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Forecasting scenarios for UK household expenditure and associated GHG emissions: outlook to 2030

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Abstract

Using the modelling tool ELESA (Econometric Lifestyle Environment Scenario Analysis), this paper describes forecast scenarios to 2030 for UK household expenditure and associated (direct and indirect) greenhouse gas (GHG) emissions for 16 expenditure categories. Using assumptions for real household disposable income, real prices, 'exogenous non-economic factors' (ExNEF), average UK temperatures and GHG intensities, three future scenarios are constructed. In each scenario, real expenditure for almost all categories of UK expenditure continues to grow up to 2030; the exceptions being 'alcoholic beverages and tobacco' and 'other fuels' (and 'gas' and 'electricity' in the 'low' scenario) leading to an increase in associated GHG emissions for most of the categories in the 'reference' and 'high' scenarios other than 'food and non-alcoholic beverages', 'alcoholic beverages and tobacco', 'electricity', 'other fuels' and 'recreation and culture'. Of the future GHG emissions, about 30% is attributed to 'direct energy' use by households and nearly 70% attributable to 'indirect energy'. UK policy makers therefore need to consider a range of policies if they wish to curtail emissions associated with household expenditure, including, for example, economic measures such as taxes alongside measures that reflect the important contribution of ExNEF to changes in expenditure for most categories of consumption.

Keywords: household expenditure; GHG emission; forecasting; scenarios;

consumption emissions.

1. Introduction

Through its Climate Change Act, the UK has a legally binding target to reduce greenhouse gas (GHG) emissions by at least 34% by 2020 relative to the 1990 baseline (the 'Interim'[1] budgets) and by at least 80% by 2050 (HM Government, 2008). This target is based upon a 'production perspective', which considers all emissions produced within the UK on a territorial basis. It thus includes all emissions that arise within the UK in the production of goods and services that are consumed overseas, but excludes emissions produced in other countries in the production of goods and services consumed in the UK. The contrasting perspective is the 'consumption perspective', which includes emissions that arise overseas and are 'embedded' in the production and distribution of goods and services consumed in the UK, but excludes those that arise within the UK in the production of goods and services exported abroad. Both the production and consumption perspectives are valuable for different aspects of policy but, arguably, the consumption perspective is more appropriate for consideration of policies concerning household consumption.

A number of recent papers have considered the issue of measuring emissions on a consumption perspective rather than a production perspective, such as Munksgaard and Pedersen (2001), Li and Hewitt (2008), Anderson et al. (2010), and Davis and Caldeira (2010). Munksgaard and Pedersen (2001) compared total emissions based on the two perspectives and developed the concept of a CO_2 trade balance. They showed that from 1989 to 1994 the CO_2 trade balance for Denmark turned into a

[1] 'Interim' budgets are one of the two sets of budgets proposed by the Committee on Climate Change (2008) and apply for the period before a global deal is reached.

deficit of 7 million tonnes from a surplus of 0.5 million tonnes in 1987, illustrating the significant amount of CO_2 that is embodied in foreign trade.

Davis and Caldeira (2010) estimated the CO_2 emissions embodied in global international trade. Based on a consumption perspective, they found that, in 2004, 23% of global CO_2 emissions were traded internationally, primarily as exports from China and other emerging markets to consumers in developed countries. Moreover, they estimated that in some wealthy countries, including the UK, more than 30% of consumption-based emissions were imported. In contrast, net exports represented 22.5% of emissions produced in China. This is in line with findings of other studies which focus on the UK, such as Druckman and Jackson (2009b) and Wiedmann et al. (2010).

Li and Hewitt (2008) estimated the amount of carbon dioxide (CO_2) embodied in bi-lateral trade between the UK and China in 2004 and found that this effectively reduced the UK's CO_2 emissions by about 11% compared with a non-trade scenario. In addition, due to the greater carbon intensity and relatively less efficient production processes of Chinese industry, they suggested that the carbon footprint of UK consumers increased by about 19% and global CO_2 emissions increased by 0.4%. Hence, through international trade and consumer choices, significant environmental impacts can be shifted from one country to another, and global GHGs can increase.

Arguably, Li and Hewitt (2008) did not adequately account for the environmental consequences of transporting goods. Anderson et al. (2010) however, did analyse the role of transport in creating CO_2 emissions for China and found that total emissions associated with the transport of import and exports exceed 300 Mt CO_2, with net export of emissions amounting to 110 Mt CO_2. They also found that transport related emissions are comparably high in China due to the lower efficiency of bunker fuel production. Therefore, countries that have seen declining emissions based on a production perspective might have seen, in recent years, increased emissions on a consumption basis when the impact of transport, is factored in.

These studies illustrate that emissions based purely on a production perspective might well give a misleading picture when compared to those based on a consumption perspective.[2] Indeed, Druckman and Jackson (2009a) estimated that GHG emissions attributed to households, when estimated from the consumption perspective, rose by around 3% per annum between 2000 and 2004. Although the economic turndown may have had the effect of reversing this trend, as demonstrated in this paper, unless there are significant changes in UK government policies, the direct and indirect emissions attributable to household consumption will continue the long-term trend of rising emissions into the future. Policies aimed at reducing these emissions are therefore required, and in order to achieve greatest future GHG reductions, the household expenditure categories associated with the highest levels of GHGs emissions should arguably be targeted.

In summary, it is vital that UK policy makers have a full understanding of expenditure patterns and their associated direct and indirect emissions, both now and in the future.

[2] However, it is worth noting that Steckel et al. (2010) show that under a global cap and trade system with full coverage and given initial allocations, the production and consumption perspectives are equivalent in terms of efficiency and distributional effects. They also show that the different perspectives do matter whenever the initial allocation rule for emission rights is related to past emissions.

An important question, addressed in this paper, is therefore how are the different categories of UK expenditure and their associated direct and indirect emissions likely to develop until 2030. It is with this issue that the remainder of this paper is concerned. Accordingly, future household GHG emissions from the consumption perspective are modelled based on past trends to construct three scenarios up to 2030 ('reference', 'high', and 'low') using the ELESA (Econometric Lifestyle Environment Scenario Analysis) model. This uses estimated household expenditure functions to build future scenarios encompassing 16 UK household expenditure categories. The scenarios are constructed using assumptions about future real household disposable income, real prices, exogenous non-economic factors (ExNEF)[3], and temperatures. Trends in the GHG intensity of each of the expenditure categories are derived from the Surrey Environmental Lifestyle Mapping (SELMA) framework (Druckman and Jackson, 2009a). In this way, the household consumption categories associated with the highest GHG emissions are identified to help policy makers and aid better planning and future GHG mitigation.

