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A comparison of the Total Energy Requirements of Rural and Urban Households in Scotland: a SAM Multiplier Analysis

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Abstract

The higher direct energy requirements (associated with high transport and heating costs) of rural households have been identified as a key issue for the Scottish Government, especially in the context of the policy goal of achieving more sustainable low-carbon lifestyles. However, patterns of direct energy consumption can mask more complex patterns of total energy requirements where the latter takes into account the indirect or embodied energy associated with consumption. An extended SAM multiplier model is used to compare the total energy requirements of rural and urban households in Scotland where households are disaggregated by income level. The results confirm the higher direct and total energy requirements of low income households compared to higher income households but do reveal differences across fuel types and locations. The findings have implications for policies aimed at encouraging low carbon economies, suggesting those targeted only at direct energy consumption may fail to address the high indirect energy consumption of certain households types. Instead they suggest the case for policies aimed at reducing the level of energy embodied within final consumption goods (for example, reducing the energy costs associated with the transportation of goods and services).

Keywords: SAM multiplier analysis; direct energy consumption; embodied energy; rural households

1. Introduction

The issue of energy dependency is acquiring growing attention, as real world prices for coal, oil and gas continue to rise, and concerns grow over national ‘fuel security’. At the same time, awareness of equity and poverty in developed countries – in both urban and rural areas – has grown, both in times of rising prosperity and during the current recession. The threat of climate change has led governments to adopt ambitious targets for greenhouse gas (GHG) emission reductions, with implications for household use of energy for both heating and transport. Together, these account for about 35% of total UK carbon dioxide emissions (AEA, 2012).

Scotland, with its devolved government, has shared these concerns, perhaps to a greater degree than other countries in the United Kingdom and elsewhere due to its close links with the energy supply sector (North Sea oil and gas, hydro and wind power generation). Particularly since 2007, there has been policy emphasis on reducing both GHG emissions and energy poverty.

The high direct energy requirements of rural households (associated with high transport and heating costs) have been identified as a key issue in the context of the Scottish Government's policy goal of moving towards more sustainable low-carbon lifestyles. Together, heating and transport costs – in approximately equal shares – amounted to about 8.5% of total Scottish household expenditure in 2008-2010, but to about 10.5% for households in rural Scotland (Thomson *et al*., 2012). Concerns over rising energy prices, and over poverty generally, have led both UK and Scottish governments to adopt various policy measures and targets, such as efforts to improve the energy efficiency of homes, payments for winter heating costs, and the "Green Deal" currently being introduced.

However, as shown by Herendeen (1974) and more generally in Weidmann *et al*. (2006), patterns of direct energy consumption by households can mask more complex patterns of total energy requirements where the latter takes into account the indirect or embodied energy associated with particular consumption patterns. In particular, while direct energy costs appear to level off with rising income, total energy consumption (allowing for the embodied energy in goods and services consumed) has been found to increase with income. This suggests that policies targeted at reducing direct consumption alone may be inefficient.

The paper compares first the direct and then the total energy requirements of rural and urban households in Scotland, where each is split to distinguish different income levels. A SAM multiplier model is used for the analysis, with the base year of the analysis 2007. The structure of the remaining paper is as follows: Section 2 briefly discusses rural-urban differences in relation to direct energy consumption; Section 3 describes the SAM multiplier model and also describes briefly the SAM and energy data used in the analysis; Section 4 presents the results and discussion; while section 5 concludes.

2. Context: household energy consumption and rural-urban differences

As discussed above, both the consumption (and cost) of energy used both within the home – mainly for space heating, but some for water heating, cooking, electrical appliances, etc. – and for transport have received considerable media and policy attention in recent years. These issues have come under increased scrutiny during the current period of austerity, although they have had to compete with other occasional economic alarms over food prices, wage and salary levels, and social welfare payments. The latter tend to ignore rural-urban distinctions, perhaps because it is assumed – problematically – that rural households are less exposed to the cost of food and/or to poverty than their urban equivalents. In contrast, there is awareness that, for structural reasons, the energy and transport needs of rural households often exceed those of urban households.

