social ecology vienna

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT

SOCIAL ECOLOGY WORKING PAPER 133

Dominik Wiedenhofer

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ISSN 1726-3816

Dezember 2011

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Social Ecology Working Paper Number 133
Vienna, December 2011

ISSN 1726-3816

Institute of Social Ecology
IFF - Faculty for Interdisciplinary Studies (Klagenfurt, Graz, Vienna)
Alpen-Adria-Universitaet
Schottenfeldgasse 29
A-1070 Vienna

www.aau.at/socec
workingpaper@aau.at

Spatial and Socio-economic Drivers of Direct and Indirect Household Energy Consumption in Australia*

Von

Dominik Wiedenhofer

** Masterarbeit verfasst am Institut für Soziale Ökologie (IFF-Wien), Studium der Sozial- und Humanökologie. Diese Arbeit wurde von Dr. Julia K. Steinberger betreut.*

Abstract:
In this working paper the results of an investigation of the direct and indirect primary energy requirements of Australian households are presented. Urban, suburban and rural consumption patterns as well as inter- and intra-regional levels of inequality are analyzed and discussed. The drivers of energy consumption for different categories of energy requirements are identified and quantified. Conclusions about the relationship between energy requirements, household characteristics, urban form and urbanization processes in the Australian context are drawn.

Zusammenfassung:
Der Inhalt dieser Master Arbeit umfasst eine Untersuchung des direkten und indirekten Primärenergieverbrauchs australischer Haushalte. Urbane, suburbane und rurale Konsummuster wurden verglichen, sowie inter- und intra- regionale Ungleichheiten quantifiziert. Unter Anwendung eines multivariaten Regressionsansatzes konnten die unterschiedlichen räumlichen und sozio-ökonomischen Einflussfaktoren auf die Energieverbrauchsmuster identifiziert und quantifiziert werden. Basierend auf den Ergebnissen der Analysen lassen sich Schlussfolgerungen über den Zusammenhang von Energieverbrauch, Haushaltscharakteristika, urbaner Form und Urbanisierungsprozessen im Australischen Kontext ziehen.

Acknowledgements

Many thanks go to Julia Karen Steinberger, who supervised me with great enthusiasm and patience and successfully guided me through the trials of advanced statistics, as well as giving some important nudges at several stages of the whole project. Manfred Lenzen also proved to be a great inspiration and support and I thank him for the generous amount of time he spent with me discussing various aspects of this work and Input-Output approaches in general. Christoph Plutzar played an important role in the beginning of this work and his GIS support is highly valued. Shonali Pachauri gave valuable comments on an early draft, which are highly appreciated. Furthermore I thank the University of Klagenfurt for supporting me with a travel grant, without which my stay at the University of Sydney would not have been possible.

Any errors and gaps in the research presented in the remainder of this work are solely the responsibility of the author.

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1. Introduction

The growing consumption of fossil fuels is one of the principal threats to global sustainability. Concurrently it has also been argued that the exponential increase in global primary energy consumption over the last century is directly linked to the functioning of the social and economic system (Sieferle, 1997; Fischer-Kowalski, Haberl, 2007; Fischer-Kowalski et al., 2011). The changes which have been induced by this energetic social metabolism at all scales and in all the regions of the world are unparalleled in human history (McNeill, 2000). Serious concerns have also been raised about the global production of conventional oil peaking now or in the next 10-30 years (Sorrell et al., 2010a, 2010b). Furthermore climate change can ultimately be expected to have dire consequences for ecological and social systems if the long term trend of increasing fossil fuel use does not change dramatically (Lynas, 2008). Some even argue that to some extent 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). Even more so it is highly 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, 2005b).

In this work, two different strands of research are being brought together to possibly shed some light on some of these issues. One important perspective on energy use in modern economies can already be found in Adam Smith's writing (1776), stating that "Consumption is the sole end and purpose of all production" (cited in Lenzen et al. 2004). With this quote in mind, it becomes clear that all economic activities and especially energy use at all the stages of the economic process are ultimately aimed at final consumption. 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, actually every single consumption activity required energy to be used at some or several stage(s) of the economic process. This notion is highly important in times of green consumerism advocating some sort of 'shopping our way out of environmental problems', which does not seem to 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 understanding of the complexity and interdependencies of modern production processes can contribute to a more substantial understanding of the challenges and possibilities for change, leading to a notion of 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 in two specific areas. Firstly, the influence of spatial configurations of settlements and cities on individual mobility behavior and the subsequent transportation energy use (Newman, Kenworthy, 1991; Kennedy et al., 2009). Secondly, issues around the quality and quantity of the housing stock influencing the residential energy use for heating and cooling. Both areas 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, Steinberger, 2010). Furthermore this area provides a close link to the first strand of research mentioned above, insofar as it strives to improve our understanding of the physical barriers and eventual 'promotors' of a sustainable lifestyle transition.

A third line of research, which would be highly relevant for the research questions laid out in the next section and the issues touched upon above encompasses more of a sociological, psychological and institutional understanding of the ‘willingness to consume’ as a driving force of consumption (Röpke, 1999; Hamilton, 2010). The spatial configuration of residential and other land-uses can also be understood as a product of sociological and economic dynamics, for example as seen in such phenomena as residential self-selection (Knox, Pinch, 2006; Cao et al., 2009). Furthermore a cognitive geography approach could also shed additional light on the afore mentioned aspects by explicitly dealing with the way people perceive and make sense of their surroundings, for example when it comes to making choices on travel mode, extent and number of trips (Weichhart, 2008). Attempts to integrate some of these aspects empirically have been presented by (Wier et al., 2001) and (Abrahamse, Steg, 2009). Unfortunately explicitly dealing with these aspects of the research questions laid out in the next section cannot be incorporated into this study because they go well beyond the scope of a single master’s thesis. Further research would definitely be interesting in this context and could definitely add to the debate.

Research questions addressed in this study

For this study, the goal is to undertake a consistent, consumption-based and spatially explicit study of direct and indirect energy requirements of Australian households. After contrasting urban, suburban and rural consumption patterns we identify the drivers of energy requirements to gain additional insights into the patterns of energy requirements of consumption and possibilities for intervention. The research focus of this thesis lies with the following five questions guiding the rest of this work.

- What are the levels and composition of direct and indirect energy requirements of Australian households?
- What influence do spatial considerations, such as urban form and urban-rural separation, have on the direct and indirect energy requirements of Australian households?
- What are the most important spatial and socio-economic factors influencing the energy requirements of Australian households?
- Can we distinguish typologies of direct and indirect energy requirements of households and urban form of Australian cities?
- What insights can be gained for guiding future urbanization and urban planning?

A theoretical discussion of existing findings from the literature in relation to the research focus will be followed by a brief treatment of the methodology applied. A longer discussion and analysis of results will then culminate in a tentative attempt to answer the fifth and arguable broadest research question.

2. What do we know about the Energy Requirements of Household Consumption?

The goal of this section is to briefly discuss the basic assumptions of this perspective, give an overview of the most important findings in the current literature, critically evaluate these insights and identify relevant research gaps.

From a consumption perspective, the primary energy supply of an economy, as well as the respective emissions caused and resources used, can be differentiated into the following two categories. Firstly, households, governments and businesses consume energy carriers in the form of heating and cooking fuels, electricity as well as petrol through driving a vehicle. These are usually defined as *direct requirements*. Secondly, the environmental pressure and resource depletion caused through the consumption of goods and services, which required energy and other resources for their production and delivery, are called *indirect requirements* (Lenzen et al., 2008). Another commonly used term is *embodied* (Peters, Hertwich, 2008; Liu et al., 2010). These indirect requirements are generally understood to be of "infinite order". "This means that they, in the case of the provision of a train journey for example, not only include environmental pressure caused by the very train journey, but also through assembling the train and running the stations, producing the steel for the train and the concrete for the station buildings, producing the materials for the steel and concrete factories, the machines to mine the iron ore, sand, etc, the steel to produce the mining equipment, and so on. This process of industrial interdependence proceeds infinitely in an upstream direction through the whole upstream life cycle of all products, like the branches of an infinite tree" (Lenzen et al., 2004). The sum of these direct and indirect requirements of resources, pollutants and energy is called *total requirements.*

The prinicipal method to investigate direct and indirect requirements and the underlying industrial interdependence is input-output analysis, as developed by Leontief (1936; 1970, among many other publications on the subject). For a general discussion of this approach, see section 0. For a more detailed description of the application in this study, see section 4.

Another indicator on household consumption, which also has been developed early on, is the energy intensity of consumption. Energy intensity is defined as the fraction of energy requirements per currency unit spent, for example in GJ / Euro. The underlying interest is the fact, "that a consumer's dollar [or Euro] can be spent with significantly different energy impact […]" (Herendeen, 1978). In effect, energy intensities of various expenditure categories are one of the most useful outcomes of input-output studies. This measure allows the investigation of the consequences of different consumption patterns as well as possibilities for reductions in total energy requirements through shifts in these patterns.

Defining System Boundaries and the Allocation of Indirect Requirements

One of the implicit starting points in all studies on energy / resource / emissions requirements of consumption is the way system boundaries are defined and whom the respective indirect requirements are being allocated to. Because of the large implications of differing system boundaries for the methodological effort as well as the scope of any investigation, this issue has received a lot of attention in the literature and policy arena (Lenzen, 1998a; Bastianoni et al., 2004; Munksgaard et al., 2005a). Three concepts have been put forward in this regard,

namely producer, consumer and recently also shared responsibility (Munksgaard, Pedersen, 2001; Lenzen et al., 2007a; Lenzen, 2007; Andrew, Forgie, 2008).
In the producer perspective administrative and territorial borders (nations, states, regions) are defined as the relevant system boundaries. Therefore all resource and energy use as well as emissions resulting from activities within a given country are being allocated to that nation. This principle is currently the basis for national emissions accounting under the Kyoto Protocol and also underlies various initiatives targeted at the household or municipal level, like the Cities for Climate Protection program (CCP) or the International Council for Local Environmental Initiatives (ICLEI). Although a production based accounting scheme is conceptually and methodologically more straightforward, it suffers from the fact that it cannot take into account the upstream or indirect requirements of the activities happening in that given nation. This lead to concerns regarding 'carbon leakage' either in its weak form between annex B countries[1], or even more importantly, as strong leakage from annex B countries to non-Annex[2] countries (Hertwich, Peters, 2009). Especially strong carbon leakage can significantly undermine efforts to reduce the total GHG emissions of the world economy by allowing annex B countries to reach their GHG mitigation goals by effectively net importing embodied emissions, instead of reaching absolute reductions. Furthermore strong leakage can lead to economic inefficiencies, because emissions are potentially not abated where most cost effective, but by outsourcing production activities (Peters, Hertwich, 2006). (Weber, Matthews, 2008) estimated that in 2004 about 30% of the carbon emissions of US household consumption actually occurred outside the national borders. Australia ranks as a net exporter of CO_2 emissions, with a 20% difference between the consumption and production accounting perspectives (Peters, Hertwich, 2008).
These issues are even more pronounced at the sub-national level when comparisons are made between cities or regions (Weisz, Steinberger, 2010). Because cities are highly open economies and are inherently dependent on their hinterlands (Kennedy et al., 2007; Lenzen, Peters, 2010), a territorial or producer based accounting of indirect requirements cannot adequately capture the industrial interdependencies and different layers of production facilitating the consumption of goods and services in a city or region. Distinguishing between emissions and resource use occurring *in* a local area, with those resulting *from* the activities required to support the local population therefore again turns into the question of producer versus consumer responsibility (Munksgaard et al., 2005b). One interesting example for this issue is reported in (Lenzen et al., 2004): using the ICLEI-CCCP methodology[3], the population of the city of Melbourne (including the CBD), has annual per capita emissions of 102 tons of CO_2 equivalents. But the inhabitants of Frankston, a municipality in Melbourne, are only being estimated at 14 tons of CO_2 equivalents. "This difference is however primarily due to the nature of the accounting of indirect emissions: people who happen to live in the CBD are largely not responsible for the large electricity use of that area which is required to service the businesses there." (Lenzen et al., 2004). A territorial (production based) scheme of emissions accounting like the ICLEI-CCP results in the emissions being attributed to the resident population of that area, whether or not they actually benefit from these activities.
If one is interested in a consistent investigation of the total requirements of consumption, it becomes therefore necessary to apply a strict consumption based accounting of energy and resource use as well as of the resulting emissions. This approach builds on Adam Smith's

[1] Annex B of the Kyoto Protocol contains a list of signatory nations which have agreed to legally binding GHG reduction goals
[2] Non-Annex countries are developing and emerging economies of the Global South which did not agree to any binding GHG mitigation obligations under the Kyoto Protocol.
[3] Australian Greenhouse Office and International Council for Local Environmental Initiatives 2000

(1776) notion, that "Consumption is the sole end and purpose of all production" (cited in Lenzen et al., 2004). This includes acknowledging that the majority of upstream production processes are ultimately intended and aimed at final consumption (Lenzen, 1998b). It then is plausible to fully assign the indirect requirements to the final consumers of the respective goods and services.

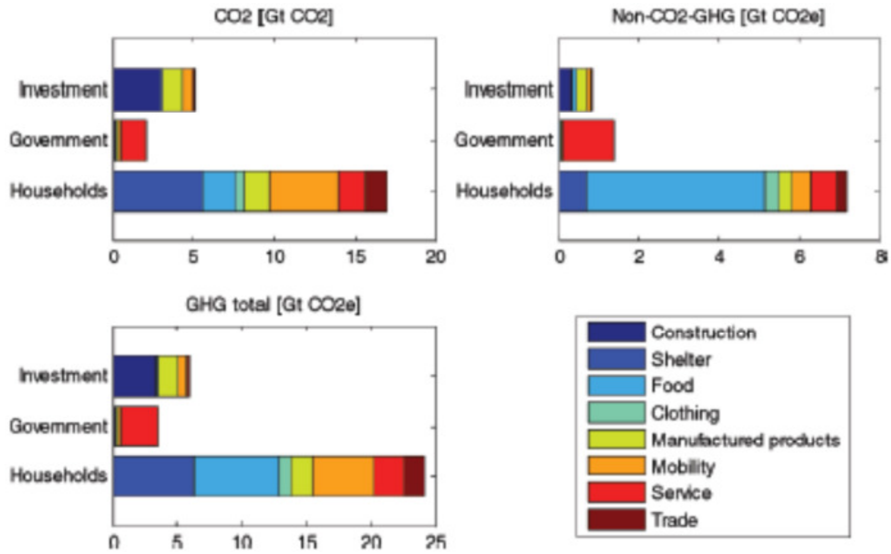
Besides households, two other 'final' consumers are usually differentiated in macro-economics, namely government entities and investment activities of businesses. Different practices of accounting for the total requirements of these two other 'final' consumers can be found in the literature. On the one hand, it is sometimes argued that governments act for the people (by providing infrastructure, running public health systems, maintaining order and a legal system, ..) and that investments are necessary to maintain production (and consequently also consumption), so therefore households ultimately benefit from both (Lenzen, 1998a, 2001; Lenzen et al., 2004; Moll et al., 2005). In this view these requirements can be distributed equally among the population. This approach is seen as being better than not accounting for capital formation at all, but implicitly assuming a steady-state economy "is not entirely satisfying because capital expenditure varies annually, and a given year may not contain investment in new aluminum factories or automobile plants" (Hertwich, 2005b).

On the other hand various authors do not include government consumption and investments in their analysis at all, or kept it as entirely separate categories (Herendeen, 1978; Vringer, Blok, 1995a; Weber, Matthews, 2008; Kerkhof et al., 2009; Hertwich, Peters, 2009; Shammin et al., 2010). Shammin et al. (2010) state that, "because taxes are a population's collective input to government expenditures, and therefore it would not be justifiable to assign to individual consumers the energy burden resulting from the public expenditure of tax revenues". This line of argument is based on the idea that household consumption is related to individual (consumer) choice and that the expenditures of governments and investments cannot be directly linked to the individual person, so therefore should not be assigned to his/her consumption pattern. As Herendeen (1978) puts it, "the dilemma therefore seems to be that this allocation appears different as viewed by the individual *consumer* looking *out* at the rest of society and the *citizen* looking *in* at his society". Analytically this issue can be seen as the question what the 'total cost of living' for each citizen actually contains, which is ultimately an issue of definitions and research interest if all three terms are to be included (Equation 1, (expanded from Herendeen, 1978).

$$\left(\begin{array}{c}\text{Total Requirements of}\\ \text{per capita Consumption}\end{array}\right) + \frac{\begin{array}{c}\text{Total Requirements of}\\ \text{Government Consumption}\end{array}}{\text{Population size}} + \frac{\begin{array}{c}\text{Total Requirements of}\\ \text{Investments}\end{array}}{\text{Population size}} \qquad \text{(Equation 1)}$$

(Hertwich, Peters, 2009) results on the size of these three terms indicate, that this question is not just a matter of accounting principles (Figure 1). According to their estimate 72% of the global greenhouse gas emissions are related to household consumption, 10% to government consumption and 18% to investments.