ELESA differs from other modelling tools in two key ways. The first is that ELESA estimates future emissions from the consumption perspective, and can thus be used to explore policy options concerning household consumption. The second is that it attempts to model non-price and non-income effects through ExNEF, described in more detail in Section 2.

[3] The inclusion of ExNEF is an important and innovative feature of ELESA - see Section 2.

The paper is organized as follows. The next section (Section 2) describes ELESA. This is followed by a description of the scenario assumptions (Section 3.1), with the scenario results being presented in Section 3.2. A discussion of the results is in Section 4 followed by a conclusion in Section 5.

2. ELESA (Econometric Lifestyle Environment Scenario Analysis)

ELESA is a modelling tool in which the Harvey's (1989) Structural Time Series Model (STSM) is used to estimate household expenditure equations for 16 categories of UK household expenditure, using quarterly time series data for 1964:q1 to 2009:q1 (Chitnis and Hunt, 2010 and 2011). The expenditure groupings are based on COICOP[4] categories, which comprise of 12 high level categories. As the focus is on GHG emissions, the four lower level categories of 'direct energy'[5] use for individual treatment are separated out, giving 16 categories altogether.[6]

The STSM used in ELESA enables examination of the relationship between household expenditure, income, price *and* a stochastic (rather than a deterministic) underlying trend, which is arguably important when estimating the elasticities of demand, as discussed by Hunt and Ninomiya (2003). This shape of the underlying trend is determined by factors such as technical progress, changes in consumer tastes

[4] Classification of Individual Consumption According to Purpose (UN, 2005).

[5] 'Direct energy' is consumed directly by households in form of 'vehicle fuels', 'gas', 'electricity' and 'other fuels'.

[6] These 16 categories are: 'food and non-alcoholic beverages', 'alcoholic beverages, tobacco and narcotics', 'clothing and footwear', 'electricity', 'gas', 'other fuels', 'other housing', 'furnishings; household equipment and routine maintenance of the house', 'vehicle fuels and lubricants', 'other transport' 'health', 'communication', 'recreation and culture', 'education', 'restaurants and hotels' and 'miscellaneous goods and services'.

and preferences, socio-demographic and geographic factors, lifestyles and values (i.e. ExNEF). Individual ExNEF are not easily measurable in terms that would provide suitable data for further disaggregation. However, their existence may still be confirmed by the analysis, and is important in terms of understanding the underlying drivers of expenditure and associated emissions. Finally, the STSM allows for stochastic seasonality so that this is also included in the long-run expenditure model:

$$exp_t = \mu_t + \lambda_t + \pi p_t + \tau y_t + \upsilon_t \qquad \upsilon_t \sim NID(0, \sigma_\upsilon^2) \qquad \textbf{(1)}$$

where $\exp_t$ is real household expenditure; λ_t represents the seasonal component; p_t is the real price; y_t is real household disposable income; μ_t is a (stochastic) underlying trend that determines the impact of ExNEF;[7] π and τ are unknown parameters to be estimated; and υ_t is a random white noise disturbance term. For 'electricity', 'gas' and 'other fuels' expenditure, temperature is also included in the equations. [8]

GHG intensities for each of the 16 expenditure categories are modelled in a similar way to that in Hunt and Ninomiya (2005), again using the STSM as presented in Chitnis and Hunt (2012). Historical GHG emissions[9] (1992-2004) attributed to household final demand are estimated using the Surrey Environmental Lifestyle MApping (SELMA) framework (Druckman and Jackson, 2008 and 2009b). There are

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[7] As explained in Hunt and Chitnis (2011 and 2012) the estimate of ExNEF is equal to the change in the estimate of the underlying trend ($\Delta\hat{\mu}_t$).

[8] For more details and estimation results, see Chitnis and Hunt (2010 and 2011).

[9] This study estimates a basket of six GHGs: carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride (ONS, 2008). The unit of measurement is carbon dioxide equivalent (CO_2e); for more information see OECD (2005).

two types of emissions attributable to household final demand: one is the GHG emissions from ‘direct’ energy use. These are relatively straightforward to estimate as they are recorded in the UK Environmental Accounts (ONS, 2008). The other type is ‘embedded’ or ‘indirect’ emissions which accounted for around two thirds of the total average UK household carbon footprint in 2004 (Druckman and Jackson, 2010). Some embedded emissions arise within the UK, but, due to the globalisation of supply chains, many arise outside the UK. Estimation of embedded emissions is carried out using the Quasi-Multi-Regional Input-Output (QMRIO) model incorporated within SELMA. For the purposes of ELESA, GHG emissions due to investment are attributed to household and government expenditure within the QMRIO sub-model. Details of SELMA’s methodology, data sources, assumptions and limitations are provided in Druckman and Jackson (2008, 2009b and 2009a). GHG intensities are calculated by dividing the GHG emissions that arise due to household expenditure in the COICOP category in question by the household real expenditure in the COICOP category. ELESA is then used to model GHG emissions for each category and for each year (t) up to 2030 using the scenario assumptions described in the next section and the following equation:

$$\text{GHG emission}_t = \text{GHG intensity}_t \times \text{expenditure}_t$$

3. Forecasting emissions

3.1. Scenarios and assumptions

In this section, ELESA is used to construct quantitative scenarios by making assumptions for the economic and non-economic factors. Three scenarios are considered: ‘high’ (H), ‘reference’ (R) and ‘low’ (L), where the values for real household disposable income, real price, ExNEF, temperature and GHG intensity are chosen accordingly. Therefore, to forecast household expenditure and GHG emissions for each of the 16 categories, three cases are considered as follows:

- *'Reference' case*: This is similar to a 'business as usual' scenario, where the assumptions for the growth in real household disposable income, real prices, temperature, ExNEF caused by the underlying trend and GHG intensities represent the 'consensus' or 'most probable' outcomes as explained below, resulting in a 'business as usual' or 'reference' scenario for real expenditure and GHGs growth.[10]

- *'Low' case:* The aim of this scenario is to represent conditions where GHG emissions attributable to households are lower than in the reference scenario. Accordingly, in this scenario real household disposable income growth is lower (e.g. due to economic recession or higher income tax rates) than in the reference scenario and real price growth is higher (e.g. due to shocks, higher energy/input prices or price taxes). In addition, ExNEF is lower due to a lower growth in the underlying trend (e.g. due to say more environmental awareness or an increase in the pace of technical progress) than in the reference scenario. In this scenario GHG intensities are assumed to be lower (e.g. due to policies for electricity generation and use of renewable energy) than in the reference scenario. These conditions will give rise to lower expenditure growth than in the reference scenario, and lower growth in GHG emissions. In this scenario the average UK

[10] For real household disposable income and real energy prices (for 'gas', 'electricity' and 'vehicle fuels') the assumptions are based on UK government's predictions that take into account the economic policies and measures in the UK. The predictions for temperature, trend and GHG intensities are based on historic data analysis.

temperature growth is assumed to be higher (e.g. due to higher total global warming) than in the reference scenario, and consumption of 'electricity', 'gas' and 'other fuels' for space heating is assumed to reduce with higher temperatures. This assumption does not take account of the increase in the use of air conditioning that may be expected with increasing temperatures (Hekkenberg et al., 2009) and therefore electricity emissions may be under-estimated.

