THE LOCAL AREA RESOURCE ANALYSIS (LARA) MODEL: CONCEPTS, METHODOLOGY AND APPLICATIONS

by

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RESOLVE Working Paper 02-07

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Acknowledgements
The support of the Economic and Social Research Council (ESRC) is gratefully acknowledged. This work is part of the interdisciplinary research programme of RESOLVE - the ESRC Research Group on Lifestyles, Values and the Environment.

ISSN 1755-7259

Abstract

Addressing resource intensive consumption patterns and lifestyles is vital in the struggle to reduce the impact of modern society on the environment. The sustainable consumption agenda not only needs to be based on robust evidence of the scale of current resource use and associated emissions but also on an understanding of the drivers of consumption. Furthermore, if we are to devise policies that move towards more sustainable consumption patterns in an equitable manner, then it is also important to have an understanding of inequalities. The subject of this paper is the Local Area Resource Analysis (LARA) model that begins to address both of these requirements. LARA estimates household resource use and associated emissions at high levels of socio-economic and geographical desegregation.

This paper focuses largely on use of LARA for modelling direct household energy use and associated carbon dioxide emissions, although LARA has also been applied to other types of resource use such as food and clothing, and in future developments LARA will be capable of estimating total (direct and embedded) resource use and associated emissions. In this paper the highly disaggregated nature of LARA is demonstrated by estimation of the energy use and associated carbon emissions for two specific case study areas, which are small local neighbourhoods chosen to represent extremes of affluence and deprivation. LARA's ability to give us insights into the resource implications of the lifestyles of specific socio-economic groups is demonstrated by modelling the energy use of "typical" types of households classified according to the UK National Output Area Classification. The results presented demonstrate the importance of factors such as type of dwelling, tenure and rural/urban location as well as relative affluence as drivers of household energy use and associated carbon dioxide emissions.

In this paper we describe two applications of LARA. The first is use of LARA to estimate local household waste arisings based on neighbourhood socio-economic characteristics. Results are demonstrated for packaging waste (specifically glass waste arisings due to wine and champagne consumption), which is assumed to enter the waste stream in the year of product purchase. Modelling of waste arisings for goods with a relatively long product lifespan, which use a household metabolism model, are demonstrated by waste arisings due to carpets. Pilot results are presented for three contrasting scenarios from 1996 to 2020 in which different assumptions are made concerning purchases of commodities and the time for which commodities reside in households.

The second application of LARA described in this paper is its use as the basis of an area-based indicator of inequalities in resource use. The indicator, called the AR-Gini, estimates inequalities between neighbourhoods with regard to the consumption of specific consumer goods. It is also capable of estimating inequalities in the emissions resulting from resource use, such as carbon dioxide emissions from energy use, and solid waste arisings from material resource use. The indicator is designed to be used as a basis for broadening the discussion concerning 'food deserts' to inequalities in other types of resource use. By estimating the AR-Gini for a wide range of goods and services we aim to enhance our understanding of resource inequalities and their drivers, identify which resources have highest inequalities, and to explore trends in inequalities. Use of the AR-Gini is illustrated by pilot applications (specifically, men's and boys' clothing, carpets, refrigerators/freezers and clothes washer/driers). The results illustrate that different levels of inequality are associated with different commodities.

1. Introduction

In order to devise strategies to move to more sustainable lifestyles in an equitable and efficient fashion that is minimally disruptive of consumer choice, policy-makers will need to understand the empirical links between people's actual or potential consumption patterns and the associated resource consumption and emissions (Jackson 2006). They will need answers to questions such as: which particular kinds of consumption patterns and lifestyles are associated with more, and which with less energy consumption? What is the relative contribution to energy demand from different socio-economic, demographic, or geographical groups or lifestyle types? How much resource use is attributable to specific functional use categories such as housing, transport, food, leisure and clothing? How have these resource demands changed over time, and what is the relative contribution to these historical trends from technology, economic structure, price, income and so on? How might the level and structure of these demands change in the future? What might be the energy and carbon implications of specific structural or volume shifts in consumer behaviours and practices?

The Local Area Resource Analysis (LARA) model has been developed to start to answer some of these questions. LARA estimates the resource use of UK households grouped by highly socio-economically and geographically disaggregated areas. In this context 'resource use' includes both energy use and material resources involved in consumer goods and services. Additionally, LARA can also be used to estimate emissions associated with resource use, such as carbon dioxide emissions due to energy use, and solid waste arisings as a result of material resource use. Importantly, LARA has the ability to estimate total resource use and associated emissions, where the total includes the upstream (otherwise known as 'embedded' or 'indirect') resources or emissions used in the supply-chain during the production of consumer goods and services (Eurostat 2001; Rosenblum et al. 2000).

Results generated by LARA add to the evidence base in several ways. They can be used to estimate the household demand for resources (and associated emissions) in a given geographical area. They can also be used to estimate the resource use (and associated emissions) of specific socio-economic and lifestyle groups. Thus LARA can, in principal, relate household resource use and associated emissions to local institutional infrastructure, and this will give us an insight into the extent to which households are "locked" into unsustainable consumption patterns through the infrastructure in which they operate (DTI 2003; Jackson 2006; Sanne 2002).

In this paper we describe LARA's methodology and illustrate some results through two case studies. The first case study is estimation of household energy consumption and associated carbon dioxide emissions in the UK. This is demonstrated for two specific areas, which are small local neighbourhoods chosen to represent extremes of affluence and deprivation. This case study emphasises the highly geographically disaggregated nature of LARA. The second case study is estimation of average domestic energy use and associated carbon dioxide emissions for "typical" households in England and Wales in 2004/5. "Typical" households are based on the

UK National Output Area Classification (OAC). This case study highlights LARA's ability to explore the resource implications of the lifestyles of specific socio-economic groups.

Further examples of results from LARA are described in other publications. Estimation of trends in meat consumption in areas of contrasting relative deprivation are described in Druckman et al (2005). In Druckman et al (2007), estimation of household resource use due to purchases of consumer commodities such as carpets, household appliances and clothing is illustrated for specific neighbourhoods representing each OAC Supergroup and also for neighbourhoods of extreme deprivation and affluence.

Two major applications of results from LARA have been developed to date and are also described in this paper. The first is use of LARA to estimate local household waste arisings based on neighbourhood socio-economic characteristics. Some types of wastes, such as packaging and food waste, are assumed to enter the waste stream in the year of product purchase. Estimation of these wastes is illustrated by a case study on glass waste arisings due to wine and champagne consumption. Waste arisings due to products with longer lifespans are assumed to depend on future product demand and the time for which commodities reside in households. To illustrate estimation of these wastes pilot results are presented for waste arisings due to carpets for three contrasting scenarios from 1996 to 2020.

The second application of LARA is the development of an area-based indicator based on results from LARA. The indicator, named the AR-Gini, estimates inequalities between neighbourhoods with regard to the consumption of specific resources (or associated emissions). The indicator is designed to be used as a basis for broadening the discussion concerning fuel poverty and food deserts[1] to other resource inequalities. The paper describes the methodology underlying the construction of the AR-Gini and illustrates its use for several pilot applications. Specifically, results are reported for men's and boys' clothing, carpets, refrigerators/freezers and clothes washer/driers).

To date, LARA has been used to model direct resource use and associated emissions only, thus excluding upstream resources and emissions. Full resource versions of LARA are currently being developed, based on input-output analysis (Jackson and Papathanasopoulou 2007; Jackson et al. 2006a; Leontief 1986; Miller and Blair 1985; Proops et al. 1993). One version will estimate upstream (indirect) waste arisings (Bradley et al. 2006; Bradley et al. 2007), and a further version will model direct and indirect energy use and associated carbon dioxide emissions.

This paper is organised as follows: after setting out the background in Section 2, we describe the methodologies in Section 3. Section 3 commences with the methodology used for LARA itself (Sections 3.1 and 3.2) and the methodologies used in two

[1] A basic definition of 'food deserts' is that they are '*areas of relative exclusion where people experience physical and economic barriers to accessing healthy food*' (Shaw 2006:231).

applications of LARA follow, with estimation of household waste arisings in Section 3.3, and estimation of inequalities in Section 3.4. Sample results are presented in Section 4, with estimates of household energy use and associated carbon dioxide emissions in specific neighbourhoods representing extremes of deprivation in Section 4.1; mean household energy use and associated emissions by OAC Supergroups in Section 4.2; estimation of household solid waste arisings in Section 4.3; and estimation of resource inequalities in Section 4.4. As mentioned above, LARA can also be used to estimate local household expenditures, and illustration of this is included in the results in Section 4.2. Section 5 describes some of the limitations of the model, improvements that could be made, and possible future work. The paper concludes with a summary of LARA's concept, methodology and two applications, and how it may be of use to policy-makers

2. Background

Resource intensive lifestyles present a major challenge to sustainability: resources are finite and the limited capacity provided by the environment for disposal of waste emissions is a major cause of global environmental problems such as climate change (Bringezu and Moriguchi 2002; Hertwich 2005b; Jackson 1996; Jackson 2006; Tukker et al. 2005). In order to move towards more sustainable lifestyles we need to develop an understanding of resource use and their associated emissions. As stated in the introduction, the Local Area Resource Analysis (LARA) model has been developed to address this task.

The chosen unit of analysis in LARA is households, which are considered to be major drivers of consumption and the associated environmental degradation (European Environment Agency 2005). In economic terms, household expenditure is the largest final demand category in most countries (Hertwich 2005a), and household expenditure represented 49% of total final demand in 2004 in the UK (Office for National Statistics 2002). In terms of environmental impacts, published studies, which focus on energy rather than material resource use, have found that over 70% of the total energy demand and associated carbon emissions in the UK economy are attributable (directly and indirectly) to household goods and services (Jackson and Papathanasopoulou 2004; Jackson et al. 2006a; Jackson et al. 2006b).

As stated in the Introduction, LARA analyses resource use of households grouped into small, highly socio-economically disaggregated areas. The area basis of LARA has been chosen as many strategies aimed at reducing resource demand are best pursued at the level of geographical areas or social communities. For example the UK Sustainable Development Strategy proposes that behaviour change towards more sustainable lifestyles can be approached by focusing on policies that *enable*, *encourage*, and *engage* people and communities towards more sustainable behaviour (HM Government 2005). Strategies for *enabling* pro-environmental choice include providing facilities such as convenient local recycling provisions and good public transport, and a move towards provision of services to consumers instead of goods (Femia et al. 2001; Jackson 1996). Strategies for *encouraging* people in initiatives to help themselves include incentive schemes, such as road pricing, grants for home insulation, and the promotion and celebration of successful community action schemes. Strategies for *engaging* consumers in a more resource lean lifestyle include support through the provision of opportunities for community involvement in local action plans, such as projects funded by Defra through the Environmental Action Fund (EAF) (Defra 2006; Sustainable Consumption Roundtable 2006). The UK Sustainable Development Strategy also proposes that the government needs to lead by example (i.e. *"exemplify")* with clear and consistent messages, for example through its Vision for Sustainable Communities. Thus it can be seen that a model that focuses on the resource use and associated emissions of local neighbourhoods is of relevance to current UK policy initiatives.

LARA can be applied to a range of resource use and associated emissions, including, for example, resources and waste arisings due to clothing, food and household appliances. A particularly important resource use, with respect to climate change, is household energy consumption, which is responsible for approximately 30% of total UK energy use and approximately 27% of total UK carbon dioxide emissions (HM Government 2006). This energy is used for space and water heating, cooking, lighting and electrical appliances, with approximately 53% of household carbon emissions being due to space heating, 22% due to water heating, and 22% due to lights and appliances (HM Government 2006). In this paper we demonstrate use of LARA to explore patterns of household energy use.

Two of the major factors that effect the energy performance of a dwelling are its type (for example, detached, semi-detached or terraced house, bungalow or flat) and the level of energy saving measures installed. The average heat loss of different types of dwellings range from 365W/^{o}C for a detached house down to 182 W/^{o}C for a flat (see Table 1) .

