

Chapter 4

Direct versus Embodied Energy – The Need for Urban Lifestyle Transitions

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4.1 Introduction: What is Embodied Energy?

Living means consuming, and consuming means needing energy. Most of the energy resources we consume today are non-renewable – hence there is the obvious problem of their depletion, among other problems of environmental pollution and climate change. We as householders are familiar with using energy in our homes – *residential energy* – mainly in the form of electricity for our appliances, as gas for cooking, or as firewood for space heating. We also use *transport energy* in the form of petrol in our private cars, and possibly in boats and other vehicles. The consumption of residential and transport energy is called *direct energy consumption* (Bin and Dowlatabadi 2005, p. 199). We experience direct energy daily, as heat, cooling, or motion. More than that, we experience that heat dissipates, and motion ceases when the energy source is switched off. We therefore have quite an intuitive feeling for the fact that consuming energy involves the irreversible use of a finite resource.

Consuming also means needing goods and services, ranging from ‘material’ items such as food, clothing, water, appliances, vehicles and equipment to ‘immaterial’ amenities such as entertainment, public transport, insurance and personal care. These commodities come to us ready to use, and they usually do not evoke any association with energy. However, producing goods and services requires substantial amounts of energy to be used – on farms, in factories, in power plants, and by corporate and public vehicles. The energy that is needed throughout the entire life cycle of a final consumer item – good or service – starting with the transformation of raw materials and ending with its final disposal, is often called the energy *embodied* in the consumer item.¹ We have often no idea how much energy is needed to produce the things we buy, and whether all of the embodied energy is higher than the direct energy we experience using in our daily lives.

These questions (and a fair few suggested answers for that matter) are not new; in fact, some of the 1970s references cited in this chapter read as if they were written in the twenty-first century. What have improved though are the analytical tools applied to these questions and the quantitative sophistication of their answers. The next section explores embodied

¹ Alternative terms are ‘embedded energy’, ‘indirect energy’, ‘life-cycle energy’, ‘cradle-to-grave energy’, or ‘supply-chain energy’.

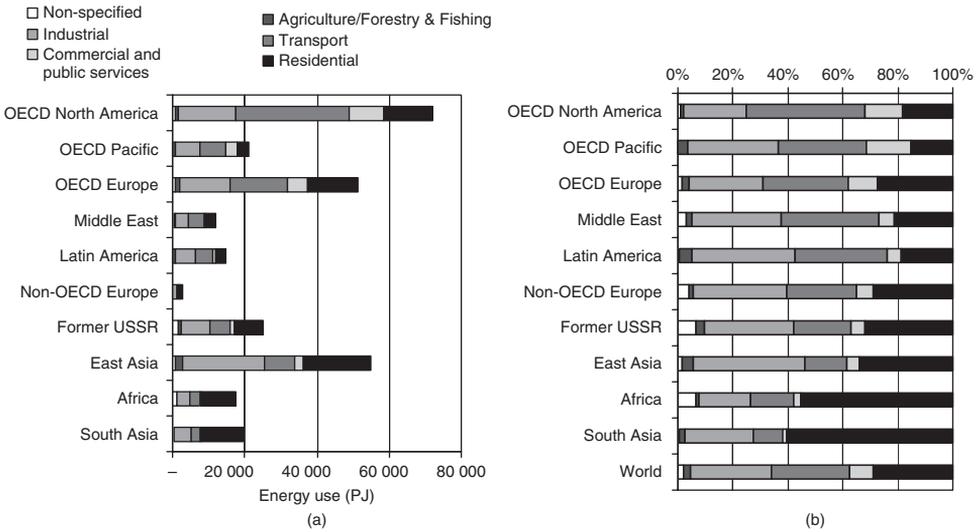


Fig. 4.1. World energy consumption by region and usage (International Energy Agency 2007). (a) Absolute values in PJ (10¹⁵ joules), (b) Percentage distribution across usage categories.

energy research and its findings about consumer items, trends over time, and the role of international trade. In particular, we investigate whether there are certain influential socio-economic-demographic traits, whether embodied energy exceeds direct energy or not, and whether international trade displaces the environmental and resource impacts of wealthy countries' energy-hungry consumption into low income countries. Following is an empirical case study of households in Australia's largest city, Sydney. The chapter concludes with an outline of the implications of embodied energy for urban lifestyles, both present and future.

It should also be noted that what can be said of energy can also be said of other resources, and also pollutants. Consuming also means using water, or emitting greenhouse gases. Once again, we can experience direct water use as it comes out of our taps, and direct greenhouse gas emissions from our cars and fireplaces. Rarely though do we think about irrigation water embodied in our food,² or greenhouse gas emissions embodied in our aluminium window frames. The indicator dealt with in this chapter – energy – is a good proxy for other environmental impacts, especially emissions from fuel combustion, such as CO₂, NO₂, and SO₂, for example (Schipper 1998).

4.2 Embodied Energy – An International Perspective

4.2.1 A comparison of direct and industrial energy use

Most of the world's energy is consumed in OECD North America, followed by East Asia and OECD Europe (Fig. 4.1a). Most of this energy is fossil energy (80%), followed by renewables (hydro, solar, and combustibles, 13%) and nuclear energy (7%) (International Energy Agency 2007). Residential energy constitutes between 20% and 60% of total energy

²In this case, the term 'virtual water' is often used.

Table 4.1. Per capita world energy consumption (GJ) by region (International Energy Agency 2007).

Region	World	South Asia	Africa	East Asia	Former USSR	Non-OECD Europe	Latin America	Middle East	OECD Europe	OECD Pacific	OECD North America
Energy use (GJ/cap)	47	15	20	30	88	49	35	56	98	107	171

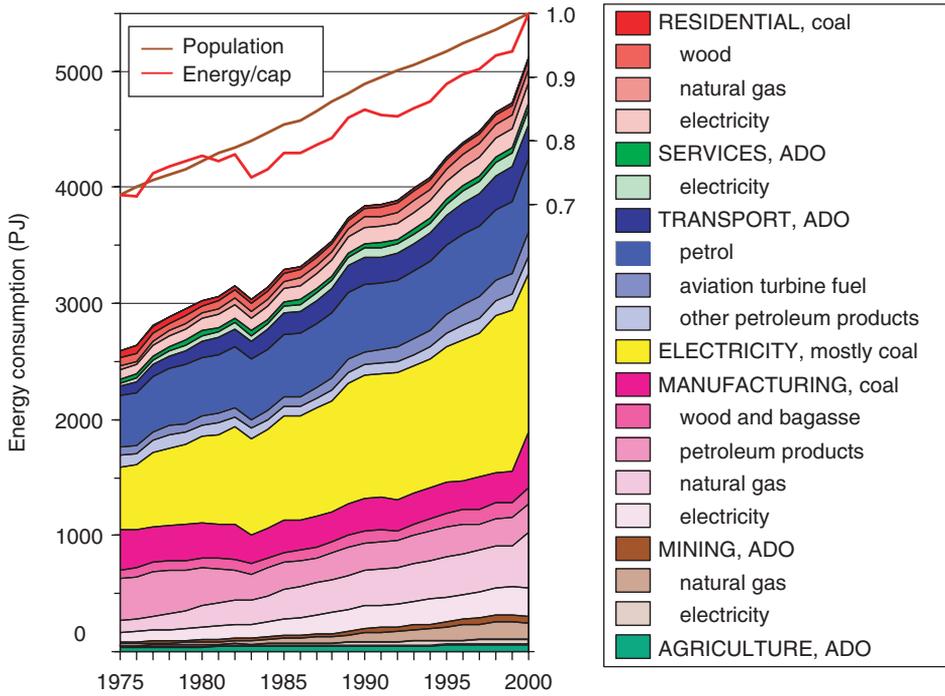


Fig. 4.2. Energy consumption in Australia 1975–2000 (Australian Bureau of Agricultural and Resource Economics 2006). Areas represent energy consumed minus derived fuels produced. Brown curve: Australian population; red curve: per capita energy consumption (both indexed to 2000 = 1). ADO = Automotive Diesel Oil. [Plate 4]

consumption (Fig. 4.1b), but this portion is mainly correlated with the level of per capita income. In Asia and Africa, residential energy is mainly supplied by combustibles such as wood, and animal and crop waste, and represents around half of national energy consumption. In contrast, residential energy is mainly supplied by commercial fuels such as gas or fossil-fuelled electricity in higher income regions, and its portion has shrunk to about 20% of national energy consumption (International Energy Agency 2007; Leach 1998).

In per capita terms, OECD countries are the top energy consumers, followed by the former Soviet Union and non-OECD Europe as well as the Middle East. Below world average are Latin America, Asia and Africa (Table 4.1).

The transport sector in Fig. 4.1 contains an unknown amount of petrol used for private vehicles. Examining more detailed Australian data (Fig. 4.2 [Plate 4]) reveals that in

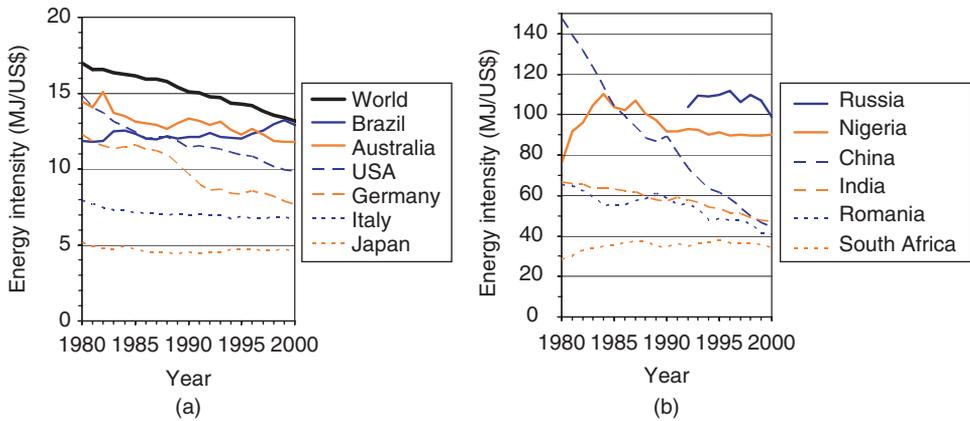


Fig. 4.3. World energy intensity trends (MJ/US\$) for selected countries (World Resources Institute 2006): (a) energy-efficient economies, (b) energy-intensive economies. [Plate 5]

Australia petrol consumption (about 600 PJ/year) actually exceeds energy use in the house (about 400 PJ/year),³ and that together they represent about 20% of Australian energy consumption. Urban consumers consume more energy per capita than rural consumers (Lenzen 1998).