Figure 1: Global GHG emissions attributable to Investments, Government and Household Consumption (Hertwich, Peters, 2009)



Regarding a fair allocation of responsibility for energy use or greenhouse gas emissions, the concept of shared responsibility has recently been advanced. Neither a full producer nor consumer responsibility perspective seems perfectly appropriate when accounting for indirect requirements with the aim of enabling abatement activities under a post-Kyoto framework. To overcome this issue a consistent approach covering the complete life-cycle of all products and services, while avoiding problems of double-counting, has been formulated (Gallego, Lenzen, 2005; Lenzen, Murray, 2010). In this approach responsibilities for indirect requirements are shared between consumer and producer, either half / half or in relation to the value added, thereby explicitly linking responsibility with economic influence. For a longer discussion of the issues connected with shared responsibility and various stakeholder views, see (Lenzen et al., 2007b).

In conclusion it is clear that assigning responsibility over the total requirements of goods, services and household consumption is not completely straightforward. Value judgments as well as different perspectives and scientific interests shape the definitions of system boundaries and the allocation procedures. For this work, following the research questions layed out in section 0 and the previous discussion, we are interested in a consistent, consumption-based perspective on the total energy requirements of Australian households. A discussion of the further implications and relations to the research focus of this study follows in the next sections.

Studying Industrial Interdependence using Input-Output Analysis and Environmental Extensions

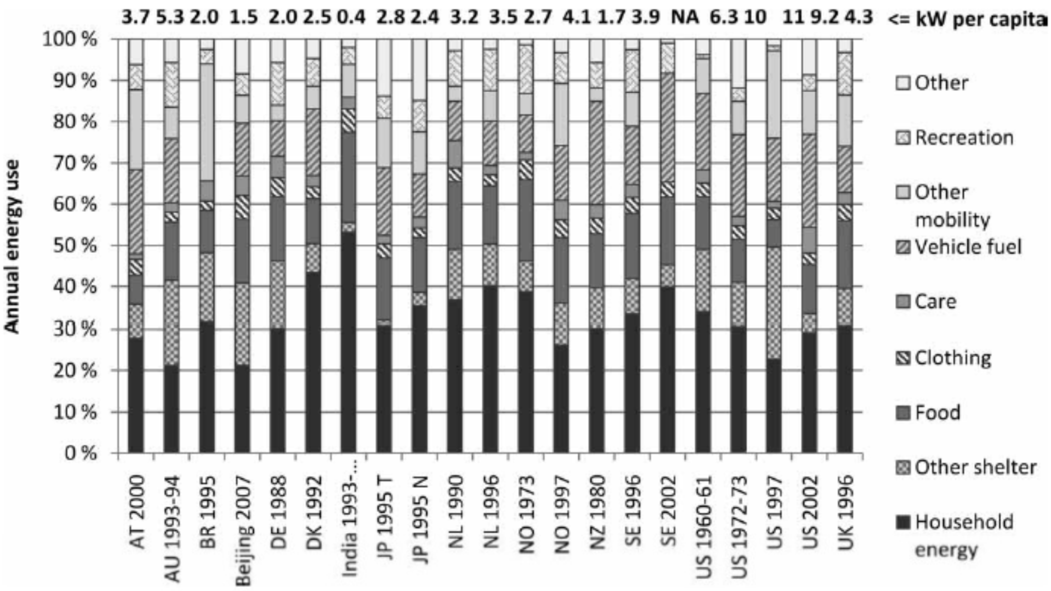
The study of industrial interdependence, using input-output methodology, goes back to the pioneering work of Wassily Leontief (1936; 1970, among many other publications), who developed and applied this method in a number of fields, thereby contributing richly to the

development of economics as a science and in its application to policy issues, projections, modeling exercises and other research areas (Duchin, 1992; Dorfman, 1995; Duchin, 1995; Augusztinovics, 1995; Rose, 1995).
The notion of industrial interdependence is based on the fact that any given economic sector requires a multitude of different inputs, usually called intermediate demand, to produce its goods and services. “Input-output analysis describes and explains the level of output of each sector of a given national economy in terms of its relationships to the corresponding levels of activities in all the other sectors” (Leontief, Ford, 1970: S. 262). Because a large fraction of the economic activity of an economy is actually directed towards other sectors, it is highly important to incorporate these intermediate outputs into any analysis of the total requirements of production and consumption. “The implications of industrial interdependence, be it via sales (forward linkage) or purchases (backward linkage), are often crucial to the understanding of the effects of changes in economic circumstances both on particular industries and on the economy as a whole” (Dixon, 1996: S. 327). Direct requirements in this context refer to all the goods and services bought by a given sector from other sectors to produce its output. But every one of the supplying sectors also need intermediate inputs, which are again linked to the outputs of other sectors, and so forth. These upstream linkages towards all other sectors constitute the indirect requirements and are generally understood to be of infinite order (Lenzen et al., 2004). When the economic process is viewed in this fashion, it becomes clear that all sectors are directly or indirectly interconnected and that changes in any sector or of final demand, to some extent affect all other sectors as well. With this approach it is possible to model the total economic effects of for example changes in household final demand (Alfredsson, 2004; Abrahamse, Steg, 2009), government outlay options (Lenzen, Dey, 2002), different production technologies and price effects (Duchin, Lange, 1995), international trade patterns (Hertwich, Peters, 2009), distribute environmental responsibility for production and consumption activities equitably among different actors (see discussion on shared responsibility in section 0), assess individual and systems level rebound effects (Alfredsson, 2004; Hertwich, 2005a), investigate aspects of waste generation and treatment (Dietzenbacher, 2005) and many others. For a collection of recent applications and advances in the application of Input-Output economics in the field of Industrial Ecology, see (Suh, 2010).
Any Input-Output analysis is based on a matrix representation of the inter-industry transactions in a given year. These are usually compiled by Statistical Offices and contain a complete table off all the monetary flows between sectors and to final demand (see for example ABS 2009 for Australian data). “These tables quantify for a given year the flows of goods and services, and of capital and labor, from one sector the other sectors and to final users” (Duchin, 1992: S. 852). To incorporate biophysical relevant information into these monetary models, so called environmental extensions are frequently used. These extensions, often compiled by statistical offices (for example NAMEA in the European Union), contain information on sectoral energy use, emissions, waste production and other relevant parameters. These can be coupled with monetary IO tables, thereby constituting for example direct and indirect energy intensities of sectoral production (or final consumption) (Lenzen, 2001). These can then be used to study the environmental impacts of different sectors and changes in the production outputs. The field of Environmentally Extended Input-Output analysis (EE-IO) has seen a rapid increase of publications since the mid 1990s (Hoekstra, 2010). See (Lenzen, 2001) for a thorough mathematical treatment of the formulation of a current EE-IO model, incorporating primary energy requirements as well as GHG emissions from other sources. For an overview of recent trends and developments in the field of EE-IO, see (Hoekstra, 2010).

Overview of current Findings on Energy Requirements of Household Consumption

Since the pioneering studies of the 1970's conducted by Herendeen and colleagues, a substantial body of research has been accumulated on household energy requirement patterns, the energy intensity of different consumption categories and the respective total costs of living. These early publications already present some important findings, for example that the indirect fraction ranged from one third to half of the total energy requirements of household consumption in the US and Norway of the 1970s (Herendeen, 1978; Herendeen et al., 1981). More recent studies have shown that in industrialized countries the fraction of indirect requirements has increased and is now on a par with, or even greater than direct energy requirements (Figure 2) and (Lenzen, 1998a; Moll et al., 2005; Hertwich, 2005b; Jackson, 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, Spreng, 2002; Pachauri, 2004; Cohen et al., 2005; Park, Heo, 2007).

Figure 2: Energy requirements of household consumption from 21 studies, (Hertwich, 2011), 1 kW = 30,7584 GJ



Note: The categories 'household energy' and 'vehicle fuel' represent direct energy use, other categories indirect energy use as identified in input–output analysis.
Source: Hertwich (2005). Numbers for Beijing are for urban areas only (Arvesen et al., 2010).

Furthermore large variations in total per capita primary energy requirements between countries can be observed, ranging from 283 GJ for the USA (in 2002), to 138 GJ for the UK (in 1996), to 12 GJ in India (in 1993-95) (Figure 2, own calculations). Moll et al. (2005) find per capita requirements of 112 GJ for the Netherlands, 135 GJ for the UK, 123 GJ for Sweden and 130 GJ for Norway. From Figure 2 it becomes furthermore clear that household energy (residential), vehicle fuel and other mobility (transportation requirements) and food compromise the largest fractions of the total energy requirements of households. Regarding energy intensity, most studies find that transportation, housing and food are the most energy intense consumption categories (Lenzen, 1998a; Moll et al., 2005). (Tukker, Jansen, 2006) furthermore corroborated this finding in their meta-study and conclude that these three categories are responsible for 70% of the environmental impacts of final consumption in the EU, while only representing 55% of the expenditure (measured as energy use, CO_2 equivalents, resource use, land use, acidification and smog formation).

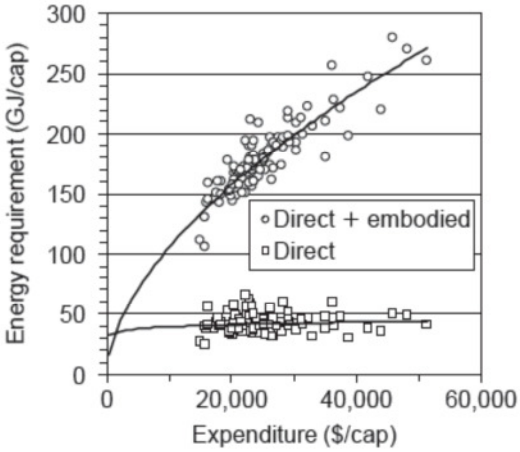
The dominant fraction in transportation energy requirements is direct energy use in the form of fuels for cars, motorbikes, etc. These end-user fuels like petrol also have a small indirect component to them, mainly from processing and distribution activities. The energy requirements of public transportation (fuel for buses, electricity for subways, etc) also fall under this category. Thirdly the smallest fraction, which is not always being included, is the embodied or indirect energy requirements of cars, buses and the relevant services like mechanics. Hertwich (2011) found in his meta-review across a large number of studies that mobility, including vehicle purchase and public transportation accounts for 23 +/- 8 % of the total requirements of average households.

Housing or residential primary energy requirements include direct energy use for heating and cooling purposes, as well as electricity use in the home. All of these also have indirect components from their relevant production process, delivery and so forth. Hertwich (2011) also includes the indirect energy component from the construction, maintenance and furnishing of homes in his analysis and finds that all of these amount to 44 +/-9% of the total energy requirements of households.

Food has both nutritional and indirect energy components: a 3000 kcal/day diet corresponds to 4.5 GJ per year in 'nutritional' energy per person. For this study the interest lies with the commercial primary energy required to produce, distribute and store food products. It can range from 2.5 to 4 GJ per capita per year for Indian urban households and 6 to 30 GJ for Brazilian urban households (where the ranges correspond to low and high income brackets) to around 40 GJ per capita per year for European households (Vringer, Blok, 1995b; Pachauri, 2004; Cohen et al., 2005). On average, food accounts for 15 +/- 4% of the energy requirements of per capita consumption (Hertwich, 2011). Because most energy use for food production happens outside city boundaries, this is also an example of the importance of an end-use consumer perspective.

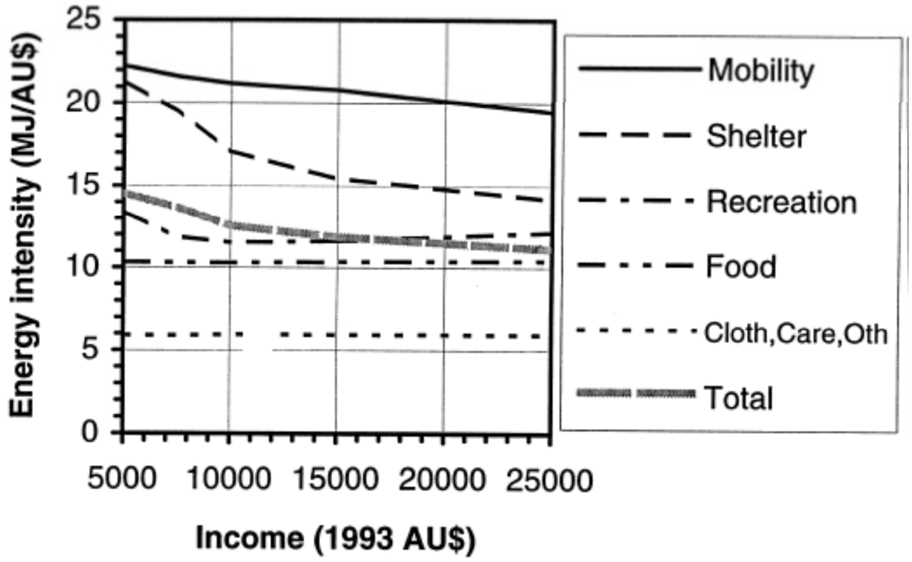
Besides the above discussed aspects it is also quite interesting to investigate the composition of consumption patterns of different income groups. Such an analysis has already been conducted in the early stages of this field (Herendeen, 1978; Herendeen et al., 1981). Current studies reconfirm the observation that with rising income, direct energy requirements increase only weakly, while most of the additional expenditures are used for more goods and services (=indirect requirements) Figure 3 and (Reinders et al., 2003a; Moll et al., 2005). The same effect interestingly also holds for urban households in Brazil (Cohen et al., 2005).

Figure 3: Relationship between expenditure and energy requirements of Australian households in 1999 (Lenzen et al. 2008)



This suggests that with rising affluence and above a certain threshold of ‘necessities’, shifts in consumption towards less energy intensive commodity groups like services and luxuries are happening (Lenzen, 1998a), possibly even to a larger extent than currently estimated (Girod, de Haan, 2010). But this is actually not that surprising if one thinks about it more closely, given that the most energy intense consumption categories compromise transportation and housing (as well as food), which largely consist of direct requirements. Lower income households have proportionally larger expenditures on direct consumption categories, but these direct requirements do not increase significantly with rising incomes (Figure 3). Rather more, richer households spend their money on more and more goods, services and luxuries, in addition to a comparable level of direct requirements as low income households. This results in a less than linear, but still absolute increase in total requirements. If a larger fraction of higher incomes is spent on additional services and luxuries, which generally have lower energy intensities than for example transportation and housing, the total energy intensity of consumption necessarily decreases. But this might actually be more an issue of a larger divisor vis a vis a slightly less increased dividend, than an actual low energy requirements consumption pattern. Therefore it could probably be more instructive to investigate and compare the energy intensities of different consumption categories for different income groups to shed more light on this issue, which has been conducted for Australia in regards to categories of human need (Figure 4).

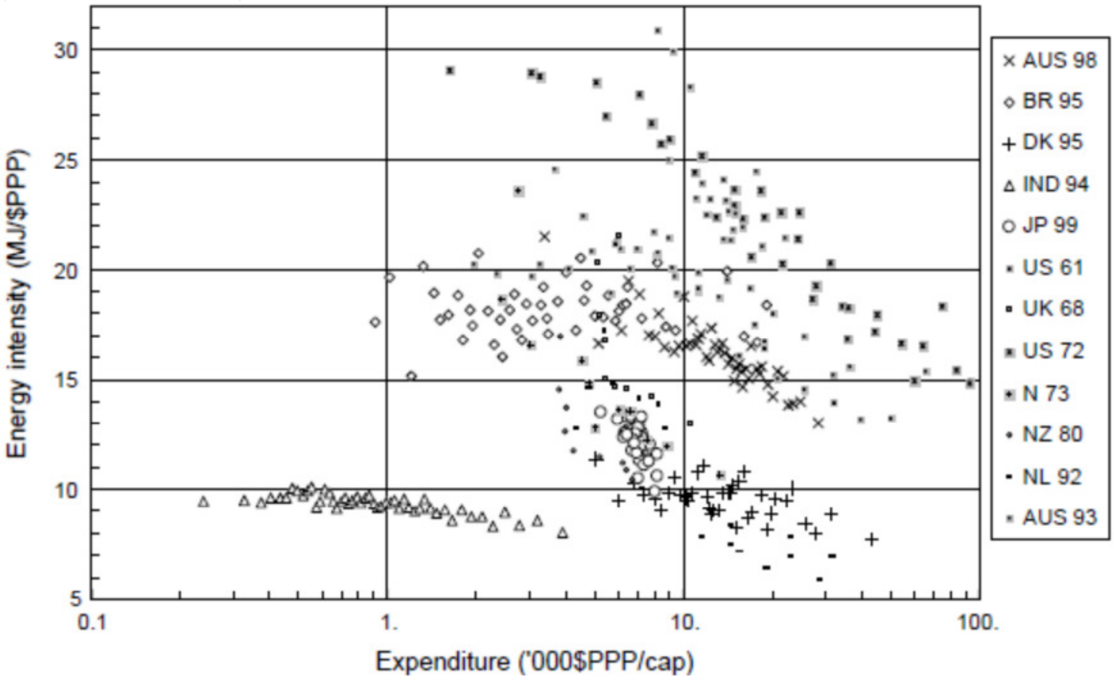
Figure 4: Energy intensities of consumption, by Income (Lenzen, 1998a: S. 511)



Lenzen (1998a: S. 511) concludes that this "[…] means 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".