Table 1. Typical average heat loss of dwelling types

Type of dwelling	Heat loss (W/^{o}C)
Detached	365
Semi-detached	276
Terraced	243
Bungalow	229
Flat	182
UK mean	259

Source: Shorrock and Utley (2003: page 34)

Investment in energy efficiency measures such as loft insulation varies with the type of tenure (Utley and Shorrock 2006). For example, in 2004, registered social landlord (RSL) dwellings had the highest proportion of dwellings (21%) with 15cm or more loft insulation[2] (Utley and Shorrock 2006). The sectors with the next highest

[2] This is because the registered social landlord sector is a relatively new sector, comprising only 2.3% of households in 1981 rising to 10.3% in 2004. The age of the housing stock in the sector is relatively young: it has a small number of pre-1918 homes and a high proportion of 1972 homes. Newer dwellings are built to higher energy efficiency standards and this is the reason why dwellings in this sector have, on average, higher thermal insulation than other tenures. See for example: (Shorrock and Utley 2003; Utley and Shorrock 2006).

proportion of homes with 15cm or more loft insulation are the owner occupied sectors (20%), and local authority rented dwellings (16%). The lowest proportion of dwellings with this depth of loft insulation are in the private rented sector, with just 9% of dwellings reaching this standard. This is because there is a mismatch in this sector between the party paying the costs of installing energy efficiency measures (the landlord) and the party receiving the benefits (the tenant) (Oxera 2006; Wilkinson and Goodacre 2002). This is a type of market failure known as the 'tenant-landlord problem' (Jackson 1992; RCEP 2000) and is the reason why dwellings in this sector have, on average, relatively low thermal insulation.

Household energy demand and associated carbon emissions are also dependent on choice of internal temperature, the average of which has risen by about 6^{o}C between 1970 and 2001 (Shorrock and Utley 2003). This rise in mean internal temperature may be considered to be a lifestyle choice. Similarly, energy use for water heating and wet appliances, such as dishwashers and washing machines, depends on technical factors such as the efficiency of the appliances. But the energy use is again also related to lifestyle choices, such as the number of times clothes are worn before being washed, or the frequency of and time taken showering. Total household energy use is therefore complex to model, as it must take account of a wide variety of technical and lifestyle factors.

Another factor that may be considered to effect household energy consumption is affordability. In the UK energy prices for domestic consumers are relatively low: gas prices (including taxes) are amongst the lowest in EU 15/G7, and electricity prices are below the median (DTI 2006). However, many UK households struggle to afford adequate heating for their homes. In fact there are around 2 million households who live in fuel poverty, which is defined as a household that has to spend more than 10% of its income on energy to heat its home to an adequate standard (DTI 2006). Whether a specific household is in fuel poverty or not depends on three major factors: the energy performance of the dwelling, the cost of energy and household income (DTI 2006).

In recent years there have been high increases in the retail price of fuels in the domestic sector. For example, the price of domestic gas rose by, on average, 16.0% between the first quarter of 2003 and the first quarter of 2005, and that for electricity rose by 10.6% over the same period (DTI 2005). The UK domestic energy market has been changing since market liberalisation in 1998. Traditionally, households were supplied by their local energy suppliers (known as their "home" supplier), but now customers have started to move away from their home suppliers. By the end of March 2005 43% of electricity consumers and the same percentage of gas consumers had moved away from their home suppliers (DTI 2005). Nevertheless, this leaves over 50% of consumers still with their home suppliers, and energy prices, even under the liberalised market regime, still have significant variation on a regional basis. Furthermore, a variety of methods of payment are available to domestic consumers, and these attract different tariffs. For both gas and electricity, customers paying by direct debit pay less than customers on other tariffs (DTI 2005). Thus the price structure for domestic fuels in 2004-05 was unstable, complex and fragmented.

From the above discussion it can be seen that analysis of the energy consumption of households should, as a minimum, take account of type of dwelling and tenure as well as income. The Local Area Resource Analysis (LARA) model described in this paper categorises households according to tenure and type of dwelling, as well as the age and economic status of the head of the household, which are used as proxies for income.

In the Introduction we emphasised the importance of avoiding regressive policies. Running in parallel to the fuel poverty debate is a discourse concerning food deserts (see, for example Shaw (2006), Guy et al (2004) and Clarke et al (2004)). In this paper we show how LARA can be used to extend the debate by adapting the Gini coefficient, which is a commonly used indicator of income inequality, to produce a new area-based indicator of resource inequality.

The conventional Gini coefficient is generally applied to measure income inequalities, but has been extended to study expenditure inequality by Goodman and Oldfield (2004). Goodman and Oldfield argue that expenditure inequality tends to reflect long-run or lifetime differences in people's circumstances, whereas income inequality has more short-term volatility. This is because people counteract fluctuations in income by saving when income is relatively plentiful and using savings when income is relatively lean. A worrying counter argument to this is that households are increasingly maintaining living standards by incurring debt (Department of Trade and Industry 2005), and therefore inequalities based on expenditure patterns may be masking underlying increasing inequality.

Papathanasopoulou and Jackson (2007) calculated a resource-based Gini coefficient using an input-output based resource allocation model to quantify fossil resource inequalities amongst income quintiles in the UK between 1968 and 2000. Their results show that the Gini coefficient for total fossil resource consumption grew by 24% over the time period. By comparison the Gini coefficient for overall household expenditure rose by only 13%. The increase in resource inequality was prompted by the rising demand by high income quintiles for goods and services such as: "fuel & light" (heating and lighting the home), "car use" (private transportation), "recreation", "travel" and "other services". Their analysis further shows that the Gini coefficient for "direct" fossil resources ("fuel & light" and "car use") was lower and rose less steeply than the Gini coefficient for fossil resources embodied in other goods and services (indirect fossil resource requirements).

3. Methodology

As stated in the introduction, LARA estimates resource use of households grouped by highly socio-economically and geographically disaggregated areas. These areas are based on Output Areas (OAs) as defined in the UK 2001 Census (Office for National Statistics 2006). OAs are small areas of approximately 124 households on average, that are as socially homogenous as possible, based on tenure of household and dwelling type. Census 2001 is considered the most complete and reliable socio-economic dataset available in the UK, providing an incomparable depth of information with comprehensive geographical coverage (Vickers et al. 2005). LARA's use of OAs gives the highest level of geographical detail available. LARA uses the Census 2001 definition of a household unit, which defines a household as "*one person living alone, or, a group of people living at the same address with common housekeeping – that is, sharing either a living room or at least one meal a day*" (Office for National Statistics 2001). Each household has a designated Household Reference Person (HRP) who, for a person living alone is that person, or for more than one person, is chosen on the basis of their economic activity, followed by age (Office for National Statistics 2001).

The main dataset used in LARA is the Expenditure Survey[3] which is an annual national survey of approximately 7,000 households. This sample size is not large enough to give information at Output Area level directly, and therefore an indirect approach is adopted in order to obtain information at Output Area level. In this indirect approach, data from the Expenditure Survey are combined with data from the Census 2001. This is a typical example of a small area estimation problem (Chambers and Chandra 2006; Heady et al. 2003; Rao 2003) and the methodology adopted in LARA may be described as a 'conditional mean value replacement' approach.

In this paper, the methodology is first described for the basic version of LARA. This version of LARA assumes that prices for resources are constant across regions and during each annual accounting period. This asssumption is considered valid for most consumer goods and services and is used to estimate resource use for various commodities such as clothing and household appliances (Druckman et al. 2007). In order to take account of the varying market conditions for modelling domestic fuels consumption (see Section 2) the methodology has been enhanced. The basic LARA methodology is described in Section 3.1, and a description of the modifications follows in Section 3.2.

3.1 LARA for a price constant market

In this section we commence by giving a high level description of LARA's methodological approach, with reference to the high level system diagram shown in Figure 1. This diagram illustrates the indirect approach used to estimate average

[3] The Expenditure Survey comprises the Expenditure and Food Survey (EFS), undertaken annually from 2001-02, which replaced the Family Expenditure Survey (FES) and the National Food Survey (NFS) which were undertaken annually in prior years (Office for National Statistics Various years).

annual household spending in an Output Area (OA). In this approach the socio-economic and demographic characteristics of households in each OA are found from the Census. The average expenditure of households with matching socio-economic characteristics is then calculated from the Expenditure Survey. These data are used to estimate average household expenditure in each OA. Expenditure is then converted into resource demand using price data.

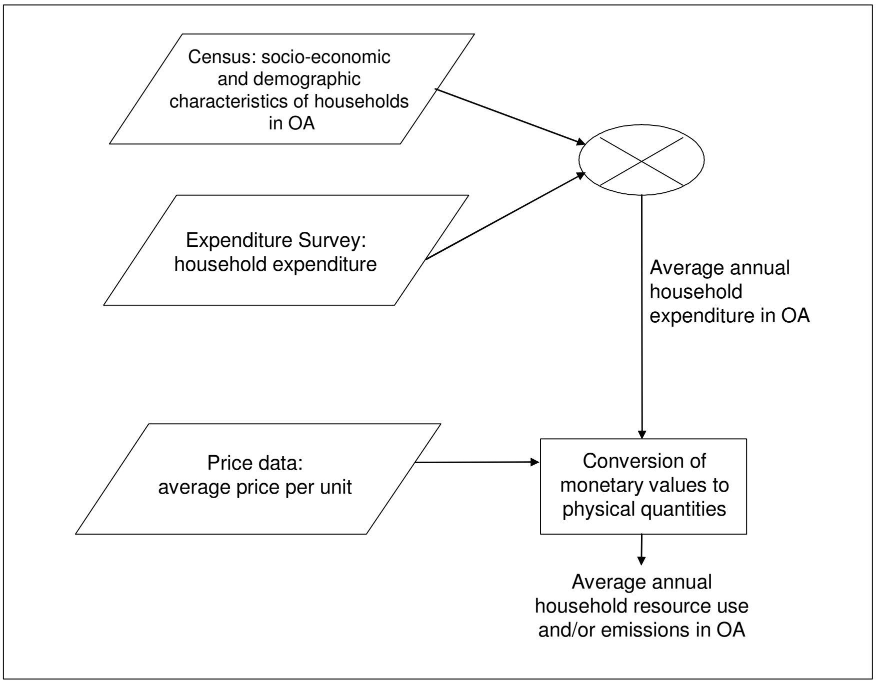

Figure 1. LARA high level system diagram

The methodology is now described in further detail with reference to the more detailed system diagram shown in Figure 2.

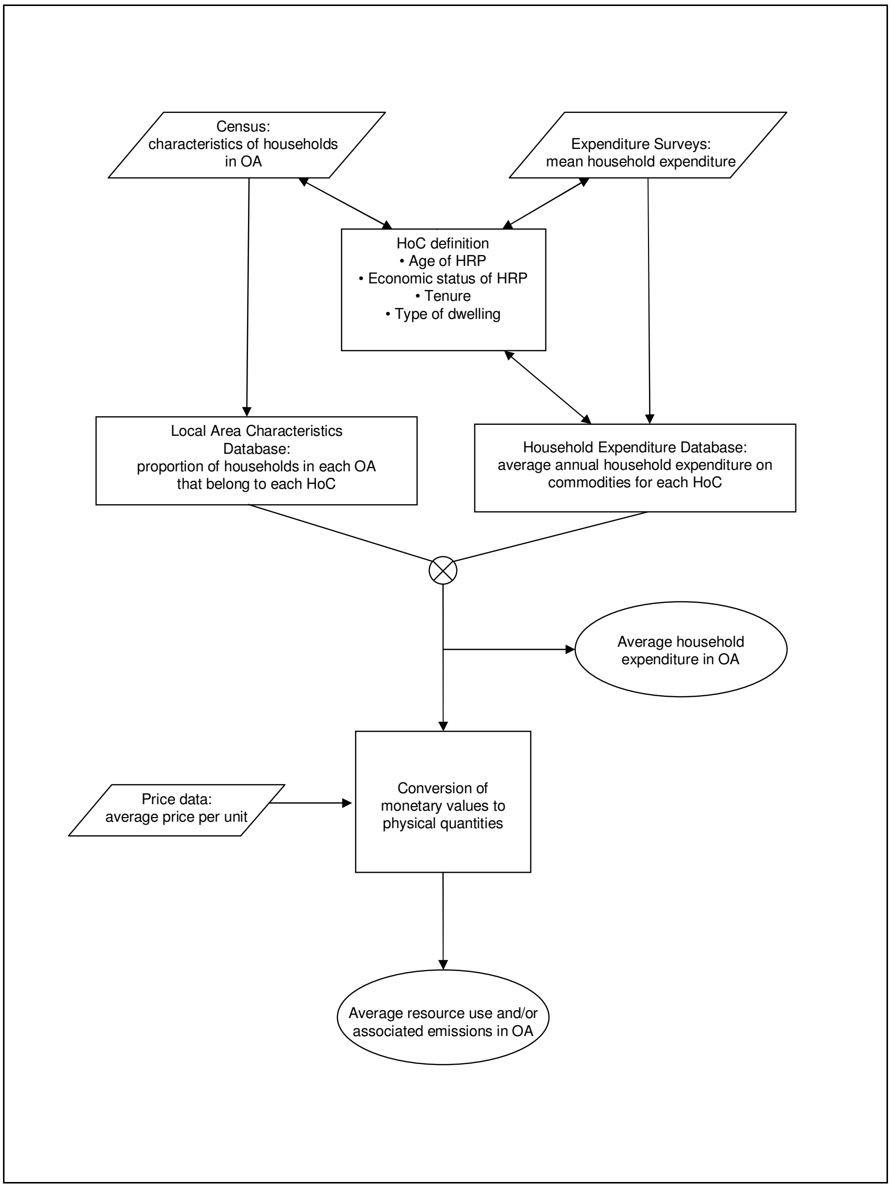

Figure 2. System diagram

Households in each OA are classified into Household Categories (HoCs). Table 2 shows how each of the 45 HoCs (labelled A-AS) is uniquely described by the characteristics of age and economic status of the Household Representative Person (HRP) and by type of dwelling and tenure. Appendix 1 gives more detail concerning the definition of HoCs. The proportion p_i of households in a local area that belong to each HoC i is found from the Census. For example, in one highly affluent local area the percentage of households in HoC category F (defined as HRP aged 30-49, employed, in a detached house which he/she owns) is 59% so p_F=0.59. In a highly deprived area where there are no households in this category p_F=0.00. The set of p values for each local area is held in the Local Area Characteristics Database, as shown in Figure 2.