Similarly, in China in 2002, direct energy amounted to about 30% of total energy consumption (Wei *et al.* 2007). Even though rural residents still outnumbered city dwellers by a factor of 1.7, the latter collectively used 2–2.5 times more energy than the former.

Non-residential energy is traditionally reported as energy used in industry (Australian Bureau of Agricultural and Resource Economics 2006). However, if we follow Adam Smith (1776) in arguing that ‘the sole end and purpose of production is consumption’, industrial energy is ultimately expended for the sake of producing commodities that someone will finally consume. In fact, the entire philosophy of *life-cycle assessment* builds on the notion that energy (and other resources and pollutants) is passed on by being embodied in the intermediate products and materials that are then passed on between producers, until they reach the final consumer.

Accordingly, looking at overall energy use from a consumer’s perspective, it becomes clear that in high income countries, the energy embodied in consumer items significantly exceeds direct energy. Hence, if the debate concluded that attention must be devoted to those aspects of our lives that consume most of our energy, then these aspects are clearly related to embodied and not direct energy (Bin and Dowlatabadi 2005).

This does not mean that we should ignore direct energy; there are certainly savings that are easily implemented without undue loss of comfort. Especially in low income countries, where the proportion of residential energy is high, energy intensities are generally high as well, leaving ample scope for reductions (Fig. 4.3b [Plate 5]). However in high income countries with a highly urbanized population, where direct energy makes up only about 25%, many technologies have been efficient for some time, and further reductions

³ With respect to electricity use we follow accounting conventions and allocate electricity to residential energy, while the primary fuels (coal etc) used in the power plant *net of* electricity produced are counted as embodied energy.

are likely to be less effective (Fig. 4.3a [Plate 5]). This means that rather than focusing on reductions of energy use in urban households of high income countries, through technological options that may be costly and/or difficult to implement, there may be 'low hanging fruit' elsewhere.⁴ There are options for changes of consumption habits involving substantial reductions in the form of embodied energy (Lenzen and Murray 2001; Melasniemi-Uutela 1999; Schipper 1993), for example simply the reduction of food intakes to recommended dietary levels, or switching to alternative items fulfilling the same need (Lenzen and Dey 2002). In the literature, they are generally referred to as *lifestyle changes*.

4.2.2 Lifestyles and energy

In the 1970s researchers started to appraise the connection of lifestyles and energy mostly because of concerns about the stability of oil supply (Mazur and Rose 1974). Two decades later the concerns started to be about climate change (Wolvén 1991). Many of the more quantitative investigations exploit data on household expenditure in order to characterize different lifestyles, as well as input/output analysis in order to calculate their *embodied energy requirement* (Bin and Dowlatabadi 2005; Weber and Perrels 2000). The latter is achieved by multiplying every expenditure item of the household by an *energy intensity* (Bullard and Herendeen 1975; Herendeen 1974). The most comprehensive survey of such studies to date is contained in a five-country analysis by Lenzen and co-workers (Lenzen *et al.* 2006).

The overarching finding of this kind of research is that energy requirements increase with overall household expenditure, which in turn depends on household income. The relationship is, however, not a proportional one, but per capita energy requirements show some saturation towards higher per capita expenditures (Fig. 4.4). This is because as societies become more affluent, their consumer baskets change to incorporate a higher proportion of services, which require less energy compared to food and other manufactured items.

In fact, the saturating expenditure/energy relationship can be explained by an *expenditure elasticity of energy*, which in the case of Fig. 4.4 is about 0.9. This means that if expenditure increases by 10%, energy requirements will increase by only 9%. Interestingly, this elasticity is higher for low income economies than for high income economies (Lenzen *et al.* 2006). In transitional economies with a large part of the population in the process of rapid building-up of appliance and car stocks, this elasticity is even higher than 1, such as measured for transport energy in Brazil (Cohen *et al.* 2005) and all direct energy in 1970s Hong Kong (Newcombe 1979). We will return to this topic in section 4.3.1 below.

While in low income and transiting economies, direct energy consumption is increasing with urbanization, electrification, and increasing work opportunities and incomes (Leach 1998; Cohen *et al.* 2005; Newcombe 1979; Kulkarni *et al.* 1994; Qiu *et al.* 1994), in wealthy economies such as Australia, direct energy is practically independent of income, which – together with the consumer basket effect – determines the 'saturating' shape of the overall household energy requirement (Fig. 4.5). This effect was measured as a time trend in Hong Kong: while in the 1970s direct energy use was heavily skewed towards rich households (Newcombe 1979), by the end of the 1980s this effect had largely levelled out (Hills 1994). At high incomes, direct energy is an economic necessity, and not consumed in

⁴ Many decision-makers have taken advantage of this basic idea, for example in emissions trading, or the Clean Development Mechanism and Activities Implemented Jointly initiatives under the Kyoto Protocol: if a company or a country found it too costly and/or difficult to reduce emissions on-site/ domestically, it should be encouraged to reduce emissions elsewhere if those reductions are more cost-effective.

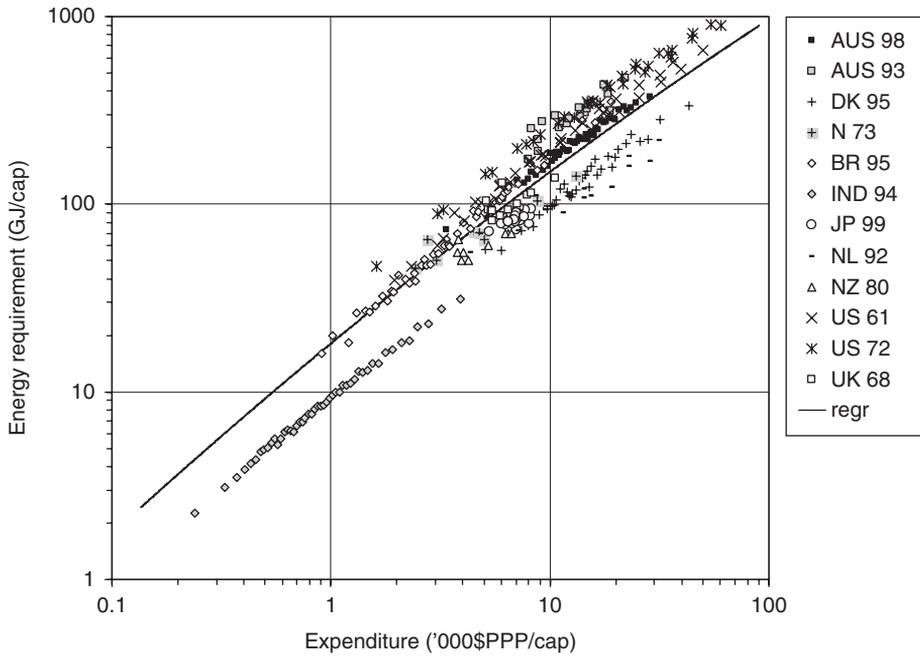


Fig. 4.4. Country comparison of energy requirements as a function of household expenditure ('000\$PPP/cap).⁵ Results from (Lenzen *et al.* 2006) (large symbols): Australia (AUS 98), Brazil (BR 95), Denmark (DK 95), India (IND 94), and Japan (JP 99). Results from other studies (grey small symbols): US 1961 (Herendeen and Tanaka 1976), UK 1968 (Roberts 1975), US 1972 (Herendeen *et al.* 1981), Norway 1973 (Herendeen 1978), New Zealand 1980 (Peet *et al.* 1985), Netherlands 1992 (Vringer and Blok 1995), Australia 1993 (Lenzen 1998) 'regr' denotes a curve fit. Data points lying below the fitted curve indicate national fuel mixes with subaverage energy intensity, and vice versa.

larger amounts when incomes increase. Figure 4.5 confirms the conclusions of section 4.0 in that embodied energy significantly exceeds direct energy.⁶

It has been proposed that as societies develop and become wealthier, energy use and associated environmental impact may initially increase, but then decrease again once these

⁵The World Bank (<http://www.worldbank.org/depweb/english/modules/glossary.htm#ppp>) defines purchasing power parities (PPP) as 'a method of measuring the relative purchasing power of different countries' currencies over the same types of goods and services. Because goods and services may cost more in one country than in another, PPP allows us to make more accurate comparisons of standards of living across countries.'

⁶One note of caution is due here: one and the same country-specific energy multiplier is applied to certain commodities, no matter whether they are bought by low or high income households. It is, however, likely that when high income households buy the same commodity as a low income household, they choose one of higher quality at a higher price. It may hence be that, even though the more pricey item in reality embodies the same amount of energy (or maybe even less, because it was made using more hand-labour), it will be charged with more embodied energy than the cheaper item, because input/output analysis assumes a proportionality between money and energy flows. What this means for Figs 4.4 and 4.5 is that the 'dips' in the curves towards higher incomes should probably be more pronounced than shown.