This indication of a curvature of total household requirements at higher income levels (Figure 3) and the decreases in energy intensity with higher incomes (Figure 4) lead to a revival of the Environmental Kuznets Curve (EKC) hypothesis. The EKC postulates that with rising incomes (or GPD or expenditure) at first environmental pressure increases, but at a certain turning point it starts to decrease again. This is presumably because " […] (1) environmental quality is a luxury good, or results from (2) structural changes in the economy […], (3) equalizing income distribution, democracy and civil rights, or 4) technological progress (cleaner production and end-of-pipe technology, pollution prevention, material and energy efficiency)" (Lenzen et al., 2006: S. 184). In a multi-country study the relationship between energy intensity and different income levels has been investigated and it has become clear that with rising expenditure the energy intensity of consumption does decrease (Figure 5) (Lenzen et al., 2006).

Figure 5: Relationship of expenditure and energy intensities of consumption, for 12 countries (Lenzen et al., 2006)



An attempt to calculate a hypothetical EKC turning point based on these decreases in total energy intensities and a slight saturation effect for total requirements, failed to produce any results anywhere close to observed levels of income (Lenzen et al., 2006). These results suggest that there is no EKC for the primary energy requirements of household consumption, now or in the near future.

The total costs of living for urban versus rural households in relation to issues of urban sprawl have also been investigated early on. Herendeen et al. (1981: S. 72f) reported suburban and rural live in the USA and Norway to be 10% more energy intense than urban living in the 1960-70's. This has been confirmed with similar results for Australia in the 1990s (Lenzen, 1998a; Lenzen et al., 2004) and the US for 2003 (Shammin et al., 2010). This means "[…] 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: S. 505). Based on various environmental pressure indicators Munksgaard et al. (2005a: S. 180) conclude that "[…] families living in rural houses perform the worst in terms of environmental friendliness, based on their relatively high consumption of [residential] energy and transportation." Both consumption categories (as well as food) have been identified as most environmentally problematic (see above Tukker, Jansen, 2006). On the other hand, urban households show consistently higher levels of total energy and CO2 requirements than suburban or rural households, largely because of their higher incomes (Lenzen, 1998a; Wier et al., 2001; Lenzen et al., 2004). Concluding this suggests that, when differences in income are being controlled for, rural and sprawl living is comparatively more resource and energy intensive than urban lifestyles, mostly because of the larger share of transportation and residential energy requirements. This necessarily raises serious questions about the sustainability of urban sprawl and rural living in general and the respective possibilities for change. For urban dwellers the situation is slightly different, where structural aspects lead to lower direct energy use and lower energy intensities of consumption, but these inherently positive aspects are negated by significantly higher incomes and a generally more affluent lifestyle (Lenzen et al., 2008). But overall it becomes clear that serious progress in reducing total energy requirements could be achieved by increasing the need for transportation and / or making it more energy efficient. The same goes for residential energy requirements.

Discussion of the Drivers of Energy Requirements of Household Consumption

Based on this overview of existing findings on energy requirements of household consumption, the respective drivers and influencing factors shall now be discussed.

Across all studies, *income / expenditure* has been identified as the main determinant of total energy consumption (Herendeen, 1978; Reinders et al., 2003a; Moll et al., 2005; Lenzen et al., 2006). Expenditure is usually preferred to income as a predictor, because it corresponds more closely to what households actually consume (Wier et al., 2001). Expenditure 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 income / expenditure are much stronger causal variables regarding indirect than direct energy requirements (Figure 3) and (Reinders et al., 2003a; Lenzen et al., 2004).

Another income/expenditure related variable is *education*. Usually education exhibits strong correlations with income (Lenzen et al., 2004). Using multivariate frameworks it has been shown that when expenditure is controlled for, weak negative influences on total requirements exist for Australia and the UK, while no significant impact has been found for Japan and Denmark (Lenzen et al., 2006; Baiocchi et al., 2010). For some this indicates possibilities for educated 'green consumerism' (Baiocchi et al., 2010), while Abrahamse and Steg (2009) point out, that while existing requirement patterns are explained quite well by socio-economic variables, energy savings and changes in consumption are much more associated with psychological factors. They conclude that "contextual variables such as income shape households' opportunities for energy consumption, whereas reductions in energy use require conscious efforts to change behaviours/adopt energy-saving measures" (Abrahamse, Steg, 2009: S. 719). Unfortunately the variable education is not included in their statistical model, leaving the question unanswered what the exact link between these psychological factors and education is and if measures of levels of formal education could serve as a reliable proxy. Interestingly for developing countries like India and Brazil a positive link between education and total requirements has been reported (Cohen et al., 2005; Lenzen et al., 2006), where it has been hypothesized that especially urban educated individuals emulate a western consumerist lifestyle, which includes an ongoing accumulation of household stocks and consumer goods.

Another important factor in understanding energy use is *household composition and size* – with more persons and especially more children resulting in reduced per capita consumption (Lenzen, 1998a; Wier et al., 2001; Lenzen et al., 2006). Because the energy intensities are the same for different household types, it can be deducted that the average composition of consumption stays the same (Lenzen, 1998a). Increased sharing of commodities therefore leads to lower per capita requirements, rather than a significantly different consumption pattern of different household types.

Furthermore *gender* differences in energy requirement patterns of single men and women have been reported for four European countries. Single "women consistently used more energy than men […] [for] food, hygiene, household effects and health although differences are rather small." (Räty, Carlsson-Kanyama, 2010: S. 648). Regarding transportation requirements and the category 'restaurants, alcohol and tobacco' men consumed considerably more energy. Furthermore significantly larger total requirements of men than women were found (Räty, Carlsson-Kanyama, 2010), although the authors unfortunately do not control for

income disparities statistically. Using data with several household types (not only singles), the independent effect of gender disappears (Abrahamse, Steg, 2009), but a significant correlation of gender and income is noted. This leaves the question unanswered if gender independently leads to significantly differing total requirements because of differences in expenditure patterns, or if this is a reflection of the general income disparities between men and women.
Another influential demographic factor is *age*, which is found to have a positive effect on total requirements (Lenzen et al., 2006). Firstly, age is correlated with education and income, but even when these factors are controlled for, a small positive effect remains. Various explanations have been put forward, ranging from higher automobile mobility of independent retirees in Australia (NSW Department of Transport 2001, cited in Lenzen et al., 2006) to larger residential energy requirements because of relatively more time spent at home compared to working age persons, combined with possibly higher indoor temperatures to achieve comfort levels in seasonally cold countries.
Regarding *climatic influences*, a close relationship with residential energy requirements for thermal comfort has been documented (Kennedy et al., 2009; Wang et al., 2010). Large variations besides climatic effects exist, which are related to the specific building envelope construction, heating system typology, thermal efficiency, controls, annual hours of use and highly important, occupant behavior (Balaras et al., 2005). In the context of direct and indirect requirements the influence of climate has not been quantified yet. Reinders et al. (2003b) do correct for it, but then only apply a univariate analysis with expenditure as explanatory variable, therefore not statistically capturing the independent effect of climate. Another study even failed to find a significant effect associated with climate variables, but as the author notes, this could also be the case of a spatially restricted sample (Sydney only) which could lead to climatic effects misleadingly being attributed to other variables (Rickwood, 2009) or simply not showing up because of a lack of variation in the data.
For the variable *population density* a weak negative influence on total household energy requirements has been found for several countries, even when expenditure is being controlled for (Lenzen et al., 2006). Many urban energy studies have noted the importance of high population density as a factor in reducing private transport energy requirements (Newman, Kenworthy, 1991; Brown et al., o. J.; Kennedy et al., 2009). Dense urban form is also a prerequisite for an efficient and attractive public transportation system, as well as greater possibilities for walking and cycling because of shorter distances (Grazi et al., 2008). In response it has been argued that this influence might actually be more of an issue of attitude induced residential self-selection[4], rather than an actual influence of the built environment on individual decision making. In a meta-review across 38 studies, Cao et al. (2009) found strong evidence suggesting that the built environment does indeed influence travel behavior, even when self-selection processes are controlled for.
Furthermore higher density urban form also means more attached dwellings and especially flats and less separate houses. This potentially leads to lower residential energy requirements because of shared walls, smaller living space per capita and potentially also more efficient heating technology such as district heating or natural gas – although these possibilities are not always fully realized (Rickwood, 2009). Furthermore, it has also been suggested that above a certain threshold, densification might lead to disproportionately large increases in embodied energy for infrastructure and dwelling constructions (Rickwood et al., 2008). But this issue is still topic of ongoing research. For a further discussion on issues of urban form see section 3.

[4] Self-selection describes the phenomena that people tend to choose their residential location based on their preferred travel modes and needs. For a further discussion see the review by (Cao et al., 2009).

Another variable which is related to population density is '*house type*', which is an index based on the local composition of flats, semi-detached dwellings and separate houses (from high to low index in the same order) used in various publications from Lenzen and colleagues. For Brazil, Denmark and India a positive relationship between total requirements and this house type index has been found, independent of income levels (Lenzen et al., 2006). To some extent this is an effect of this index serving as a proxy for the actual living space per capita - which means more space needing heating and light as well as possible efficiency gains for attached dwellings and flats (shared walls, etc) (Rickwood, 2009).
Furthermore it has to be noted that this discussion of different drivers of energy requirements might implicitly suggest possibilities for change leading to savings in total energy requirements, for example due to lower private transportation requirements or intra-household sharing. But it is important to keep in mind that these changes do not automatically translate to proportionally lower total energy requirements, because of the well known rebound effect, also known as Jevon's paradox (Hertwich, 2005a). This issue will be discussed further in the concluding section.

Critical Remarks and Research Gaps in the Literature

From this overview of the existing literature it becomes quite clear that some findings, like the relationship between direct and indirect energy requirements or the importance of income/expenditure, have been established quite well in the field. Others are still under debate, for example the exact impact of gender, nationally differing influences for education and also the exact role of population density. While income and expenditure elasticities of consumption have been a wide and fruitful topic of research, driving factors beside income/expenditure have only been investigated in some cases. Most studies only apply univariate methods, thereby possibly missing out on other influential variables, like those discussed in section 0. To investigate these impacts requires a multivariate regression methodology, coupled with enough data to make statistical statements viable. Furthermore rarely are more disaggregated consumption categories besides total, direct and indirect requirements being interrogated regarding their driving factors, which might be interesting to shed some light on different specific possibilities and barriers for change.

3. Sustainability and Urban Form(s)

The purpose of this section is to draw together points from the literature reviewed so far and put them into the context of the debates on the sustainability of cities and different settlement patterns in general.

The Importance of Cities

Cities are inherently dependent on their hinterlands (Bai, 2007a; Kennedy et al., 2007; Lenzen, Peters, 2010) and constitute an important nexus of production and consumption (Weisz, Steinberger, 2010). In connection with ongoing urbanization trends around the globe this has led to a surge of research activities in the relationship between cities and sustainability issues (Simon, 2007).

Although cities are constrained by international economic processes, they can play a critical role within a multi-level governance approach necessary to effectively tackle issues of global climate change (Bulkeley, Betsill, 2005). Cities are furthermore places where resource and energy use meets local government capacities and therefore constitute one of the major avenues for the implementation and formulation for effective sustainability and climate policy (Bulkeley, Betsill, 2003).

Policy instruments can generally be categorized as carrots (economic incentives), sticks (regulatory approaches) and sermons (information and educational instruments) (Bemelmans-Videc et al., 1998). For more detailed discussions on policy instruments on the urban level I have to refer the reader to the literature, for example in regard to transportation (Grazi, van den Bergh, 2008), urban energy policy options and its implications (Keirstead, Schulz, 2010), GHG mitigation in a suburban setting (Knuth, 2010) and for a more general treatment of the obstacles and beneficial pathways for the integration of different types of environmental concerns into urban management strategies (Bai, 2007b). A detailed discussion of energy requirements and the role of urban planning in combination with other policy instruments in the Australian context can be found in (Gray, Gleeson, 2007).

Urban Form: Definitions, Ideals and Political Planning

One of the widely discussed aspects of cities in the context of sustainability and climate policy relates to their physical structure, or urban form (various contributions in Jenks et al., 2000; Buxton, Scheurer, 2005; Gray, Gleeson, 2007; Grazi, van den Bergh, 2008). The term urban form and structure "[…] covers such aspects as density, geometric shape, use of land (residential, industrial) and infrastructure (road, rail, waterway), with implications for indicators such as density, fragmentation and accessibility" (Grazi et al., 2008: S. 97). Furthermore it "[…] refers to the arrangement of the larger functional units of a city, reflecting both the historical development of the city and its more recent planning history […]" (Rose, 1967). Urban form can be measured as population density (Newman, Kenworthy, 1991; Grazi et al., 2008; Kennedy et al., 2009). Generally more complex land-use indicators would be desirable, but are very complicated to construct, mostly only feasible for intra-city research and can rarely be used in international comparative studies (Rickwood, Glazebrook, 2009). They (2009) furthermore show that density can serve as useful proxy for more complex indicators. The impact of population density on different categories energy requirements has been discussed in section 0.

The broader debate on the ideal urban form dates back to the early 19th century and most of the protagonists can be categorized as either 'decentrist' (dispersed and decentralized living) or 'centrist' (high density living) (Breheny, 1998). Breheney (1998) traces the origins of the debate in concerns about the effects of industrialization on cities in the 19th and early 20th

century and documents the renewed interest in large scale planning interventions with the birth of 'sustainable development' in the 1980s. Based on a review of the whole debate (up to the publication of book) he furthermore suggests a middle ground, incorporating the merits of all positions: "From the centrist case it can adopt continued, indeed tougher, containment, urban regeneration strategies, and a whole range of new intra-urban environmental initiatives. There will be environmental gains, but not at the expense of quality of life. From the decentrist case it can allow for the controlled direction of inevitable decentralization – to suburbs and towns able to support a full range of facilities and public transport, and to sites that cause the least environmental damage. It takes account of the grain of the market, without being subservient to it. It might allow for some development in the form of environmentally-conscious new settlements" (Breheny, 1998: S. 32). In connection it has been noted that the whole debate on sustainable cities is fraught with interests and values on what a city should be (Bulkeley, Betsill, 2003) and that strong ideological positions towards urban living strongly influences the various positions taken in the debate (Breheney 1998). Recent work has also argued for an understanding that there does not exist *one* ideal form, but many, depending on the local context, existing urban structure and political possibilities (Guy, Marvin, 2000). Forster (2006), based on a review of existing planning strategies throughout Australia concludes that the current 'official' vision of future urban structure in 20-30 years is one of "limited suburban expansion, a strong multi-nuclear structure with high density housing around centres and transport corridors, and infill and densification throughout the current inner and middle suburbs. Residents will live closer their work in largely self-contained suburban labour sheds, and will inhabit smaller, more energy-efficient and water–efficient houses. The percentage of trips using public transport, walking or cycling will have doubled. Regeneration programs will have broken up large concentrations of disadvantage, and […] low-income households will be able to find affordable dwellings […] within consolidation developments" (Forster, 2006: S. 179). These planning visions have been critiqued heavily for their overly narrow focus, based on the increasing geographical complexity of urban life in Australia (Forster, 2006). For further contributions on the implications and prospects for urban consolidation in the Australian context, see (Randolph, 2006; Buxton, Scheurer, 2005; Forster, 2006; Dodson, Sipe, 2008).

The two consumption areas directly connected to urban form and structure are mobility and housing as well as their respective energy and resource requirements (Rickwood et al., 2008). Incidentally these have also been identified as the most energy intense and environmentally problematic consumption categories (see section 0 and (Moll et al., 2005; Tukker, Jansen, 2006). "The physical infrastructure of a particular neighborhood could be one key determinant of lifestyle-related emissions that could also act as a barrier to lifestyle change. Such potential infrastructure bottlenecks to emission reductions are still relatively little understood and are one important avenue of research […]." (Baiocchi et al., 2010: S. 67).

4. Methodology and Data Sources

In this study, input-output analysis coupled with spatially resolved household expenditure information is used to analyze the total primary energy consumption of households throughout Australia (see annex 0, 0). Environmentally extended input-output analysis can be used to model industrial interdependence and estimate the physical requirements of final demand in an economy (see also the discussion in section 0); for example, for energy, greenhouse gas emissions, pollutant emissions, nitrogen flows, water or ecological footprints (Leontief, Ford, 1970; Duchin, 1992; Dixon, 1996; Carter, Petri, 1989; Forssell, Polenske, 1998). This method was pioneered for energy in the 1970s (Herendeen, Sebald, 1975; Bullard, Herendeen, 1975; Herendeen, Tanaka, 1976) and has since been applied to many countries: Australia (Lenzen, 2001; Lenzen et al., 2008), Japan (Aoyagi et al., 1995), the Netherlands (Vringer, Blok, 1995b; Biesiot, Noorman, 1999; Weber, Perrels, 2000), Brazil (Cohen et al., 2005), Denmark (Munksgaard et al., 2000; Wier et al., 2001), the USA (Herendeen et al., 1981; Shammin et al., 2010) and India (Pachauri, Spreng, 2002).