Table 2. Definition of household characteristics classification (HoC)

HoC			Dwelling											
			Owned				Private rented				Social rented			
	Age of HRP	Economic Status of HRP	Detached	Semi	Terraced	Purpose Built	Detached	Semi	Terraced	Purpose Built	Detached	Semi	Terraced	Purpose Built
Household Representative Person (HRP)	<30	Employed	A	A	B	B	E	E	E	E	D	D	D	D
		Unemployed/Economically inactive	C	C	C	C	C	C	C	C	C	C	C	C
	30-49	Employed	F	G	H	I	Q	Q	R	R	K	K	L	M
		Unemployed/ Economically inactive	J	J	J	J	S	S	S	S	N	N	O	P
	50-64	Employed	T	U	V	W	AE	AE	AE	AE	AA	AA	AA	AA
		Unemployed/Economically inactive	X	Y	Z	Z	AE	AE	AE	AE	AB	AB	AC	AD
	65-74	N/A	AF	AG	AH	AI	AF	AG	AH	AI	AJ	AJ	AK	AL
	>74	N/A	AM	AN	AO	AP	AM	AN	AO	AP	AQ	AQ	AR	AS

Explanatory Notes

Detached: Detached house or bungalow.
Semi: Semi-detached house or bungalow
Terraced: Terraced house or bungalow; flat, maisonette or apartment which is part of a converted or shared house; or in a commercial building.
Purpose Built: Purpose built flat, maisonette or apartment, caravan or other mobile structure.
Private Rented: Rented, private or rent free
Social Rented: Rented, from council or Registered Social Landlord or Housing Association.
Employed: Full-time/part-time employee or self employed

Expenditure data are obtained from the Expenditure Survey[4] (Office for National Statistics Various years). The Expenditure Survey captures detailed family spending for a sample of approximately 7,000 households per annum and includes details of household characteristics. By classifying each case study household in the Expenditure Survey into its appropriate HoC, average annual expenditure (e_i) of each

[4] The Expenditure Survey uses multi-stage stratified random sample with clustering methodology with addresses being drawn from the Small Users file of the Postcode Address File. Postal sectors (ward size) are the primary sample unit. As stated above, the smallest geographic unit for which data from this are made available are Government Office Regions, of which there are 9 in England. Further details concerning the sampling process can be found in Office for National Statistics (2004).

HoC is calculated. This is held in the Household Expenditure Database (Figure 2). Expenditure data are classified in functional use categories until 2000-01, and according to Classification of Individual Consumption by Purpose (COICOP) (United Nations 2005) thereafter.

Average household expenditure E^{kl} on consumer commodity k in local area l is found by summing the average annual expenditure e_i^k of households in HoC i on commodity k (from the Household Expenditure Database) weighted by the proportion p_i^l of households in local area l that are members of HOC i (from the Neighbourhood Characteristics Database).

$$E^{kl} = \sum_{i=1}^{i=N} p_i^l e_i^k \tag{1}$$

where
E^{kl} = average annual household expenditure in local area l, on commodity k
p_i^l = proportion of households in local area l, that are members of HoC i
e_i^k = average annual household expenditure commodity on k, of households in HoC i
i = HoC number, such that i=1 to N, where N= total number of HoCs (N=45)

In order to produce time-series results, adjustments are made to E^{kl} to account for inflation by normalising expenditure to 2005 prices using the Consumer Prices Index (CPI)[5].

Physical material flows are calculated from expenditure, E^{kl} by using price data from a variety of sources. The sources used for domestic energy are addressed in Section 3.2. For food and drink, information from Family Food (which is part of the Expenditure Surveys) is used, where annual data on average expenditure per capita and consumption in physical units (kg, litres) are given (Office for National Statistics 2003); from this the average price per unit of physical commodity is calculated for each year. For other consumer commodities UK Trade Data are used[6]. This dataset provides import and export data in both monetary and weight terms for a range of commodities, from which the average price per unit weight of goods is computed[7]. Ideally domestic production data would also be used. These are available from PRODCOM[8]. However, due to disclosure issues, there are gaps in this dataset at high levels of disaggregation. Therefore only import data are used in the current version of the model, under the assumption that imports are competitive with domestic production. As domestic production often represents the high quality end of the

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[5] Available from the Office for National Statistics (www.statistics.gov.uk).
[6] Available from UKTradeInfo (www.uktradeinfo.com/).
[7] UK Trade Data provides data on gross weight of commodities, which includes the weight of packaging; this is assumed to be negligible for the commodities selected from this data.
[8] PRODucts of the European COMmunity (PRODCOM) is a survey of UK manufacturers carried out by The Office for National Statistics (Office for National Statistics 2005a).

market, the monetary price per unit weight may be under-estimated in the model, and therefore total weight demand slightly over-estimated.

3.2 LARA for a price varying market

The methodology described above is based on the assumptions that (a) prices of consumer goods can be assumed to apply nationally and that regional variations are not significant; (b) prices are constant throughout each sample year. As described in Section 2, domestic energy prices have historically varied regionally, and, in recent years prices have fluctuated significantly within the accounting year. To take account of these market conditions, LARA's methodology is modified as described below.

Under price constant assumptions, equation (1) is calculated in terms of expenditure. In a price varying market, equation (1) is calculated in terms of resource use, or associated emissions. Thus instead of expenditure data being held in the Household Expenditure Database, as described above, energy and associated emissions data are held in a Household Energy Database.

The enhancements to LARA's methodology require three steps of data preparation to prepare data for the Household Energy Database: (1) household expenditure on each type of fuel is taken from the Expenditure and Food Survey (EFS); (2) household expenditure is converted to quantity of energy used, using price information for each type of fuel; (3) carbon dioxide emissions are estimated by using carbon emissions factors for each type of fuel.

3.2.1 Household expenditure on fuel

The Expenditure and Food Survey (EFS) gives details of the expenditure by each of the sampled households in the survey on household fuels by the various payment methods shown in Table 3.

3.2.2 Estimation of energy use

As described above, fuel prices vary regionally and there were also significant price rises during the year of study (2004-05). Furthermore, prices also vary depending on the type of payment method used (Table 3). In order to reflect these variations a matrix of energy prices was developed by the Centre for Sustainable Energy (CSE)[9]. The matrix of prices gives the price paid for each type of fuel for each Government Office Region, for each payment method and for different time bands (April-July 04; August-December 04; January-March 05). The prices are based on data from DTI[10], Sutherland (SALKENT) Tables[11], EnergyWatch[12] and BRE[13]. Further details

[9] See http://www.cse.org.uk/
[10] See http://www.dti.gov.uk/energy/statistics/publications/prices/index.html
[11] See http://www.sutherlandtables.co.uk/
[12] See http://www.energywatch.org.uk/
[13] See http://www.bre.co.uk/

concerning the methodology used in compiling this price matrix is given in Preston (2007).

Table 3. Fuel categories and their carbon dioxide emissions factors

Payment categories	Price categories	Carbon dioxide emission factor (kg CO2 per kWh)
Electricity Slot meter Account Board budget scheme Second dwelling	Electricity Pre-payment Credit Direct debit Credit	0.526[14]
Gas (metered) Slot meter Account Board budget scheme Second dwelling	Gas (metered) Pre-payment Credit Direct debit Credit	0.190
Other Fuels		
Bottled gas for central heating	Bottle Gas Propane	0.214
Bottled gas – other	Bulk LPG[15]	0.214
Coal & coke	Coal	0.320
Oil for central heating	Heating oil	0.245
Paraffin	Heating oil	0.259[16]
Wood & peat	Wood	0.025

Energy consumption for each EFS case household is calculated by dividing expenditure by the appropriate price. From this the mean UK energy consumption is estimated. A validation check and adjustment process is carried out to ensure that the figures used in this study (which are generated from household expenditures) concur with published delivered energy totals from other sources. The estimated total UK consumption from this study for each type of fuel is found by scaling up to the number of households in the UK[17]. These totals are compared to the UK delivered fuel totals published in Energy Trends (DTI various years) and in the Digest of United Kingdom Energy Statistics (DUKES) (Department of Trade and Industry various years). The ratio of the results expected from DUKES to those estimated in this study is found and the estimations are adjusted as necessary to ensure

[14] The carbon dioxide emission intensity factor for electricity is based on total carbon due to electricity generation of 46.38mtC provided by AEA Energy & Environment from the 2007 NAEI / UK Greenhouse Gas Inventory. Total electricity supply is taken generation the Digest of UK Energy Statistics 2006 (DUKES) Table 5.6 and losses are accounted for according to DUKES Table 5.2. DUKES is available from http://www.dti.gov.uk/energy/statistics/publications/dukes/page29812.html. The figure is very close to that of 0.527kg CO2/kWh published by Defra (2007).

[15] LPG is the generic name for commercial propane (http://www.lpga.co.uk/fr_ab_lp.htm)

[16] The value for Kerosene (or "Burning Oil") is used.

[17] The total number of households in the UK is taken from the EFS 2004-05. This is an estimate only, as the true number of households is unknown, and measurements are only attempted every 10 years through the census.

agreement with published UK totals. This adjustment is required as, in essence, this study uses a sample of approximately 7,000 households to estimate total fuel demand in the UK. The households used in the EFS will not necessarily have been chosen to be representative of UK households in terms of energy use, hence an adjustment is expected. Additionally, various inaccuracies in the price matrices and combining them with energy consumption may contribute to the potential discrepancies (see Section 5 for more details).

3.2.3 Estimation of carbon emissions

The carbon emissions factors used to estimate the amount of carbon dioxide emitted due to use of each type of fuel are shown in Table 3. These carbon emissions factors are obtained from Defra (2005), IPCC (1997), the 2007 NAEI/UK Greenhouse Gas Inventory and the Digest of United kingdom Energy Statistics (Department of Trade and Industry 2006). The carbon emissions estimated for electricity and gas are assumed not to require adjustment, but inaccuracies arise in the emissions estimated due to 'Other Fuel' use. This is mainly due to the small number of household cases in the EFS that purchased Other Fuels. The adjustment procedure is carried out on the lines described above, but applied to Other Fuels only.

3.3 Choice of case studies

LARA has been used to estimate household energy use and associated carbon dioxide emissions for each of the 175,434 Output Areas in England and Wales. To demonstrate this we have chosen just two Output Areas, chosen to represent extremes of relative deprivation. These areas were selected with reference to the Index of Multiple Deprivation (IMD) 2004 (Office of the Deputy Prime Minister 2003)[18] and are within the lowest and highest 1% on the IMD scale.

By classifying each of the Output Areas according to a segmentation system (Anable 2005; Barr et al. 2006; Darnton and Sharp 2006; Energy Savings Trust 2006; Hora and Ursula 2004) such as the UK National Output Area Classification (OAC) system (Vickers and Rees 2007; Vickers et al. 2005), or commercial systems such as Acorn (CACI Ltd 2005) or Mosaic (Experian 2003), LARA can be used to estimate the resource use (and associated emissions) of typical socio-economic or lifestyle groups. In this paper the UK National Output Area Classification (OAC) segmentation is chosen. OAC classifies OAs into 7 Supergroups called, for example '*Prospering Suburbs*', '*Constrained by Circumstances*', '*Countryside*' and '*Multicultural*' (Vickers et al. 2005).