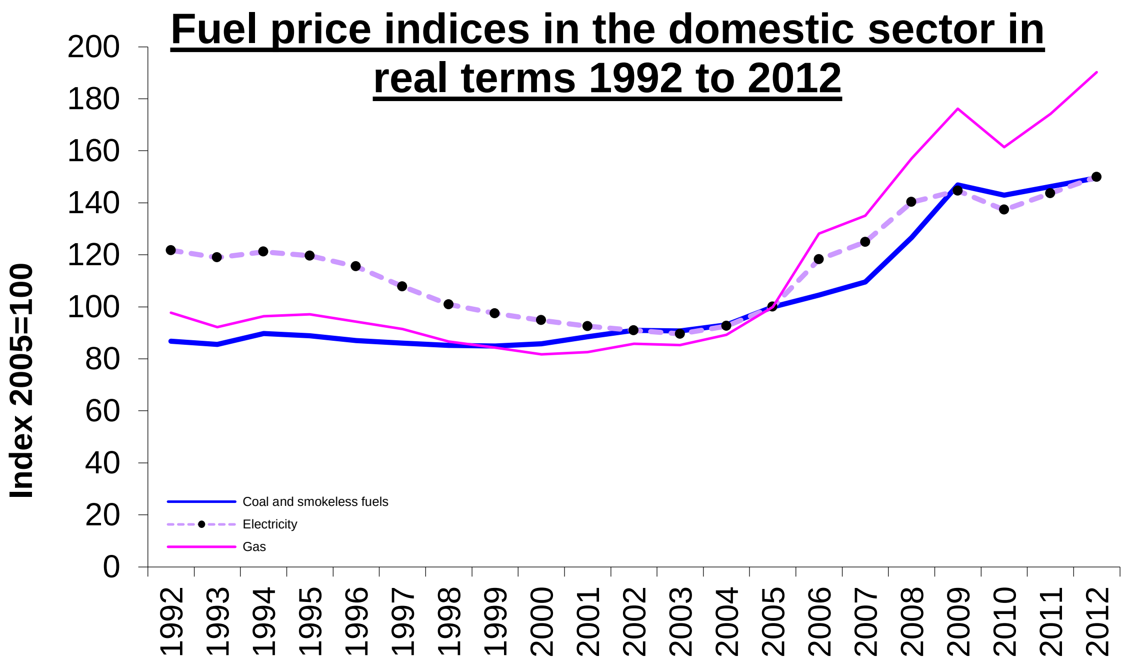
The well-known concept of "fuel poverty" is an attempt to establish a clear quantitative measure for home-based exposure and vulnerability to domestic energy costs. It is generally defined as the need to spend at least 10% of household income (over 20% for the 'extreme' fuel-poor) to achieve an adequate level of warmth at home through the year. Within the UK, national definitions vary slightly[1], but it will be appreciated that the concepts of "household income", "need" and "adequate", and the extent of under-occupancy and the energy (in) efficiency of the home all require consideration. It should be noted that estimated, not actual, household expenditure is used when assessing fuel poverty. Although there is no simple connection between general poverty and fuel poverty, nearly all low-income families are considered fuel-poor, but the reverse is not the case: a relatively high-income family living in a many-roomed energy-inefficient home might be similarly classified.

The Hills Review (2012) of fuel poverty has suggested a new "low income high costs" (LIHC) indicator of fuel poverty, "defined as the amounts by which the assessed energy needs of fuel poor households exceed the threshold for reasonable costs". In other words, the LIHC index would identify the 'poverty gap' in costs/expenditures, at both household and aggregate levels. This would move away from the 10%/20% expenditure shares currently used, to measure that shows the 'depth' or degree of fuel poverty. The measure would also take into account household size and composition, by way of 'equivalisation factors', such as 1.15 for a couple with children. The Review's analysis (for England) shows that, while the current 10% measure shows a dramatic rise in the number of fuel-poor households (and individuals) since 2003, the LIHC definition would have led to only a slight rise level over that period.

In terms of price changes, Figure 1 below suggests that the real prices of household fuel have risen sharply since the mid-2000s – by about 40% for electricity and coal and by about 80% for gas – although it should be borne in mind that these rises followed a long period of stability or even decline. The lack of access to certain forms of energy in rural areas (due to for example, no access to the national gas grid) suggests that rural households may face higher prices than their urban peers or at least have less potential to adjust between energy sources in response to changes in energy prices over time.

[1] Official thresholds are 21°C in the living room and 18°C in other rooms for a period of 9 hours in every 24 (or 16 in 24 over the weekend), with two hours being in the morning and seven hours in the evening. For elderly and infirm households (and specific to Scotland), a higher standard temperature of 23°C in the living room and 18°C in other rooms is required to be achieved for 16 hours in every 24, and there are no adjustments for under-occupancy.

Figure 1: Fuel price indices in the domestic sector in real terms 1992 to 2012



Source: DECC website, accessed 21 March 2013: https://www.gov.uk/government/statistical-data-sets/monthly-domestic-energy-price-stastics (*sic*).