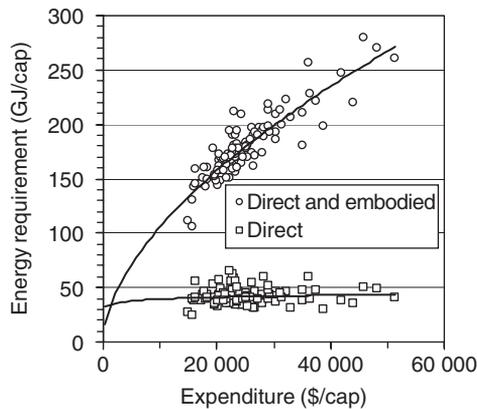


Fig. 4.5. Direct and embodied energy of Australian households. Compiled using household expenditure data (Australian Bureau of Statistics 2000), energy statistics (Australian Bureau of Agricultural and Resource Economics 2006), and input/output tables (Australian Bureau of Statistics 2004) for 1999.

societies have attained a level of prosperity that allows them to improve resource efficiency and environmental conditions (the so-called 'environmental Kuznets hypothesis').⁷ This is true, for example, for SO_2 emissions because there are clean technologies, which producers in wealthy countries can afford to install, and hence governments can afford to legislate. However, without exception, energy requirements analyses find that while a weak saturation exists, there appears to be no wealth threshold above which energy requirements will actually start to decrease. This is because there exists today no renewable energy technology that, once economical and affordable, provides for unrestrained energy needs.⁸

4.2.3 Driving forces of energy consumption over time

Energy requirement studies provide insights about cross-sections of countries at a particular point in time, but do not necessarily allow extrapolating these trends over time. A number of factors have influenced energy consumption in the past, and will continue to do so in the future. An obvious 'upwards' driving force is population – the more people there are the more energy is needed. Similarly, affluence potentially drives up energy use, since wealthier people demand more commodities. On the other hand, these upwards trends can in principle be offset by improvements in energy efficiency, structural changes in the economy, and compositional changes in final demand, for example by shifting consumptive emphasis from goods to services. In the following we examine trends in both direct and embodied energy consumption. While direct energy is often investigated using detailed bottom-up analyses (Schipper and Ketoff 1985) or index decomposition approaches (Ang 2000), Structural Decomposition Analysis (SDA) (Dietzenbacher and Los 1997;

⁷For further reading see (Pearson 1994; Selden and Song 1994; Shafik 1994; Grossman and Krueger 1995; Stern *et al.* 1996; Cole *et al.* 1997; Ekins 1997; Ehrhardt-Martinez *et al.* 2002; Stern 2003).

⁸The same holds for CO_2 and other emissions for which there is no cost-effective end-of-pipe retention technology.

Hoekstra and van den Bergh 2002)) is often applied to unravel embodied energy trends over time.⁹

4.2.3.1 Residential energy

In high income countries, the per capita requirement of residential energy has changed remarkably little during the past 25 years. Unander *et al.* (2004) show that in the USA, Canada, France, the UK, Denmark and Sweden, people used as much energy in their homes in 1973 as they did in 1998.¹⁰ This is due to equal but opposing trends, such as the simultaneous increase in floor space of houses and efficiency of space heating devices and other building and equipment stock (Schipper and Ketoff 1985).¹¹ Between 1973 and 1990, space heating was the energy demand category growing fastest (Schipper and Ketoff 1985); however, between 1990 and 1998 it was overtaken by appliance energy (Unander *et al.* 2004). It seems that while the need for space heat was able to saturate at some stage, rising incomes provided time-poor consumers with continuing opportunities to purchase new types of appliances that did automatically what previously had to be done manually (Schipper and Ketoff 1985, pp. 393ff).¹² Over time, these appliances penetrate successive household cohorts as they climb up the income ladder (Newcombe 1979).

Between 1976 and 1995 US energy consumption for miscellaneous items such as microwave ovens, bed heaters, swimming pool pumps, air cleaners, video equipment, coffee makers and computers has grown more than 4% per year, which is twice as fast as the growth of energy used in traditional appliances (Sanchez *et al.* 1998). In 1995, miscellaneous electricity uses by the top 50 products amounted to 235 TWh of electricity per year, which converts to roughly 25 GJ of primary fossil energy per household per year.¹³ The energy embodied in those products is probably in the order of 250 GJ per household.¹⁴ In Japan, a similar long-term trend is observed, involving increasing penetration of rice cookers, electric blankets (*kotatsu*) and carpets, bath heaters, air conditioners, and microwave ovens (Nakagami 1996). Hong Kong underwent a similar trend for air conditioners, heaters, stoves and washing machines (Newcombe 1979; Hills 1994), and India for refrigerators, fans, television sets (Kulkarni *et al.* 1994). While energy-intensive uses may vary among cultures (for example, lighting and heating in Norway versus bathing in Japan (Wilhite *et al.* 1996)), the growth of appliance stock and/or living space is common to households of all provenances.

While in most OECD countries, the growth in appliance ownership and residential energy use has been relatively slow, Germany, Italy and Japan have experienced higher growth rates because of their post-war recovery (Schipper and Ketoff 1985; Nakagami

⁹ Many decomposition case studies are couched in CO₂ rather than energy terms; however, since the majority of CO₂ emissions stem from energy use, we regard CO₂ decompositions as relevant for the purpose of this chapter.

¹⁰ Exceptions are Norway, where high incomes combined with cheap and abundant hydro-electricity have led to about 65% of homes being electrically heated (Unander *et al.* 2004).

¹¹ Such *rebound* effects are well known in energy research: money saved on energy bills through energy-efficient devices is spent on new appliances and other goods, the embodied energy of which often exceeds the previous energy savings (Lenzen and Dey 2002).

¹² Newcombe (1979) refers to these appliances as 'energy slaves' employed by upper income groups.

¹³ Assuming 100 million households, and a power generation efficiency of 33%.

¹⁴ Assuming each household buys one product of 50 types each at \$500, and that the energy intensity of equipment manufacturing is about 10 MJ/\$.

1996; Schipper *et al.* 1997; 1989). Even higher growth rates are perhaps experienced in economies in transition, where traditional biofuels are rapidly replaced by commercial fuels¹⁵ as newly urbanized aspiring households acquire appliances for convenience, comfort and status (Leach 1998; Garcia *et al.* 1994; Pongsapich and Wongsekiarttirat 1994), often leading to shortages and blackouts (Tyler 1994).

4.2.3.2 *Transport energy*

In absolute terms, passenger transport by private car represents the majority of transport energy use, which in turn has been one of the fastest growing sectors of OECD economies (Lenzen *et al.* 2003; Schipper and Fulton 2003). Linked principally to income, both car ownership and mileage per vehicle have increased, although the latter only slightly (Schipper *et al.* 1997; Scholl *et al.* 1996).

The energy efficiency of private mobility (MJ/passenger-km) has stayed about constant (Schipper *et al.* 1997), which is due to the combination of more fuel-efficient engines on the one hand, but larger engines and increases in travel activity on the other (Scholl *et al.* 1996). Whether this trend can be reversed in the future depends on many factors. Further future reductions of fuel intake per vehicle-km of 25% by 2020 are technically possible (Schipper and Fulton 2003). The effect of fuel taxes may be diminished by relatively price-inelastic demand for mobility.¹⁶ Alternative renewable transport fuels are still fraught with problems such as efficient storage of hydrogen (Johansson 2003), or the negative impact of large-scale biofuel cropping on biodiversity (UN-Energy 2007). While these factors can all contribute to reducing the effect of personal transport on energy resource depletion, they may have to be complemented with more long-term structural measures such as public transport systems and urban planning (Smith and Raemaekers 1998) which are aimed at the main driving force – demand for travel.

Especially in Asia's rapidly growing large metropolises, increased mobility is expressed by income-driven increased car ownership. By 2020, car ownership in China could increase by a factor of 20 compared to 2000 levels (Schipper *et al.* 2001). Further growth may only be curbed by untenable congestion and/or air pollution (Sathaye *et al.* 1994).

4.2.3.3 *Embodied energy*

There is one outstanding phenomenon that can explain why efficiency improvements have not led to a proportional improvement in overall environmental and resource pressure. Better technology will often save the consumer not only time, effort and energy, but also money. These savings are invariably spent on other (new) purposes, leading to what is called a *rebound effect*. At the very least, the impacts of the rebound consumption will partly cancel the efficiency improvements achieved, such as when people will drive more and heat more after switching to more energy-efficient vehicles and appliances. But often rebounds occur in patterns that actually undo and overturn any efficiency gains (Lenzen and Dey 2002; Heyes and Liston-Heyes 1993).

¹⁵The 'energy ladder' (Smith *et al.* 1994), or 'transition ladder' (Leach 1998). Since this fuel transition is driven by urbanization, Leach (1998) refers to this process as the 'urban energy transition', which interestingly coincides with the title of this book.

¹⁶Scholl *et al.* (1996) find that despite significant differences in petrol prices, Europeans and Americans spend roughly the same percentage of their incomes on car travel.

Decomposing time series spanning three decades, Wood and Wachsmann (2003; 2005) both come to the conclusion that the growth of final consumption, of which households form the largest component, represents the strongest upward driving force for overall national energy consumption in economies as different as Australia and Brazil. These recent findings confirm results from previous studies on energy and CO₂ emissions by Wier (1998) for Denmark, Proops and co-workers (1993) for Germany and the UK, and Common (1992) for Australia. Mélanie and co-workers (1994) decompose overall final consumption into population growth and per capita affluence components. They present graphs for Australia, Canada, France, the UK, the USA, and China, showing that in all of these countries, personal affluence growth outstrips all other positive and negative drivers of CO₂ emissions, including population growth and improvements in energy intensity. Similarly, Hamilton and Turton (1999) show convincingly that without exception affluence is the dominant driving force of greenhouse gas emissions in the USA, Japan, the EC, Australia, New Zealand, and Canada.

In the world's most populous nations, India (Mukhopadhyay and Chakraborty 1999) and China (Lin and Polenske), increases in final demand levels in the 1980s outstripped technological improvements by a factor of seven and three, respectively. In the Chinese case, capital investment proved to be the strongest driving force, with household consumption and exports following close behind. Similarly, in Chung's analysis of Korea (Chung and Rhee 2001), the effect of the growth of the economy in accelerating CO₂ emissions is four times stronger than all retarding impacts combined. In Taiwan (Chen and Rose 1990), only strong exports orientation and rapid increase of material inputs between 1971 and 1984 exceeded final demand as positive drivers for energy use. A decade later (Chang and Lin 1998), this trend was continuing unabated, and domestic final demand had overtaken exports as the main driving force.