[18] The IMD measures deprivation based on performance in seven domains: income; employment; health and disability; education, skills and training; barriers to housing and services; living environment; and incidence of recorded crime in the area (Office of the Deputy Prime Minister 2003).

3.4 Use of LARA to estimate household waste arisings

This part of the study shows how direct resource use calculated using LARA can be used to estimate household waste arisings. For the purposes of this paper all commodities that are discarded from households are classed as waste arisings: no distinction is made between various disposal options such as re-use, recycling or remanufacturing.

Household waste arisings depend on gross mass of material resources entering households, the nature of the commodity, its packaging, and the time for which the commodity resides in the household before being discarded. It is reasonable to assume that all packaging has a short lifespan and some commodities, typically food and drink, also have short product lifespans; for these items we assume that the time in stock is less than one year and therefore waste arises in the year the product is purchased. To demonstrate estimation of household waste arisings due to short product lifespan commodities, glass waste from wine and champagne consumption in two case study areas is modelled. The calculation assumes all purchases in this category are packaged in 750ml glass bottles. The average weight of a wine bottle is assumed to be 0.47kg (British Glass Manufacturer's Confederation 2006), and this is adjusted proportionally to take account of the weight of champagne bottles using empirical measurements. From this the average mass of glass per litre fluid is found, and hence the mass of waste arisings is estimated.

To estimate waste arisings due to items that remain in stock for a number of years the Weibull function is used (Davis et al. 2006). The Weibull function is considered preferable to a normal distribution as it enables all material resources to eventually fail and enter the waste stream, whereas with a normal distribution some products never enter the waste stream (Spatari et al. 2005). The Weibull distribution does not take account of failures that occur early in the product life, but, as these are generally manufacturing faults, it is assumed that such commodities are taken back by distributors and therefore do not enter the domestic waste stream.

Using the Weibull distribution, the mass W_p^x of commodity entering the waste stream at year x due to purchase of mass m_p of commodity in each prior year p of the study ($0 \le p \le x$) is given by:

$$W_p^x = \sum_{p=0}^{p=x} m_p \left(\frac{\alpha}{\beta^{\alpha}} \right) x^{(\alpha - 1)} e^{-\left(\frac{x}{\beta} \right)^{\alpha}} \qquad (2)$$

where

α is the shape parameter, which is set to 4 in order to approximate a normal distribution curve (Spatari et al. 2005)

β is the scale parameter, set to mean residence time; this is the number of years within which 63.2% of the product will have failed (Minitab 2005).

x is the year at which to evaluate the mass entering the waste the waste stream

m_p is the mass of product purchased in year p ($0 \le p \le x$)

The time for which a commodity resides in a household is represented by mean residence time *β* in Equation 2. This is assumed to be partly determined by manufacturer's designed product lifespan and partly by the household metabolism. The household metabolism may be related to household socio-economic characteristics and lifestyles (Alexander 2006; B. Muller 2006; Moll et al. 2005). Use of LARA combined with the Weibull function enables household waste arisings to be estimated, in principle, specific to local area characteristics by modulating mean residence time (*β*) depending on the set of *p* values held in the Local Area Characteristics Database.

The methodology is demonstrated for a sample commodity ('Carpets and rugs') in one case study area for three different scenarios (High Sustainability, Low Sustainability, and Constancy) for years 1996/7-2018/9. The assumptions made in each of these scenarios are summarised in Table 4. High Sustainability assumes that product lifespans increase and demand decreases after 2003/4, and Low Sustainability assumes that product lifespans decrease and demand increases after 2003/4. Constancy assumes constant lifespans and demand after 2003/4. For the purposes of this exercise, changes in product lifespans are assumed to combine effects due to manufacturer's design life and household metabolism effects.

Table 4. Assumptions concerning product lifespans and demand for 'Carpets and rugs' for three scenarios.

Scenario	Years	Product Demand	Product Lifespan
High sustainability	Pre 1996/7	As found from LARA for 1996/7	10 years[a]
	1996/7 – 2003/4	As found from LARA	Increases by 2.5% p.a.
	Post 2003/4	Decreases by 2% p.a.	
Low sustainability	Pre 1996/7	As found from LARA for 1996/7	10 years[a]
	1996/7 – 2003/4	As found from LARA	Decreases by 1.0% p.a.
	Post 2003/4	Increases by 2% p.a.	
Constancy	Pre 1996/7	As found from LARA for 1996/7	10 years[a]
	1996/7 – 2003/4	As found from LARA	Constant (10 years)
	Post 2003/4	Constant, as found from LARA for 2003/04	

[a] Average product lifespan is taken from Holloway et al (2002).

3.5 Use of LARA to explore inequalities

This section of the paper explains how results from LARA can be used to explore inequalities between small local areas (OAs). We show how results from LARA are used to calculate an Area-based Resource Gini (AR-Gini) coefficient which is based on the conventional Gini coefficient. The following paragraphs describe the Gini coefficient and the AR-Gini coefficient.

The Gini coefficient is a measure of income inequality. It is measured as "*half of the arithmetic average of the absolute differences between all pairs of relative incomes, the total being normalized on mean income*" (Barr 1998: page 151). An easier way to explain the Gini coefficient is to draw a graphical representation using the Lorenz curve, as shown in Figure 3. Figure 3 shows a plot of cumulative household income against cumulative population. In a totally equitable society, 50% of the population would have 50% of total income (represented by point P on the graph), and the income distribution would be given by straight line AB. In a less equitable society, income distribution may be represented by curve AQB; in this case 50% of the population may have, say, just 15% of total income. The shaded area is a measure of the extent of inequality in income: the larger the shaded area the higher the inequality. The Gini coefficient is calculated as the ratio of the shaded area to the area of triangle ABC. Thus a Gini coefficient of 1 represents absolute inequality, and a Gini coefficient of 0 represents perfect equity.

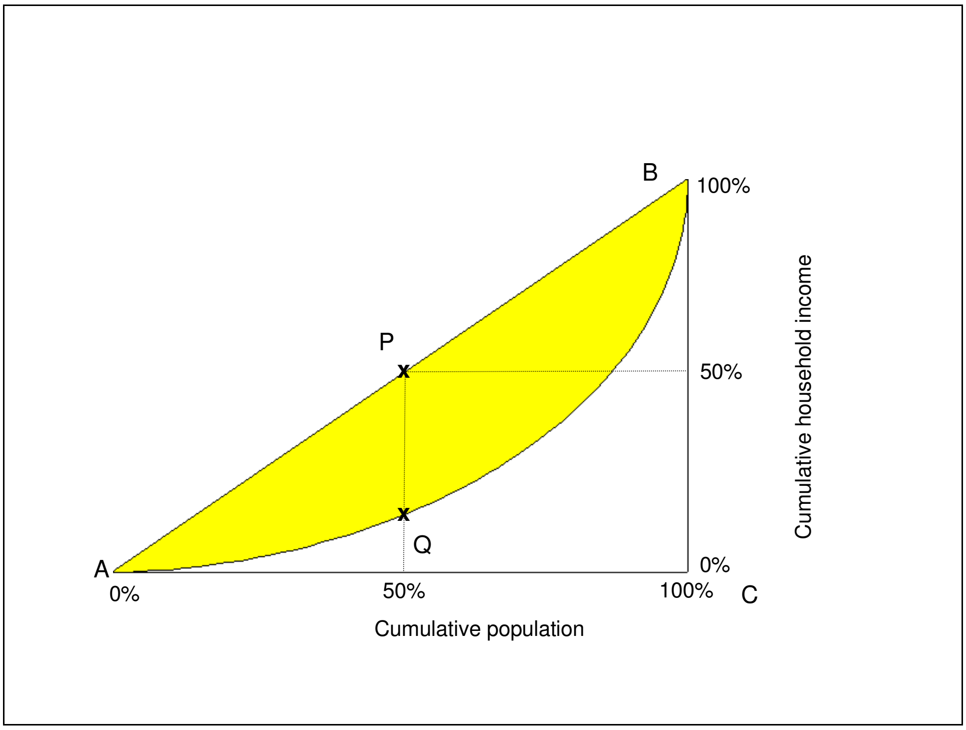


Figure 3. Calculation of Gini Coefficient using the Lorenz curve.

Source: Goodman and Oldfield (2004).

As stated above, this study extends the use of the Gini coefficient by demonstrating a methodology for calculating the Area-based Resource Gini (AR-Gini) coefficient, which is a measure of resource inequalities by area. The AR-Gini differs from the conventional Gini coefficient in two ways. First it is a measure of inequality in terms of resource use instead of being a monetary measurement; in other words, it reflects resource inequalities in society. The second way in which the AR-Gini differs from the conventional Gini is that it is calculated on an area-basis, giving a measure of inequality by comparing the resource use of neighbourhoods, whereas the conventional Gini compares household or per capita incomes or expenditures. Table 5 summarizes the differences between the AR-Gini and the conventional Gini.

Table 5. Comparison of AR-Gini coefficient with conventional Gini coefficient

AR-Gini (Area Resource Gini)	**Gini**
Calculated on an area basis	Calculated on a per capita or household basis
Calculated on a resource basis	Calculated on a monetary basis

In this paper the AR-Gini for selected consumer commodities ('Carpets and rugs', 'Clothes washing and drying machines', 'Refrigerators, freezers & fridge freezers', and 'Men's and boys' outer clothing') is calculated using LARA. For comparison purposes, an area-based expenditure Gini for 'Total expenditure', and also an expenditure Gini coefficient for 'Total expenditure' calculated on a household basis are also calculated.

Estimation of the AR-Gini requires data to be available for calculation of the resource use using LARA for every Output Area in England and Wales. However, at the time this work was carried out, the complete dataset from the Census covering all England and Wales at Output Area level was unavailable. Therefore a dataset at a less detailed geographical level has been used to demonstrate the methodology. The dataset we used covers England and Wales at Ward level. Wards are larger than Output Areas and are not socio-economically homogeneous[19]. Therefore, using Wards instead of Output Areas leads to a loss in the level of detail of pockets of extreme deprivation and extreme affluence that can be identified using the model, thus in future work the AR-Gini will be calculated on Output Area basis.

Although the AR-Gini is primarily an indicator of resource inequalities, it can of course be applied to estimate inequalities in carbon emissions.

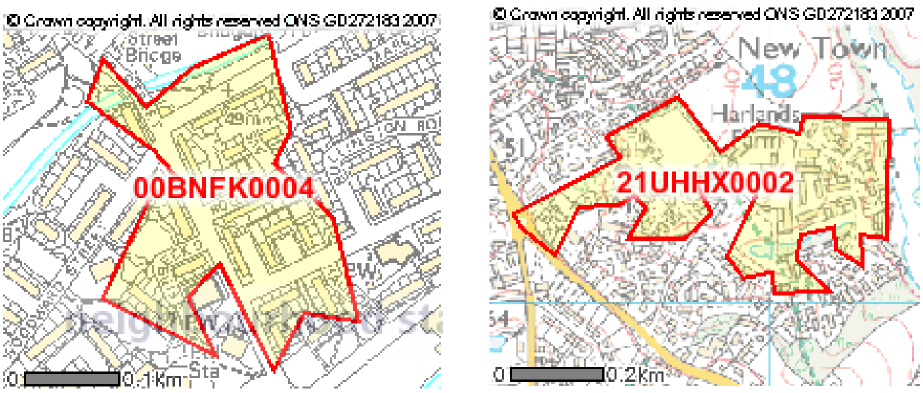
[19] There are 8,800 Wards in England and Wales compared to 175,434 Output Areas.

4 Results

In the sections that follow we first illustrate of estimates of domestic energy consumption (and associated emissions) obtained from LARA for 2004/5 (Sections 4.1 and 4.2). The results of two applications of LARA are then presented: Section 4.3 shows estimates of local household waste arisings, and Section 4.4 shows pilot estimates of the AR-Gini.