- *High' case:* In contrast to the low scenario, in this scenario real household disposable income growth is higher (e.g. due to increased economic growth or lower income tax rates) than in the reference scenario, real price growth is lower (e.g. due to lower energy/input prices or lower price taxes), ExNEF is higher due to higher growth in the underlying trend (e.g. due to say less environmental awareness or a slowdown in the pace of technical progress), average UK temperature is assumed to be lower (e.g. due to lower total global warming) and GHG intensities are higher (e.g. due to production in countries with less efficient technologies). This results in the 'high' case scenario for real expenditure and GHGs growth.

In summary, the 'reference' scenario represents 'business as usual', whereas the 'low' ('high') case is characterised by lower (higher) household disposable income growth, higher (lower) real price growth, higher (lower) temperatures, lower (higher) ExNEF and lower (higher) GHG intensities. The actual assumptions for the key variables in the scenarios are as follows:

Real household disposable income

To guide the assumptions for the 'reference' scenario, the average independent growth rate forecasts from 2011 to 2012 are used for real household disposable income, taken from HMT (2011a). The average independent growth rate forecasts for GDP from 2013 to 2015 are taken from HMT (2011b) and converted to real household disposable income growth.[11] Thereafter, assuming that economic conditions will return to 'normal' the assumption is based upon the long run growth rate for real household disposable income. For the 'low' and 'high' scenarios the assumed growth rates are 0.5% per annum lower and 0.5% per annum higher than the reference growth assumption respectively. These assumptions are shown in Table 1.

{Table 1 about here}

Real prices

For real prices, the assumptions for the 'reference', 'low' and 'high' cases for 'electricity', 'gas' and 'vehicle fuels and lubricants' categories are guided by the Department of Energy and Climate Change (DEEC) predictions[12] for 2009 to 2030. For all other categories, 'reference' assumptions are set with regard to historical price data i.e. the business as usual with modification where required. The categories with modified price are mentioned in the Appendix; otherwise the historic average annual growth rate is applied for the future with appropriate variation around this for the

[11] To do this, the relationship between real household disposable income growth and GDP growth is estimated; using the UK annual time series data from 1948 to 2008:

$$\Delta y = 0.011994 + 0.57869\,\Delta gdp$$

where y and gdp are logarithm of real household disposable income and real GDP respectively. Note that the first difference of logarithm of a variable is equal to its growth.

[12] www.decc.gov.uk

‘low’ and ‘high’ scenarios. The price assumptions for each of the 16 expenditure categories are summarised in Table 2.

ExNEF

For the future projection of the ExNEF component, the slope of the underlying trend at the end of the estimation period (over the whole sample) is assumed to continue into the future for the ‘reference’ scenario (equation 2) for each of the 16 expenditure categories with variation around this for the ‘low’ and ‘high’ scenarios, as shown in Table 2.[13]

GHG intensities

Future GHG intensities for the ‘reference’ scenario are based upon the future trends of the 16 STSM equations, similar to Hunt and Ninomiya (2005) and Chitnis and Hunt (2012), with appropriate variation around these for the ‘low’ and ‘high’ scenarios; as shown in Table 2. When looking at these estimated future GHG intensities it must be remembered that these figures are a result of historic changes in both the real expenditure in each category and the emissions in the same category.

{Table 2 about here}

Temperature

The temperature component is used for estimating household expenditure for

[13] This excludes ‘miscellaneous goods and services’ where the expenditure equation has a fixed level but stochastic slope. In this case, for consistency, the average slope 1990q1-2009q1 at the end of the estimation is assumed to continue into the future for the ‘reference’ scenario with appropriate variation around this for the ‘high’ and ‘low’ scenarios.

‘electricity’, ‘gas’ and ‘other fuels’ only. When estimating expenditure in these categories, future UK temperatures are estimated using the future trend of temperature equation[14] as the ‘reference’ scenario, with the ‘high’ and ‘low’ assumptions 0.5 Degree Celsius higher and 0.5 Degree Celsius lower than the reference assumption respectively.[15] The resulting average annual increases in average UK temperatures are shown in Table 3.

{Table 3 about here}

3.2. Results

Expenditure

Future predictions for expenditure are generated through the estimated expenditure equations for each category as described above. The assumptions discussed in the previous section and summarised in Tables 1 to 3 are applied to the explanatory variables in the estimated household expenditure equations. This gives the expenditure forecasts for the 16 COICOP categories, which are shown in Figure 1.

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[14] The estimated STSM for temperature, using the UK quarterly time series data from 1964q1 to 2009q1 (leaving 8 observations for prediction Failure test), is as follow:

$$temp_t = \tau_t$$

where $temp_t$ *is* temperature and τ_t is the stochastic trend.

Std. Error= 0.75; Normality= 5.26; H(57)= 1.14; $r_{(1)}$= - 0.02; $r_{(4)}$= 0.14; ; $r_{(8)}$= - 0.06; D.W.= 2.02; $Q_{(8,6)}$= 11.81; Rs^2= 0.48; $Normality_{(Irr)}$= 3.98; Normality $_{(Lvl)}$= 0.70; Failure= 10.33; LR= 11.37.

The nature of trend is local level with drift. For more information regarding diagnostics please see Chitnis et.al 2010, 2011.

[15] This is arguably an arbitrary assumption to allow for a sensible upper and lower bound, however they are not that dissimilar to those of the Intergovernmental Panel on Climate Change (IPCC), see www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html.

The actual data in Figure 1 are shown from 1964 to 2008 and thereafter predicted from 2009 to 2030 with three different scenarios; ‘reference’, ‘low’ and ‘high’.