Interestingly, in Brazil, Germany and the UK, overall energy consumption increased because of final consumption even though direct energy use decreased over some subperiods (Wachsmann 2005; Proops *et al.* 1993). This clearly demonstrates how the desire for increased material wealth can negate reductions achieved for the direct energy needs more obvious to the householder.

If the past and present are in any way indicative for the foreseeable future, energy requirements and resource depletion will increase as people strive towards the affluent lifestyles of the high income world. In order for energy transitions to be truly effective, they will have to address embodied energy before direct energy. In the absence of readily available technological fixes, this means that energy transitions must involve radical lifestyle transitions.

4.2.4 Embodied energy trade

In our globalized world, there are very few people left whose consumption habits have no or very little impact on the rest of the world. Life in modern urban centres of the affluent part of the world is underpinned by a complex trade network that funnels resources in to cities and wastes out (Folke *et al.* 1997; Rees and Wackernagel 1996). While the notion of a 'resource hinterland' seems to suggest that the area supplying these resources borders the outskirts of the city, in reality this hinterland is scattered all over the world.

As the commodities consumed by city dwellers are imported from foreign countries, so is the energy embodied in them 'foreign energy'. Translating financial trade balances of countries into embodied energy trade balances allows identifying net suppliers and net

demanders of embodied energy. In analogy to the National Accounting Identity

$$\begin{aligned} & \text{Gross Domestic Product (GDP) + Imports} - \text{Exports} \\ & = \text{Gross National Expenditure (GNE)}, \end{aligned}$$

where GDP in an embodied energy account represents the energy that a national production system embodies into commodities, no matter where these are consumed, while GNE represents the energy that is embodied in what is consumed nationally, no matter where it is produced (compare with (Bourque 1981)). The trade balance is the difference between imports and exports. There exists a large number of studies that present energy and other resource and environmental balances for single countries; they are probably most comprehensively reviewed by Wiedmann *et al.* (2007).

It appears that resource-rich energy-intensive economies top the list of net energy exporters, while population-dense, service-oriented economies top the list of net energy importers (Table 4.2). Through occupying markets for value-added commodities, the latter countries have successfully displaced energy- and resource-intensive production processes abroad, along with the environmental pressure these processes involved (Muradian *et al.* 2002). This phenomenon is widely known as pollution leakage. The net import of

Table 4.2. National Embodied Energy Accounts (PJ, 10^{15} joules) of the world's top ten producers, importers, exporters and consumers of embodied energy. Compiled using a multi-region input/output model of the world economy (World Resources Institute 2006; United Nations Statistics Division 2007).

Rank	GDP	Imports	Exports
1	United States of America 96 197	United States of America 13 732	United States of America 6 319
2	China 51 600	Germany 6 003	China 5 738
3	Russian Federation 25 949	China 5 760	Russian Federation 5 144
4	India 22 609	Japan 4 549	Germany 4 673
5	Japan 21 711	United Kingdom 4 064	Saudi Arabia 4 127
6	Germany 14 547	France 3 789	Japan 3 240
7	France 11 167	Italy 3 197	Canada 2 812
8	Canada 10 501	Netherlands 2 856	Korea, Republic of 2 203
9	United Kingdom 9 513	Canada 2 512	France 2 194
10	Korea, Republic of 8 547	Belgium 2 231	United Kingdom 1 551

Rank	GNE	Trade balance, top 10	Trade balance, bottom 10
1	United States of America 103 610	Russian Federation 4 069	United States of America -7 413
2	China 51 623	Saudi Arabia 3 675	United Kingdom -2 512
3	India 23 543	Venezuela 899	Hong Kong -2 201
4	Japan 23 020	Nigeria 841	Italy -1 872
5	Russian Federation 21 880	Qatar 608	France -1 596
6	Germany 15 877	Kuwait 443	Spain -1 450
7	France 12 763	Iran 417	Netherlands -1 367
8	United Kingdom 12 026	Canada 299	Germany -1 331
9	Canada 10 202	Libya 279	Japan -1 309
10	Italy 9 127	Kazakhstan 271	Singapore -1 179

Table 4.3. Structural Path Analysis of the world's embodied energy trade (PJ, 10^{15} joules), calculated using a multi-region input/output model of the world economy (World Resources Institute 2006; United Nations Statistics Division 2007). Paths are interpreted, for example, as 'the commodity trade from Japan to China embodies 427 PJ of energy'. 'nes' = not elsewhere specified.

Rank	Energy (PJ)	Path
1	2123	Canada > United States of America
2	1286	China > United States of America
3	993	United States of America > Canada
4	865	Mexico > United States of America
5	635	United States of America > Mexico
6	635	Japan > United States of America
7	491	Nigeria > United States of America
8	489	China > Japan
9	471	Korea, Republic of > China
10	467	Venezuela > United States of America
11	427	Japan > China
12	401	Saudi Arabia > Other Asia, nes > China
13	380	Germany > United States of America
14	370	Germany > France
15	357	United States of America > Japan
16	335	Saudi Arabia > United States of America
17	318	Russian Federation > Areas, nes > India
18	315	China > Hong Kong
19	302	Saudi Arabia > Japan
20	300	Russian Federation > Germany

embodied energy into the USA is of the order of the total energy consumption of an entire medium-sized economy such as Australia.

At one end on a continuum, countries with either resource abundance or cheap labour will deliver raw energy or embodied energy in basic goods at historically low prices. At the other end of the continuum, countries that import low cost direct or embodied energy generally exchange in return sophisticated goods and services costing much more than their physical inputs. Historically, exactly this exchange of embodied energy has provided cities their success, and with the ability to retain and cement power, affluence and influence for its citizens.

Each of the countries in Table 4.2 will in general have a large number of trading partners that either supply or receive the energy embodied in the traded commodities. Structural Path Analysis (Treloar 1997) is a method for extracting single paths that link the original source of energy use with the location of final consumption. Based on an input/output analysis of a one-sector world economy, the most important structural paths stretch only one node, that is they involve two countries (Table 4.3). The USA dominates the list of embodied energy 'sinks', which is fed by Canada and China, among others. Ranks 12 and 17 show paths stretching two nodes, where China and India are the recipients of embodied energy originating in Saudi Arabia and Russia, respectively, but traded via other countries.¹⁷

¹⁷If only two-node and higher order paths were analysed, city-territories such as Hong Kong are often situated as intermediaries (compare Newcombe 1975). Prominent paths are China > Hong Kong > China (158 PJ), China > Hong Kong > USA (59 PJ), Japan > Hong Kong > China (38 PJ), Korea > Hong Kong > China (24 PJ), USA > Hong Kong > China (23 PJ), China > Hong Kong > Japan (18 PJ), and Singapore > Hong Kong > China (17 PJ).

Taking into account that global trade exacerbates even further the discrepancy between direct and embodied energy use, residences in modern societies such as the USA, Europe and Japan may be equipped with efficient technology, but in addition to domestic embodied energy, their inhabitants consume a substantial amount of energy embodied in goods produced at high energy intensities, often in low income countries such as Mexico, China, Nigeria, and Venezuela. This once more underlines the need for taking embodied energy and lifestyle changes into account.

To account for the energy realities of globalized trade would require revamping the System of National Accounts in that energy and greenhouse gas accounts be attributed to the country of consumption rather than the country of production (Munksgaard and Pedersen 2001; Lenzen *et al.* 2004). Attributing responsibility for energy and emissions alongside trade flows would overturn many core assumptions in the economic and political settings of the globe. Implemented, it would lead to substantial transformation, because any country seeking to reduce its national energy consumption or greenhouse gas emissions would need to limit imports of goods from production chains with high energy/greenhouse gas content, and perhaps advantage local production chains.

4.3 Sydney – A Case Study

Cities are almost entirely dependent on the influx of resources from outside,¹⁸ and urbanization is proceeding rapidly around the world. Australia is one of the most urbanized countries in the world, and Sydney is its largest city, with roughly 4.5 million residents. In addition to growing personal incomes and expenditures – as described in the previous sections – we can expect the energy needs of Sydney residents to be influenced over time by a host of other societal factors: examples are the tendency for young people to move into single-person households, to marry late, and to have fewer children; more extensive child-care facilities and generous maternity-leave policies allowing women to enter the workforce; longer opening hours and more consumption possibilities; longer hours spent commuting to work and family social events;¹⁹ improved health and longevity, and increased leisure activity of the elderly; legislation such as tax rules, vehicle road worthiness criteria and building construction standards; regional population density and climate; and cultural traditions such as holiday cottages, expectations of comfort, etc. (Schipper 1998; Schipper *et al.* 1989). Unfortunately, data were not available on all of the above factors, but only on a set of 11 socio-economic-demographic variables (Table 4.4).²⁰

The results presented in the following were obtained by (1) applying generalized input/output analysis (Lenzen 2001) to the most recent Australian Household Expenditure Survey (Australian Bureau of Statistics 2000),²¹ (2) extracting the set of socio-economic-demographic data from the survey, and using these data as explanatory variables in a multiple-regression

¹⁸ This circumstance becomes drastically clear for residents of a city-territory, such as Hong Kong (Newcombe 1975; Part I and Part II).

¹⁹ Per unit of time, travel exhibits by far the highest energy intensity of all household activities (Schipper *et al.* 1989).

²⁰ Especially climate has been shown to significantly influence residential energy use in Australia (Newman 1982), so future studies could add data on this variable. However, for a comparison of Sydney SLAs the omission of climate data is inconsequential, since the mean annual temperature is similar across all SLAs.

²¹ At the spatial level of Statistical Divisions (SDs) and Statistical Sub-Divisions (SSDs).

Table 4.4. Explanatory variables for energy consumption.