4.1 Household energy use for specific Output Areas representing extremes of deprivation

In this section the estimated energy consumption and associated carbon dioxide emissions are reported for two specific Output Areas. The first area is highly deprived. It is in Manchester in the North West Government Office Region (Output Area code 00BNFK0004; postcode M4 7JD). The area is a member of the *Constrained by Circumstances* OAC Supergroup. It is predominantly composed of terraced housing (72%) with 15% semi-detached houses, 10% purpose built flats and 3% detached houses[20]. The second area is in Uckfield in the South East Government Office Region (Output Area Code 21UHHX0002; postcode TN22 5NE). The area is a member of *Prospering Suburbs* OAC Supergroup. It is dominated by detached houses. Maps of the two areas are shown in Figure 4.



Output Area code 00BNFK0004

Manchester, North West

In most deprived 1% of Index of Multiple Deprivation

Output Area Code 21UHHX0002

Uckfield, South East

In least deprived 1% of Index of Multiple Deprivation

Figure 4. Maps of the case study areas representing extremes of deprivation.

Source: ONS http://neighbourhood.statistics.gov.uk

[20] Census 2001 Table UV56. http://neighbourhood.statistics.gov.uk

A graph of the estimated household fuel demand and associated emissions for the two contrasting areas is shown in Figure 5. From this graph it can be seen that energy consumption in the highly deprived area is just 55% of that in the relatively affluent area, and associated carbon emissions in the highly deprived area are 57% of those in the affluent area. In addition, from the graph, when comparing with the UK mean, the energy use of the deprived area is 75% of the mean, whereas that of the extremely affluent area is 137% of the mean. This reinforces the finding that there is a highly skewed distribution of energy use and carbon emissions in the UK (Druckman and Jackson 2007).

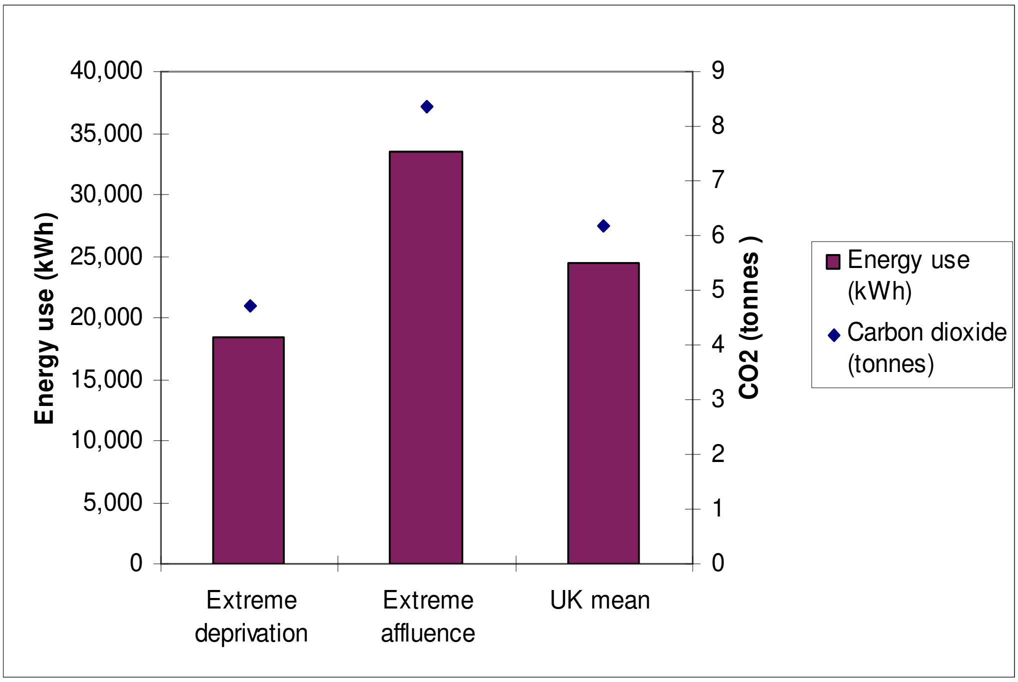


Figure 5. Annual household energy consumption and associated carbon dioxide emissions for specific Output Areas representing extremes of deprivation

4.2 Mean household energy use for OAC Supergroups

In this section the mean household energy consumption and associated carbon emissions for each OAC Supergroup in England and Wales are presented and the results discussed. A summary of OAC Supergroup characteristics is shown in Appendix 2.

As mentioned in the Introduction, LARA is also able to estimate household income and expenditure on specific goods and services, at extremely high levels of socio-economic and geographic disaggregation. This is illustrated by estimates of household expenditure on energy in relation to income for each Supergroup. Figure 6 shows normal weekly disposable income and the percentage of this that is spent on household energy for each OAC Supergroup. Households in *Constrained by Circumstances* have, as expected from the Supergroup name, the lowest average disposable income. These areas are dominated by social rented flats, with high proportions of single pensioner or lone parent households and the head of the household is likely to be unemployed. Households in *Constrained by Circumstances* spend a higher percentage of disposable income on household fuel, on average, than those in other Supergroups. This is expected as, being the most deprived Supergroup, households in this Supergroup can be assumed to be in most danger of fuel poverty (Papathanasopoulou and Jackson 2007).

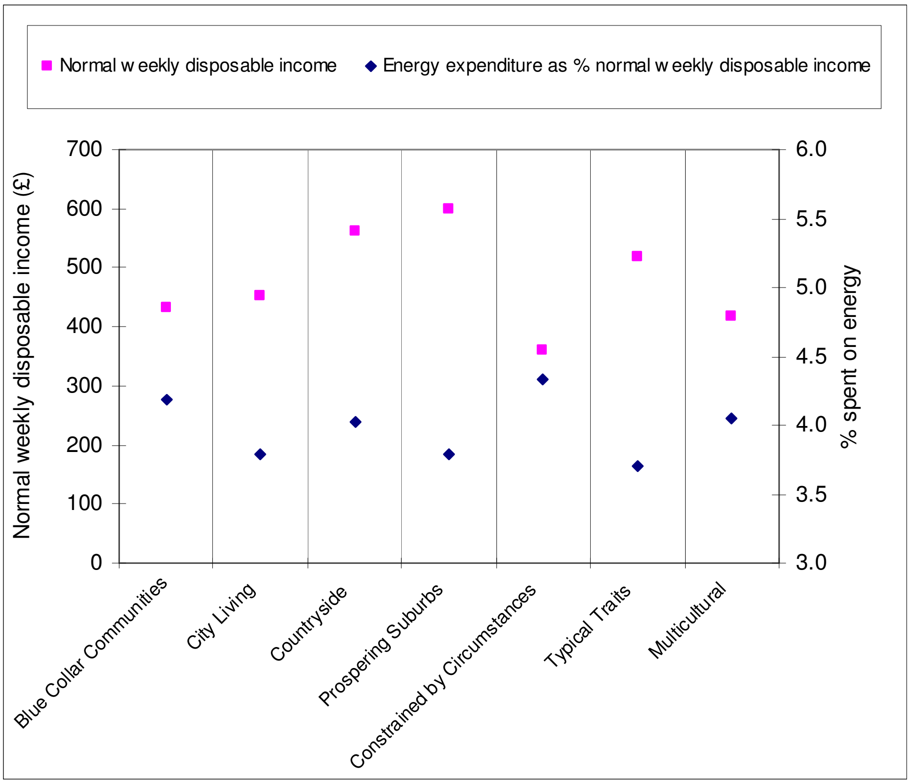


Figure 6. Normal weekly disposable income and the percentage spent on energy for OAC Supergroups

The households that spend the lowest proportion of disposable income on fuel are those in *City Living*, *Prospering Suburbs* and *Typical Traits*. These may be called "fuel rich" households, reflecting that the amount these households spend on fuel is not a significant factor in their weekly budget. These households are less likely to change their energy consumption in response to price increases. In other words, for these households, energy use can be assumed to be relatively inelastic. It is notable that the fuel rich households are not, according to this analysis, simply the most affluent households in *Prospering Suburbs* (mean weekly disposable income of £600), but include *City Living* and *Typical Traits* households (with lower mean weekly disposable incomes of £453 and £519 respectively). We can explain the presence of *City Living* households in this group as they are predominantly flats. They can be assumed to be fuel rich due to the thermal advantage that flats have compared to other types of dwellings. *Typical Traits*, as the name implies, is characterised by its closeness to the UK mean in terms of socio-demographic characteristics. This group has few values which are high or low in comparison with other Supergroups (Vickers et al. 2005). The categorisation of these households as fuel rich indicates that "average" households are generally well-off in fuel terms. *Prospering Suburbs*, the wealthiest Supergroup, have a high proportion of larger than average detached dwellings and a high proportion of 2+ car households. The dwellings are predominantly owner occupied, and the owner is unlikely to be unemployed. Inclusion of this Supergroup in the fuel rich category is expected due to their comparatively high income levels.

Figure 7 shows estimated household energy consumption (all fuels) and associated carbon emissions, for each of the seven OAC Supergroups. The graph includes the UK mean for comparison purposes. The picture for middle income households is not simply based on income. It shows that households in rural locations (*Countryside*) have much higher average energy use than those urban locations (*Multicultural* and *City Living*). It also reflects that flats (of which there are high proportions in *City Living* and *Multicultural*) are more energy efficient than, for example, terraced housing (which is found in high proportions in *Blue Collar Communities*). Looking at the extremes of the income range, however, the results are in agreement with accepted understanding that energy use is related to income levels. Energy demand is highest in *Prospering Suburbs*, being 21% higher than the UK mean, with associated carbon dioxide emissions 20% above UK mean. The lowest energy demand and carbon dioxide emissions occurs in *Constrained by Circumstances* (21% below UK mean for energy and emissions).

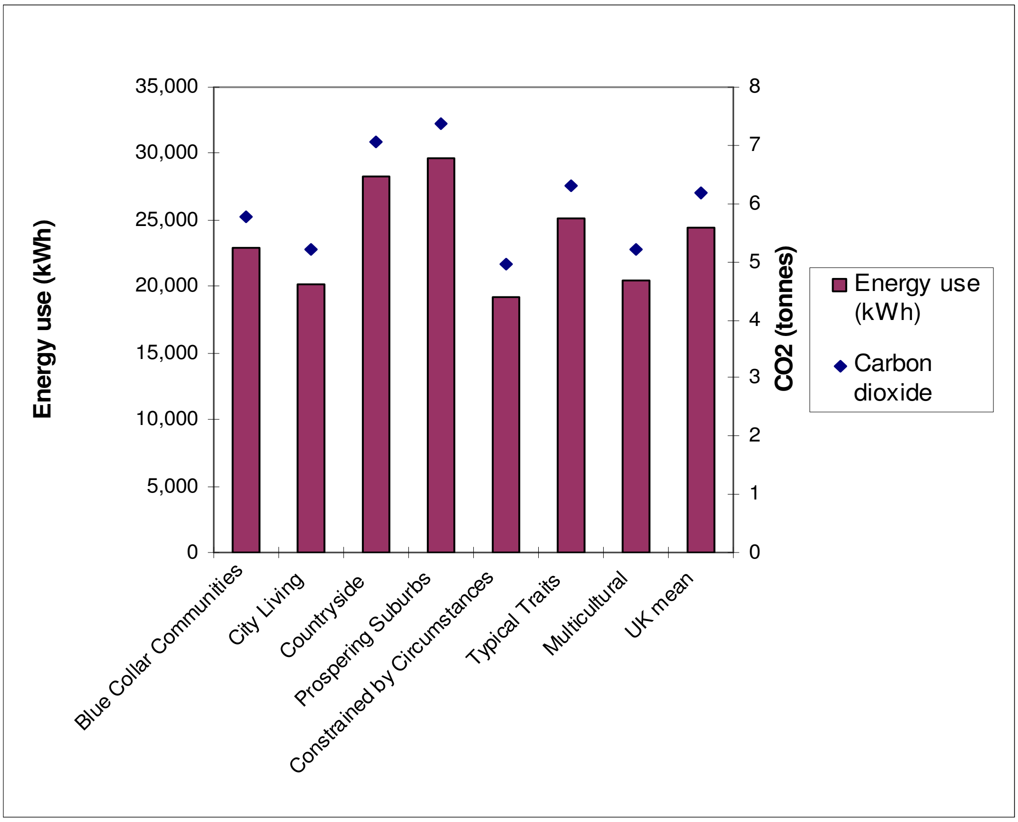


Figure 7. Annual household energy use and associated carbon dioxide emissions (all fuels).