{Figure 1 about here}

Figure 1 shows that household expenditure in almost all categories is predicted to increase throughout the period to 2030 under the different scenarios. The only exceptions are ‘alcoholic beverages and tobacco’ and ‘other fuels’ expenditure which are predicted to decrease in the future under all three sets of assumptions. In addition, ‘electricity’ and ‘gas’ expenditure are predicted to decrease under the ‘low’ scenario only.

Figure 2 presents total household expenditure in all 16 categories for the ‘high’, ‘reference’ and ‘low’ scenarios in terms of actual values. As shown in this figure, total expenditure is predicted to increase in 2020 by 27% (41%, 15%) and in 2030 by 74% (114%, 42%) compared to 2010 level under the ‘reference’ (‘high’, ‘low’) scenario(s).

Figure 2 also shows the contribution of each category of expenditure to total expenditure in each year. In 2010, according to the scenarios, ‘other housing’ and ‘other fuels’ will have the highest and lowest expenditure respectively. While ‘other fuels’ are predicted to remain the lowest expenditure category in 2020 and 2030, the estimates show that ‘recreation and culture’ will take over ‘other housing’ as the highest expenditure category in these years.

{Figure 2 about here}

Although from Figures 1 and 2 the amount of expenditure in most of the categories is predicted to increase in the future, the share of each category within total household expenditure is predicted to vary with time. Figure 3 shows the predicted percentage shares of expenditure for each COICOP category to total expenditure for the different scenarios. This suggests that the share will *decrease* for the categories 'food and non-alcoholic beverages', 'alcoholic beverages and tobacco', 'furnishings; household equipment & routine maintenance of the house', 'health', 'restaurants and hotels', 'miscellaneous goods and services', 'electricity', 'gas', 'other fuels', 'other housing' and 'vehicle fuels and lubricants'.[16] In contrast, Figure 3 suggests that the share will *increase* for 'clothing and footwear', 'communication', 'recreation and culture', 'education' and 'other transport'.

The estimates show that over 50% of future predicted total expenditure in 2030 will come from only four categories i.e. 'recreation and culture', 'miscellaneous goods and services', 'other housing' and 'other transport'. With regard to GHG emissions then, what really matters is how GHG-intensive these categories are relative to other categories; whether these four are the categories associated with the highest amount of GHG emission and whether reducing expenditure in these categories will lower the future emissions appreciably. This is investigated further below.

{Figure 3 about here}

[16] The expenditure share for 'vehicle fuels and lubricants' would increase in 2020 compared to 2010 under the 'low' scenario only.

GHG Emissions

Estimated GHG emissions attributable to each category from 1992 to 2030 are illustrated in Figure 4. The graphs suggest that total GHG emissions for most of the COICOP categories will generally increase in the 'reference'[17] and 'high' scenarios. However, 'alcoholic beverages and tobacco' and 'other fuels' are the two exceptions in which GHG emissions are predicted to decrease in the future under all three scenarios.

{Figure 4 about here}

Figure 5 presents total GHG emissions in all 16 categories for the three scenarios and shows that total emissions are predicted to increase by 8% (36%, -15%) in 2020 and by 27% (107%, -22%) in 2030 compared to 2010 under the 'reference' ('high', 'low') scenario(s). Figure 5 also shows the composition of total emissions and the contribution of each category to total emissions. In 2010, 'other transport' and 'alcoholic beverages and tobacco' are predicted to be the highest and lowest emissions categories, respectively. Whilst 'other transport' continues to remain the highest emission category in 2020 and 2030, 'other fuels' will replace 'alcoholic beverages and tobacco' as the lowest emissions' category in these years.

{Figure 5 about here}

As shown in Figure 5, the actual amount of GHG emissions in most of the categories

[17] The exceptions are 'food and non-alcoholic beverages', 'electricity' and 'recreation and culture' which the GHG emissions will decrease in the 'reference' scenario.

is predicted to increase in the future under the ‘reference’ and ‘high’ scenarios; but the share of each category to total GHGs emitted by households will not necessarily follow the same pattern. The predicted percentage share of emissions for each category of consumption to total emissions is therefore presented in Figure 6 for the different scenarios. This shows that the share is predicted to *decrease* for ‘food and non-alcoholic beverages’, ‘alcoholic beverages and tobacco’, ‘clothing and footwear’ (except under ‘high’ assumption), ‘electricity’, ‘gas’, ‘other fuels’, ‘furnishings; household equipment & routine maintenance of the house’, ‘communication’ and ‘recreation and culture’. In contrast, the share is predicted to *increase* for ‘health’, ‘vehicle fuels and lubricants’, ‘education’, ‘other transport’, ‘restaurants and hotels’ and ‘miscellaneous goods and services’. For ‘other housing’, the share will increase in 2020 but decreases in 2030.

However, ‘direct energy’ use by households for ‘vehicle fuels and lubricants’, ‘gas’ ‘electricity’ and ‘other fuels’ is predicted to be responsible for about 30% of total emissions in 2030. This means that nearly 70% of GHG emissions could be attributable to ‘indirect energy’[18] use by households, with ‘other transport’[19] having the largest share of any single category, at almost 20% of total emissions from direct and indirect energy.[20] Consequently, ‘other transport’ will have the highest emission share in 2030 despite not having the highest expenditure share in this year.

{Figure 6 about here}

[18] ‘Indirect energy’ or ‘embedded energy’ is the energy used in supply chains in the production and distribution of goods and services purchased by UK households.

[19] The category ‘other transport’ includes buses, trains and air travel.

[20] These shares are similar in 2010.

4. Discussion

The above analysis suggests that household total expenditure is predicted to increase under all scenarios. From this, it can be seen that, without a change in policy and barring any unexpected exogenous shocks, the expenditure is predicted to continue to increase over time. Assuming policy makers do not wish to curtail income, possible policies that could be introduced to counteract this trend include, for example, indirect taxation, incentives for higher saving rates[21] or 'softer' types of intervention, such as increasing environmental awareness to bring about behavioural change.

According to the results, in the 'reference' and 'high' scenarios, rather than seeing emissions *falling*, emissions are predicted to *rise*. Moreover, the rate at which they are predicted to rise increases with time up to 2030. This implies a radical departure from the targeted *reduction* of at least 34% in UK emissions by 2030, from a production perspective unless expenditure is controlled through the previously mentioned policies.

The scenarios act as a reminder that in order to move towards future GHG mitigation the focus should be on the categories of consumption that show high and increasing patterns of associated GHG emissions. According to the results, the highest GHG emissions in 2030 will be the categories 'other transport' and 'vehicle fuels and lubricants' (those concerned with the transportation sector) and 'gas'. Therefore, reducing consumption in this group could significantly lead to lower future emissions.