In summary, analyses of rural-urban differences in fuel poverty have generally shown that levels are higher in rural areas, due to:

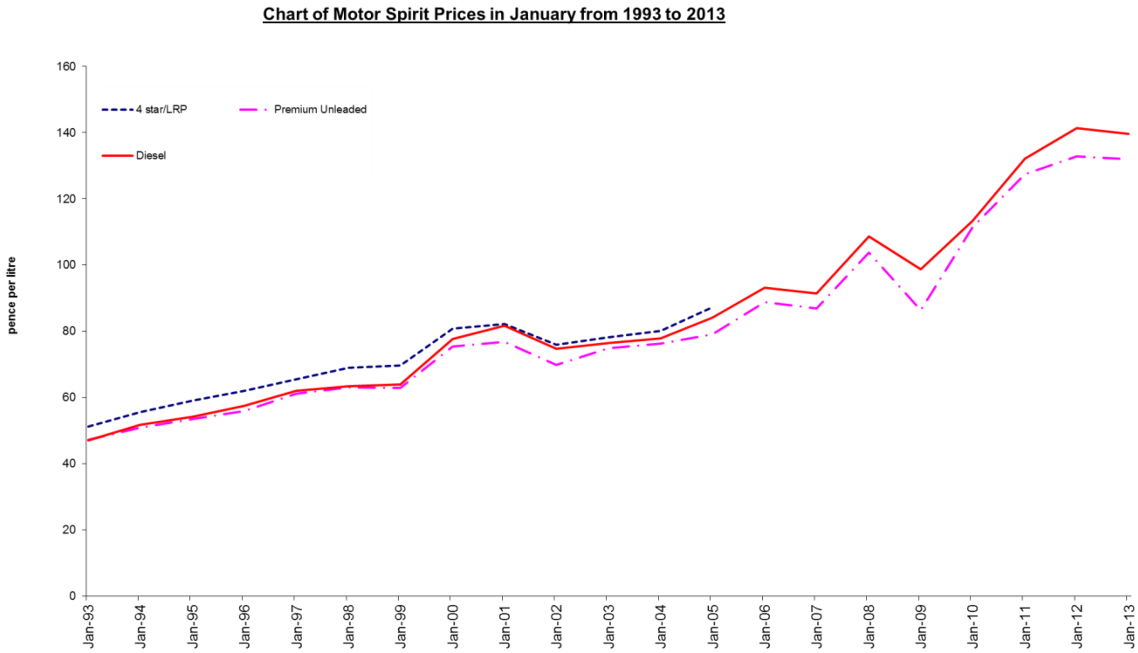
- higher domestic heating fuel prices,
- different house structures, e.g. fewer flats, and more detached houses
- lower levels of household energy efficiency (insulation, etc.)

Turning to transport, as identified by Atterton (2011), a number of factors distinguish rural from urban households in relation to their demand for transport fuel:

- Car ownership levels are higher, with multiple vehicles per household
- Average travel times to work or services (education, health, shopping, recreation) are longer
- Road fuel prices are higher, and access to fuel sources (garages, supermarkets) is limited and/or expensive

In relation to price changes, road fuel prices in the UK have risen much more continuously in recent decades than heating fuel prices, as shown by Figure 2. This was largely as a result of the “fuel duty escalator” of RPI+3% introduced in 1993. In recent years, the escalator has been virtually abandoned (most recently in the March 2013 Budget), and the current UK government seems generally content to leave transport fuel prices open to the international market (plus high domestic taxation) and retail competition e.g. between supermarkets. The latter have been investigated several times, with no strong findings of monopolistic or oligopolistic practices, but a limited programme of rural fuel duty relief scheme for retailers, and (in Scotland) a “road equivalent tariff" for island ferries has been introduced. In recent years, the steady fall in sterling has had a noticeable influence.

Figure 2: Motor Spirit Prices in January, UK, 1993 to 2013



Source: DECC website, accessed 21 March 2013. https://www.gov.uk/government/statistical-data-sets/oil-and-petroleum-products-annual-statistics.

In summary, rural households have, for various structural reasons, higher energy requirements than their urban counterparts and can face higher energy prices. For this reason, fuel security and fuel poverty in rural areas have been highlighted as key issues for the Scottish Government. However, when considering policies aimed at encouraging more sustainable low carbon economies, direct household energy consumption patterns provide an incomplete and possibly misleading picture. In particular, to the extent that households with different income levels based in different locations have different final consumption patterns, this may alter the pattern of total energy requirements from that suggested by direct consumption data alone.

This paper uses a SAM multiplier model to compare direct and embodied energy requirement by household income level and place of residence.

3. Methodological approach

The analysis is based on the accounting structure shown in Table 1.

Table 1 Overview of the structure of accounts used in the analysis

	Industries	Commod-ities	Factors	House-holds	Exog.	Total
Monetary accounts						
Industries		M				y_1
Commodities	U			Y	x_2	y_2
Factors	V					y_3
Households			W		x_4	y_4
Exogenous	t_1	t_2		t_4		y_5
Total	y_1'	y_2'	y_3'	y_4'	y_5'	
Physical accounts						
Energy	S			P		j

Within the monetary accounts framework, with *m* commodities, *n* industries, *k* fcators, and *h* households,
M a (*nxm*) a "make" matrix showing how industriessupply commodities
U a (*mxn*) combined use matrix showing purchases of commodities by industries
V a (*kxn*) value added matrix showing payments of industries to factors
W a (*hxk*) matix showing the distribution of factor income to households
Y a (*mxh*) matrix of final consumption of commodities by households
t_i row vectors of payments to exogenous accounts (including government, rest of world and capital accounts)
x_i column vectors of payments from exogenous accounts
y_i are the row totals for the industry, commodity, factor, household and exogenous accounts respectively.

