamilton, 2010). Anyways it is desirable to achieve a thorough understanding of the structure, patterns and drivers of energy consumption, since they can indicate possibilities and barriers for change (Hertwich, 2005a).

In this work, two different strands of research are being brought together to shed some light on these issues. From a consumption-based accounting perspective all economic activities and the related energy use at all the stages of the economic process can be understood as being ultimately aimed at final consumption (Lenzen et al., 2008). This fruitfully expands the notion of energy use from the conceptually straightforward usage of fuel or electricity, towards an understanding that all goods and services required energy to be used

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during the stages of the economic process. This understanding is highly relevant when green consumerism advocates some sort of 'shopping our way out of environmental problems' – which does not live up to its promise if dealt with in a perspective formally incorporating the indirect or embodied energy requirements of consumption (Alfredsson, 2004). Rather more this perspective on the complexity and interdependencies of the modern production processes can contribute to a more substantial understanding of the challenges and possibilities for change towards a sustainable lifestyle transition (Lenzen et al., 2008).

The second line of research on which this study draws has focused on structural and spatial determinants of energy use. The influence of spatial configurations of settlements and cities on individual mobility behavior and the subsequent transportation energy use has been under investigation for quite a while (Newman and Kenworthy, 1991; Kennedy et al., 2009). This rekindled the debate around the environmental impacts of urban and rural living (Shammin et al., 2010). The quality and quantity of the housing stock has also been identified as an important influence on the individual residential energy use for heating and cooling (Santin et al., 2009; Haas et al., 1998). These strands connect to the wider debate around the sustainability of ongoing urbanization around the globe, as well as possibilities for strategic interventions and economies of scale provided by cities (Jenks et al., 2000; Weisz and Steinberger, 2010).

For this study Australia is divided into three broad human settlement categories – urban, suburban and rural – as a basis for examining the differences and similarities in direct and indirect energy requirements of the average resident of these regions, from a consumer lifestyle approach (Bin and Dowlatabadi, 2005). Secondly, the area-based inequalities in energy requirements and income on a national level, and within the urban, suburban and rural classifications are quantified, using a novel method proposed by Druckman and Jackson (2008a) and Steinberger et al. (2010). Finally, multivariate regression analyses are conducted, using socio-economic, spatial and climatic variables to model and identify the dominant drivers for total, direct and indirect energy requirements, as well as direct private transport energy use, public transport energy requirements, residential energy and food-related energy requirements. A discussion of these results yields interesting policy implications, especially for countries with similar settlement patterns and urban forms as found in Australia as well as for ongoing urbanization trends around the globe.

2. The literature on energy requirements of consumption and existing insights on the relationship between consumption and urban form

From a consumption based accounting perspective, the primary energy supply of an economy, as well as the related emissions caused and resources used, can be differentiated into direct and indirect requirements. Households, governments and businesses consume energy carriers *directly* in the form of heating and cooking fuels, electricity as well as petrol through driving a vehicle. The *indirect requirements* of consumption include the industrial energy use throughout the whole production process which were required to produce all goods and services (Herendeen, 1978; Lenzen, 2001) – which are also commonly called *embodied energy* (Peters and Hertwich, 2008; Liu et al., 2010).

In industrialized countries the fraction of indirect requirements is usually on a par with or even greater than the direct energy requirements (Lenzen, 1998a; Hertwich, 2005a; Moll et al., 2005; Jackson and Papathanasopoulou, 2008). For those developing countries which have been investigated yet, indirect requirements are found to be on par or slightly below direct energy use (Pachauri and Spreng, 2002; Pachauri, 2004; Cohen et al., 2005; Park and Heo, 2007), which interestingly is quite similar to USA and Norway of the 1970s (Herendeen, 1978; Herendeen et al., 1981).

Total per capita primary energy requirements of consumption range from 283 GJ for the USA (in 2002), to 138 GJ for the UK (in 1996), to 12 GJ in India (in 1993–95) (Hertwich, 2011), 112 GJ for the Netherlands, 135 GJ for the UK, 123 GJ for Sweden and 130 GJ for Norway (Moll et al., 2005). Household energy (residential requirements), vehicle fuel and other mobility (transportation requirements) and food related requirement generally compromise the largest fractions of the total energy requirements of households, while also being the most energy intense[1] ones (Hertwich, 2011). Overall these three categories are responsible for 70% of the environmental impacts of final consumption in the EU (measured as energy use, CO_2 equivalents, resource use, land use, acidification and smog formation), while only representing 55% of the expenditure (Tukker and Jansen, 2006).

Furthermore it has been found that with rising income, direct energy requirements only increase weakly, while the indirect requirements increase strongly (Lenzen, 1998a; Reinders et al., 2003; Lenzen et al., 2004; Moll et al., 2005). This is due to the fact "[…] that the commodities which are purchased by high income households but not by low income households are less energy intensive than the commodities purchased by both types of household. In other words, necessities are on average more energy intensive than luxuries, and the decrease of energy intensity with income is due to a saturation of necessities" (Lenzen, 1998a).

Differences in energy requirements of urban and rural live are mainly due to differential expenditure patterns and inequalities in income. Suburban and rural live are about 10% more energy intense than urban live (Herendeen et al., 1981; Lenzen, 1998a; Lenzen et al., 2004; Shammin et al., 2010). This is due to the fact "[…] that the average person in a rural household spends their money on more energy intensive commodities than a person living in a city" (Lenzen, 1998a), namely residential energy use and mobility requirements (Munksgaard et al., 2005). At the same time urban households show consistently higher levels of total energy requirements than suburban or rural households, largely because of their overall higher incomes (Lenzen, 1998a; Wier et al., 2001; Lenzen et al., 2004).

2.1. Past studies on the drivers of energy requirements of household consumption

Income/expenditure have been identified as the main determinants of total energy consumption (Herendeen, 1978; Reinders et al., 2003; Moll et al., 2005; Lenzen et al., 2006). Expenditure is usually preferred to income as a predictor variable, because it corresponds more closely to what households actually consume (Wier et al., 2001). Expenditure also includes social benefit transfers and various non-consumption expenses are already deducted, for example savings, taxes, donations and fines. Data on income levels on the other hand is much more readily available, for example from census data or international studies. This allows easier comparisons to other studies. Generally for income/expenditure much stronger correlations are found for indirect than for direct energy requirements (Reinders et al., 2003; Lenzen et al., 2004).

Household composition and size has been found to have a significant influence, with more persons and especially more children per household leading to lower per capita consumption, even under comparable per capita incomes (Lenzen, 1998a; Wier et al., 2001; Lenzen et al., 2006). This effect is mainly due to increased sharing of commodities, living space and utilities, rather

[1] Measured as total energy requirements per dollar spent.