Explanatory variable	Symbol	Comments
Per capita household income	Inc	Weekly
Household size	Size	Number of people in the household
Average age	Age	Calculated from age bracket occupancies; in units of 100 years
Average qualification	Qual	Dummy variable: Postgraduate Degree = 5, Graduate Diploma and Graduate Certificate = 4, Bachelor Degree = 3, Advanced Diploma and Diploma = 2, Certificate = 1
Population density	Dens	Calculated as a weighted sum with population weights; in units of '000 people per km ²
Tenure type	Ten	Dummy variable: Owners without a mortgage = 5, Owners with a mortgage = 4, Renters from state or territory housing authority = 3, Other renters = 2, Other = 1
Employment status	Empl	% of employed persons in household aged 18–64
Provenance	Prov	% of householders born overseas
Car ownership	Car	Number of cars per person
Travel to work by car	Trav	% of householders
Dwelling type	Dwel	Dummy variable: Separate house = 4, Semi-detached House = 3, Flat = 2, Other = 1

analysis (Lenzen *et al.* 2004), and (3) applying the regression formula to the same set of variables, but extracted for smaller spatial units from the Australian National Census (Australian Bureau of Statistics 2007).²² While task 1 is documented elsewhere (Lenzen 1998; Lenzen *et al.* 2006), tasks 2 and 3 are described in the following two subsections.

4.3.1 Explaining energy requirements

Before regressing energy data against potential explanatory variables, the latter have to be tested for pairwise correlation. Take, for example, the variables 'travel by car', 'dwelling type', and 'population density' which, in Australia, seem to be highly correlated (Table 4.5). This is probably because where population density is low (rural areas and city fringes), the percentage of people driving to work is high (correlation coefficient of -0.71), and the dwelling type index is high (-0.78), indicating a high percentage of separate houses instead of flats. In principle, any of these variables could explain part of the energy requirement, but not all of them simultaneously, since they really measure one and the same thing. Analysts often isolate the original causal variable; in this case it is likely that the availability of space enables the abundance of separate houses, but the sparse occupation of space also brings with it a lack of public transit. For this reason we have omitted the variables 'travel by car' and 'dwelling type' from our regression.²³

²²At the spatial level of Statistical Local Areas (SLAs).

²³All other variables were considered in a step-up-type iterative selection process: first, a regression with one variable – the one showing the highest correlation with energy consumption – was carried out, then the next most-correlated variable added, and so on, until the adjusted R^2 value of the regression did not increase anymore.

Table 4.5. Pearson product moment correlation coefficients between explanatory variables, extracted from about 6900 household samples.

	Size	Age	Qual	Dens	Ten	Empl	Prov	Car	Trav	Dwel
Inc	-0.16	0.25	<i>0.59</i>	0.36	-0.05	<i>0.56</i>	0.33	-0.22	-0.46	-0.50
Size		-0.58	-0.09	-0.17	0.18	0.14	0.10	-0.10	0.10	0.16
Age			0.23	0.23	0.29	-0.11	0.07	0.05	-0.13	-0.21
Qual				<i>0.54</i>	-0.12	0.11	<i>0.52</i>	-0.18	-0.60	-0.64
Dens					-0.19	0.08	0.39	-0.40	-0.71	-0.78
Ten						-0.02	0.00	0.18	0.36	0.34
Empl							-0.08	0.01	-0.09	-0.07
Prov								-0.41	-0.35	-0.41
Car									0.62	0.51
Trav										0.84

Table 4.6. Results of a multiple regression of the per capita energy requirement against variables in Table 4.4. Rows marked 'Residential' etc. list regression coefficients.²⁴ Rows marked *t* list results from a Students-*t* test for significance. Coefficients in bold font are significant at the 99% significance level, regular font – 95%, italic – 90%, underlined – not significant.

	Inc	Size	Age	Qual	Dens	Ten	Empl	Prov	Car
Residential	0.07	-0.10	1.41	-0.16	0.00	0.02	0.18	-0.29	0.92
<i>t</i>	0.48	<u>2.00</u>	1.98	1.29	0.08	0.17	0.51	0.89	1.87
Transport	0.32	0.02	<u>1.03</u>	-0.07	-0.07	0.05	-0.01	0.01	0.33
<i>t</i>	3.61	0.54	<u>2.33</u>	0.95	<u>2.54</u>	0.78	0.05	0.06	1.09
Embodied	0.40	-0.06	<u>0.66</u>	0.20	0.00	-0.01	0.04	-0.10	-0.34
<i>t</i>	6.48	2.84	<u>2.19</u>	3.65	0.03	0.20	0.27	0.76	1.63
Total	0.34	-0.06	0.83	<u>0.12</u>	0.00	0.00	0.07	-0.13	-0.09
<i>t</i>	6.41	2.96	3.15	<u>2.55</u>	0.23	0.02	0.51	1.13	0.47

Other relatively highly correlated pairs are car ownership and travel to work by car (+), employment status and income (+), and qualification and income (+), all for obvious reasons. People with high qualifications tend to live in densely populated areas, and hence in flats rather than separate houses. Interestingly, people born overseas tend to have higher qualifications.

A multiple regression yields that (Table 4.6)

- residential energy is best explained by household size: the more people occupy the household the lower the per capita residential energy consumption;
- increasing age also explains increasing per capita residential energy, independent of higher income or lower household sizes older households may have;

²⁴We chose the functional form $\ln(E) = \alpha + \beta \ln(Inc) + \sum_i \gamma_i x_i$, where the x_i are *Size*, *Age*, *Qual*, etc., and α , β and γ_i are regression coefficients (Wier *et al.* 2001). Using $\partial \ln(E)/\partial \ln(Inc) = E^{-1}$, it can easily be shown that $\beta = (\partial E/E)/(\partial Inc/Inc)$ is the income elasticity of the energy requirement, which describes the percentage change in the energy requirement as a result of a percentage change in per capita income. Similarly, $\gamma_{Size} = (\partial E/E)/(\partial Size)$ describes the percentage change in the energy requirement as a result of the addition of one family member, $\gamma_{Age} = (\partial E/E)/(\partial Age)$ the percentage change in the energy requirement as a result of an increase in the average age by one year, and so on.

- car ownership appears to explain residential energy, although the connection is unclear;
- per capita transport energy tends to be high when incomes are high, for households in less densely populated areas, and for older households;²⁵
- per capita embodied energy is clearly and most strongly driven by income, followed by qualification (independent of income);
- per capita embodied energy decreases with increasing household size, which is probably due to people sharing things such as appliances;
- per capita embodied energy increases with age, independent of higher income or lower household sizes older households may have;
- tenure type, employment status and provenance do not appear to influence energy consumption;
- the variability of the total energy requirement is dominated by embodied energy.

We measure the income elasticity of the total energy requirement at 0.34 (Table 4.6), which means that for a 10% increase in expenditure, the energy requirement increases only by 3.4%. This is due to the fact that when income increases, the proportion of services compared to goods in the consumer basket increases, so that each additionally purchased commodity tends to be less energy intensive.²⁶ The size and age elasticities of the energy requirement are -6% per additional household member, and $+0.8\%$ per year, respectively.

Applying the regression coefficients in Table 4.6 to Australian average socio-economic-demographic variables yields a per capita energy requirement of 180GJ, which is in excellent agreement with the energy requirement of 176GJ/cap calculated directly from household expenditure data (Australian Bureau of Statistics 2000).

4.3.2 A spatial view of direct and embodied energy consumption

There are a number of studies that attribute energy use or greenhouse gas emissions to residents of a city, and depict the result as shaded maps (Newcombe 1976; Kalma and Newcombe 1976; VandeWeghe and Kennedy 2007). This has even been done for Sydney, our own case study (Kalma *et al.* 1972). However, to our knowledge, these studies only deal with residential and not with embodied energy. The first publication to present embodied energy in a spatial context is Lenzen *et al.*'s analysis of Sydney (2004). The work presented in the following case study replicates this previous study's methodology, but updates the results, and significantly increases the spatial resolution by applying the regression coefficients in Table 4.6 to information on lifestyles contained in the Australian Census, which holds data on all of the variables in Table 4.6 at a detailed spatial level.

²⁵ Interestingly, Schipper *et al.* (1989) finds that in the 1980s US, elderly people spent more time at home and drove less, so that their residential and transport energy requirements were above and below average, respectively. Already in 1989, Schipper conjectures that 'tomorrow's energetic retirees . . . could carry with them their mobility patterns of younger years, while they continue to live in homes originally built to house families with two or three children'. In our regression we see exactly this phenomenon: Both residential and transport energy use are accelerated by average household age.

²⁶ The income elasticity of 0.34 reported here is lower than the expenditure elasticities in Fig. 4.5, which range between 0.7 and 1.0. This is because (a) a multivariate regression as in Table 4.6 involves explanatory variables in addition to income, and as such the income elasticity of 0.34 is lower than would have resulted from a univariate regression with only income as a variable; and (b) Fig. 4.5 depicts energy versus expenditure, while Table 4.6 analyses energy versus income. Expenditure elasticities are always higher than income elasticities because expenditure is a better proxy for the energy requirement than income (Newcombe 1979; Wier *et al.* 2001).

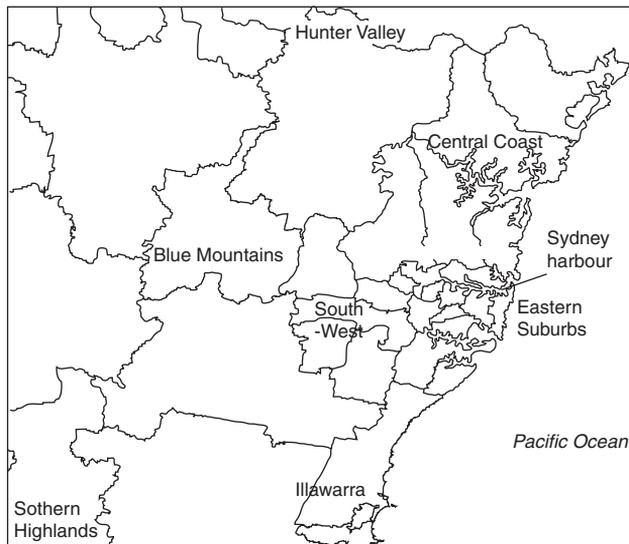


Fig. 4.6. Regions of Greater Sydney.