City Living areas are interesting as they are characterised by a high proportion of flats, and also a high proportion of privately rented properties. As discussed in Section 2, flats are, in terms of space heating, relatively efficient, with lower heat loss than other types of dwelling (Shorrock and Utley 2003). On the other hand, privately rented accommodation is less likely to have good levels of loft insulation and other energy saving measures due to the landlord-tenant problem, as described in Section 2. Mean household electricity use in *City Living* areas is 9% below UK mean, whereas gas use is 18% below the mean (Figures 1 and 2, Appendix 3). This implies that the energy efficiency gained by being in a flat, on average, outweighs the general lack of energy efficient measures that tend to be put in place by private landlords.

The pattern for electricity varies slightly from that for all fuels and gas, and the disparities are less pronounced. This reflects that the consumption of electricity for lighting and running appliances is less dependent on the type of dwelling and tenure of a household than the fuel required for space heating, which is not, in general, electricity. Graphs for household gas[21] and electricity demand, with their associated carbon emissions, are shown in Appendix 3.

The pattern differs substantially for 'Other Fuels'[22]. The number of households purchasing these fuels is smaller, and hence the uncertainties are higher. Therefore these results should be treated with a certain amount of caution. 'Other Fuel' use is dominated, in terms of energy demand, by Oil for Central Heating and Coal. Urban demand for 'Other fuels' is hence expected to be small as urban areas are generally connected to the main gas supply. The results support this hypothesis, with *Countryside* consuming the greatest quantity of Other Fuels (55% above UK mean). A graph of these results is presented in Figure 3 in Appendix 3.

4.3 Estimation of Local Household Waste Arisings

This part of the paper describes how the results from LARA can be used to estimate household waste arisings. Two examples are described: first, packaging waste from drinks bottles, which can be assumed to enter the waste stream in the year of product purchase; second, waste from carpets, which must take account of residence time in households.

The trend for glass waste arisings 1996/7-2003/4 for case study areas representing *Prospering Suburbs* and *Constrained by Circumstances* due to wine and champagne consumption is shown in Figure 8a. The areas are Output Area 35UGFU0001 in Wansbeck and 00CHFF0002 in Gateshead, both in the North East of England. The graph shows a slight overall increase in both local areas with time, in line with national trends of waste arisings (Strategy Unit 2002). The highest volume of glass waste arisings is in *Prospering Suburbs* and the lowest in *Constrained by Circumstances*. This information, particularly when coupled with GIS, can be invaluable to councils when, for example, planning glass recycling facilities.

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[21] For the purposes of this document, 'gas' refers to metered gas.

[22] The fuels that make up Other Fuels are listed in Table 2.

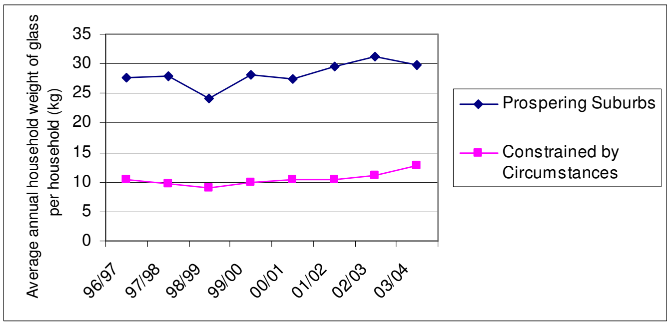

Figure 8(a). Trends for household glass waste arisings for *Prospering Suburbs* and *Constrained by Circumstances* due to wine and champagne consumption

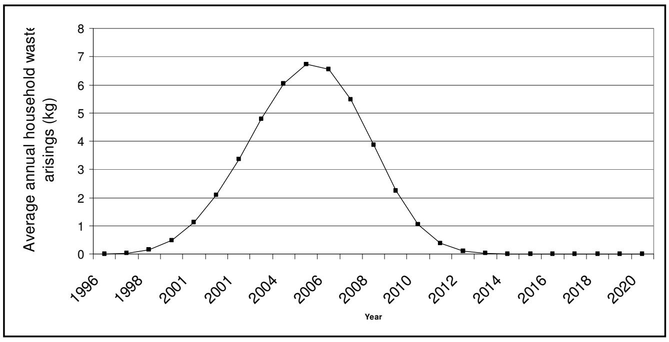

Figure 8(b) Graph to show Weibull distribution of waste arisings for products purchased in 1996 with mean product residence time 10 years

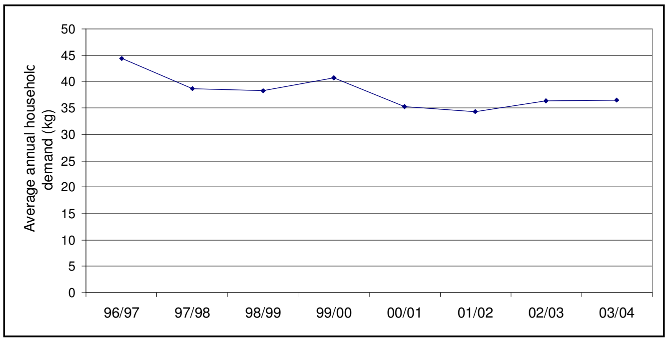

Figure 8(c). Average demand for carpets in the *Constrained by Circumstances* case study area 1996/7 to 2003/4

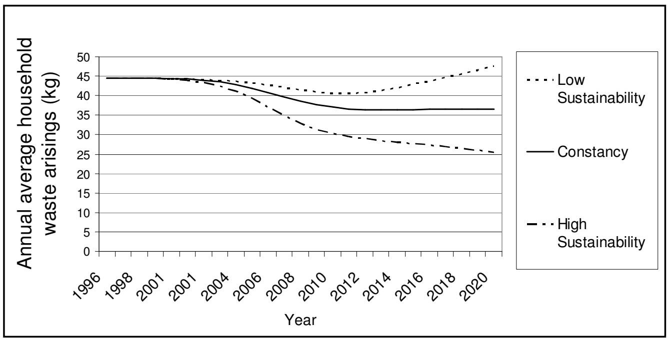

Figure 8(d). Estimated waste arisings due to carpets for three scenarios

An example of waste arisings due to the average weight of 'Carpets' (44.4 kg) purchased per household in a case study area representing *Constrained by Circumstances* in 1996/7 is plotted using the Weibull distribution (Figure 8b). The graph, based on an average product life of 10 years[23], shows a near normal distribution in which the peak of wastes arise in the tenth year after purchase (6.7 kg). The graph shows the entire mass of carpets purchased in year one eventually entering the waste stream, with over 99.99% having been discarded by nineteenth year after purchase.

Carpet demand during the study years (1996/7-2003/4) for the *Constrained by Circumstances* case study area, shows a general decreasing trend with time (Figure 8c). This case study area is used to demonstrate waste arisings in the three scenarios: Low Sustainability, High Sustainability, and Constancy (as detailed in Table 4). The decreasing demand trend dominates all waste arisings scenarios until approximately 2009, as shown in Figure 8d. From approximately 2011 onwards, waste arisings are dominated by the scenario assumptions. As expected, long term waste arisings are estimated to rise in the Low Sustainability scenario, remain constant in Constancy, and fall in the High Sustainability scenario. This illustrates the importance of accurate estimations concerning future demand trends, product lifespan data, and the influence of household metabolisms when predicting future waste arisings. It also demonstrates how the model can be used in waste management planning.

4.4 Inequalities in the resource usage of areas: AR-Gini results

This section presents the results of estimates of the AR-Gini for selected commodities. Figure 9 shows the trend in the AR-Gini for 'Men's and Boys' Garments' over the period 1996/7 to 2003/4. This is compared to an area-based expenditure Gini coefficient for 'Total Expenditure', and also to an expenditure Gini coefficient for 'Total Expenditure' calculated on a household basis. The coefficients are indexed to 1.0 at year 1996/7 as the absolute values of Gini coefficients calculated on different bases (area or household) are not directly comparable. When looking at Total Expenditure the area-based coefficient shows greater variation over time than the household-based coefficient. This could be due to accumulated inaccuracies such as rounding errors in the modelling process; further work is required to investigate this.

[23] Average product lifespan is taken from Holloway et al (2002).

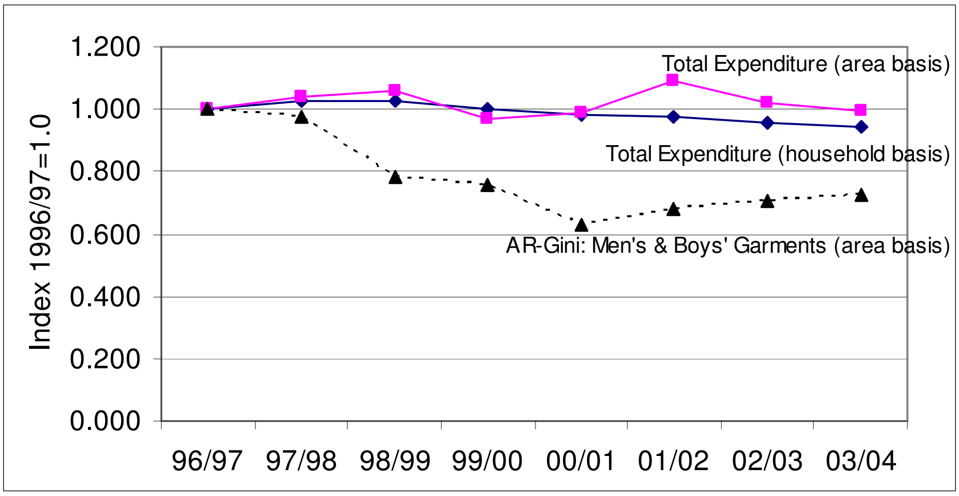

Figure 9. Trends in Gini and AR-Gini coefficients (Index 1996/97=1.00)

The plot shows that the AR-Gini for 'Men's and Boys' Garments' is 27% lower in the final year of the study than in the first year of the study, implying a significant decrease in inequality in clothing resource use during the years of the study. This is comprised of a steep initial downward trend with a slight small reversal in the final three years of the study. The Consumer Price Index (CPI) for Clothing fell sharply from 163 in 1997 to 116 in 2002 (on 2005=100 basis) and then continued falling, but less steeply, reaching 100 in 2005[24]. The fall in CPI implies an increasing availability of cheaper clothing and is likely to be the reason for lower inequality in this category over time. The reasons behind the slight rise in AR-Gini for clothing in the final three years of the study require further investigation.

Table 6. AR-Gini coefficient for selected commodities (2000-04)

Commodity	**AR-Gini Coefficient (2000-04)**
Carpets	0.085
Clothes Washer/Driers	0.050
Refrigerators, Freezers & Fridge Freezers	0.053
Men's and Boys' Garments	0.064
(Total Expenditure *	0.073)

** This is an area-based expenditure Gini coefficient included for comparison purposes.*

Table 6 shows the AR-Gini for selected commodities averaged over years 2000/01 to 2003/04. The figures indicate higher inequality for 'Carpets' than for other commodities such as 'Clothes Washer/Driers', and 'Refrigerators, Freezers and Fridge Freezers', and 'Men's and Boys' Garments'; this is in line with the analysis carried out in Section 4.1, which showed a greater disparity for 'Carpets' than for

[24] The CPI is available from http://www.statistics.gov.uk/statbase/TSDdownload1.asp. Accessed 30.10.06

'Household Appliances'. These results may be used to prioritise which commodities should be subject to further investigations into inequalities in resource use, and also indicate that policy interventions should take possible exclusion issues into account more with respect to policies concerning floor coverings than household appliances and men's clothing.

5 Assumptions and limitations

In this section we outline the major assumptions and limitations of LARA.

In order to examine long-term trends and to model waste arisings due to purchase of durable goods, for example, it is necessary to model back in time. However comparison across time is often problematic as inconsistencies occur in the boundaries of geographical regions, the variables reported, the social and political context, and the access mechanisms used (Martin et al. 2001). Ideally the model should to track changes over the last 20 years as a minimum.

LARA has, to date, been used to estimate resource use for the years 1996/7 to 2004/5 based on annual expenditure data from the Expenditure Surveys (Druckman and Jackson 2007; Druckman et al. 2007). Household characteristics data are, however, taken from a single year using Census 2001. The Census is carried out at 10 year intervals, and the study period start year of 1996 is the midpoint between the 1991 and 2001 Census. As discussed above, the 2001 Census is considered the most complete and reliable socio-economic dataset that is available in the UK, providing an incomparable depth of information with comprehensive geographical coverage (SDC 2003; Vickers et al. 2005). However, one may inquire how stable the socio-economic characteristics of an area over time are? In a study of London, Orford (2002) found that, excluding redevelopment of the docklands area, the poorest people occupy the same areas as were occupied by the poor when Charles Booth carried out his survey in 1886-1903 (LSE 2006). Therefore, although some exceptional areas may change notably due to regeneration initiatives, it is assumed that the general socio-economic hierarchy of geographic areas is relatively static throughout the study period (Vickers et al. 2005).