Three recent studies (Centre for Integrated Sustainability Analysis, Australian Conservation Foundation, 2007; Dey et al., 2007; Lenzen, Peters, 2010) achieved a complete household expenditure input-output map for energy, water and ecological footprints in Australia, which can be viewed on-line in the Australian Environmental Atlas, <http://www.acfonline.org.au>.

Further explanations of the relevance of combining input-output methods and tables (ABS, 2009), energy statistics (ABS, 2003) and household expenditure data for the understanding of urban energy metabolisms can be found in Lenzen et al. (2008). Given this wealth of prior work, the standardization of the methodology and the scope of this study, the description of the methodology will be kept brief and the reader is referred to the existing literature, for example (Lenzen, 2001; Kok et al., 2006; Suh, 2010). Furthermore also annex 0 contains more detailed information.

In essence, the national Australian input-output tables **T** (ABS 2009) and Australian energy statistics **Q** (ABARE, 2008) are combined in a generalized input-output analysis, national electricity data is replaced with region-specific values, and energy multipliers are calculate (Lenzen, 2001), where $\hat{\mathbf{x}}$ holds gross economic output, and **I** is the identity matrix.

$$\mathbf{m} = \mathbf{Q}\hat{\mathbf{x}}^{-1}(\mathbf{I} - \mathbf{T}\hat{\mathbf{x}}^{-1})^{-1} \qquad \text{(Equation 2)}$$

These multipliers are then applied to spatially disaggregated household expenditure data **y** from the Australian Household Expenditure Survey (HES, ABS, 2009), to yield indirect energy requirements.

$$\mathbf{E}^{\mathbf{ind}} = \mathbf{m} * \mathbf{y} \qquad \text{(Equation 3)}$$

Adding direct energy requirements $\mathbf{E}^{\mathbf{dir}}$ yield total energy requirements $\mathbf{E}^{\mathbf{tot}}$.

$$\boldsymbol{E}^{tot} = \boldsymbol{E}^{dir} + \boldsymbol{E}^{ind} \qquad \text{(Equation 4)}$$

The energy requirements for different categories of household expenditure, and for each spatial region of Australia, are then available for analysis. The HES also contains a range of socio-economic-demographic variables **s**, which we first submit to a correlation analysis in order to control for multicollinearity (Table 1, see also annex 0 for more information). For example, separate houses and the share of under 18-year-olds are closely correlated (0.8), which indicates that both variables express the same underlying issues and therefore possibly lead to model misspecification when used simultaneously. These socio-economic, demographic and spatial variables are then used as explanatory variables in various multiple regression exercises of the form:

$$\ln(E) = \sum \beta_i \ln(s_i) \Leftrightarrow E = \prod s_i^{\beta_i} \quad \text{(Equation 5)}$$

Given that

$$\frac{\partial E}{\partial s_i} = \frac{\partial \prod s_i^{\beta_i}}{\partial s_i} = \beta_i s_i^{\beta_i - 1} = \frac{\beta_i s_i^{\beta_i}}{s_i} = \frac{E}{s_i} \quad \text{(Equation 6)}$$

and in line with previous assessments (for example Wier et al., 2001), we interpret the $\boldsymbol{\beta_i}$ coefficients as consumption-elasticities of energy requirements with respect to their socio-economic drivers $\boldsymbol{s_i}$: as:

$$\beta_i = \frac{\frac{\partial E}{E}}{\frac{\partial s_i}{s_i}} \quad \text{(Equation 7)}$$

The interpretation of these elasticities is particularly straightforward: a 1% increase in the explanatory variable $\mathbf{s_i}$ will result in a $\boldsymbol{\beta_i}$% change in energy consumption. Furthermore if $\boldsymbol{\beta_i}$ =1, the relationship is exactly proportional, if $\boldsymbol{\beta_i}$<1, the relationship is said to be inelastic, if $\boldsymbol{\beta_i}$ >1, the relationship is elastic (if $\boldsymbol{\beta_i}$ <0, the same terms hold for - $\boldsymbol{\beta_i}$ and the inverse of the socio-economic variable). The size of the respective student *t* – test additionally conveys information about the statistical significance of the interaction, with higher values indicating a stronger relationship. The goodness-of-fit statistic $\boldsymbol{R^2}$ also contains valuable information insofar as it indicates what fraction of the variation found in the sample can be modeled by the regression.

Table 1: Correlation of socio-demographic attributes and energy requirements

n = 85		1	2	3	4	5	6	7	8	9	10	11
Income per capita	1		-0.56	0.50	0.52	-0.57	0.67	-0.18	0.47	-0.53	-0.27	-0.05
Separate dwellings	2	-0.56		-0.66	**-0.76**	**0.80**	-0.57	0.46	-0.40	**0.83**	0.41	0.17
Medium density	3	0.50	-0.66		0.65	-0.51	0.47	-0.24	0.63	-0.52	-0.35	-0.16
Apartments	4	0.52	**-0.76**	0.65		-0.65	0.45	-0.38	0.51	-0.64	-0.40	-0.25
Under 18-year-olds	5	-0.57	**0.80**	-0.51	-0.65		-0.61	0.60	-0.42	0.58	0.17	-0.02
18–64 years	6	0.67	-0.57	0.47	0.45	-0.61		-0.08	0.36	-0.46	-0.35	-0.15
Household size	7	-0.18	0.46	-0.24	-0.38	0.60	-0.08		-0.03	0.33	-0.13	-0.01
Population density	8	0.47	-0.40	0.63	0.51	-0.42	0.36	-0.03		-0.22	-0.20	0.02
To work by car	9	-0.53	**0.83**	-0.52	-0.64	0.58	-0.46	0.33	-0.22		0.62	0.22
Car ownership	10	-0.27	0.41	-0.35	-0.40	0.17	-0.35	-0.13	-0.20	0.62		0.35
Heating degree days	11	-0.05	0.17	-0.16	-0.24	-0.02	-0.15	-0.01	0.02	0.22	0.35	
Total energy	12	**0.80**	-0.51	0.37	0.48	-0.57	0.47	-0.32	0.31	-0.53	-0.16	0.09
Indirect energy	13	**0.82**	-0.58	0.50	0.59	-0.58	0.53	-0.27	0.47	-0.59	-0.27	-0.05
Direct energy	14	0.05	0.21	-0.32	-0.31	-0.02	-0.06	-0.16	-0.42	0.18	0.29	0.42
Private transport	15	-0.17	0.29	-0.43	-0.41	0.13	-0.09	0.00	-0.46	0.28	0.31	0.18
Public transport	16	0.45	-0.43	0.62	0.52	-0.32	0.32	-0.11	**0.72**	-0.39	-0.38	0.01
Residential energy	17	0.29	-0.03	-0.03	-0.01	-0.21	0.07	-0.24	-0.13	-0.05	0.09	0.45
Food-related energy	18	**0.72**	-0.55	0.46	0.50	-0.63	0.54	-0.23	0.33	-0.51	-0.23	-0.06

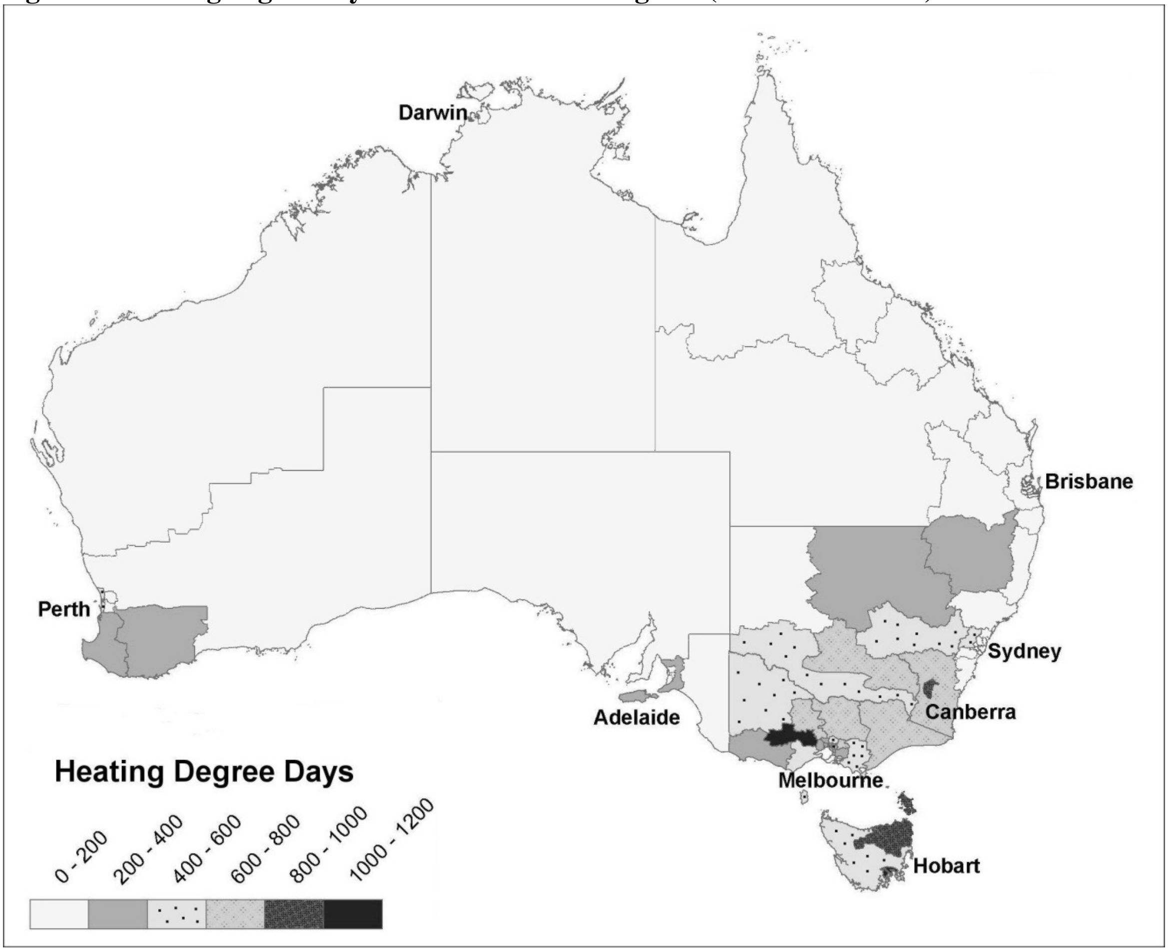
Note: Values below 0.5 are printed in grey, values above 0.7 in bold for ease of reading

These socio-economic, demographic and spatial variables are then used as explanatory variables in various stepwise multiple regression analyses to identify the most relevant variables in the explanations of levels of energy consumption and to eliminate less significant influences which could potentially confuse the regression estimation. Therefore a cut-off point of $t = 2.2$ (~95% significance) has been chosen for model building. To avoid the *omitted variable bias,* which occurs when relevant regressors are not included in the model, or issues of *overfitting*, which means that too many correlated variables are used for modelling, extensive testing has been conducted (Verbeek, 2008). Different variable combinations have been tried against relevant diagnostic statistics (students' t tests, F tests between models, not using highly collinear variables simultaneously), theoretical expectations and the clustering of variables to find the most stable models and therefore relevant drivers.

Data Sources

The assembly of an Australian input-output table has been thoroughly described elsewhere, also the derivation of the respective *energy intensities* (Lenzen, 2001; Lenzen et al., 2004). The Australian Bureau of Statistics conducts regular *household expenditure surveys* (ABS 2000) whose data are released as average annual household expenditure per statistical district. For this work, a national dataset disaggregated into 85 districts is used where about half cover the major urban centres (Perth, Melbourne, Adelaide, Sydney and Brisbane) and the other half the rest of Australia. *Heating degree days* (HDD) were chosen as a proxy for climatic conditions They are frequently used for building energy demand management and approximate the heating needs of buildings in relation to a specified base temperature (Day, 2006; Kennedy et al., 2009; Hillman, Ramaswami, 2010). Data from 782 weather stations which are operated by the Australian Bureau of Meteorology were used to extrapolate average annual HDD for all 85 regions (see Figure 6 and annex 0 for more information). For comparison, Vienna has 1596, London 1053, New York 1238, Barcelona 368 and Tokyo 589 HDD. Generally the Australian climate is dominated by three climatic zones: tropical in the north-east, arid in the centre and western areas and temperate in the south-east (Peel et al., 2007). This roughly corresponds to the steadily increasing HDD values when moving from north to south(east).

Figure 6: Heating degree days for Australia's 85 regions (own calculations)



Methodological and Data Limitations

For a thorough treatment of the uncertainties and limitations of input-output models and survey data, see (Lenzen, 1998b; Lenzen et al., 2004; Kok et al., 2006; Girod, de Haan, 2010). Spatial datasets pose additional problems (Páez, Scott, 2005; Getis, 2007). First, the Modifiable Area Unit Problem relates to issues with the definition of boundaries for spatial districts and the subsequent process of aggregation (Openshaw, 1984; Atkinson, 2005). All studies based on spatially defined datasets (such as census data), are influenced by the underlying system of zoning and aggregation, which introduces additional uncertainties. The suggestions from the literature (using several different aggregation schemes, rastering of zonal data, individual level data) are not always possible and are still being researched.

Second, geo-referenced variables often exhibit spatial autocorrelation, which means that not all observations in a spatial dataset can be assumed to be independent, violating the basic assumptions of any statistical analysis (Cliff, Ord, 1970; Páez, Scott, 2005; Getis, 2007). Moran's *I* index is commonly estimated in order to address this issue, where the residuals of a regression analysis are tested to check if the regression model properly captures all spatial effects (Getis 2007). Moran's *I* ranges from -1 to +1, where values around 0 indicate no spatial autocorrelation, while -1 / +1 means that there is perfect negative / positive autocorrelation.

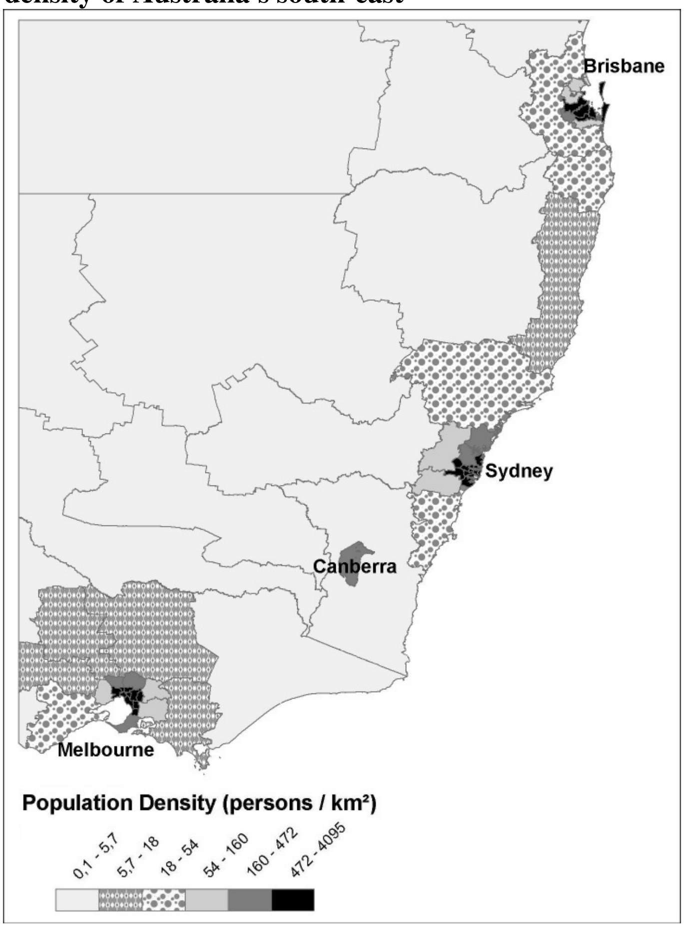
5. Discussion of Results

As a first step, population density patterns have been used to divide Australia into three broad human settlement categories – urban, suburban and rural – as a basis for examining the differences and similarities in energy requirements between the residents of these regions. Secondly, the area-resource inequalities in energy requirements and income on a national level, and within the urban, suburban and rural classifications were quantified. Finally, multivariate regressions, using socio-economic and spatial variables to model nationwide energy requirements to identify the dominant drivers have been conducted.