The maps shown in the following sections contain the city of Greater Sydney, which includes the Blue Mountains and the Lower Central Coast. Bordering are the Illawarra and Southern Highland regions, the Hunter Valley, and the Pacific Ocean (Fig. 4.6). These maps may suggest viewing the embodied energy issue as an issue of geographic location; however, we ask the reader to interpret spatial units as entities of certain socio-economic-demographic characteristics. Where the maps show ‘hot spots’ of high embodied energy, this is where the *drivers* of embodied energy – for example, affluence – are strong. Hence, we will investigate why certain areas feature certain characteristics, which then lead to consumption habits, and in turn to the embodied energy pattern.²⁷

4.3.2.1 Residential energy

The majority of residential energy in Australia is consumed as electricity, natural gas, and firewood (Table 4.7). In our analysis of Sydney, firewood is likely to play a minor role compared to the whole nation, so that our multiple regression is most sensitive to households’ electricity and gas bills.

Residential energy appears to be high in the SLAs around Sydney Harbour, and in rural areas to the north-west of the city (Fig. 4.7 [Plate 6]). Our regression (Table 4.6) shows that per capita residential energy is high for small and old households, so one would expect to see a spatial correlation of residential energy with these factors.

Household size exerts the strongest influence (Table 4.6) and is therefore shown for comparison in Fig. 4.8 [Plate 7]. Indeed, for the city itself, we find that residential energy is low where many people share a household, and vice versa. This could simply be because

²⁷ Maps are available also for greenhouse gas emissions, water use and the Ecological Footprint for SLAs in all Australian States and Territories (<http://www.acfonline.org.au/consumptionatlas>).

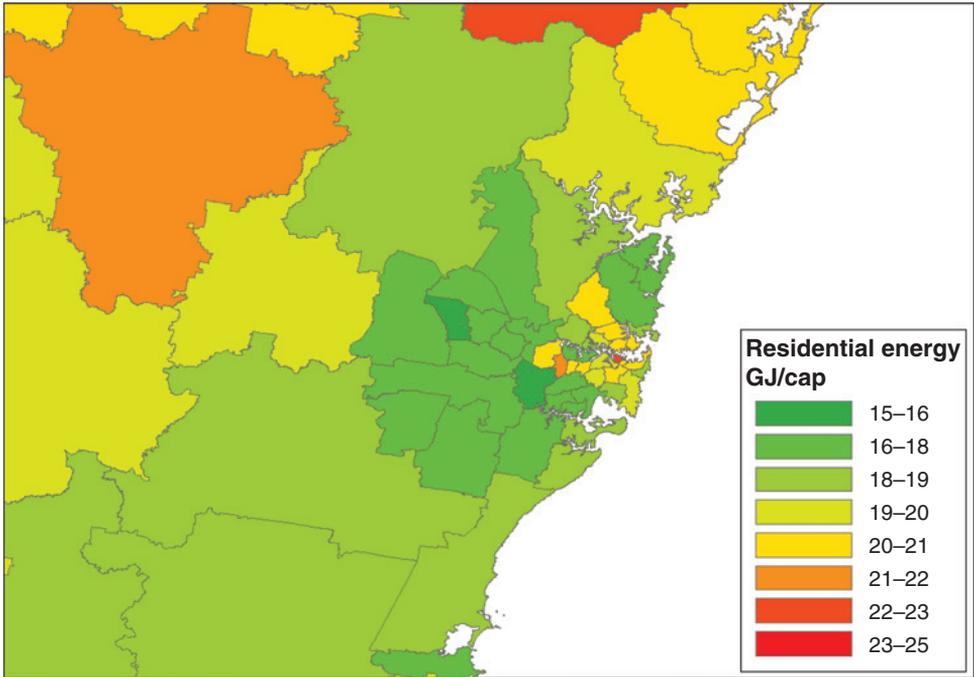


Fig. 4.7. Per capita residential energy in Greater Sydney SLAs. [Plate 6]

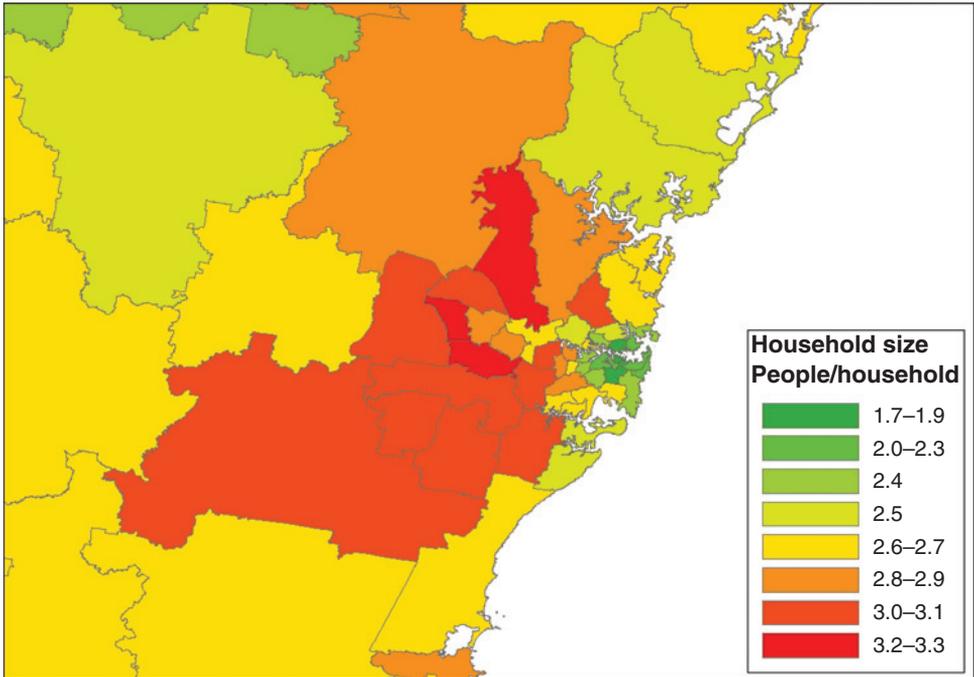


Fig. 4.8. Household size in Greater Sydney SLAs (Australian Bureau of Statistics 2007). [Plate 7]

Table 4.7. Breakdown of Australian residential energy into fuel types (Australian Bureau of Agricultural and Resource Economics 2006).

Energy carrier	% of total
Electricity	44.1
Natural gas	30.1
Firewood	21.1
LPG, LNG	2.6
Solar energy	1.0
Heating oil	0.6
Diesel oil	0.4
Kerosene	0.1
Black and brown coal	0.04

these people share energy services such as light and heat that are largely independent of how many people live in a flat or house.

Sydney's age structure (older households in the seaside suburbs, younger households towards the south-west) reinforces the spatial distribution in Fig. 4.7 [Plate 6]. The two outer high energy SLAs (Lithgow and Cessnock/Hunter Valley) are caused by the two remaining explanatory factors (high car ownership and low percentage of people born overseas), and are perhaps an artefact of the regression analysis.

4.3.2.2 *Transport energy*

Energy used for private passenger transport (almost all petrol) is clearly related to geographical location, with energy use increasing with increasing distance from the city centre (Fig. 4.9 [Plate 8]). People living in the centre and along major bus and train arteries have at their disposal various transport options, leading to below-average petrol consumption.

Population density is the strongest explanatory variable for transport energy (Table 4.6), and this relationship is well depicted by contrasting the maps for both factors (Figs 4.9 [Plate 8] and 4.10 [Plate 9]). Major train lines only reach west into the Blue Mountains, north toward the Central NSW Coast, and south to the Illawarra and Southern Highlands regions. Compared to urban rail transport in other megacities, these services are infrequent and slow. Frequent buses run mostly in SLAs denser than 500 km^{-2} , so that most people living well outside of the city proper rely entirely on the private car.

4.3.2.3 *Embodied energy*

By far the most significant relationship in our entire regression ties embodied energy to income (Table 4.6). This is why perhaps the most striking resemblance can be found between the maps depicting these two variables (Figs 4.11 [Plate 10] and 4.12 [Plate 11]).