[21] Higher saving rates could be incentivised through for example, an extension of tax fee saving such as the ISA accounts in the UK.

Obviously not all categories with high expenditure are associated with higher GHG emissions as they may have a lower GHG intensity, which more than compensates for the high expenditure resulting in lower GHG emission for that particular category of consumption.

The goods and services comprising ‘vehicle fuels and lubricants’ and ‘gas’ categories are self explanatory, however the 'other transport' category would ideally be subject to further disaggregation and estimation in order to gain a more comprehensive understanding of the relative share of expenditure on road, rail, air and sea transport, and the GHG intensity associated with each. Even a cursory examination of the historical data suggests that these sub-categories have undergone very different trajectories, and may be expected to continue along unique pathways according to the assumptions adopted in the context of a scenario forecast.

Clearly, some of the policies designed to meet the production perspective target will have a desirable impact from a consumption perspective also, e.g. through reduced GHG intensity of electricity. However, the prediction within these scenarios of 70% of total emissions being attributable to 'indirect energy' use, highlights the need for a complementary consumption perspective, particularly one that teases out the relative share of embodied emissions resulting from production in the UK versus other regions. In the absence of such a shadow accounting perspective, there is a risk that production perspective policies may in fact exacerbate consumption emissions by encouraging further off shoring of energy intensive industry, perhaps to less energy efficient economic regions, and requiring increased transportation to bring those goods to the UK market (Milne, 2011).

Peters and Hertwich (2008) argued that consumption-based GHG inventories have many advantages over production-based inventories since they encourage production to occur where environmental impacts are minimized. They believed that addressing carbon leakage, reducing the importance of emission commitments for developing countries, increasing options for mitigation, encouraging environmental comparative advantage and technology diffusion, addressing competitiveness concerns, are among the advantages of consumption perspective.

Bastianoni et al. (2004) presented an approach to assign the responsibility of GHG emissions in a measure that was a trade-off between consumption and production accounting perspectives. They believed that this approach allows sharing the responsibilities among all the interested subjects in an efficacious and fairer way. Consumers were taken as responsible for most of the emissions and were encouraged to find the producers with the best environmental performances. Producers were involved in the responsibility of the emissions and were encouraged to reduce them. This approach was further developed by Lenzen et al. (2007) who discussed a method of consistently delineating the supply chains, into mutually exclusive and collectively exhaustive portions of responsibility to be shared by consumers and producers; who were interested to enter into a dialogue about what to do to improve supply chain performance and the profile of consumer products.

5. Conclusion

This paper describes the ELESA model and its use to produce future scenarios up to 2030 for 16 categories of UK household expenditure and the GHG emissions associated with each of these categories. As mentioned in the Introduction, ELESA differs from other modelling tools in that it takes the consumption perspective, and also models ExNEF.

A novel feature of this study is that modelling of expenditure (and thus GHG emissions) is based on not just the standard factors such as prices and incomes but also on ExNEF. As noted above the ExNEF is derived from the estimated underlying trend that encompasses unobserved components that are usually too hard to actually measure, such as technical progress, changes in tastes, consumer preferences, socio-demographic and geographic factors, lifestyles and values. Chitnis and Hunt (2010 and 2011) found that ExNEF made a contribution in all of the household expenditure categories, which demonstrated the importance of considering these factors when devising policies to reduce expenditures and associated GHG emissions. Specifically, ExNEF had a relatively high contribution to changes in expenditure in 'other transport', 'vehicle fuels and lubricants', 'gas' and 'miscellaneous goods and services' categories: thus influencing ExNEF could be particularly effective in attempts to reduce household expenditure and associated emissions in these categories. Policies that influence ExNEF include, for example, educational campaigns to increase environmental awareness, research and development in new technologies, incentives to increase savings and investments (particularly in low carbon technologies as discussed in Druckman et al. (2011), restrictions on advertising and so on (see Jackson, 2011). The results suggested that such policies might be especially effective in these specific expenditure categories. Of course, beside such policies, economic incentives such as price increases through (carbon) taxes should be carefully considered, while, of course, keeping in mind possible negative side effects such as price increases in other associated sectors. It is also particularly important that policies are put in place to protect against regressive effects.

ELESA is a modelling tool, and this paper illustrates its power by modelling three specific scenarios based on the current conditions. The assumptions on which these scenarios are based are, of course, all uncertain and, as with any scenario-forecasting tool, appropriate assumptions will change as time progresses.[22] This is especially true at the time of writing this paper when Western economies are in extreme economic turbulence, with countries such as the USA and France having lost their AAA credit rating (S & P, 2012) and the Euro in danger of collapse (The Economist, 2012).

Finally, it should be noted that the ELESA model quantifies the effect of all non-economic factors as one composite factor called ExNEF. Clearly, it is possible and indeed likely that components of ExNEF have competing (positive and negative) impacts on expenditure, such that these forces may cancel each other out to some extent, leaving a relatively small overall effect. As a result, it is impossible to determine the true significance of non-economic as opposed to economic factors unless more work is done to disaggregate the contributions to ExNEF made by different factors. These may include technical progress, changes in consumer tastes and preferences, socio-demographic and geographic factors, lifestyles and values, etc. Crucially, identifying such factors would be a step towards understanding the real mechanisms of change that may be more or less subject to intervention by policymakers, thus aiding the transition towards lower carbon lifestyles.

[22] ELESA is a new model that, unlike a number of other models, allows an analysis of UK expenditure categories and their associated emissions. Nevertheless, it would be good to see other similar types of models developed that could be compared with ELESA and the forecast scenarios presented here.

Acknowledgements

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Appendix: Price growth rate assumptions for the reference scenario for selected COICOP categories

‘Food’ real prices generally decreased between 1977 and 2006, with a slight reduction in the rate of decrease 2001-2006. In 2007 the international food price increased dramatically and this, coupled with the depreciation of sterling, caused UK food prices to increase sharply. In the scenarios it is assumed that ‘food’ real prices will return to their long term trend of negative growth with a rate between the rate seen before and after 2001.

‘Health’ real prices generally increased between 1975 and 2003, after which they levelled off and decreased slightly. It is assumed that ‘health’ real price will continue to increase in the future but with a lower growth rate than it had before 2004.

The ‘other transport’ real price had a very stochastic pattern in the past. However, since 2004 the real price has decreased significantly. Assuming that the car and train prices will continue to decrease and increase respectively, these two will almost offset each other’s effect. Therefore, it is assumed that the real price will continue to reduce for few years and then stay relatively constant until 2030.