In relation to the physical energy accounts, with *l* types of energy:
S is a (*lxn*) matrix showing the energy consumed by each industry
P is a (*lxh*) matrix showing each type of household's final energy consumption
j a vector of total energy consumption by type

Based on this framework, the basic SAM monetary accounts balance can be written

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} 0 & D & 0 & 0 \\ B & 0 & 0 & C \\ V & 0 & 0 & 0 \\ 0 & 0 & F & 0 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} + \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \quad (1)$$

$$y_5 = t_1 y_1 + t_2 y_2 + t_4 y_4 \quad (2)$$

The sub matrices in equation (1) have been formed by normalising the values in the monetary accounts by their column totals. In other words, *B* is a matrix showing the demand for commodity inputs per unit industry output, *V* shows value added payments per unit output, *D* is a coefficients make matrix showing the extent to which each industry contributes to a commodities overall supply, *F* shows the pattern of distribution of factor income to each household type, and finally C indicates the expenditure coefficients of households.

In a similar way, direct energy coefficients matrices Q and Z can be formed by dividing S and P above by the total industry output and household expenditure respectively. Thus the energy balance can be written

$$j = [Q\ 0\ 0\ Z]y \qquad (3)$$

Equations (1) and (3) can be simplified to

$$y = Ay + x$$
$$j = Ey$$

By assuming that every sub-matrix of coefficients has constant elements, the modeller is left with a fully determined system where for any given level of exogenous variables (x_i) it is possible to solve for the endogenous variables (y_i) and total energy requirements (j).[2]

In other words,

$$y = (I - A)^{-1}x \qquad (4)$$

And

$$j = E(I - A)^{-1}x \qquad (5)$$

In the context of this paper, the post multiplication of the direct energy coefficients matrix SAM multiplier matrix, $E(I - A)^{-1}$ in equation (5) provides a means of identifying the embodied energy requirements of each household type.[3] The results below thus focus on the comparison between the household elements within this multiplier matrix and those in the direct coefficients requirements, E.

The database for this analysis is the Scottish 2007 SAM. Based on the Scottish 2007 input-output table[4] and other data sources such as public expenditure reports[5], the SAM was constructed with 21 production sectors/commodities (detailed sectors can be seen in Appendix A), 5 institutional agents (Scottish households, Scottish Government, UK Government, rest of the UK, and rest of world), and 2 production factors (labour and capital). Using data provided by the official Living Costs and Food Survey (LCFS), the household account was further disaggregated into ten household accounts (by income quintile and by urban/rural location)[6].

[2] Equation (2) represents a variant of Walras's Law and implies that injections to and leakages from the model equate on aggregate (Pyatt and Round, 1979).
[3] Given the structure of the SAM (with commodity and industries shown separately) these are multipliers are consistent with the industry-technology assumption (Roberts, 2000).
[4] http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/Downloads
[5] For example, data on household benefits from SG and UK government, data on SG expenditure on investment from Scottish Government (2009) *Government Expenditure and Revenue Scotland 2007-2008*.
[6] The technical document describing how to disaggregate the household accounts can be obtained from authors upon request.

The categories of goods and services in the LCFS are based on those in the "Classification of Individual Consumption by Purpose" (COICOP), an internationally agreed system for reporting consumption expenditure within national accounts. Appendix B shows the commodity/service mapping between the categories in the LCFS data and the 21 SAM production sectors/commodities. So as to avoid double counting (and following standard SAM conventions, household expenditure on "Purchase of vehicles" was split between the "Wholesale and retail", and "Other manufacturing" SAM accounts while expenditure on the "Operation of personal transport" was split between "Wholesale and retail", and the SAM commodity "Petrol fuel". For "Forestry", "Mining" and "Public Administration" commodities, no matches were available in LCFS classification. In order to disaggregate the household group expenditures on these three commodities, the shares of total Survey household expenditures were used.

Table 2 presents household expenditure for key commodities by urban/rural location. It can be seen that the average weekly expenditure per rural household is about 10% higher than the expenditure of per urban household. Furthermore, rural households spend more on food, domestic fuel, and transport fuel than urban households but public transport expenditure by rural households is 30% lower than that by urban households.