Differences and Similarities in Energy Requirements of Urban, Suburban and Rural Households

At the time of census (2001) about 11.2 million people, or 64% of the population, lived in major urban centres (ABS, 2003). Melbourne, Sydney and Brisbane (Figure 2) are home to about 9 million people. The statistical district of Sydney has a population density of 3,291 persons / km², Melbourne 1,218 persons / km², Brisbane 3,483 persons / km², Perth 2,488 persons / km² and Adelaide 5,871 persons / km². Comparing these figures with population densities listed in Kennedy et al. (2009) indicates that Australian urban areas lie between the lower densities of North America (Denver 1,460, Los Angeles 905 and Toronto 772 persons / km²) and European cities (Barcelona 16,056 and London 4,664 persons / km²). Generally, in the Australian context, population density follows a steep gradient from high density areas in inner city districts to very low densities in suburban and rural areas (Figure 7).

Figure 7: Population density of Australia's south-east



For the purpose of this study, urban areas are defined as districts with a population density of more than 1,000 persons/km², suburban areas with 1,000 to 100 persons/km² and rural areas with less than 100 persons/km². These ranges are based on two requirements: that districts with very low densities be clustered, and that districts connected with the CBDs of all five major cities be included in the 'urban' category. The remaining districts of these five major cities were defined as suburban. Based on these definitions, 24% of the Australian population lives in urban, 40% in suburban and 36% in rural areas (Table 2). To ensure that small modifications in the definition of the urban/suburban/rural boundaries do not lead to significant changes in the results, sensitivity analyses have been conducted. This is necessary to ensure that there are no districts close to the boundaries which strongly influence the results (for example with a population density of 999 persons / km² but a strongly different consumption pattern than all other suburban districts). The results shown below are robust under this sensitivity analysis, and therefore I am confident in the validity of our interpretations.

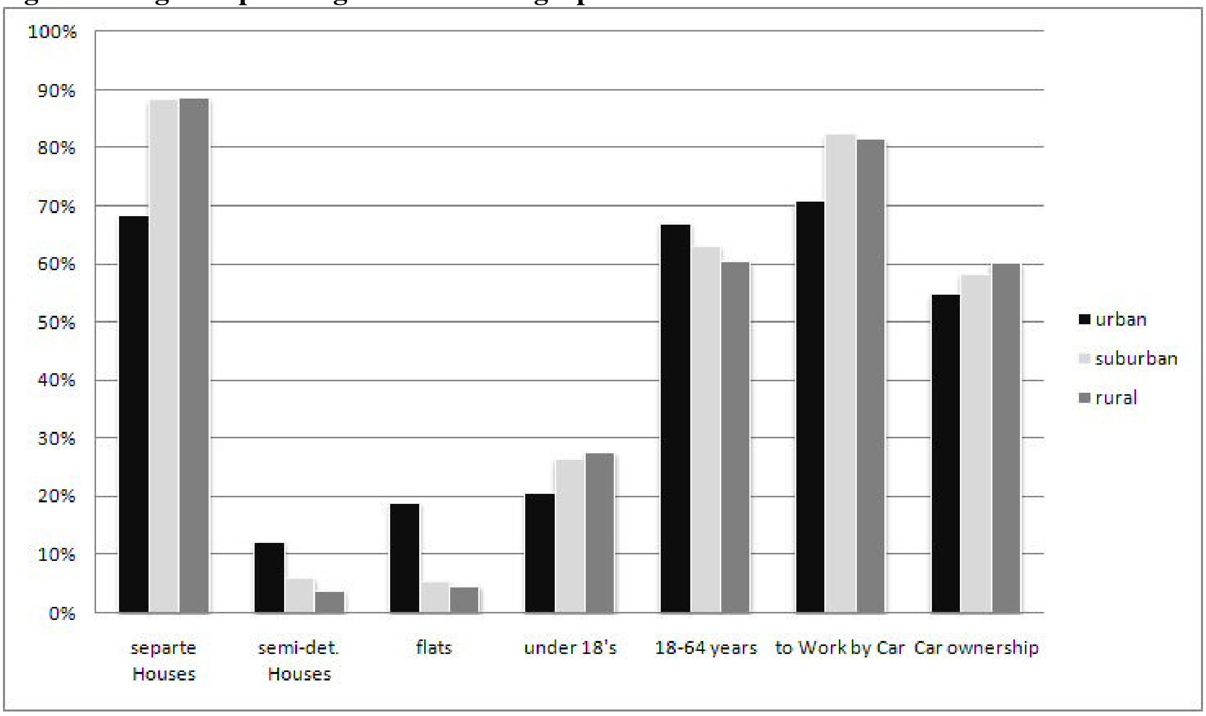
Table 2: Spatial differences in per capita energy requirements (GJ/cap) and income

n = 85	Urban (n = 18)		Suburban (n = 30)		Rural (n = 37)	
Annual income per capita	A$21,003 (4,798)		A$17,729 (2,994)		A$15,456 (2,766)	
Annual income per household	A$51,572 (8,245)		A$48,449 (9,696)		A$39,978 (8,517)	
Household size	2.5 (0.3)		2.74 (0.35)		2.58 (0.21)	
Total energy	243 (34.7)	100%	218 (23.1)	100%	213 (20.5)	100%
Indirect energy	180 (30.9)	74%	152 (21.4)	70%	143 (18.2)	67%
Direct energy	63 (7.3)	26%	65 (7.8)	30%	69 (8.4)	33%
Private transport (direct)	25 (3.8)	10%	27 (3.9)	13%	30 (5.5)	14%
Public transport (direct)	2 (0.9)	1%	0.9 (0.6)	0.4%	0.5 (0.5)	0.2%
Residential energy (direct)	38 (4.9)	16%	37 (5.9)	17%	38 (6.2)	18%
Food-related (indirect)	21 (3)	9%	19 (2.1)	9%	18 (2)	8%
Population (%)	24%		40%		36%	

Note: Figures in brackets are standard deviations

Annual per capita income is highest in urban areas, significantly less in the suburbs and lowest in rural areas: a 26 % decrease from urban to rural areas. For household income, the same trend is visible, namely 23% lower household incomes in rural areas, compared to the average urban households. The differences in total energy consumption are about half the income differences: a 12% decrease from urban to rural districts. Moreover, indirect energy is the dominant share in total consumption for all areas, representing over two-thirds of the total. Levels of direct consumption increase slightly from urban to rural, principally because of changes in transport energy requirements, with the more sparsely settled (and public transport poor) suburban and rural areas more dependent on private transportation. Residential energy consumption is roughly the same for all three regional groupings, constituting a certain basic level of consumption which in relation to human needs could be interpreted as 'necessities' (Lenzen 1998a) – at least for the current Australian context, which is obviously not the worldwide norm. Food-related (indirect) energy is highest for the average urban inhabitant, with slightly lower levels for suburban and rural areas. Looking at the demographics of the urban/suburban/rural categories (Figure 8), shows that the shares of under 18-year-olds are significantly higher in suburban and rural areas than in urban areas. The strong population density gradient between urban and rural areas (Figure 7) is also evident in the shares of housing types, with significantly higher levels of flats and semi-detached houses in urban areas. The attributes relating to personal mobility reveal that the inhabitants of urban areas own significantly fewer cars and also use them less to get to work, compared to people living in suburban and rural areas.

Figure 8: Regional profiling on socio-demographic variables



Regional Inequalities in Income and Energy Requirements

To further investigate urban/suburban/rural differences, area-resource (AR) Gini coefficients are calculated in order to quantify levels of inequality between districts (Druckman, Jackson, 2008b; Steinberger et al., 2010). The AR-Gini employs geographical distribution rather than income cohorts to measure inequalities, and can be used for energy or resource use as well as income (see annex 0 for more details).

Table 3: AR-Gini coefficients for income and energy requirements

	National	Urban	Suburban	Rural
Income per capita	0.32	0.20	0.31	0.33
Total energy	0.30	0.20	0.30	0.33
Indirect energy	0.32	0.18	0.32	0.34
Direct energy	0.28	0.23	0.25	0.31
Private transport	0.30	0.24	0.27	0.34
Public transport	0.46	0.24	0.43	0.51
Residential energy	0.27	0.22	0.25	0.29
Food-related energy	0.31	0.20	0.30	0.34

Note: 0 = perfect equality, 1 = total inequality

Nationwide income inequalities between districts reveal an AR-Gini coefficient of 0.32 (Table 3) The geographical distribution of the different categories of energy requirements is about as unequal as the income distribution, with the significant exception of public transport, with a much higher AR-Gini coefficient of 0.46. Because of the novelty of an area-resource Gini calculation, no international comparisons can be made at this point. When performing the same analysis on the subsets of urban, suburban and rural districts, the levels of intra-urban, intra-suburban and intra-rural inequalities are obtained. Typically, inequalities within more homogeneous areas are expected to be lower than nationwide. Indeed, 'urban' inequalities are much lower in all categories. For suburban areas they are only slightly below national levels. AR-Gini coefficients for rural areas are all somewhat higher than nationwide results. These elevated intra-rural inequalities are a sign that this regional category is more heterogeneous than either urban or suburban, which is not surprising: it encompasses rich coastal settled areas to the south-east as well as low income northern outback regions. (The attentive reader may have noticed that, upon first sight, this is in contradiction with the higher standard deviations for income found for urban areas (Table 2); this can be attributed to lower sample sizes for urban (n=18) than for suburban (n=30) and rural (n=37) areas, rather than inconsistencies in results.)

Cross-correlations of Socio-Economic and Spatial Variables

Additional insights into determinants of regional energy requirements and its spatial variability can be gained by isolating the effects of various explanatory factors utilizing a multivariate regression approach. For this purpose an analysis of the relationships between the explanatory variables and the energy consumption categories has been conducted (see Table 1). These interpretations could also be used to derive a typology of "typical" urban / suburban / rural average households.

Generally the results confirm the socio-demographic consumption patterns of affluent inner urban dwellers vs car-dependent suburban and rural families. The first clustering of correlations can be identified around the variables semi-detached houses and flats which are predominantly found in inner urban areas, namely, income (+), population density (+), working age population (+), household size (-), to work by car and car ownership (-) as well as total, indirect, public transport and food-related energy requirements (+). A second clustering around the variable separate houses with income (-), population density (-), under 18-year-olds (+), household size (+), to work by car and car ownership (+) and total, indirect and food-related (-), but direct and private transport energy requirements (+) can also be found.

As expected, population density correlates positively with total, indirect and public transport energy consumption, and negatively with direct and private transport requirements. HDD also show the expected positive relationship with direct and residential energy requirements.
Quantifying the Drivers of Energy Requirements through Multivariate Regression Analysis
Income has a significant and strong influence on levels of total, direct and indirect energy requirements (Table 4). Comparing the β regression coefficients for income shows that this influence is not uniform, but much stronger for indirect than for direct requirements, while for total energy consumption the impact of income falls in between. Because the β regression coefficients can be interpreted like consumption-elasticities (see methods section), this means that changes in income levels can be expected to have the strongest influence on indirect energy requirements, and the least on direct energy consumption.

Table 4: Regression models for total, indirect and direct requirements

n = 85	Total energy requirements		Indirect energy requirements		Direct energy requirements	
	β	$\lvert t \rvert$	β	$\lvert t \rvert$	β	$\lvert t \rvert$
Income per capita	0.41	11.8	0.51	9.8	0.20	3.8
Household size	-0.19	2.9	-	-	-	-
Population density	-	-	-	-	-0.02	6.4
To work by car	-	-	-0.28	3.1	-	-
Heating degree days	-	-	-	-	0.03	5.4
R^2	0.67		0.70		0.45	
adj. R^2	0.66		0.69		0.43	
F stat	81.9		96.0		60.9	
Moran's *I*	0.02		-0.01		0.04	

Note: Blank fields indicate that the variable was omitted in this model for reasons of colinearity or lack of significance. The R^2, F stat, t-statistic and Moran's I are all described in the methodology section.

Household size has a significant negative influence on total energy requirements, possibly due to economies of scale caused by increased sharing of space and appliances among household members. This would lead to lower per capita expenditure on the goods and services affected by such household economies of scale. However, the shares of expenditures on various commodities do not change between large and smaller households, and the energy intensity of these consumption patterns is similarly unchanged (Lenzen 1998a). Indeed, it is surprising that the household size variable is only significant for total energy requirements, because other studies also identified it for direct and indirect energy requirements, although the strength of the effect tends to be much smaller than the one identified here (Wier et al., 2001; Lenzen et al., 2004; Cohen et al., 2005; Druckman, Jackson, 2008a). However, since I was using a different set of variables than the previous studies, it is possible that the household size influence seen in other studies appears in this work through these other variables. For instance the variable 'travel to work by car' is positively correlated with household size (Table 1) and its negative influence on indirect energy requirements could be seen by other studies with different variable sets as a household size effect.
Indeed, our analysis reveals a negative influence of 'travel to work by car' on indirect energy requirements, even when controlling for differences in income levels between districts (Table 4). This means that independent of average incomes, higher shares of commuting by car are associated with lower average indirect energy consumption. This effect can be understood as a combination of car dependency, oil price vulnerability and high shares of mortgage financed

housing especially in suburban and rural districts having a strong adverse impact on household spending (Dodson, Sipe, 2007, 2008).
As expected, heating degree days and population density have very significant, albeit weak, negative influences on direct energy requirements. Both are consistent with previous findings and are discussed below. A further disaggregation of direct (private and public transport as well as residential energy requirements) and indirect (food-related) consumption should yield additional insights (see Table 5).

Table 5: Regression results for private and public transport, residential and food-related energy requirements

n = 85	Private transport		Public transport		Residential		Food-related	
	β	|t|	*β*	|t|	*β*	|t|	*β*	|t|
Income per capita	-	-	-	-	0.35	5.0	0.31	6.3
Under 18-year-olds	-	-	-	-	-	-	-0.15	3.9
Population density	-0.02	4.3	0.2	9.0	-0.02	3.8	-	-
Car ownership	0.38	2.4	-1.96	3.3	-	-	-	-
Heating degree days	-	-	-	-	0.04	5.6	-	-
R^2	0.26		0.57		0.41		0.6	
adj. R^2	0.25		0.56		0.38		0.59	
F stat	14.6		54.5		18.5		60.9	
Moran's *I*	0.15		-0.01		0.25		-0.01	

The modelling suggests that income does not play a significant role for the determination of public or private transport energy requirements. Using the variables at our disposal, private transport energy requirements is best explained by population density and car ownership, although these only explain 25% of the variation in the data. The remaining spatial autocorrelation indicates that there are spatial processes at work which, with the variables at hand, cannot be captured properly (see Moran's *I*, Table 5). The same variables, however with much higher coefficients and opposite signs, explain 55% of the variation in public transport energy requirements, with no spatial autocorrelation remaining in the model residuals. The connection between population density and levels of private transport energy requirements has been well documented (Newman, Kenworthy, 1991; Camagni et al., 2002; Grazi et al., 2008; Rickwood, Glazebrook, 2009). However, it is still not exactly clear what the causal links between population density and private transport are, besides the obvious shorter average distances travelled and greater public transport availability (Cameron et al., 2003). Car ownership rates can be understood as a combination of behavioural response to infrastructural issues (or urban form), social aspirations and income (Lenzen et al., 2008). Beyond private transport, the public transport result points to the same phenomenon: that mobility behaviour depends on availability and access to public transport infrastructure as well as broader issues related to urban form (such as mixed vs single use areas), spatial distribution of workplaces, facilities and shops, as well as individual preferences regarding automobile ownership and use (Camagni et al., 2002; Buxton, Scheurer, 2005; Grazi et al., 2008).
Residential energy requirements can be modeled by income, population density and heating degree days, although these variables are still far from providing a satisfactory fit or removing the spatial autocorrelation from the data. The effects of income on this category are likely related to appliance ownership rates, floor sizes as well as individual heating behaviour. The negative influence of population density can be understood by less per capita floor space in

higher density residential areas where flats and semi-detached houses are dominant, which also tend to be more energy-efficient than separate houses. The effects of heating degree days are consistent with other findings (Kennedy et al. 2009).

I find that the variable ‘under 18-year-olds’ exhibits a negative influence on food-related energy requirements, even when controlling for household income. Two explanations are possible here. First, lower dietary requirements of children compared to adults could lead to significantly less spending on food by the average family. Second, young families with children often live in car-dependent, mortgage-financed separate houses in suburban areas, which again leads to smaller per capita budgetary options for food (Dodson and Sipe 2007, 2008). Further research with household-level data and complementary information would be needed to explore either of these interpretations.

6. Discussion and Conclusions

To overcome some of the methodological and data limitations of this study, more detailed datasets, especially at an individual household level, are required. The limitations of averaged household data (Firebaugh, 2001) allows us to only draw general conclusions, in particular when it comes to potentials for intervention and changes at the individual level. More spatially disaggregated data would also yield more detailed insights into the relationship between urban form and different energy requirement categories and would almost definitely refine the results.