First, note that the magnitude of the scale in Fig. 4.11 [Plate 10] is five to ten times higher than those in Figs 4.6 and 4.8 [Plate 7], once more emphasizing the dominance of embodied energy. Any visitor to Sydney can easily tell from the size and style of houses, and the water views, that the most affluent people congregate around Sydney Harbour, along the

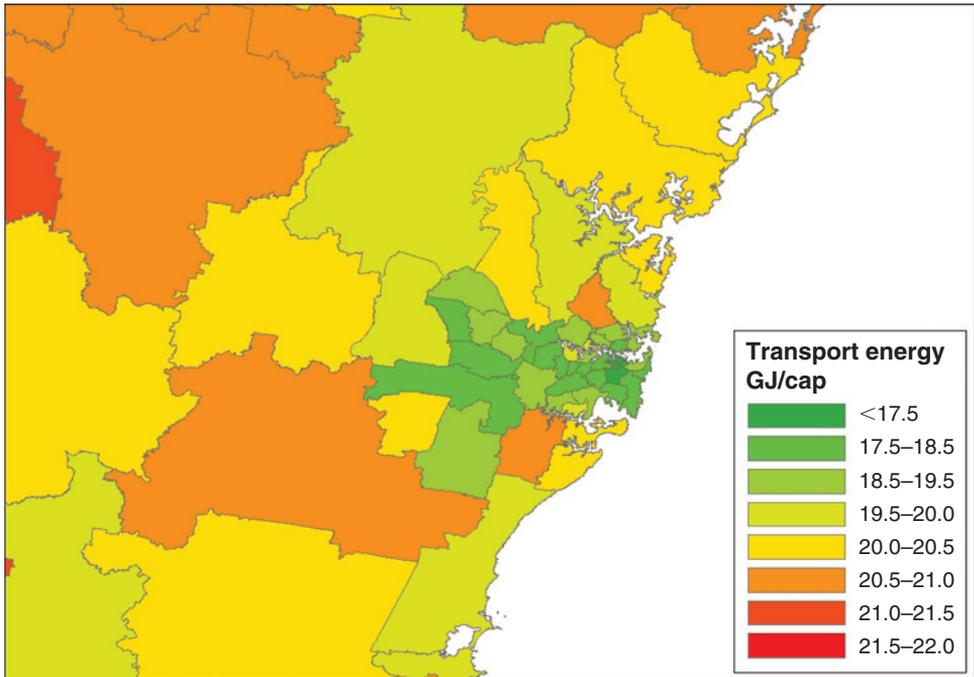


Fig. 4.9. Per capita transport energy in Greater Sydney SLAs. [Plate 8]

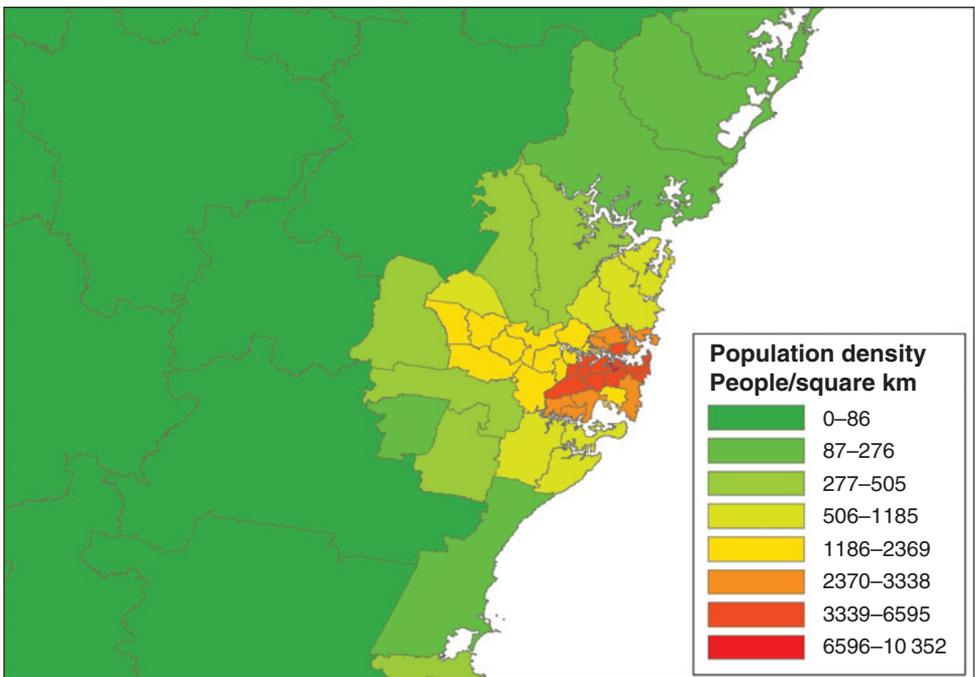


Fig. 4.10. Population density in Greater Sydney SLAs (Australian Bureau of Statistics 2007). [Plate 9]

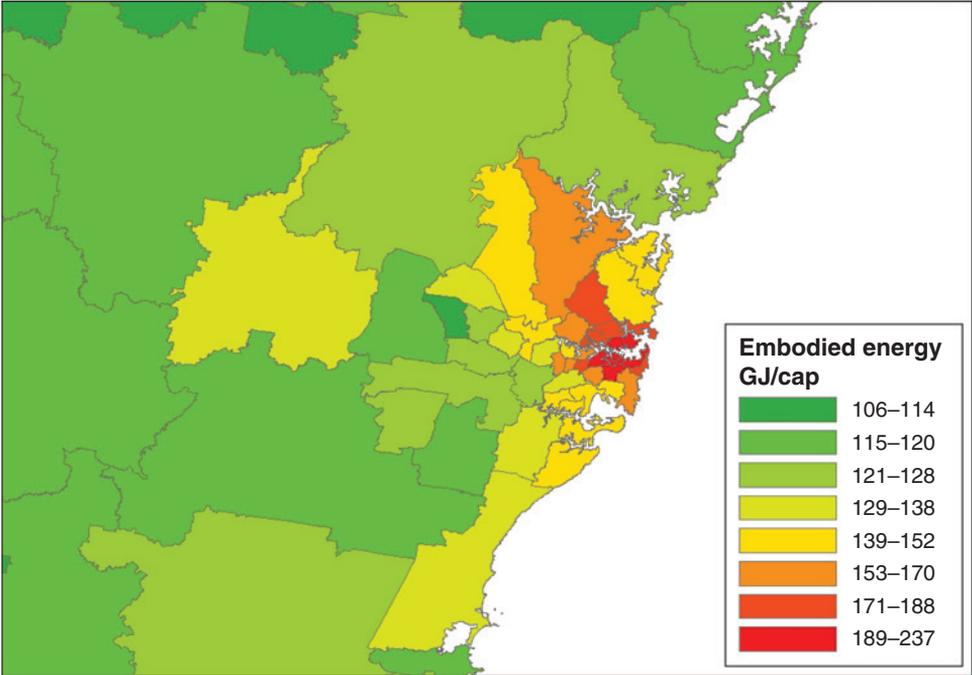


Fig. 4.11. Per capita embodied energy in Greater Sydney SLAs. [Plate 10]

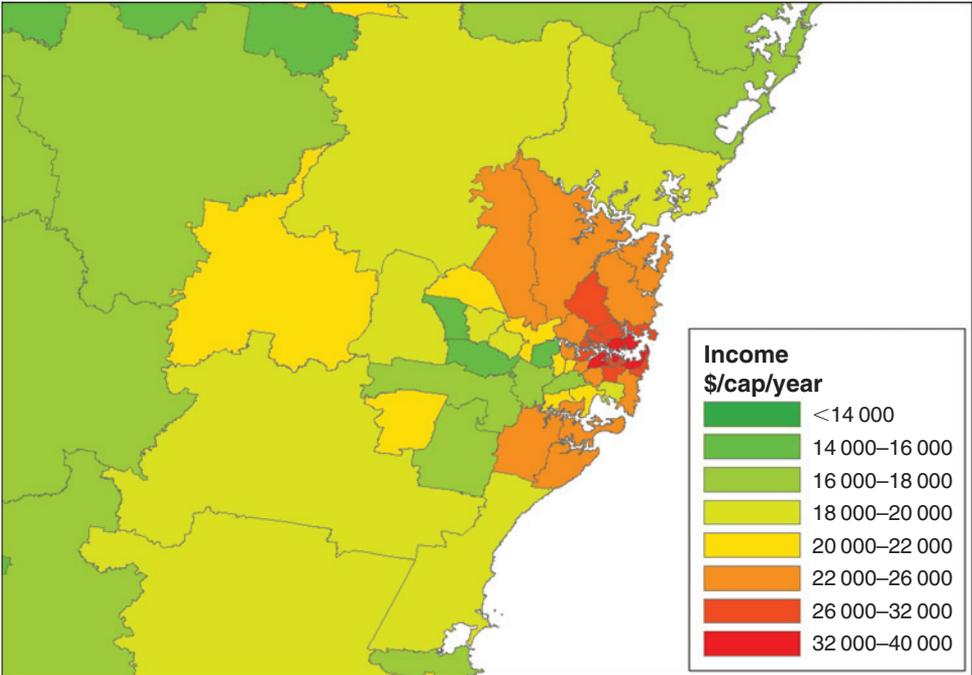


Fig. 4.12. Per capita annual income in Greater Sydney SLAs (Australian Bureau of Statistics 2007). [Plate 11]

Eastern Suburbs beaches, and on the North Shore. This is where some of the nation's most wealthy and vigorous consumers reside, and where embodied energy accumulates.

In contrast, the south-west of Sydney and the rural areas to the west (except the Blue Mountains) are characterized by young, larger families with mostly low incomes and, as a consequence, low embodied energy budgets.

4.3.2.4 Energy – a way of life

Sydney adheres strongly to the conventional measures of success implied by the last three centuries of industrialization and globalization. Its metabolism is based on the manner in which it attracts global citizens seeking modern lifestyles with the best-quality goods and services, and is facilitated by a well-connected port and airport. The city 'believes' in economic growth, affluence, population growth and a continuing real-estate boom. Occupancy rates for domestic and commercial building stocks remain high and reap good financial returns for their owners.

In terms of direct energy, Sydney faces many structural impediments caused by its settlement geography and history, which surface as a range of engineering difficulties, particularly for better urban transit. In energy terms it is mostly dependent on black-coal electricity generated in the Hunter Valley to the north of the city, thus locking in a high carbon content for its electricity. The strategic encouragement of car transport by continual freeway construction along with a massive underinvestment in efficient urban transit further imposes a higher carbon content of mobility than technology suggests is available. The relative age (in Australian terms) of the inner city means that retrofitting of building stock can be physically difficult and expensive. Finally, the marginalized and fragmented nature of local, state and federal representation means that energy politics has never mustered sufficient medium-term support and financing to achieve a 'great leap forward' in the city's energy metabolism. There are few politicians prepared to put their votes at risk for difficult transitions that might take two decades to return real energy savings, particularly given the dominant conventional view that equates embodied energy consumption with success.