The real price of ‘communication’ has reduced sharply since 1986, which is not surprising given the internet has to a large extent replaced conventional communication tools such as post, phone calls etc. It is expected that the real price will continue to decrease in the future with a similar (negative) growth rate to past.

The real price of ‘recreation and culture’ has been decreasing since 1972 with the rate of decrease being higher since 1996. High energy prices affect the price in this category and it is assumed that the real price will continue to decrease but with a less negative growth rate than before.

The real price of ‘restaurants and hotels’ has been increasing since 1975, with the rate of increase being higher since 1997. It is assumed that the real price will continue to increase in the future with a rate between the rate seen before and after 1997.

The category ‘miscellaneous goods and services’ has a discontinuity as jewellery was added to the category in 1987. Since 1987 the real price has been relatively stochastic, but with a slight increase. It is assumed that real prices will rise in line with the average annual growth rate since 1987.

Table 1: Real household disposable income average annual growth rate assumptions 2009-2030 (%)

	'Low'	'Ref'	'High'
Real household disposable income	1.37	1.85	2.33

Note: 'Low', 'Ref', and 'High' refer to the assumptions for the 'low', 'reference', and 'high scenarios respectively.

Table 2: Real price, underlying trend caused by ExNEF and GHG intensity average annual growth rate assumptions

	Prices (*P*) 2009-2030 (%)			**Underlying Trend (*μ*)** 2009-2030 (%)			**GHG Intensity (*ci*)** 2005-2030 (%)		
	'High'	**'Ref'**	**'Low'**	**'Low'**	**'Ref'**	**'High'**	**'Low'**	**'Ref'**	**'High'**
Food and non-alcoholic beverages	-1.14	-0.66	-0.19	-0.2	0.3	0.7	-3.4	-2.0	-0.6
Alcoholic beverages and tobacco	1.24	1.71	2.19	-0.8	-0.5	-0.2	-6.7	-4.9	-3.0
Clothing and footwear	-5.62	-3.71	-1.80	0.4	0.8	1.1	-6.3	-4.5	-2.8
Electricity	1.18	2.12	2.98	0.1	0.2	0.3	-3.4	-2.3	-1.3
Gas	-0.47	0.66	1.75	0.3	0.4	0.6	-0.9	0.0	0.9
Other fuels	3.70	4.18	4.66	-6.0	-3.6	-1.7	-6.3	-5.2	-4.1
Other housing	3.22	3.69	4.17	1.3	1.7	2.2	-1.2	0.4	1.9
Furnishings; household equipment & routine maintenance of the house	-1.67	-1.19	-0.72	-0.3	-0.1	0.1	-3.5	-2.0	-0.5
Health	0.10	0.58	1.05	1.6	2.0	2.3	-1.1	0.5	2.1
Vehicle fuels and lubricants	0.60	1.63	2.26	1.9	2.3	2.7	-1.0	0.2	1.4
Other transport	-0.23	0.25	0.73	1.8	2.3	2.8	-2.1	-0.7	0.6
Communication	-5.47	-3.56	-1.65	3.5	3.8	4.1	-7.2	-5.5	-3.8
Recreation and culture	-2.42	-1.47	-0.52	2.6	2.8	3.1	-8.0	-6.2	-4.5
Education	2.90	3.38	3.85	0.8	1.0	1.2	2.2	3.6	4.9
Restaurants and hotels	0.63	1.11	1.58	0.5	0.7	0.9	-0.5	1.0	2.4
Miscellaneous goods and services	-0.58	-0.11	0.37	0.9	1.1	1.4	-1.5	0.00	1.5

Note: 'Low', 'Ref', and 'High' refer to the assumptions for the 'low', 'reference', and 'high scenarios respectively.

Table 3: Temperature average annual growth rate assumptions 2009-2030 (%)

	'High'	'Ref'	'Low'
Temperature	-0.47	-0.0001	0.47

Note: 'Low', 'Ref', and 'High' refer to the assumptions for the 'low', 'reference', and 'high scenarios respectively.