This work has revealed significant differences in per capita energy requirement patterns for average urban, suburban and rural households throughout Australia. The results are consistent with earlier findings for Sydney (Lenzen et al. 2004): in the more urban and wealthier districts, indirect and total energy requirements are highest, while direct energy requirements is lowest compared to average suburban and rural households. Public transport energy requirements decrease steadily when moving from urban to rural districts, while private transport energy requirements increase. At equal incomes, districts with high levels of car dependency have lower levels of indirect energy requirements. Additionally, the lowest area-based inequalities for all energy requirement categories were found for urban districts, indicating more uniform consumption patterns than nationwide or in suburban and rural areas, which all have quite similar levels of inequality of energy requirements.

The drivers of different energy requirement categories were explored using a combination of spatial and socioeconomic variables. Interestingly, income is far from playing a uniform role, since the income elasticities of energy consumption vary greatly: highest for indirect energy, and smallest for direct energy, with residential and food-related energy requirements between the two. Private and public transport energy requirements even seem to be independent of income and best modeled by car ownership and population density. There is a negative relationship between high rates of car ownership and lower average incomes (Table 1), while population density is positively correlated with higher incomes. This means that rising fuel costs are going to impact car-dependent and on average less affluent districts, such as most of the suburbs and rural Australia, much more than already wealthy urban areas, where there are also more possibilities and resources for adaptation, for instance, increased public transport use (Dodson and Sipe, 2008). In particular, suburban areas in their current form are locked into an energy intensive, automobile-dependent lifestyle built on uncontrolled low-density urban sprawl (Buxton, Scheurer, 2005; Gleeson, 2006; Frost, O'Hanlon, 2009; Spearritt, 2009). Policies which aim to decrease car use for the sake of the environment or public health have therefore to be carefully targeted so as not to disproportionately burden the lower income households through increasing prices. More importantly, issues of urban form have to be also taken into account, meaning that there need to be viable alternatives to automobile-based mobility such as serviceable public transportation systems, car sharing initiatives and alternative forms of transport to make changes possible. This is going to be a large challenge for most parts of Australia, especially outside the five major cities, where current very low density settlement patterns developed in combination with easy and cheap private automobile mobility.

Furthermore, as our analysis shows, lowering private transportation energy requirements for environmental reasons may not be as effective as expected. In order to make these changes politically and socially viable, they would probably need to be cost saving in comparison to private car use, which in turn would lead to increases in indirect energy consumption (Table 4). This is an example of the household-level indirect rebound effect (Hertwich, 2005a). Although expenditure on indirect energy requirements is likely to be less energy intensive than car use (Lenzen, 1998a), shifts in expenditure patterns from automobile use to other goods and services will lead to significantly lower reductions in total energy requirements than expected from the decrease in car use alone.

The small but very significant influence of climatic conditions on residential energy requirements will have an increasing importance under future climate change, with increased pressure of the existing housing stock on local energy systems to be expected (Wang et al., 2010). Mitigation strategies need to take high efficiency standards for new buildings, improvements of the existing housing stock and future temperature levels as well as increased variability into account, so as not to overestimate potential gains (Wang et al., 2011).

Following from all this, a new form of urbanism and human settlement patterns are necessary to enable households to actually decrease their total energy requirements. However, current developments in Australian urban and transport policy seem to keep focusing on large infrastructure projects as well as unchecked and hardly discussed (sub)urban sprawl (Dodson, 2009; Spearritt, 2009). Overall, it is also clear that the reductions required for serious climate change mitigation will be only possible with much more systemic and fundamental changes of production and consumption patterns than indicated here – a challenge faced by all developed and developing societies.

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8. Appendices

Appendix 1: Household Expenditure Survey Data and the Combination with Environmentally Extended Input – Output derived Energy Intensities

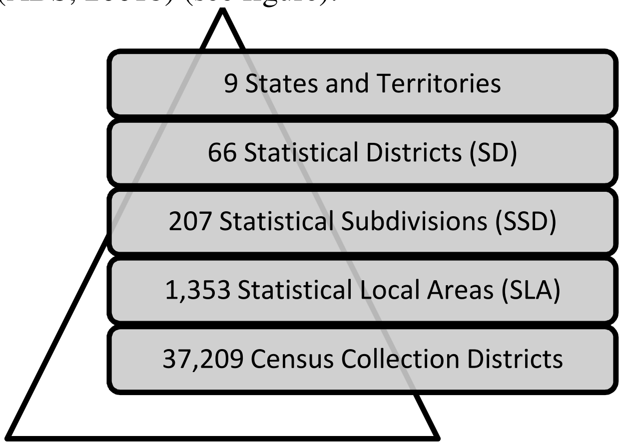
The *Household Expenditure Survey* is a nationwide questionnaire conducted by the Australian Bureau of Statistics (ABS), where expenditure information from 6,893 households is collected in the time period from June 1998 – July 1999. Access to this dataset is only possible in the form of *Confidentialised Unit Record Files* (CURF), which means that for privacy reasons only average household expenditure per statistical district is available (ABS, 2000). Because for some districts the sample size would be too low to ensure statistical reliability and also confidentiality of household information, a selection of 23 districts were merged by the ABS to form 11 larger units (all rural areas) (see table in appendix two). A short description of the structure of statistical geographical data released by the Australian Bureau of Statistics is also presented there.

Manfred Lenzen and his team at the Institute of Integrated Sustainability Analysis (ISA) used these CURF datasets for a range of other publications and also provided them for this study (Lenzen et al., 2004; Cohen et al., 2005; Dey et al., 2007). A description of this process can be found in Dey et al. *(*2007). An extensive treatment of uncertainties and methodological issues relating to the combination of Input-Output Data with household expenditure data can be found in (Lenzen, 2001; Lenzen et al., 2004; Kok et al., 2006) (also see methods section). The data received contained the average household expenditure on 344 commodity groups in 1999 $ AUD for 90 districts, covering the complete Australian continent (see appendix 5). These 344 commodity groups are based on the *Australian and New Zealand Standard Industry Classification* (ANZSIC). Because the major urban centres (Sydney, Brisbane, Melbourne, Adelaide and Perth) are included in the data set in an aggregated (SD level) and in a disaggregated level (SSD level), the five entries relating to these cities at the SD level were removed as well (see appendix 2). This leaves 85 districts, covering the whole country, for this study.

To calculate the primary energy requirements of Australian households, three steps had to be taken. Firstly the indirect energy requirements are calculated by transforming household expenditure in $ AUD into GJ primary energy, using input-output derived *energy intensities,* which were also provided by Manfred Lenzen and his team (Lenzen 2001). These intensities represent the amount of primary energy (in GJ) per $ AUD (GJ / $), used in the economic system for the production and provision of the respective commodity group. Secondly the energy content of fuel, natural gas and electricity consumed directly by the households was estimated (see Lenzen et al., 2004). Thirdly, not only households but also government consumption and investment activities are final consumers in an economy. Based on input-output tables (Lenzen, 2001; ABS, 2009) and the already mentioned *energy intensities*, the energy requirements of government consumption and investments were calculated and evenly allocated to all Australian households (see section 0 for a discussion of system boundaries). By combining these three steps, it becomes possible to allocate all primary energy requirements of the Australian society to household consumption patterns. To check the reliability of the results, comparisons with previous publications were conducted (Dey et al., 2007; Lenzen et al., 2004). This highly disaggregated data of energy requirements was then aggregated for further analysis (see appendix 5 and appendix 6).

Appendix 2: GIS, digital boundaries and the districts of interest

For the purpose of spatial investigation, calculating HDD values (appendix 3) and mapping results, a geographic information system (GIS) was used. A digital map of Australia was provided by the Australian Bureau of Statistics. These maps are all based on census units, where the following structure is used to aggregate the data while having complete coverage of Australia at every level (ABS, 2001b) (see figure):



Because the *household expenditure data* is released as a combination of SD and SSDs, the respective districts had to be identified and combined into one digital GIS map (see table below). This was done using database queries in GIS, as well as the application of the spatial join tool to merge the appropriate districts (see appendix one on why this had to be done). The result is one GIS map including all SDs and SSDs for which there is household expenditure data available. After addressing for the districts to be merged, individual numerical codes were also assigned to the final study districts to ensure data consistency and enable data import into the GIS environment.

Districts with IDs from 1 - 44 refer to rural areas and city SDs. Districts with an ID of 45 – 90 are covering the five major cities: Sydney, Melbourne, Brisbane, Adelaide and Perth. For further analysis the five SDs covering the major cities were also removed (ID 1, 13, 22, 30, 35), because these cities are available at a higher resolution (SSDs 45-90) and having both spatial levels in the dataset would constitute double counting.

Table 6: Overview of officical statistical districts and districts used in the study

District name	District-ID	Official nomenclature from the ABS	districts merged
Sydney	1	105 Sydney (Statistical Division)	
Hunter	2	110 Hunter (Statistical Division)	
Illawarra	3	115 Illawarra (Statistical Division)	
Richmond-Tweed	4	120 Richmond-Tweed (Statistical Division)	
Mid-North Coast	5	125 Mid-North Coast (Statistical Division)	
Northern	6	130 Northern (Statistical Division)	
North Western	7	135 North Western (Statistical Division)	
Central West	8	140 Central West (Statistical Division)	
South Eastern	9	145 South Eastern (Statistical Division)	
Murrumbidgee	10	150 Murrumbidgee (Statistical Division)	
Murray	11	155 Murray (Statistical Division)	
Far West	12	160 Far West (Statistical Division)	
Melbourne	13	205 Melbourne (Statistical Division)	
Barwon	14	210 Barwon (Statistical Division)	

Western District	15	215 Western District (Statistical Division)	
Central Highlands	16	220 Central Highlands (Statistical Division)	
Wimmera & Mallee	17	225 Wimmera (Statistical Division)	230 Mallee (Statistical Division)
Loddon	18	235 Loddon (Statistical Division)	
Goulburn	19	240 Goulburn (Statistical Division)	
Ovens-Murray & East Gippsland	20	245 Ovens-Murray (Statistical Division)	250 East Gippsland (Statistical Division)
Gippsland	21	255 Gippsland (Statistical Division)	
Brisbane	22	305 Brisbane (Statistical Division)	
Moreton	23	310 Moreton (Statistical Division)	
Wide Bay-Burnett	24	315 Wide Bay-Burnett (Statistical Division)	
Darling Downs	25	320 Darling Downs (Statistical Division)	
South West, Fitzroy & Central West	26	325 South West (Statistical Division)	330 Fitzroy (Statistical Division) 335 Central West (Statistical Division)
Mackay	27	340 Mackay (Statistical Division)	
Northern	28	345	
Far North & North West	29	350	355
Perth	30	505 Perth (Statistical Division)	
South West	31	510 South West (Statistical Division)	
Lower Great Southern & Upper Great Southern	32	520 Upper Great Southern (Statistical Division)	
Midlands & South Eastern	33	525 Midlands (Statistical Division)	530 South Eastern (Statistical Division)
Central, Pilbara & Kimberley	34	535 Central (Statistical Division)	540 Pilbara (Statistical Division) 545 Kimberley (Statistical Division)
Adelaide	35	405 Adelaide (Statistical Division)	
Outer Adelaide	36	410 Outer Adelaide (Statistical Division)	
Murray Lands & South East	37	420 Murray Lands (Statistical Division)	425 South East (Statistical Division)
Yorke and Lower North, Eyre & Northern	38	415 Yorke and Lower North (Statistical Division)	430 Eyre (Statistical Division) 435 Northern (Statistical Division)
Greater Hobart	39	605 Greater Hobart (Statistical Division)	
Northern	40	615 Northern (Statistical Division)	
Southern & Mersey-Lyell	41	610 Southern (Statistical Division)	620 Mersey-Lyell (Statistical Division)
Darwin	42	705 Darwin (Statistical Division)	
Northern Territory - Balance	43	710 Northern Territory - Bal (Statistical Division)	
Canberra	44	805 Canberra (Statistical Division)	
Inner Sydney	45	10505 Inner Sydney	
Eastern Suburbs	46	10510 Eastern Suburbs	
St George - Sutherland	47	10515 St George-Sutherland	
Canterbury - Bankstown	48	10520 Canterbury-Bankstown (Statistical Subdivision)	
Fairfield - Liverpool	49	10525 Fairfield-Liverpool (Statistical Subdivision)	
Outer South Western Sydney	50	10530 Outer South Western Sydney (Statistical Subdivision)	
Inner Western Sydney	51	10535 Inner Western Sydney (Statistical Subdivision)	
Central Western Sydney	52	10540 Central Western Sydney (Statistical Subdivision)	
Outer Western Sydney	53	10545 Outer Western Sydney (Statistical Subdivision)	
Blacktown - Baulkham Hills	54	10553 Blacktown (Statistical Subdivision)	
Lower Northern Sydney	55	10555 Lower Northern Sydney (Statistical Subdivision)	
Hornsby - Ku-ring-gai	56	10560 Central Northern Sydney (Statistical Subdivision)	

Northern Beaches	57	10565 Northern Beaches (Statistical Subdivision)	
Gosford - Wyong	58	10570 Gosford-Wyong (Statistical Subdivision)	
Inner Melbourne	59	20505 Inner Melbourne (Statistical Subdivision)	
Western Melbourne	60	20510 Western Melbourne (Statistical Subdivision)	
Melton-Wyndham	61	20520 Melton-Wyndham (Statistical Subdivision)	
Moreland	62	20525 Moreland City (Statistical Subdivision)	
Northern Middle Melbourne	63	20530 Northern Middle Melbourne (Statistical Subdivision)	
Hume City	64	20535 Hume City (Statistical Subdivision)	
Northern Outer Melbourne	65	20540 Northern Outer Melbourne (Statistical Subdivision)	
Boroondara	66	20545 Boroondara City (Statistical Subdivision)	
Eastern Middle Melbourne	67	20550 Eastern Middle Melbourne (Statistical Subdivision)	
Eatern Outer Melbourne	68	20555 Eastern Outer Melbourne (Statistical Subdivision)	
Yarra Ranges	69	20560 Yarra Ranges Shire Part A (Statistical Subdivision)	
Southern Melbourne	70	20565 Southern Melbourne (Statistical Subdivision)	
Greater Dandenong City	71	20575 Greater Dandenong City (Statistical Subdivision)	
South East Outer Melbourne	72	20580 South Eastern Outer Melbourne (Statistical Subdivision)	
Frankston	73	20585 Frankston City (Statistical Subdivision)	
Mornington Peninsula	74	20590 Mornington Peninsula Shire (Statistical Subdivision)	
Brisbane City	75	30505 Brisbane City (Statistical Subdivision)	
Gold Coast City Part A & Beaudesert Shire Part A	76	30510	30515 Beaudesert Shire Part A (Statistical Subdivision)
Caboolture Shire Part A	77	30520 Caboolture Shire Part A (Statistical Subdivision)	
Ipswich City (Part in BSD)	78	30525 Ipswich City (Part in BSD) (Statistical Subdivision)	
Logan City	79	30530 Logan City (Statistical Subdivision)	
Pine Rivers Shire	80	30540 Pine Rivers Shire (Statistical Subdivision)	
Redcliffe City & Redland Shire	81	30545 Redcliffe City (Statistical Subdivision)	30550 Redland Shire (Statistical Subdivision)
Central Metropolitan Perth	82	50505 Central Metropolitan (Statistical Subdivision)	
East Metropolitan Perth	83	50510 East Metropolitan (Statistical Subdivision)	
North Metropolitan Perth	84	50515 North Metropolitan (Statistical Subdivision)	
South West Metropolitan Perth	85	50520 South West Metropolitan (Statistical Subdivision)	
South East Metropolitan Perth	86	50525 South East Metropolitan (Statistical Subdivision)	
Northern Adelaide	87	40505 Northern Adelaide (Statistical Subdivision)	
Western Adelaide	88	40510 Western Adelaide (Statistical Subdivision)	
Eastern Adelaide	89	40515 Eastern Adelaide (Statistical Subdivision)	
Southern Adelaide	90	40520 Southern Adelaide (Statistical Subdivision)	

Appendix 3: Weather Data, Heating Degree Days and GIS procedures

As described in the methods section, Heating Degree Days (HDD) are frequently used as a proxy for weather conditions. There are different approximation methods for the calculation of HDD values (Day, 2006). The one used for this study is the most exact and is based on the daily average of the difference between hourly temperature readings and a specified base temperature, see (Equation 8). 12°C were used as a base temperature, which is the standard offered by the Australian Bureau of Meteorology.