Table 2: Household expenditure by urban/rural location, 2008-2010, Scotland

Commodity or service	Average weekly household expenditure (£)		Expenditure as a share of total household expenditure (%)	
	Urban	Rural	Urban	Rural
Food & non-alcoholic drinks	**49.10**	**54.70**	**11.3**	**11.5**
Alcoholic drinks, tobacco & narcotics	12.90	11.50	3.0	2.4
Clothing & footwear	22.40	19.90	5.2	4.2
Housing (net), fuel & power	51.10	49.80	11.8	10.5
Net rent	18.6	11.8	4.3	2.5
Maintenance and repair of dwelling	6	5.8	1.4	1.2
Water supply and miscellaneous services relating to the dwelling	7.2	6.7	1.7	1.4
Electricity, gas and other fuels	**19.3**	**25.5**	**4.5**	**5.4**
Household goods & services	26.40	30.10	6.1	6.3
Health	4.00	4.20	0.9	0.9
Purchase of vehicles	19.3	31.1	4.5	6.5
Other operation cost of personal transport	7.7	10.1	1.8	2.1
Petrol, diesel, and other motor oils	**16.4**	**24.8**	**3.8**	**5.2**
Public transport services(air, land, water)	**13.50**	**9.3**	**3.1**	**2.0**
Communication	11.70	11.60	2.7	2.4
Recreation & culture	54.90	64.90	12.7	13.6
Education	3.40	9.00	0.8	1.9
Restaurants & hotels	37.60	33.90	8.7	7.1
Miscellaneous goods & services	33.70	31.80	7.8	6.7
Other expenditure items	69.50	79.50	16.0	16.7
Total expenditure	433.6	476.2	100.0	100.0

Source: ONS, 2012

As explained above, the method requires physical energy consumption data by sector and by each household type in the model. Detailed industrial energy consumption by fuel for the UK[7] was used to estimate sectoral energy consumption in Scotland, based on the assumption of similar production techniques in both regions. Estimates of household energy consumption were also based on UK data disaggregated into household types using a combination of fuel expenditure information taken from LCFS and price information. While no rural-urban price difference was assumed for most types of fuels, evidence from the 2003 Rural Scotland Price Survey[8] was used to disaggregate consumption of "Petroleum products". The detailed table on final energy consumption by sector and by household type can be seen in Tables 3 and 4 below.

Table 3: Energy consumption by sector (Thousand tonnes of oil equivalent)

	Coal	Manufactured fuels*	Petroleum products	Gas	Electricity	bioenergy and waste	All fuels
Agriculture	0.1	0.0	17.8	12.2	17.6	16.7	64.4
Forestry	0.0	0.0	2.9	2.0	2.9	2.8	10.6
Fishing	0.0	0.0	4.5	3.1	4.4	4.2	16.2
Mining	0.0	0.0	14.1	10.7	10.6	0.0	35.4
Meat processing	0.0	0.0	3.9	18.3	15.1	0.0	37.3
Fish, fruit & vegetable processing	0.2	0.0	0.7	23.3	7.6	0.0	31.9
Other food	1.2	0.0	15.5	110.6	40.4	0.0	167.7
Alcoholic and soft drinks	0.1	0.0	4.1	45.5	10.1	0.0	59.9
Coke, refined petroleum & nuclear fuel	64.8	71.1	113.5	51.2	38.1	0.0	338.6
Chemical	0.0	0.0	16.5	257.9	121.2	0.0	395.6
Other Manufacturing	75.9	17.0	216.3	662.2	444.4	0.0	**1415.8**
Electricity, gas and hot water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	9.7	2.7	32.0	0.0	44.4
Construction	0.0	0.0	14.5	20.5	11.0	0.0	46.0
Wholesale & retail	0.0	0.0	34.0	156.8	266.2	0.0	**456.9**
Hotels, catering & pubs	0.0	0.1	5.2	113.7	68.8	3.7	191.6
Transport and communication	0.8	0.0	5084.4	5.7	54.9	96.8	**5242.6**
Finance and business	0.0	0.0	9.1	60.7	55.7	0.0	125.4
Public admin	0.0	0.1	8.2	92.2	38.1	4.6	143.2
Education, health and social work	0.0	0.5	18.6	238.9	79.1	23.3	360.5
Other services	0.0	0.0	5.4	77.5	59.1	0.5	142.5
Domestic	29.7	5.5	247.6	2607.9	977.8	105.7	**3974.2**
Total	172.9	94.3	5846.6	4573.5	2355.2	258.2	13300.7

*Includes all manufactured solid fuels, benzole, tars, coke oven gas and blast furnace gas.