In embodied energy terms, the residents of Sydney are generally aspirational of a lifestyle that implies style, fashion and a diversity of possessions. They have higher skills on average than the rest of Australia, get higher pay and thus consume more in embodied energy terms. In the wealth and consumption stakes Sydney is Australia's showcase city in world and national terms. Within its city boundaries it displays a strong gradient in per capita embodied energy requirements from the longer settled and more affluent areas around its harbour and coastlines, to the less affluent suburbs at the western and southern extremities. These embodied energy gradients reflect social equity barriers that have possibly locked in less affluent residents to energy dependence as a way of life. Since social disadvantage usually means poorer health and educational outcomes, any hypothetical energy transition will be doubly difficult because of lower levels of human capital and understanding of why these transitions should take place.

Given this hierarchy of global and functional influences, it seems unlikely that our city of interest, Sydney, or for that matter any first-world city, will be able to effect an energy transition with sufficient leverage to reformat its metabolism and thus meet its global environmental goals. Notwithstanding this dour conclusion, there are five policy strategies which Sydney's managers must work towards as follows. The first is to create new attributes of wealth, human development and status where social richness and community vitality replace volumetric consumption as the key driving forces and measures of success

of advanced societies. The second is to cap absolute population numbers over the next two to three human generations, while achieving a population structure that is reasonably balanced by age (no booms and busts) and age by spatial location (no very old and very young suburbs). The third is to introduce carbon rationing and trading for consumers on a full production chain basis so that the full embodied greenhouse content is accounted for, and priced into consumer transactions at the point of sale. The fourth is to form a multimodal city well linked by low carbon transport options and to constrain single-person vehicle transport. The fifth is to mandate leading-edge energy regulations for all new buildings, and, in parallel, begin retrofitting suburb by suburb the existing built infrastructure to constrain energy use, while meeting reasonable economic and social requirements.

4.3.3 Forecasting energy requirements

Just before the manuscript for this book went to print, the 2006 Australian Census was released by the Australian Bureau of Statistics, prompting the main Sydney daily newspaper to describe Australians as 'richer, older, and lonelier than before' (Wade *et al.* 2007). These comments refer to increasing real incomes, an ageing society, and the trend towards single or couple households. Such developments have become daily topics of debate among politicians and the general public alike, and therefore it is intriguing to examine the energy implications of a few future scenarios.

The business-as-usual (BAU) scenario assumes that the historical 2% real economic growth (World Resources Institute 2006) continues until 2050. By that time the average Australian is assumed to live in suburbs that are as dense as city fringes are today (800 km^{-2}). Immigration and procreation are assumed to balance the age pyramid, and household sizes will stay the same (two generous assumptions). According to our lifestyle regression, under this scenario, even though affluence rises, the per capita energy requirement will stay about constant at 180 GJ/cap, thanks to (a) energy efficiency improvements of 0.8%/year or an overall 40%, (b) higher population densities that make better use of transport infrastructure, and (c) the 'consumer basket effect' described at the end of the previous subsection. Overall (national) energy consumption will be 70% higher than in 1999, because Australia's population will have grown by 70% from 20 million to just above 30 million.

The 'Fast' scenario assumes an accelerated real growth of 3%/year, which among other influences will drive the trend towards smaller households. An aged Australian population is assumed to live in families typical for today's North Shore (see Figs 4.8 [Plate 7 and 4.12

Table 4.8. Results for three simple future scenarios for 2050. All scenarios assume the continuation of historical trends for the overall energy intensity (-0.8% /year, technology driven) and population ($+1\%$ /year, immigration plus procreation) (Foran and Poldy 2002).

Scenario	Australia, average	BAU	Fast	Slow
Income growth		2%	3%	1%
Income	\$337	\$924	\$1520	\$559
Household size	2.8	2.8	2.2	3.6
Age	35	35	38	33
Population density	554	800	554	1000
Per capita energy requirement	180	180	225	141
Total energy requirement (1999 = 1)	1	1.7	2.1	1.3

Plate 11]; 2.2 people/household, 38 years), and new settlements are assumed to sprawl by copying the existing spatial structure (554 km^{-2}). Under this scenario, socio-economic-demographic trends outrun efficiency gains, and per capita energy requirements will exceed 220 GJ. Australia's total energy use will more than double until 2050.

The 'Slow' scenario features only 1%/year real growth, and consolidated urban and family structures. A younger Australian population is assumed to live in households typical for today's Fairfield-Liverpool (a low income Sydney suburb, 3.6 people/household, 33 years), but at densities of 1000 km^{-2} .²⁸ Under this scenario, per capita energy requirements will have significantly decreased to about 140 GJ. Australia's total energy use will still increase by 30%.

Under every scenario, the growth of Australia's energy metabolism is underpinned by more people wanting a more comfortable and convenient life, travelling more often and further, and enjoying more material wealth. This shows once again, and drastically, that an urban energy transition cannot be viewed without considering embodied energy.

4.4 Conclusions: Technological vs Lifestyle Transition

As people flock to the cities in search of opportunities, and societies become more urbanized, they also become more affluent, and their energy systems more efficient. At the same time the demands of people for material wealth, comfort and convenience increase rapidly, causing the increase of industrial energy demand, which in turn often outstrips all energy efficiency gains. Generally the cities are the places where money is made, and which become the home of the wealthy, while the countryside is the place where resources are taken. Urban centres thus become sinks of rural resources and energy (Various authors 2007).

Many growing urban metropolises are reaching their limits of domestic resource availability or environmental pollution, while at the same time further efficiency improvements become costly. By increasingly drawing on cheap resources and energy beyond their borders, facilitated by an increasingly globalized international trade, they export their environmental pressure into resource-rich, but often technology-poor, low wage regions. The domestic resource hinterland turns into the global resource hinterland.

Human civilization is thus a story of urban civilization which, over the past 300 years of industrialization, has become rich and successful on the back of energy exploitation, almost exclusively by combusting fossil fuels that accumulate in form of embodied energy and atmospheric greenhouse gas concentrations. This development has now led to the prospects of diminishing oil supply and runaway global climate change. Thus the affluent citizens of the world's cities are responsible historically for this situation, and are now central to any future prospect of retreating to safer conditions.

In these affluent, urbanized societies, direct energy is less important than embodied energy. More so, the latter has been increasing so strongly that it appears that measures aimed at improving technology on their own have not been able to counteract trends of looming resource depletion and climate change (Trainer 1997).²⁹ Combining this with the fact that the overarching driving force for the magnitude and the rate of increase of energy

²⁸ For comparison, Australian inner city centres have about $2000\text{--}4000 \text{ km}^{-2}$.

²⁹ Caldwell (1976) has argued that, given the structure of social institutions of modern industrial societies, a cheap and inexhaustible energy supply may pose far greater problems than energy shortages: 'There is no quicker way to destroy a society than to confer upon it power that it lacks wisdom, consensus, restraint, and institutional means to handle.'

consumption is personal affluence, we conclude that the urban energy transition can only be effective if technology transitions are complemented by far-reaching lifestyle transitions (Trainer 1995).

It is possible that such lifestyle transitions are doomed to failure. Cities seem to have escaped, for the time being at least, the physical dependence on their immediate hinterland, which may have led to a feeling of invincibility where people's aspirations have transgressed natural limits and are now driven only by human ingenuity. Thus, having formally escaped physical realities, city dwellers fail to read the danger signs of their existence and may even deny those signs totally. This manifests itself in the missing knowledge-concern-action link: By and large, people become concerned once they know about an environmental problem, but there appear to be no signs whatsoever that concerned people cause less environmental impact than people who are not concerned, or do not even know about environmental issues (Kempton 1993; Stokes *et al.* 1994; Vringer *et al.*; Hastings 2007; Wilby 2007; McKibben 2003).

To consider transforming the escalator of aspirations, from one that is forever outrunning unhappiness, to one that allows fulfilment, beggars belief as to what drives a modern city resident in a time-poor and globally connected world. Changing the storyline of the century just gone will require focused social engineering for many human generations.

Like most of the general public, public policy in developed countries has also failed to appreciate, or deliberately avoided addressing, the link between affluence and energy. This is evident in policies focused purely on energy efficiency without constraints on total energy use and greenhouse gas emissions. As we have shown, once the cost of energy efficient infrastructure is paid back, the dollar savings allow for more production or expenditure, thus setting in train the requirement for more energy, either directly or indirectly.

It is understandable why policy has more readily embraced supporting technological change rather than promoting lifestyle change. After all, what can be achieved by new technology is easy to sell to the consumer: no one has to give up their habits, and governments do not need to risk losing votes, because they do not need to initiate a potentially painful and difficult public discourse, let alone intervention into consumers' choices. In a functioning democracy, convincing the public to forgo certain types of unsustainable consumption now for the sake of future generations is without doubt a formidable challenge, prone to resistance, requiring respected leadership (Beekman 1997).

Decades of unabated and unrestrained economic growth, nurtured by advertising affluent, material lifestyles to an ever-growing portion of the world population makes one wonder whether some sort of lifestyle change is indeed unavoidable. One would hope for such changes to be brought about by conscious and collective decisions rather than by involuntary and unilateral force, or perhaps worse, by natural and socio-economic circumstances.

A compelling reminder of the latter option is Ronald Wright's recount of the fallibility of human civilizations in his book *A Short History of Progress* (Wright 2004, p. 79) as he describes the collapse of the Empire of Ur around 2000 BC located in what is now Southern Iraq:

The short-lived Empire of Ur exhibits the same behaviour we saw on Easter Island: sticking to entrenched beliefs and practices, robbing the future to pay for the present, spending the last reserves of natural capital on a reckless binge of excessive wealth and glory. Canals were lengthened, fallow periods reduced, population increased and the economic surplus concentrated on Ur to support grandiose building projects. The result was a few generations of prosperity (for the rulers) followed by a collapse from which Southern Mesopotamia has never recovered.

In spite of their impressive technological underpinnings, modern cities such as Sydney display many of the fragilities that could in the long term lead to their decline, and then the collapse of what were pre-eminent civilizations in their day. The challenge for the modern city-state is to learn from lessons of the past millennia, and to begin the transition process at least one century before physical problems become intractable. The one thing that has changed from the Empire of Ur is that the problems of tomorrow will be driven by global dynamics rather than local or regional ones.

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