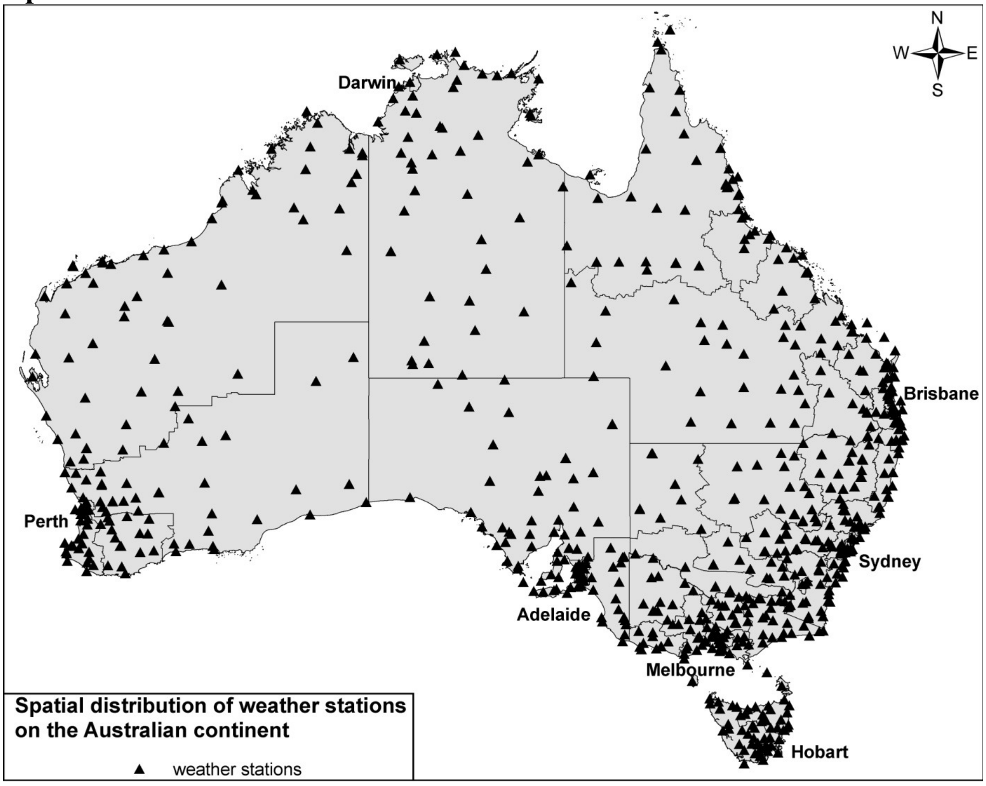
$$HDD = \Sigma_{\downarrow}(j = 1)^{\uparrow}24 \; (\theta_{\downarrow}b - \theta_{\downarrow}(o, j)) \;)_{\downarrow}((\theta_{\downarrow}b - \theta_{\downarrow}(o, j)) > 0)) / 24 \qquad \text{(Equation 8)}$$

Weather Records for the whole of Australia were requested at the Australian Bureau of Meteorology for the time from 1.6.1998 to 1.7.1999. This exact time frame was chosen to ensure the exact matching of calculated HDD with the coverage of the household expenditure survey. Data was delivered in a notepad file and had to be converted into excel files. Maximum and minimum daily temperature readings were provided, as well as an average daily temperature and pre-calculated HDD values. Furthermore GPS coordinates for all stations were also provided, which allowed us to import all the data into a GIS system (see Figure 9 on the spatial distribution of weather stations).

The spatial distribution of weather stations on the Australian continent is quite heterogeneous, with more stations close to the major urban centres and more densely settled areas (as indicated in the map). Even so, coverage of remote Australia still seems satisfactorily for reliable statements about weather patterns for this study, especially in the light of very low population densities in these areas (especially the centre of the continent).

As a next step, average annual HDD values for all districts had to be calculated (see methods section and appendix 2 for a description of the respective districts). Using GIS tools, all stations were matched with the respective districts they fall in. Based on this, average annual HDD for every district were calculated.

Figure 9: Spatial distribution of weather stations from which HDD values were derived



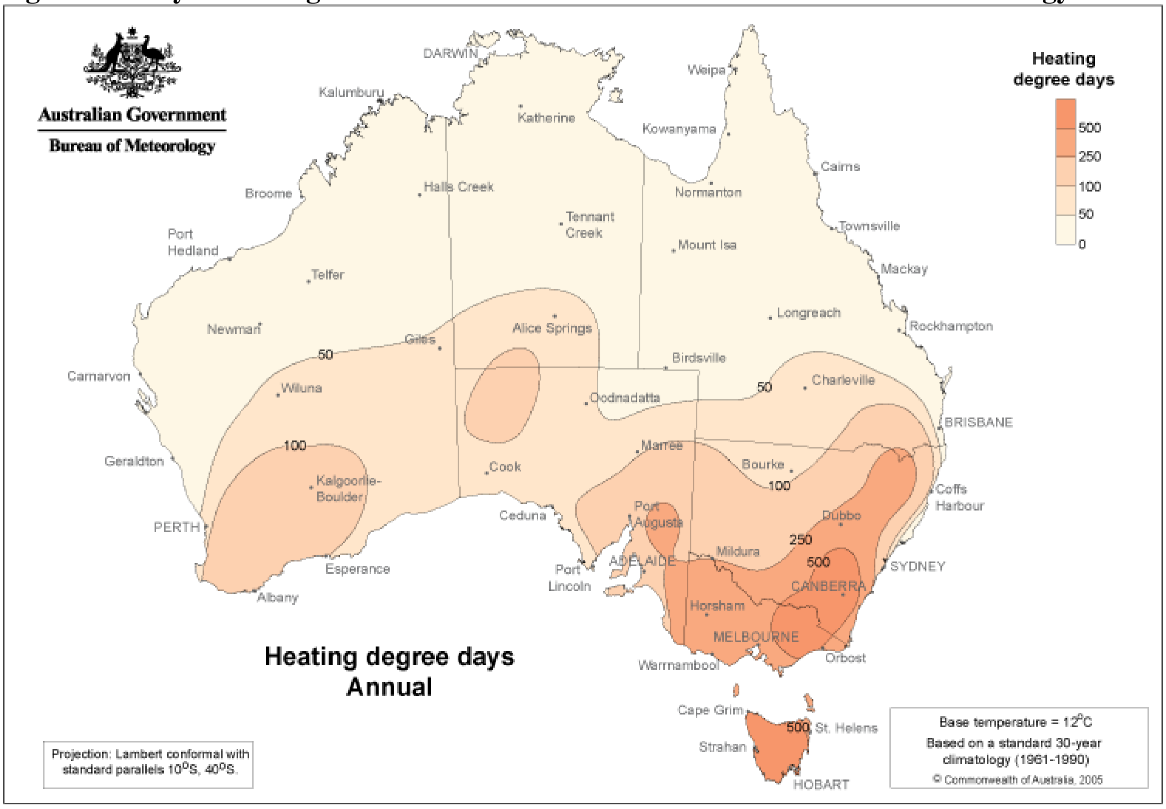
For 13 districts no matching station was found (see Table 7). All of those districts are part of major cities, where a) districts are quite small and b) there are several weather stations in the neighbouring districts. Therefore a trend-surface modelling procedure was applied, extrapolation average HDD values from the surrounding stations (method IDW, 12 stations as basis for trend, output grid cell size 0.05).

Table 7: Districts were HDD values had to be approximated from weather stations in the vicinity

district name	avg_HDD	std_dev	Stations used for extrapolation	district_ID
Eastern Suburbs	30	3.1	2	46
St George-Sutherland	57	9.9	17	47
Inner Western Sydney	44	0.8	2	51
Northern Beaches	39	12.3	11	57
Gold Coast City Part A, Beaudesert Shire	9	3.0	24	76
Caboolture Shire Part A	4	1.4	26	77
Pine Rivers Shire	8	2.7	29	80
Western Melbourne	324	26.0	11	60
Moreland City	296	39.3	2	62
Northern Outer Melbourne	489	56.7	37	65
Boroondara City	341	27.5	2	66
Eastern Middle Melbourne	400	24.7	10	67
Greater Dandenong City	380	21.3	6	71

The final results of these procedures can be viewed in the methods section (Figure 6). As a comparison the official 30 years HDD average calculated by the Australian Bureau of Meteorology is presented in Figure 10. A comparison of both figures (Figure 6 and Figure 10) shows a good agreement between the 1999 values and the 30 year average.

Figure 10: 30 year average of annual HDD from the Australian Bureau of Meterology



Appendix 4: Calculation Method for the Area-based Gini coefficients of Energy Requirements

Gini coefficients were originally developed to quantify levels of income inequality in any given population. They are obtained from Lorenz curves, which plot the cumulative population fractions on the horizontal axis, sorted by the special per capita value of interest, with respect to cumulative fractions of interest on the vertical axis. The Gini coefficient then measures the Lorenz curve's deviation from the diagonal of perfect equality and ranges from zero to one, where zero indicates total equality and one total inequality. This measurement is usually applied to quantify income or wealth distributions in an economy. Goodman and Oldfield (2004) argued for the extension of the Gini coefficient to measure expenditure inequality, as it may reflect long-run differences in people's circumstances much better than income, which can exhibit short term fluctuations. These are usually smoothed out by the use of savings – or more recently by increasing debt-based consumption (La Cava, Simon, 2005). Therefore focusing on expenditure inequalities can potentially mask long term trends in socio-economic inequalities (Druckman, Jackson, 2008c). Recently the Gini coefficient indicator has been modified to investigate "a wide variety of other kinds of area-based resource and associated emissions inequalities" (Druckman, Jackson, 2008b: S. 242). Various authors deployed Gini coefficients to investigate national inequalities in energy consumption at the household or at the per capita level (Herendeen 1974; Kok et al. 2003; Papathanasopoulou and Jackson 2009). Gini coefficients *G* are formally calculated as presented in (Equation 9.

$$G = \frac{1}{2n^2 * \eta} \sum_{i=1} n \sum_{j=1} n \; \left| y^i - y^j \right| \qquad \text{(Equation 9)}$$

where $\mathbf{y_i}$ and $\mathbf{y_j}$ are the incomes of the $\boldsymbol{i}$th and $\boldsymbol{j}$th household, $\boldsymbol{\eta}$ represents the average income and there are $\boldsymbol{n}$ households (Barr 1998). When the formula is adapted to calculate the AR-Gini coefficient, $\mathbf{y_i}$ and $\mathbf{y_j}$ represent the average amount of resources/energy/emissions used in the $\boldsymbol{i}$th and $\boldsymbol{j}$th district or region, $\boldsymbol{n}$ stands for the number of districts in the sample and $\boldsymbol{\eta}$ is the average resource use across all districts (Druckman and Jackson, 2008b). The empirical basis for the application presented by Druckman and Jackson (2008b) is the average resource use by districts, which are established on account of their socio-economic homogeneity. For the application in this study, only 85 rather large districts could be utilized (see appendix 2 for more details). This potentially decreases the absolute levels of inequality observable in this approach, because small pockets of very high / low levels of energy requirements could get lost in the process of aggregation and averaging. More detailed studies at several scales and different levels of spatial aggregation would be necessary to investigate the size of this effect. This goes beyond the scope of this study.

Another important point raised in the literature relates to the fact that "it is possible to have two economies that have the same Gini coefficient but have different income distributions. [...] This ambiguity occurs when the Lorenz curves intersect" (Druckman, Jackson, 2008c: S. 244). When conducting a visual investigation of the Lorenz curves for energy requirements as well as income levels no case of intersection can be found. Therefore the application and interpretation of the AR-Gini is quite straightforward (see results chapter).

Figure 11: Area based Lorenz curves I

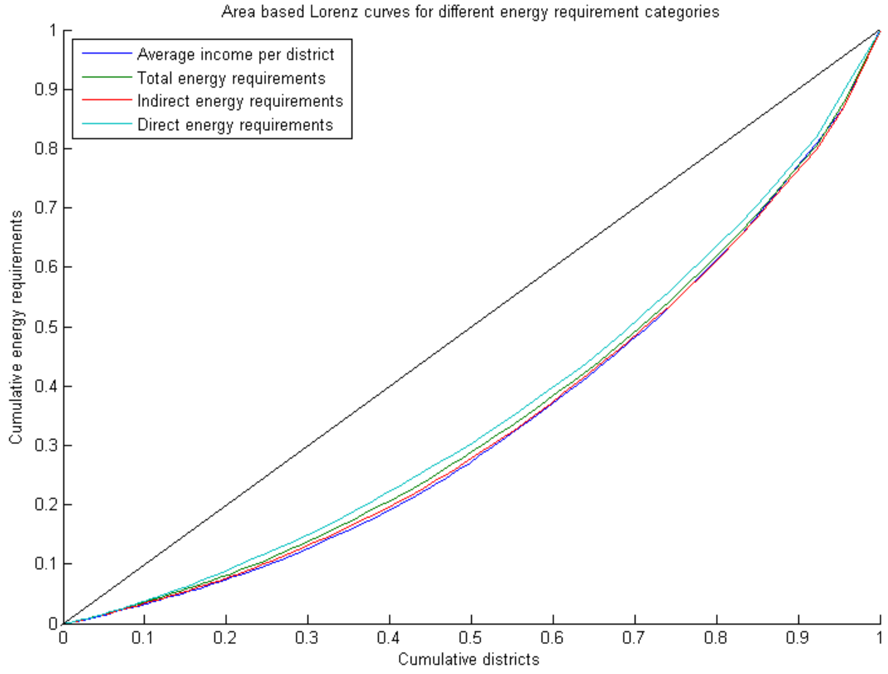
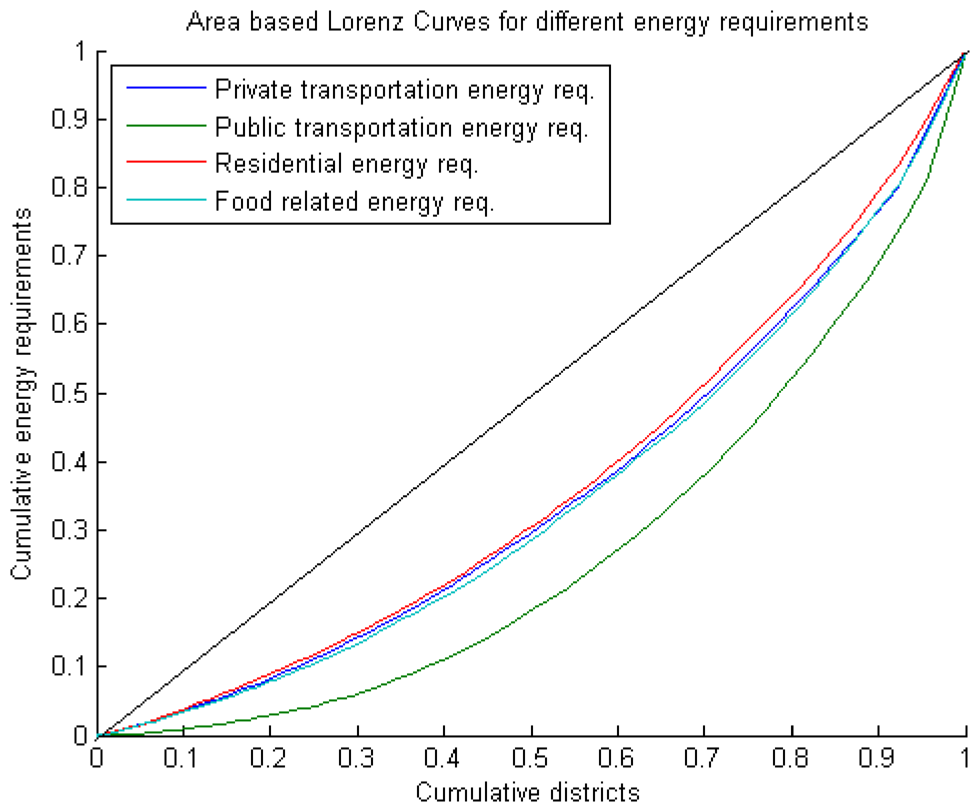


Figure 12: Area based Lorenz curves II



Appendix 5: The Household Expenditure Survey and Socio-Demographic Data – preparing for statistical analysis

For the application of statistical methods, including multivariate regression analysis, socio-demographic information about the 85 districts of interest (appendix 1 and 2) is necessary. This data was supplied in the form of supplemental data (ABS, 2000), as well as census data (ABS, 2003). Based on previous work (Dey et al., 2007), these data sources were combined and prepared for statistical analysis. For this study, further data was added (HDD – see appendix 0). All statistical analysis presented in this work has undergone extensive model testing and statistical reliability checks (see methods section).