The geographical basis of census data changed radically with Census 2001. Before 2001, the census used the same geographical areas for both data collection and output purposes; the size and shape of these areas was primarily determined by the requirements of data collection. In Census 2001 the boundaries used for data collection and output were separated, and socio-economically homogeneous Output Areas were introduced. Output Areas used in Census 2001 are therefore different from the areas used in previous censuses, and consequently trends in areas across the 1991 and 2001 censuses cannot be found. Extending the study to years before 1996 is therefore problematic, and other means of extending the study back in time must be sought. At the time of writing, plans for the 2011 Census were under consideration, with the current recommendation being to maintain the 2001 geographical areas in the 2011 Census, incorporating changes to take account of any significant population changes as appropriate.[25]

LARA is a resource analysis tool designed for estimation of general resource use. The categorisation of Household Categories (HoCs, see Table 2) is therefore aimed at capturing expenditure with the greatest accuracy possible, and is not necessarily optimum for estimating household energy use. It would be interesting to investigate the effect of using different categorisation of HoCs that avoids merging across types of dwelling and tenure, and perhaps includes household composition (see Druckman and Jackson (2007) and Appendix 1).

A specific limitation of LARA, when applied to consumer commodities such as clothing and household appliances (Druckman et al. 2007), is use of average price per unit weight to convert monetary values into weight for all items within one commodity category. When purchasing any commodity, a consumer is generally presented with a range of prices, from expensive luxury goods to cut-price goods. The choice of purchase within this range can be considered to depend on three major factors. The first factor concerns affordability. Affordability may be modelled using price elasticities, and we may generally expect the elasticity of goods to be higher for deprived socio-economic groups than for more affluent groups. According to this assumption, material demand will be over-estimated in affluent areas and under-estimated in deprived areas. It is possible that, in future work, a module could be added to LARA, which would model the price elasticities of various consumer goods against socio-economic characteristics, and this could be used to modify the expenditure to physical unit conversion values used within LARA.

The second factor influencing the purchase choice of a consumer good within a given price range can be considered to be lifestyle. To understand this we need to look at the different roles that consumer goods play in modern society. Consumption satisfies our functional needs for food, housing, transport and so on, but consumer goods also play important symbolic roles in our lives which allow us to engage in vital 'social conversations' about status, identity, social cohesion, and the pursuit of personal and cultural meaning (Jackson 2005; Jackson 2006). Thus, for example, people to whom the status provided by the make and model of the car they purchase is of extreme importance, may choose a more expensive vehicle than someone of comparable affluence to whom such status symbols have little importance. The relationship between the choice of consumer goods within a given price range with lifestyles is complex and hard to take account of within LARA.

The third major influence on the choice of purchase of a consumer good from a given price range depends on access to, and perfect information of, the entire price range. Residents in deprived areas tend to have restricted access to affordable goods either due to physical inaccessibility (as documented in the debate concerning 'food deserts'), lack of private or public transport, and lack of internet access (Cabinet

[25] See http://www.statistics.gov.uk/census/2011Census/ProducingData/OutputGeography.asp, accessed 01.08.07.

Office 2003; Clarke et al. 2004; Guy et al. 2004). Therefore, according to this argument, material demand in deprived neighbourhoods may be over-estimated. From this discussion it can be seen that relating the purchase choice of a consumer good within a given price range to the socio-economic characteristics of households or neighbourhoods is a complex task, which is beyond the remit of the current LARA study, but which may be addressed in future work.

LARA is based on data from the Expenditure Surveys, which covers consumer commodities purchased in exchange for money that are declared by households that take part in the Expenditure Survey. Therefore the study includes resource use that is recorded as part of the formal economy but excludes commodities that enter households through informal means (Alexander 2006). This means that gifts and, for example, goods such as children's clothes that are frequently passed between households without payment, are excluded from the study, as are also, of course, goods acquired through the black market.

Inaccuracies arise in LARA as different classification systems are often used in the Expenditure Survey and the various sources of price data. For example, in the case of consumer commodities for which price data are sourced from UK Trade Data, UK Trade Data are provided using EU Combined Nomenclature (CN) (Intrastat 2004) whereas data from the Expenditure Survey is, as described above, in functional units before 2001/2 and COICOP thereafter. The classifications used in these three datasets often do not correspond precisely, and hence cross correlation involving some aggregation and pro-rata assignments is necessary.

With regard to household energy, household expenditure on fuels is recorded for a variety of different payment categories in the Expenditure and Food Survey (EFS), as shown in Table 3. Assumptions are required in order to match these categories to the more standard categories used in energy publications for the purposes of identifying prices and carbon emission factors. In a few cases in the EFS it is evident that electricity and gas payments were combined or mixed, and this may be a cause of errors. Some household cases in the sample recorded zero electricity payments which, on the face of it, is surprising. This is due to the method used to collect expenditure data in the EFS, and is compensated for by over-estimates in other values[26].

The ability of LARA to estimate resource use at high levels of socio-economic and commodity disaggregation is limited by the sample size of the Expenditure Survey. In particular, analysis of relatively infrequently purchased commodities such as hard floor coverings and household 'Other Fuels' is limited, whereas analysis of more frequently purchased commodities, such as electricity, gas and clothing, is less constrained. An important policy conclusion from this study is that the sample size

[26] The majority of households with zero electricity expenditure use the 'card, disc, token or electronic key' method for electricity payment. Expenditure using these methods is collected via the two-week diary and not the questionnaire, which covers three months (Dunstan 2007).

of the Expenditure Survey needs to be considerably larger if it is to be useful in this kind of analysis.

6 Discussion

In policy-making, a targeted approach to the implementation of energy savings measures, such as energy efficiency advice and subsidies, or resource reduction schemes such as repair, re-use, re-manufacture and recycling services, is more likely to achieve socially acceptable results in an efficient and equitable manner. Therefore effective policies must be based on an understanding of the resource use and associated emissions of different socio-economic groups and lifestyle types, and consideration of how this relates to social and institutional infrastructure. It is also important to be able to geographically locate specific target groups. The Local Area Resource Analysis (LARA) model, that is the subject of this paper, has been designed to address these needs.

LARA estimates the resource use of small (124 households on average) socio-economically homogeneous neighbourhoods from a consumption perspective. This paper has described LARA's methodology and presented some example results. To demonstrate the highly geographically disaggregated nature of LARA, estimates of household energy consumption and associated carbon dioxide emissions for two specific small geographical areas chosen to represent extremes of affluence and deprivation based on the Index of Multiple Deprivation have been presented. In order to demonstrate the insights LARA can give us concerning the resource and emissions implications of different socio-economic groups, LARA has been used to estimate the mean energy use and associated carbon emissions for "typical" types of households classified according to the UK National Output Area Classification (OAC).

LARA is a general model capable of being applied to different types of resource use and associated emissions, and is subject to on-going development, and integration with other modelling tools. By integrating LARA with an input-output framework in planned future work, upstream carbon dioxide emissions and solid waste arisings 'embedded' in the goods and services consumed by households will be modelled, demonstrating LARA's capability as a full local area resource and emissions analysis model (Bradley et al. 2006; Bradley et al. 2007; Carbon Trust 2006; Jackson et al. 2007).

LARA is currently constrained in its ability to analyse at high levels of disaggregation due to the small sample size of the UK Expenditure Survey. A specific policy conclusion from this study is that the sample size of the UK Expenditure Survey should be increased in future years to further this kind of analysis.

In this paper we have also presented two applications of the results of LARA. The paper shows how, using a household metabolism model, outputs from LARA can be used to estimate local household waste arisings depending on neighbourhood socio-economic characteristics. This is demonstrated for three contrasting scenarios in which disparate assumptions are made concerning future purchases of commodities and the time for which commodities reside in households. This application of LARA will be of particular use in local waste strategy planning.

The development and application of a novel indicator, the AR-Gini, which is based on results obtained from LARA, has also been described in this paper. The AR-Gini, which is an area-based indicator of resource (and associated emissions) inequalities, has been designed to enhance our understanding of resource inequalities and their drivers. In this paper its use is illustrated by pilot applications (specifically, men's and boys' clothing, carpets, refrigerators/freezers and clothes washer/driers). The results illustrate that different levels of inequality are associated with different commodities.

In conclusion, this paper has presented LARA, which is a model that helps us understand patterns of resource use and associated emissions. Results from LARA add to the evidence base that can be used in the development of policies to achieve a transition to more sustainable lifestyles in an efficient and equitable manner.

Glossary of abbreviations

AR-Gini	Area-based Resource Gini coefficient
CN	EU Combined Nomenclature
COICOP	Classification of Individual Consumption by Purpose
CPI	Consumer Price Index
GIS	Geographical Information System
GOR	Government Office Region
HoC	Household Characteristics Classification
HRP	Household Representative Person
IMD	Index of Multiple Deprivation
LARA	Local Area Resource Analysis model
NS-SeC	National Statistics Socio-Economic Classification
OA	Census 2001 Output Area.
OAC	UK National Output Area Classification system
PRODCOM	Products of the European Community
SIC	Standard Industrial Classification

Acknowledgements
The authors would like to thank Philip Sinclair of the Centre for Environmental Strategy at the University of Surrey for his early contribution to the work, and David Broadstock (Surrey Energy Economics Centre, University of Surrey) for his help and advice. We are also grateful to Ian Preston and Joshua Thumim at the Centre for Sustainable Energy, Bristol. The research was made possible through funding from the EPSRC Sustainable Urban Environment Waste Consortium programme (Grant Number GR/S79626/01), and ESRC Research Group on Lifestyles Values and Environment (RESOLVE) (Grant Number RES-152-25-1004). Data from the 2001 Census are provided by the Commissioned Output Census Service of the Office for National Statistics (Crown Copyright 2005).

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Appendices

Appendix 1. Definition of HoCs

The definition of HoCs is a critical aspect of the model. This section explains the reasoning behind the choice of parameters used to define HoCs, and the process of refinement into the final 45 HoC categories.

The parameters that define the HoCs must be chosen according to the following criteria: first, the factors must be available and compatible in both the Census and Expenditure Surveys. Second, they must be exhaustive and mutually exclusive in both surveys. Third, they must be chosen to capture the major variances in household spending patterns and give the highest possible definition whilst maintaining a sufficient quantity of data in any cell.

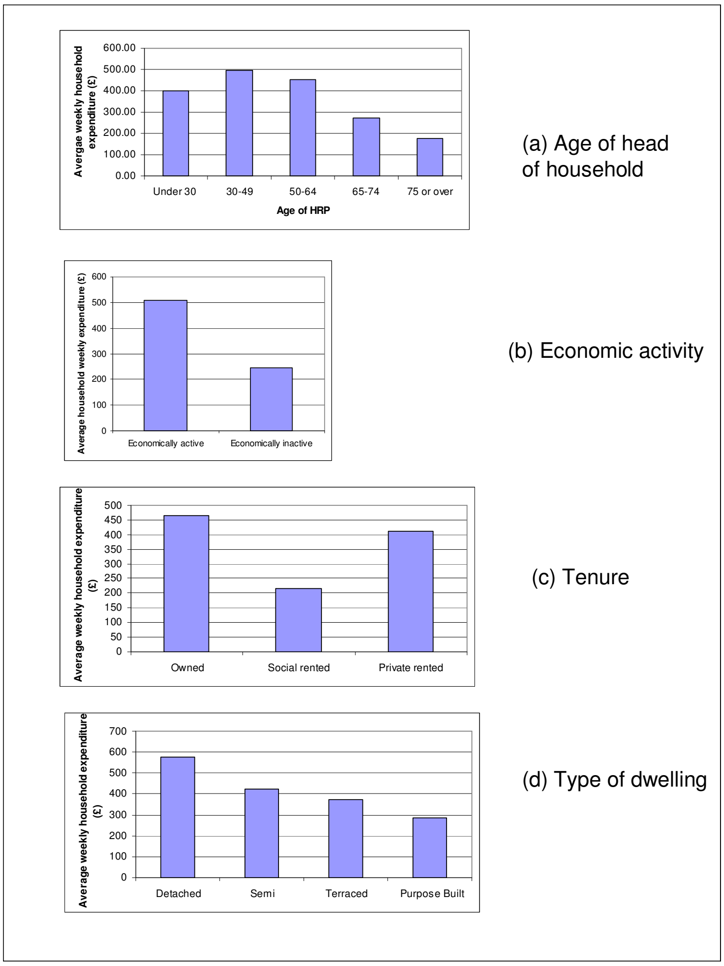

Figure A1.1. Graphs to show how expenditure varies with factors chosen to represent HoCs

Income has been shown to be a major factor in the energy and resource demands of households (Kok et al. 2003; Wilting and Biesiot 1998), but income data are not available in the Census, and hence cannot be used in LARA. Proxies were sought. The best proxy for income is socio-economic status (Rose and Pevalin 2003; Rose and Pevalin 2005). However, in the Census 2001 approximately 22% of all heads of households in England & Wales have National Statistics Socio-economic Classification (NS-SeC) "unclassified" and therefore NS-SeC is not suitable for use in LARA. Other proxies for income had to be chosen. In this study we selected the following the factors shown in Table A1.1. Figure A1.1 shows how expenditure varies with the chosen factors.