[7] https://www.gov.uk/government/publications/energy-consumption-in-the-uk
[8] http://www.snedecon.co.uk/docs/2003%20RSPS%20Report.pdf

Table 4: Energy consumption by household (Thousand tonnes of oil equivalent)

	Coal	Man. ufactured fuels*	Petroleum products	Gas	Electricity	Bioenergy and waste	All fuels	All fuels per household (toe)
U_HH1 low	0.1	0.0	5.4	269.3	102.3	0.5	377.7	**0.23**
U_HH2	0.3	0.1	15.7	275.2	113.7	1.2	406.2	0.25
U_HH3	0.2	0.0	27.9	366.9	121.5	0.7	517.2	0.32
U_HH4	0.3	0.0	44.2	409.9	132.3	0.9	587.6	0.36
U_HH5 high	0.3	0.1	56.4	519.2	155.2	1.2	732.4	0.45
R_HH1 low	3.0	0.6	3.6	112.3	57.7	10.8	188.0	0.25
R_HH2	7.5	1.4	10.3	114.8	64.2	26.5	224.5	0.30
R_HH3	4.4	0.8	18.2	153.0	68.6	15.7	260.7	0.35
R_HH4	5.8	1.1	28.9	170.9	74.7	20.5	301.8	0.40
R_HH5 high	7.8	1.4	36.9	216.5	87.6	27.7	378.0	**0.50**
Total	29.7	5.5	247.6	2607.9	977.8	105.7	3974.2	

Note: U-urban, R-rural, HH1 to HH5, low income to high income; Source: own elaboration
*Includes all manufactured solid fuels, benzole, tars, coke oven gas and blast furnace gas.

It can be seen from Table 3 that "Transport and communication", "Other manufacturing", "Wholesale & retail" are the top three energy consuming industrial sectors, accounting for 76% of the total energy consumption by production sectors. Domestic or direct household energy use accounts for almost 30% of total energy consumption. The disaggregated figures in Table 4 show that energy use in income elastic, increasing with income levels but with rural households having higher consumption than their equivalent urban peer groups. In total, gas and electricity are the most important types of fuel in terms of household energy consumption.

4. Results and discussion

Using SAM multiplier analysis described above, it is possible to compare the direct and total energy requirements of households by location and income level. Here "direct energy requirement" means quantity of energy consumed per pounds expenditure, while "Total energy requirement" is quantity of energy consumed per pound expenditure both directly and through indirect and induced linkages in the economy (that is after allowing for embodied energy in goods consumed). Before considering individual energy types, the aggregate "all fuel" situation is presented (see Table 5).

Table 5 indicates that, aggregating across all fuel types, low income households have highest direct demands per unit expenditure. This is consistent with the concept of fuel poverty in section 2. However the Table also indicates the magnitude of energy embodied within the goods and services with the values in the fourth column of the table considerably higher than those in the second column. In particular, the ratio of direct to total energy consumed varies from just 0.26 for highest income rural and urban household categories to 0.48 for the lowest income urban household group. This suggests that high income household groups consume more energy intensive goods, such as “Other manufacturing”, and thus have higher indirect energy consumption. However, this is insufficient to change the rank positions of households apart form in the highest income category where urban households have lower direct energy consumption per £ expenditure than their rural peers but higher indirect consumption of energy.

Table 5: Comparison of direct to total energy by household location and income level

	Direct		TOTAL		Ratio
	All fuels	Rank	All fuels	Rank	direct :total
U_HH1 low	0.0884	1	0.1854	1	0.48
U_HH2	0.0433	3	0.1329	3	0.33
U_HH3	0.0409	5	0.1252	5	0.33
U_HH4	0.0337	7	0.1152	7	0.29
U_HH5 high	0.0232	10	0.0904	9	0.26
R_HH1 low	0.0804	2	0.1727	2	0.47
R_HH2	0.0415	4	0.1283	4	0.32
R_HH3	0.0376	6	0.1196	6	0.31
R_HH4	0.0329	8	0.1120	8	0.29
R_HH5 high	0.0234	9	0.0886	10	0.26

The analysis of all fuel energy use masks considerable differences between the different types of energy. Table 6 compares for example, direct to total energy requirement by household type for “Coal” and “Gas”.

Table 6: Comparison of direct and total coal and gas consumption by household type

	Coal					Gas				
	Direct	Rank	Total	Rank	Ratio: Direct to Total	Direct	Rank	Total	Rank	Ratio: Direct to Total
U_HH1 low	3.17E-05	7	0.0012	8	0.027	0.0631	1	0.0904	1	0.698
U_HH2	3.52E-05	6	0.0012	6	0.029	0.0293	3	0.0554	3	0.530
U_HH3	1.54E-05	8	0.0012	7	0.013	0.0290	4	0.0538	4	0.539
U_HH4	1.46E-05	9	0.0011	9	0.013	0.0235	5	0.0473	6	0.496
U_HH5 high	1.1E-05	10	0.0009	10	0.012	0.0165	9	0.0372	9	0.442
R_HH1 low	0.0013	2	0.0025	2	0.525	0.0480	2	0.0756	2	0.635
R_HH2	0.0014	1	0.0026	1	0.522	0.0212	7	0.0476	5	0.446
R_HH3	0.0006	3	0.0019	3	0.339	0.0220	6	0.0472	7	0.467
R_HH4	0.0006	4	0.0018	4	0.350	0.0186	8	0.0428	8	0.435
R_HH5 high	0.0005	5	0.0014	5	0.337	0.0134	10	0.0343	10	0.391

Table 6 indicates that coal is far more important in rural areas than urban in terms of direct use (coal consumption by urban households is close to zero) but this form of energy is embodied within goods and services consumed by urban households. A similar (but opposite) situation holds for gas where urban households dominate direct consumption but gas is embodied (at least to a limited degree) in goods and services consumed by rural households. As regards the ratio of direct to total energy use, a similar is observed as with the case for "all fuel", that is, higher income groups have lower ratio than lower income group due to the fact they consume energy indirectly, through their demand for other goods and services.