Appendix 6: Household Expenditure data by Australian and New Zealand Standard Industry Classification (ANZSIC)

ISA-ID	ANZSIC-ID	ANZSIC-Abbrevation	
		Agriculture, Forestry, Fishing	
1	0101000	She	Sheep and lambs
2	0101001	Woo	Shorn wool
3	0102000	Oat	Oats, sorghum and other cereal grains
4	0102001	Wht	Wheat
5	0102002	Bar	Barley
6	0102003	Ric	Rice
7	0102004	Osd	Oilseeds
8	0102005	Leg	Legumes
9	0103000	Bfc	Beef cattle
10	0104000	Umk	Untreated milk
11	0104001	Dyc	Dairy cattle
12	0105000	Pig	Pigs
13	0106000	Pty	Poultry
14	0106001	Egg	Eggs
15	0107000	Veg	Vegetables
16	0107001	Frt	Fruit
17	0107002	Nur	Plant nurseries
18	0107003	Flo	Flowers
19	0107004	Gra	Grapes for wine
20	0107005	Hor	Horses
21	0107006	Dee	Deer
22	0107007	Pet	Pet breeding
23	0107008	Suc	Sugar cane
24	0107009	Cot	Unginned cotton
25	0107010	Hop	Hops
26	0107011	Grs	Grass seed
27	0107012	Hay	Hay
28	0107013	Rub	Natural rubber
29	0200000	Skn	Skins and other agricultural services
30	0200001	Ctg	Ginned cotton

31	0200002	Cts	Cotton seed
32	0200003	Shs	Sheap shearing
33	0200004	Aea	Aerial agriculture
34	0300000	Fop	Other forest products
35	0300001	For	Forestry
36	0300002	Swd	Softwoods
37	0300003	Hwd	Hardwoods
38	0400000	Ssq	Services to fishing and squid jigging
39	0400001	Rlo	Rock lobsters
40	0400002	Pra	Prawns
41	0400003	Raf	Raw fish
42	0400004	Oys	Shellfish
43	0400005	Aqc	Aquaculture
		Mining	
44	1100001	Blc	Black coal
45	1100002	Brc	Brown coal
46	1100003	Oil	Crude oil
47	1100004	Ngs	Natural gas
			natural gas direct (energy content)
48	1100005	Lpg	LPG, LNG
			LPG; LNG direct (energy content)
49	1100006	Cog	Other coal, oil and gas
50	1301000	Iro	Iron ores
51	1302000	Nfo	Other non-ferrous ores
52	1302001	Bxt	Bauxite
53	1302002	Cop	Copper concentrates and ores
54	1302003	Gol	Gold
55	1302004	Ilm	Ilmenite and Leucoxene
56	1302005	Rut	Rutile
57	1302006	Msd	Other mineral sands
58	1302007	Nic	Nickel
59	1302008	Lea	Lead
60	1302009	Siz	Silver and zinc
61	1302010	Tin	Tin
62	1302011	Urn	Uranium
63	1302012	Man	Manganese
64	1400000	Ggs	Gemstones, gypsum, silica
65	1400001	Grv	Gravel
66	1400002	San	Sand
67	1400003	Dst	Dimension stone
68	1400004	Cmt	Construction materials nec
69	1400005	Lst	Limestone
70	1400006	Cly	Clays
71	1400007	Sal	Salt

Manufacturing

74	2101000	Mep	Meat products
75	2101001	Mea	Fresh meat
76	2101002	Off	Offal, hides, skins, blood meal
77	2101003	Pts	Poultry, slaughtered
78	2102000	Dap	Dairy products remainder
79	2102001	Tmk	Treated milk
80	2102002	Chs	Cheese
81	2102003	Bto	Butter oil
82	2102004	But	Butter
83	2103000	Vpr	Vegetable products
84	2103001	Fpr	Fruit products
85	2104000	Oif	Oils and fats
86	2105000	Rip	Rice products
87	2105001	Wfl	Wheat flour
88	2105002	Fod	Fodder and feed
89	2105003	Cer	Flour mill products nec
90	2105004	Glt	Gluten
91	2105005	Brf	Breakfast foods
92	2105006	Flr	Flour
93	2105007	Cak	Cakes
94	2105009	Pas	Pasta
95	2106000	Pcb	Pies, cakes, biscuits
96	2106001	Brd	Bread and bread rolls
97	2107000	Con	Confectionery
98	2108000	Ofd	Other food products
99	2108001	Rsg	Raw sugar
100	2108002	Sug	Refined sugar
101	2108003	Fis	Fish
102	2108004	Lob	Lobster
103	2108005	Sef	Processed seafoods
104	2108006	Anf	Animal food
105	2109000	Sfd	Soft drinks
106	2110000	Bee	Beer and malt
107	2111000	Spi	Spirits
108	2111001	Win	Wine
109	2112000	Tob	Tobacco
110	2121000	Wsc	Wool scouring
111	2122000	Hmf	Human-made fibres
112	2123000	Cof	Cotton fabrics
113	2124000	Wof	Wool fabrics
114	2125000	Txf	Textile finishing
115	2202000	Txp	Textile products
116	2202001	Tcb	Textile and canvas bags
117	2203000	Knm	Knitting mill products
118	2204000	Clo	Clothing
119	2205000	Ftw	Footwear

120	2206000	Lth	Leather products
121	2301000	Saw	Sawmill products
122	2301001	Ust	Undressed sawn timber
123	2301002	Scp	Softwood woodchips
124	2301003	Rst	Undressed resawn timber
125	2301004	Hcp	Hardwood woodchips
126	2303000	Ppp	Pulp, paper and paperboard
127	2311000	Mfw	Manufactured wood
128	2312000	Joi	Joinery products
129	2313000	Pac	Paper containers
130	2314000	Pap	Paper products
131	2401000	Prn	Printing
132	2401001	Tad	Trade advertising
133	2402000	Pub	Recorded media and publishing nec
134	2402001	Nad	Newspaper advertising
135	2402002	New	Newspapers
136	2402003	Per	Periodicals
137	2402004	Bok	Books, maps, magazines
138	2501000	Pcp	Petroleum and coal products
139	2501001	Ptr	Petrol
			Petrol direct (energy content)
140	2501002	Ker	Kerosene
141	2501003	Gfo	Gas oil or fuel oil
142	2501004	Bit	Bitumen
143	2501005	Rlp	Refinery LPG
144	2502000	Bcm	Basic chemicals
145	2502001	Gas	Gases
146	2503000	Pnt	Paints
147	2504000	Pim	Pesticides, insecticides and medicinal goods
148	2504001	Pha	Pharmaceutical goods for human use
149	2505000	Sod	Soap and other detergents
150	2506000	Cos	Cosmetics and toiletry preparations
151	2507000	Chp	Other chemical products
152	2507001	Exp	Explosives and matches
153	2507002	Mun	Munitions
154	2507003	Ink	Inks
155	2507004	Glu	Glue
156	2508000	Rup	Rubber products
157	2508001	Tyr	Tyres
158	2508002	Ret	Retreading strips
159	2509000	Plp	Plastic products
160	2511001	Sph	Superphosphate
161	2511002	Mfe	Mixed fertilisers
162	2511003	Cfe	Other Chemical fertilisers
163	2601000	Glp	Glass products
164	2602000	Crp	Ceramic products
165	2603000	Cml	Cement, lime
166	2603001	Rmc	Ready-mixed concrete

167	2604000	Ccp	Concrete products
168	2604001	Pls	Plaster boards and plaster
169	2605000	Miw	Other non-metallic mineral products
170	2605001	Stn	Worked monumental or building stone
171	2605002	Glf	Glass fibre and glass wool products
172	2605003	Gmn	Ground minerals
173	2701000	Ist	Iron and steel semi-manufactures
174	2702000	Nfs	Non-ferrous non-aluminium semi-manufactures
175	2702001	Csl	Copper, silver, lead, zinc
176	2702002	Ala	Alumina
177	2702003	Alm	Aluminium
178	2702004	Nik	Nickel
179	2702005	Prm	Precious metals
180	2702006	Als	Aluminium semi-manufactures
181	2702007	Alf	Aluminium foil
182	2703000	Stm	Structural metal products
183	2703001	Fcs	Fabricated construction steel
184	2703002	Rrd	Reinforcing rods
185	2703003	Ald	Aluminium doors
186	2703004	Aal	Architectural aluminium
187	2703005	Smr	Structural metal products repairing
188	2704000	Shm	Sheet metal products
189	2705000	Fbm	Fabricated metal products
190	2705001	Fir	Firearms
191	2705002	Fmr	Fabricated metal products repairing
192	2801000	Par	Motor vehicle parts
193	2801001	Car	Finished cars
194	2801002	Trk	Trucks
195	2801003	Mvr	Motor vehicle repairing
196	2802000	Shp	Ships and boats
197	2802001	Sbr	Ships and boat repairing
198	2803000	Rwy	Railway equipment
199	2803001	Rwr	Railway equipment repairing
200	2804000	Aic	Aircraft
201	2804001	Acr	Aircraft repairing
202	2805000	Pse	Photographic and scientific equipment
203	2805001	Meq	Surgical and medical
204	2805002	Sgl	Spectacles and sunglasses
205	2806000	Enq	Electronic equipment
206	2806001	Gam	Gaming and vending machines
207	2807000	Hha	Household appliances
208	2807001	Htg	Space heaters, gas
209	2807002	Hte	Space heaters, electric
210	2807003	Drf	Domestic refrigerators
211	2807004	Rac	Room air con
212	2807005	Crf	Commercial refrigerators
213	2807006	Clw	Clothes washing machines
214	2807007	Whs	Water heater, solar

215	2807008	Whn	Water heater, non-electric
216	2807009	Whe	Water heater, electric
217	2808000	Elq	Other electrical equipment
218	2809000	Cnm	Construction machinery
219	2809001	Lif	Hoists, cranes, lifting and loading machinery
220	2809002	Cgm	Machinery for crushing, grinding, mixing
221	2809003	Drl	Mining or drilling machinery and parts
222	2809004	Elv	Elevators and escalators
223	2810000	Inm	Industrial machinery and equipment
224	2810001	Pmp	Pumps
225	2810002	Acn	Air conditioning
226	2811001	Lwm	Lawn mowers
227	2811002	Til	Tillage, seeding, planting and fertilising equipment
228	2811003	Har	Harvesting, haymaking and silage making equipment
229	2811004	Trc	Agricultural tractors
230	2811005	Irr	Irrigation equipment
231	2811006	Agm	Agricultural machinery and parts nec
232	2901000	Pfb	Prefabricated buildings
233	2902000	Fur	Furniture
234	2902001	Wfn	Wooden furniture
235	2902002	Mfn	Sheet metal furniture
236	2902003	Mat	Mattresses
237	2903000	Mmf	Miscellaneous manufacturing
238	2903001	Jew	Jewellerey
239	2903002	Sig	Advertising signs
		Electricity, Gas and Water Supply	
240	3601000	Els	Electricity supply
241	3602000	Gss	Gas supply indirect
			Gas supply direct (energy content)
242	3701000	Wts	Water supply; sewerage and drainage services
		Construction	
243	4101000	Rsm	Residential building repair and maintenance
244	4101001	Rsc	Residential building construction
245	4102001	Nrc	Non-residential building construction
246	4102002	Nrm	Non-residential building repair and maintenance
247	4102003	Rdb	Roads and bridges
248	4102004	Nbc	Non-building construction
249	4102005	Nbm	Non-building repair
		Retail Trade	
250	4501000	Wst	Wholesale trade
251	5101000	Rtt	Retail trade
252	5401000	Mlr	Motor vehicle and lawn mower repairs
253	5401001	Imr	Industrial machinery repairs
254	5402000	Bmr	Business machines and equipment repairing and services

255	5402001	Wsr	Wholesale repair and servicing
256	5402002	Hha	Household elec applicances repair and service
257	5402003	Rtr	Retail repair and service
		Accommodation, Cafes and Restaurants	
258	5701000	Hoc	Hotels, clubs, restaurants and cafes
259	5701002	Acc	Accommodation
		Transport and Storage	
260	6101000	Rdf	Road freight
261	6101002	Bus	Bus and tramway
262	6101003	Tax	Taxi and hire car
263	6201001	Rwf	Railway freight transport services
264	6201003	Rwp	Railway passenger transport services
265	6201004	Ppt	Pipeline transport
266	6201005	Tra	Transport services nec
267	6301000	Wtt	Water transport
268	6401000	Ast	Air and space transport
269	6601001	Prk	Parking services
270	6601002	Srd	Services to road transport
271	6601003	Swt	Services to water transport
272	6601006	Sai	Services to air transport
273	6601007	Tag	Travel and tourist agency services
274	6601008	Rff	Road freight forwarding
275	6601009	Fwa	Forwarding agencies
276	6601010	Cus	Customs agencies
277	6601011	Sto	Storage
		Communication Services	
278	7101000	Otc	Overseas communication services and Pay TV
279	7101001	Pos	Postal services
280	7101002	Cou	Courier services
281	7101003	Dtc	Domestic telecommunication services
		Finance and Insurance	
282	7301000	Bnk	Banking
283	7302000	Nbk	Non-bank finance
284	7401000	Ins	Insurance
285	7401001	Lin	Life insurance
286	7401002	Hin	Health insurance
287	7401003	Pli	Public liability
288	7501000	Sbd	Security broking and dealing
289	7501001	Sfi	Services to finance and investment
290	7501002	Sin	Services to insurance
		Property and Business Services	
291	7701000	Odw	Ownership of dwellings

292	7702000	Apb	Other property services
293	7702001	Pod	Property operator and developer services
294	7702003	Rea	Real estate agent services
295	7702005	Mvh	Motor vehicle hire
296	7702007	Plh	Plant leasing, hiring and renting services
297	7801000	Coc	Scientific research, technical and computer services
298	7801001	Res	Research and meteorology services
299	7801002	Ars	Architectural services
300	7801003	Svs	Surveying services
301	7801004	Tcs	Technical services nec
302	7801005	Dps	Data processing services
303	7802001	Lgs	Legal services
304	7802002	Acs	Accounting services
305	7802003	Adv	Advertising services
306	7802004	Mbs	Market research and other business management services
307	7803001	Plc	Employment placement
308	7803002	Tcm	Typing, copying and mailing
309	7803003	Sec	Security and investigation
310	7803004	Pcs	Pest control
311	7803005	Cls	Cleaning
312	7803006	Pak	Packing
313	7803007	Cre	Collecting and credit reporting
314	7803008	Bss	Business services nec

Government Administration and Defence

315	8101000	Jud	Judicial services
316	8101001	Fed	Federal government
317	8101002	Sta	State government
318	8101003	Loc	Local government
319	8201000	Def	Defence

Education

320	8401000	Edu	Education

Health and Community Services

321	8601000	Hth	GPs, dentists, optometrists, ambulance
322	8601001	Hos	Hospitals and nursing homes
323	8601002	Chc	Community health centres
324	8601003	Vet	Veterinary services

Cultural and Recreational Services

325	9101000	Pic	Motion pictures
326	9101001	Rtv	Radio and television stations
327	9201001	Lib	Library, museum and art gallery services
328	9201002	Pbz	Parks, botanical gardens and zoos
329	9201003	Mus	Music and theatre production

330	9201004	Art	Creative arts
331	9201005	Nws	News reporting
332	9201006	Ent	Entertainment
333	9301001	Lot	Lottery
334	9301002	Gmb	Gambling
335	9301003	Tab	TAB agencies
336	9301005	Spo	Sport and recreation services (incl horse and dog racing, sports grounds, services)
		Personal and Other Services	
337	9501000	Psv	Personal services
338	9501001	Phf	Photographic film processing
339	9601001	Csr	Community services and religious organisations
340	9601002	Int	Interest groups and community organisations
341	9601003	Pol	Police
342	9601004	Cor	Corrective centres
343	9601005	Fbg	Fire brigade
344	9601006	Gar	Sanitary and garbage disposal

Appendix 7: Composition of energy requirement categories for statistical analysis

ISA-ID	
Total energy requirements	
	All categories
Direct energy requirements	
47	Natural gas direct, indirect
48	LPG & LNG direct, indirect
139	Petrol direct, indirect
140	Kerosene
141	Gas oil or fuel oil
240	Electricity supply,
241	Gas supply direct, indirect
Indirect energy requirements	
	total - direct requirements
Private transportation requirements	
48	LPG & LNG direct, indirect
139	Petrol direct, indirect
262	Taxi and hire car
Public transportation requirements	
261	Bus and Tramway
264	Railway passenger
Residential direct requirements	
47	Natural gas direct, indirect
240	Electricity supply,
241	Gas supply direct, indirect
Food related requirements (indirect)	
1	Sheep and lambs
2	Shorn wool
3	Oats, sorghum and other cereal grains
4	Wheat
5	Barley
6	Rice
7	Oilseeds
8	Legumes
9	Beef cattle
10	Untreated milk
11	Dairy cattle
12	Pigs
13	Poultry
14	Eggs
15	Vegetables
16	Fruit
19	Grapes for wine

21	Deer
23	Sugar cane
25	Hops
39	Rock lobsters
40	Prawns
41	Raw fish
42	Shellfish
43	Aquaculture
74	Meat products
75	Fresh meat
76	Offal, hides, skins, blood meal
77	Poultry, slaughtered
78	Dairy products remainder
79	Treated milk
80	Cheese
81	Butter oil
82	Butter
83	Vegetable products
84	Fruit products
85	Oils and fats
86	Rice products
87	Wheat flour
88	Fodder and feed
89	Flour mill products nec
90	Gluten
91	Breakfast foods
92	Flour
93	Cakes
94	Pasta
95	Pies, cakes, biscuits
96	Bread and bread rolls
97	Confectionery
98	Other food products
99	Raw sugar
100	Refined sugar
101	Fish
102	Lobster
103	Processed seafoods
104	Animal food
105	Soft drinks
106	Beer and malt
107	Spirits
108	Wine

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