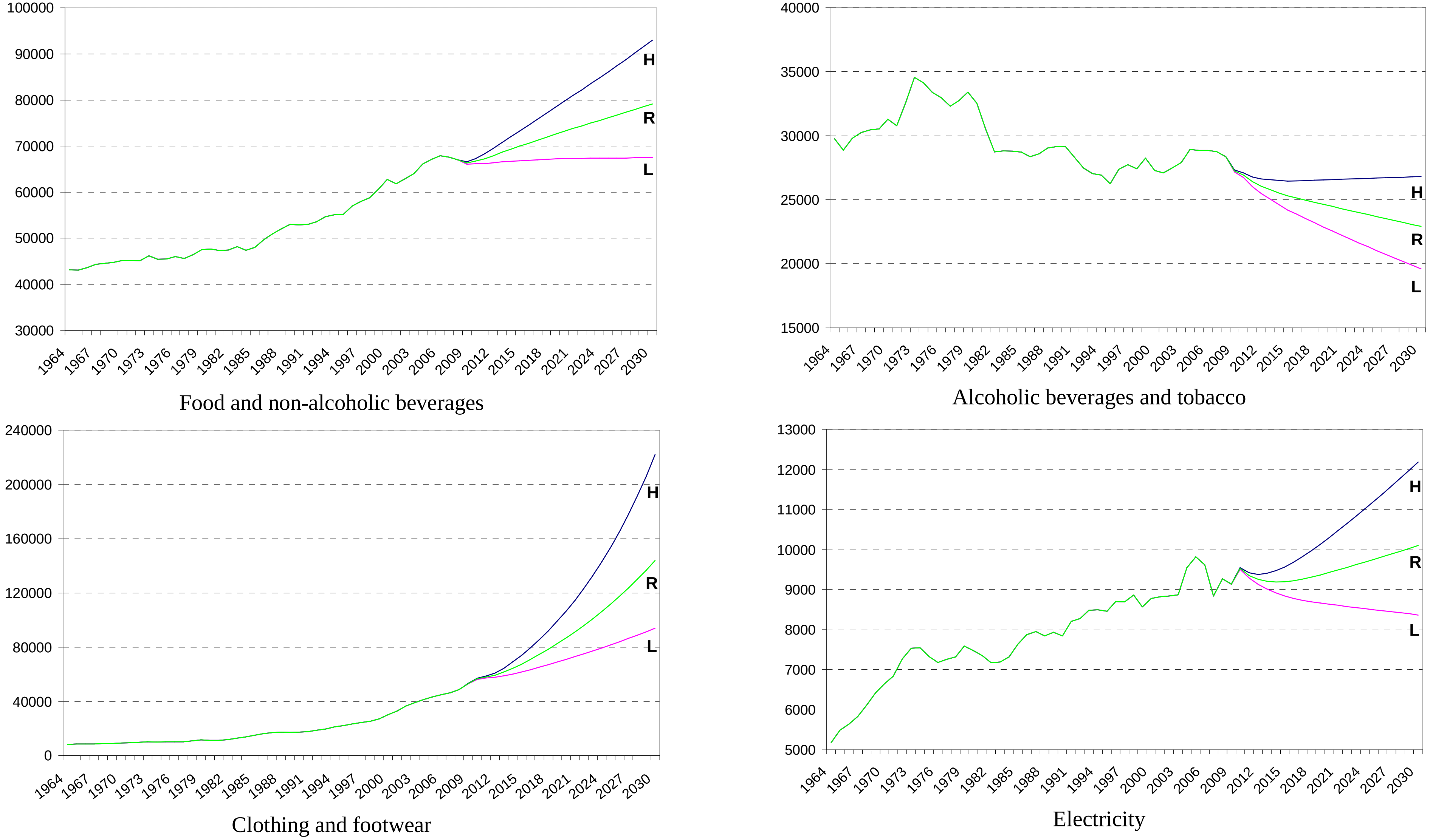


Figure 1: Household expenditure (million pounds) 1964-2030 (H: ‘high’, R: ‘reference’, L: ‘low’)

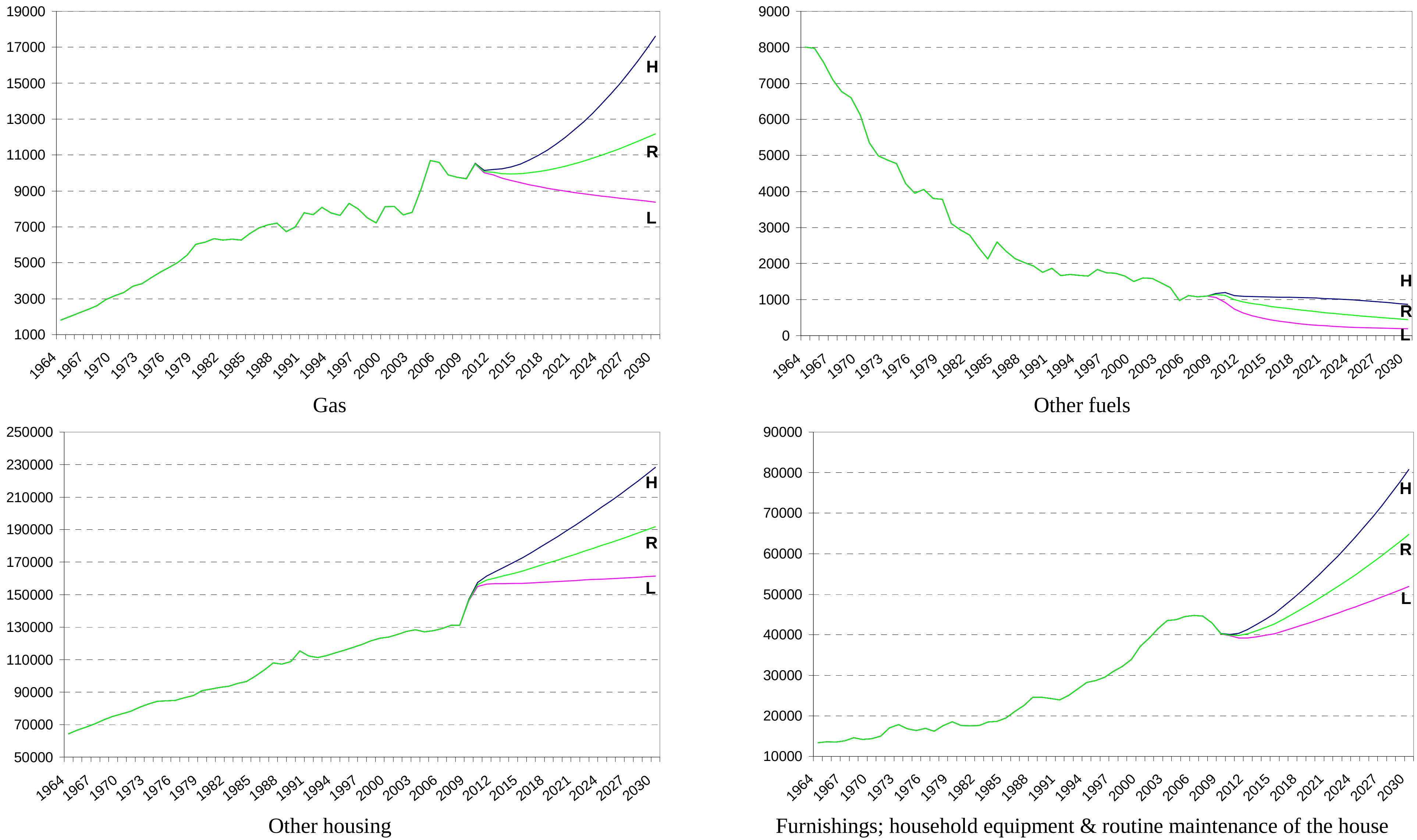
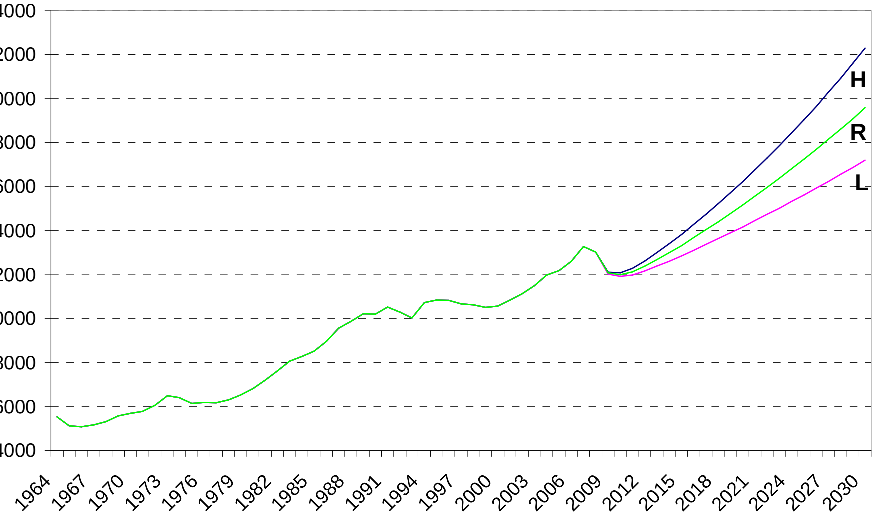
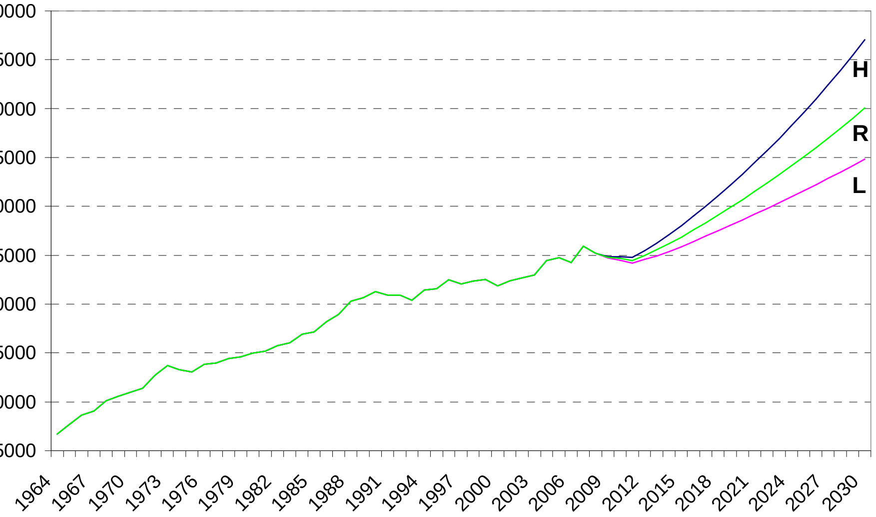