Table 7 presents equivalent results for the electricity and petroleum consumption of different household types. Rural households consume more electricity per £ total expenditure, but this declines with income levels. Allowing for indirect consumption does not alter the rank positions of each household type and, in this case, the magnitude of extra indirect consumption of energy is limited, particularly in the case of the low income households (with, for these groups, 61% of total electricity consumption being direct consumption regardless of the place of residence).

As expected, the rural-urban pattern of direct dependence on petrol is closely associated to income level. In this case, in contrast to electricity, there is a very low ratio of direct to total, due to the petrol associated with distribution of goods. This results in considerable changes in rank positions which indicate that lowest income groups have the most embedded petroleum consumption and, contrary to expectations, urban households have more embedded petroleum consumption than rural households.

Table 7: Comparison of direct and total electricity and petroleum consumption by household type

	Electricity					Petroleum				
	Direct	Rank	Total	Rank	Ratio: Direct to Total	Direct	Rank	Total	Rank	Ratio: Direct to Total
U_HH1 low	0.0239	2	0.0395	2	0.61	0.0013	10	0.0519	1	0.025
U_HH2	0.0121	3	0.0272	4	0.45	0.0017	8	0.0467	3	0.036
U_HH3	0.0096	6	0.0241	6	0.40	0.0022	5	0.0439	4	0.050
U_HH4	0.0076	8	0.0214	8	0.35	0.0025	3	0.0432	6	0.059
U_HH5 high	0.0049	10	0.0169	10	0.29	0.0018	7	0.0337	9	0.053
R_HH1 low	0.0247	1	0.0404	1	0.61	0.0015	9	0.0470	2	0.032
R_HH2	0.0119	4	0.0273	3	0.44	0.0019	6	0.0433	5	0.044
R_HH3	0.0099	5	0.0247	5	0.40	0.0026	2	0.0413	7	0.064
R_HH4	0.0081	7	0.0223	7	0.36	0.0032	1	0.0406	8	0.078
R_HH5 high	0.0054	9	0.0175	9	0.31	0.0023	4	0.0319	10	0.072

5. Conclusions

Fuel security and fuel poverty are gaining increasing policy attention, especially in rural areas where for structural reasons, energy demand is higher and energy prices often higher. In face of social and political concerns, government policy towards energy consumption has been varied, and arguably influenced as much by national climate change commitments as by poverty considerations. Various schemes to improve home energy efficiency have been introduced, most recently in the UK government's "Green Deal", a financial mechanism by which households can have energy efficiency improvements installed at no upfront capital cost, and pay for them, over a period of years, through a charge on their energy bill, with a 'Golden Rule' that savings must outweigh costs. The Energy Company Obligation (ECO) commits companies to include 'affordable warmth' for the lower income and most vulnerable households, and to focus on properties needing cost-effective measures (e.g. solid wall insulation) that do not meet the Golden Rule.

However while much attention has been focused on assessing and influencing the direct energy requirements of rural households, there has been far less attention on understanding the magnitude of embodied energy within the final goods and services consumed by households and, in particular whether this varies by income level and household location. This paper uses a SAM multiplier model to address this shortcoming.

The findings confirm that low income households, in general, have highest direct demands per unit expenditure, except for "petrol"; while for total energy requirement, low income group has the highest rank for all types of fuels. This is consistent with the concept of "fuel poverty" discussed in section 2. In relation to rural-urban differences, rural households have higher direct demands than their urban peels for "coal" and "electricity", but lower direct demands than urban households for "gas", and "All fuels". The case of petrol is particularly interesting as, while rural households have the highest direct energy requirements for this petrol, urban households turn out to have more embedded petrol consumption due to the high level of petrol consumption embodied within final consumption.

The above findings suggest that policies to eradicate fuel poverty should continue to pay attention to low income groups as they have higher direct and total energy requirement per unit income. However, when considering policies aimed at encouraging more sustainable low carbon economies, policies targeting direct energy consumption alone may miss certain issues such as the high levels of embedded petrol consumption in final goods. Addressing such issues will require policies aimed at industries, especially the transport sector.

The analysis is still preliminary, and the following further research is required. First, the treatment of transport distribution costs within the model needs to be improved. In particular, the current research treats the transport and distribution margins as the same across rural and urban space, which may underestimate embodied energy cost of rural households, especially in terms of for petrol consumption. Second, disaggregation by household composition rather than or in addition to) income level may provide more interesting findings in terms of indirect energy consumption. Finally, it is also necessary to work more on extent to which prices of energy vary between rural areas and urban areas and the ability of households to switch between types of energy for direct consumption. These would require a CGE modelling framework.