Table A1.1 Variables used in LARA

Variable used in LARA	Number of categories
Age of Household Representative Person (HRP)	5
Economic status of HRP	2
Tenure	3
Type of dwelling	4

In theory, greater accuracy may be obtained by using more factors to describe HoCs, such as household composition, ethnicity of HRP, number of cars, number of economically active people per household, central heating, or number rooms. However, the number of exhaustive and mutually exclusive factors that can be provided by Census 2001 data is limited due to disclosure issues, which become highly restrictive at Output Area level.

The process of refinement of HoCs into the final 45 HoC categories is now explained. Four factors are used as shown in Table A1.1: Age of Household Representative Person (HRP) (5 categories); Economic status of HRP (2 categories); Tenure (3 categories); Type of dwelling (4 categories). In theory this enables 5x2x3x4=120 HoCs to be defined. However, the annual sample size of 7,000 reporting households used in the Expenditure Surveys limits the number of HoCs that can be used[27]. Each reporting household in the Expenditure Survey is allocated into its appropriate HoC, as explained above. After this allocation the number of reporting households in each HoC is examined. A HoC that contains fewer than 50 reporting households from the Expenditure Survey is judged to be too small. The minimum of 50 reporting households per cell is based on guidance from the Office for National Statistics which recommends that figures should be used with caution where there are fewer than 20 reporting households in each cell (Office for National Statistics 2005b: page xiii). As the number of purchases of some commodities (such as household appliances and carpets) by households taking part in the Expenditure Survey in any given year are small[28] resulting in a high standard error, the limit is set to a minimum of 50 reporting households in any HoC.

HoCs with fewer than 50 reporting households are merged with neighbouring cells (see Table 2) until there are at least 50 reporting households in each HoC. Table A1.2 shows the average number of reporting households in each of the final 45 HoCs averaged over years 1996/7-2003/4. Examples of cells that required merging are the two cells labelled Q in Table 2. These cells are defined by Age of HRP 30-49, employed, living in detached or semi-detached dwelling that is privately rented. Table A1.2 shows that the average number of cases in these combined cells is just 54. An example of a cell that did not require merging is cell F in Table 2, which is defined as Age of HRP 30-49 and employed, living in a detached house which is owned. It can be seen from Table A1.2 that the average number of cases in this cell is 487 and therefore it does not require merging.

[27] It should also be noted that disclosure rules for data from the Census 2001 also prohibit the use of 120 HoCs.

[28] See table A1 of Family Spending Report 2003-04 (Office for National Statistics 2005b).

Table A1.2. Average number of reporting households from the Expenditure Surveys in each HoC

HoC Name	Average number of reporting households from Expenditure Survey in each HoC (1996/7 – 2003/4)
A	119
B	203
C	210
D	94
E	171
F	487
G	674
H	570
I	128
J	118
K	88
L	105
M	85
N	69
O	103
P	91
Q	54
R	122
S	63
T	321
U	329
V	214
W	55
X	123
Y	124
Z	120
AA	114
AB	51
AC	70
AD	75
AE	72
AF	224
AG	242
AH	163
AI	61
AJ	69
AK	76
AL	99
AM	166
AN	183
AO	131
AP	68
AQ	76
AR	78
AS	140
Total (average number of cases in Expenditure Surveys 1996/7-2003/4)	**6998**

Appendix 2. Selected characteristics of OAC Supergroups

	Blue Collar Communities	City Living	Countryside	Prospering Suburbs	Constrained by Circumstances	Typical Traits	Multicultural
Variables distinctively above national average	• Age 5-14 • Rent (public) • Terraced housing • Lone parent households	• Age 25-44 • Population density • Rent (private) • Flats • No central heating	• Age 45+ • Detached housing • Rooms per household • 2+ car households	• Age 45-64 • Detached housing • Rooms per household • 2+ car households • Two adults no children • Households with non-dependant children	• Age 65+ • Single pensioner households • Rent (Public) • Flats • People room • Unemployment	*Typical traits is characterised by its 'averageness'. This Supergroup has few values which are high or low in comparison to the other groups.*	• Age 0-15 • Born outside UK • Population density • No central heating • People per room • Flats • Unemployment • Rent (public and private)
Variables distinctively below national average	• Rent (private) • Flats	• Ages 0-14 • Rooms per household	• Population density • Flats • People per room • Single person household	• No central heating • Terraced housing • Flats • Single person household • Rent (private and public)	• Two adults no children • Rent (private) • Detached housing • Rooms per household • 2+ car household		• Age 45+ • Single pensioner households • Detached housing

Source: Vickers et al (2005)

Appendix 3. Household energy consumption and associated carbon emissions for OAC Supergroups

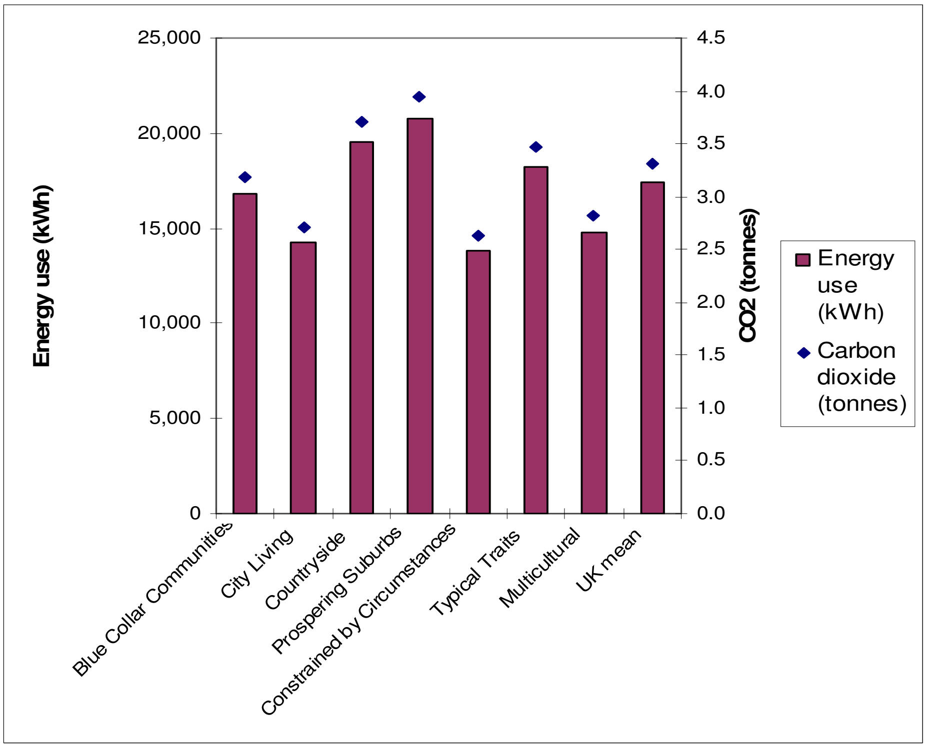

Figure A3.1. Household gas demand and associated carbon dioxide emissions.

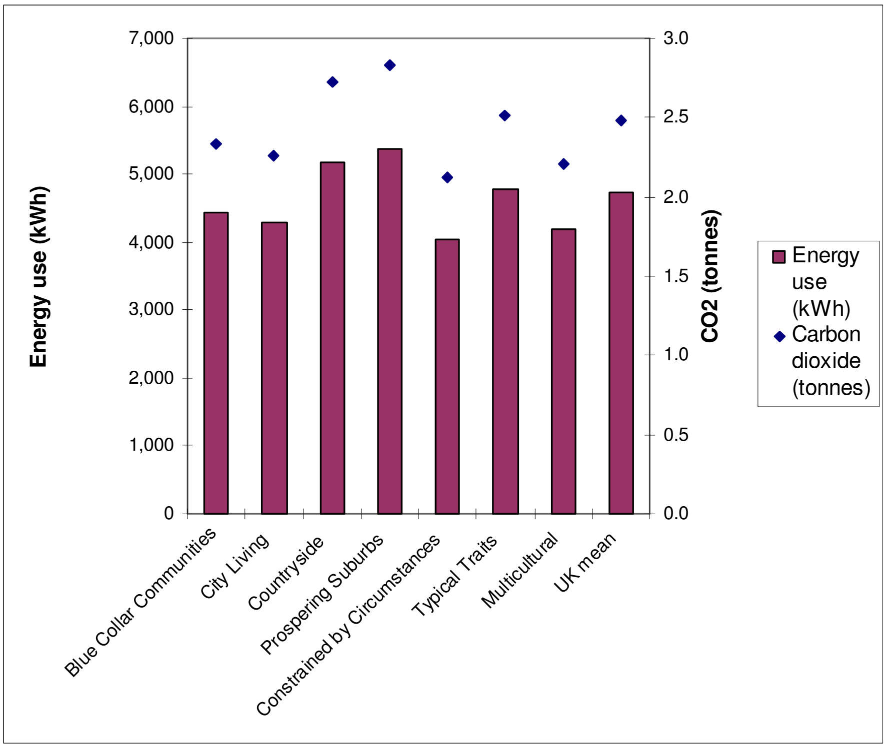

Figure A3.2. Household electricity use and associated carbon dioxide emissions.

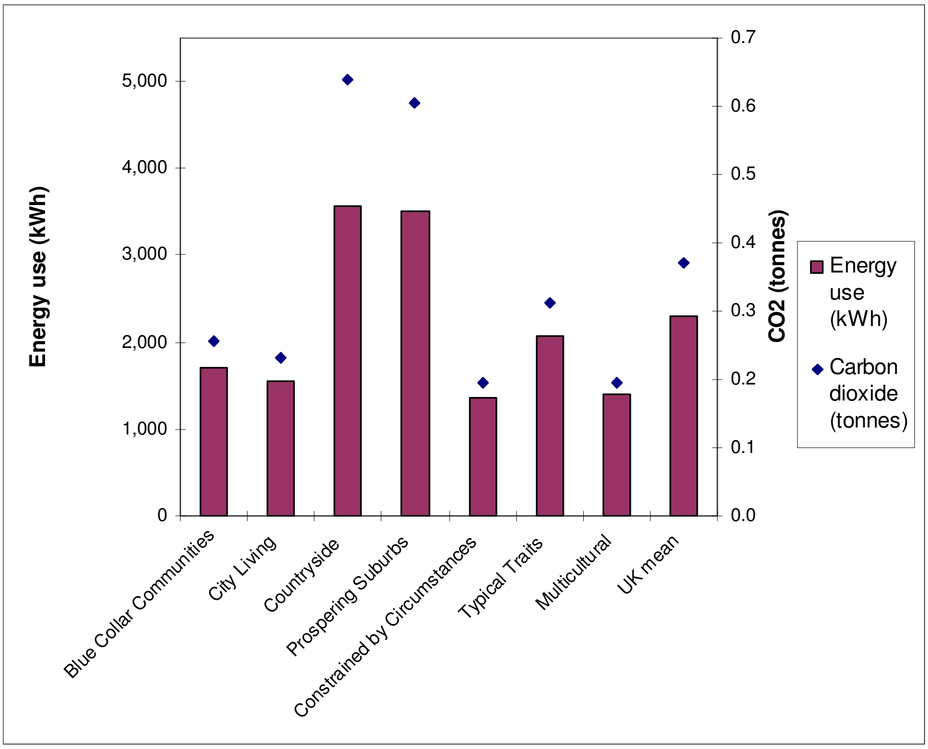

Figure A3.3. Household demand for Other Fuels, and associated carbon dioxide emissions.