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Appendix A: Sectors and commodities in the SAM

Sectors and commodities in the SAM	**SIC (2003)**
Agriculture	01
Forestry	02
Fishing	05
Mining	10-14
Meat processing	15.1
Fish, fruit & vegetable processing	15.2,15.3
Alcoholic and soft drinks	15.9
Other food	15.4,15.5,15.6, 15.7,15.81-15.89
Coke, refined petroleum & nuclear fuel	23
Chemical	24.1-24.6
Other Manufacturing	16-22,24.7,25-37
Electricity, gas and other fuels	40
Water	41
Construction	45
Wholesale & retail	50,51,52
Hotels, catering & pubs etc	55
Transport and communication	60-64
Finance and business	65-67,70-74
Public admin	75
Education, health and social work	80,85
Other services	90-93,95

Appendix B: Mapping the SAM sectors to the COICOP sections in the LCFS 2008-2010

Sectors in the SAM	Section classifications based on COICOP from the LCFS 2008-2010	Section and sub-section names
Agriculture	1.1.26	Potatoes
	1.1.27	Other tubers and products of tuber vegetables
	1.1.19	Fresh fruit
	1.1.20	Other fresh, chilled or frozen fruits
	1.1.23	Fresh vegetables
	1.1.12	Milk
	1.1.14	Eggs
Forestry		
Fishing	1.1.11	Fish and fish products (0.333)
Mining		
Meat processing	1.1.5	Beef (fresh, chilled or frozen)
	1.1.7	Lamb (fresh, chilled or frozen)
	1.1.6	Pork (fresh, chilled or frozen)
	1.1.8	Poultry (fresh, chilled or frozen)
	1.1.9	Bacon and ham
	1.1.10	Other meat and meat preparations
Fish, fruit & vegetable processing	1.1.11	Fish and fish products (0.667)
	1.1.21	Dried fruit and nuts
	1.1.22	Preserved fruit and fruit based products
	1.1.24	Dried vegetables
	1.1.25	Other preserved or processed vegetables
Other food	1.1.1	Bread, rice and cereals
	1.1.2	Pasta products
	1.1.3	Buns, cakes, biscuits etc.
	1.1.4	Pastry (savoury)
	1.1.13	Cheese and curd
	1.1.15	Other milk products
	1.1.16	Butter
	1.1.17	Margarine, other vegetable fats and peanut butter
	1.1.18	Cooking oils and fats
	1.1.28	Sugar and sugar products
	1.1.29	Jams, marmalades
	1.1.30	Chocolate
	1.1.31	Confectionery products
	1.1.32	Edible ices and ice cream
	1.1.33	Other food products
	1.2.1	Coffee
	1.2.2	Tea
	1.2.3	Cocoa and powdered chocolate
Alcoholic and soft drinks	2.1	Alcoholic drinks
	1.2.4	Fruit and vegetable juices, mineral waters
	1.2.5	Mineral or spring waters
	1.2.6	Soft drinks
Coke, refined petroleum & nuclear fuel	7.2	Operation of personal transport (excluding margin)
Chemical	12.1.3	Toiletries and soap
	12.1.4	Baby toiletries and accessories (disposable)

Other Manufacturing	2.2	Tobacco and narcotics
	3	Clothing & footwear
	5	Household goods & services
	6.1	Medical products, appliances and equipment
	7.1	Purchase of vehicles (excluding margin)
	9.1	Audio-visual, photographic and information processing equipment
	9.2	Other major durables for recreation and culture
	9.3	Other recreational items and equipment, gardens and pets
	12.1.2	Toilet paper
	12.1.5	Hair products, cosmetics and related electrical appliances
Electricity, gas and other fuels	4.4	Electricity, gas and other fuels
Water	4.3	Water supply and miscellaneous services
Construction	4.2	Maintenance and repair of dwelling
Wholesale & retail	7.1	Purchase of vehicles (margin)
	7.2	Operation of personal transport (margin)
Hotels, catering & pubs etc	11	Restaurants & hotels
Transport and communication	7.3	Transport services
	8	Communication
Finance and business	12.4	Insurance
	12.5	Other services
	13.2	Licenses, fines and transfers
	13.4	Money transfers and credit
	14.1	Life assurance and contributions to pension funds
	14.2	Other insurance inc. friendly societies
Public admin		
Education, health and social work	6.2	Hospital services
	10	Education
	12.3	Social protection
Other services	9.4	Recreational and cultural services
	9.5	Newspapers, books and stationery
	9.6	Package holidays
	12.1.1	Hairdressing, beauty treatment
	12.2	Personal effects
	13.3	Holiday spending