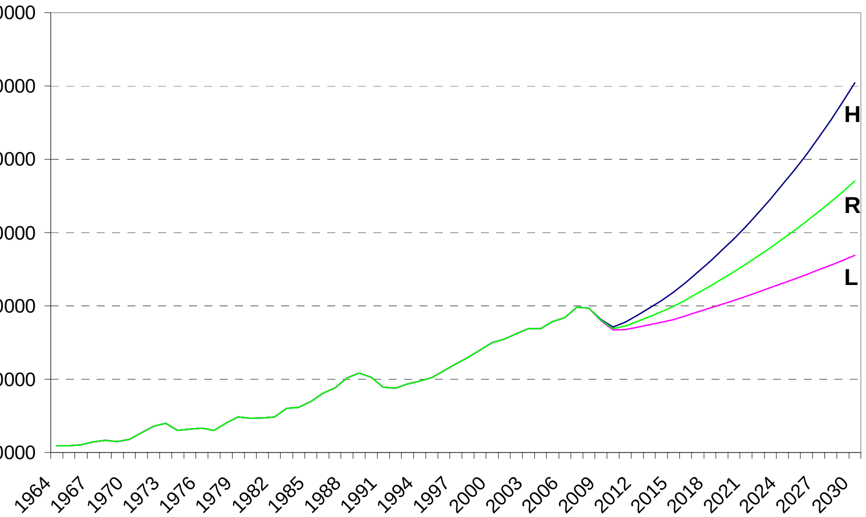
Figure 1 (continued): Household expenditure (million pounds) 1964-2030 (H: 'high', R: 'reference', L: 'low')



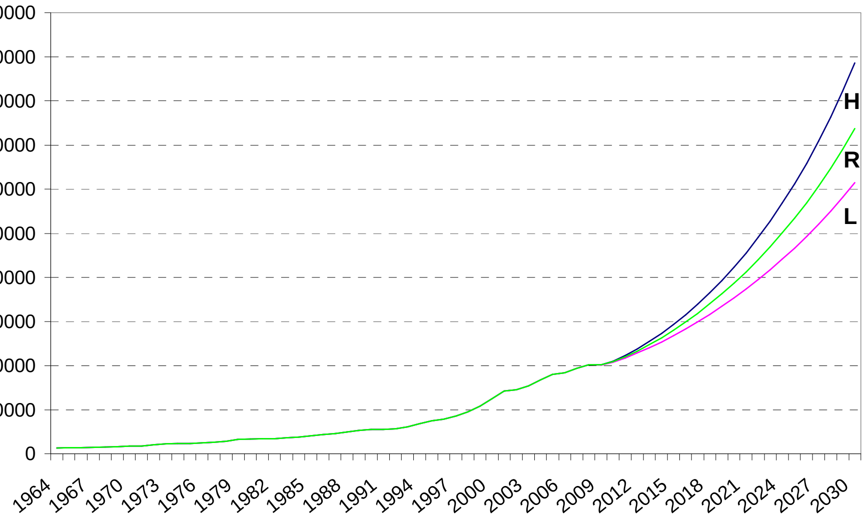
Health



Vehicle fuels and lubricants

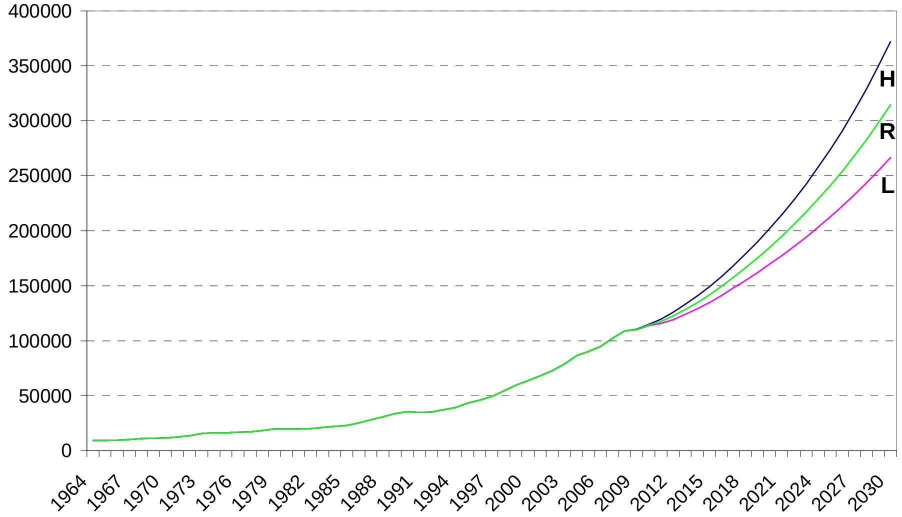


Other transport

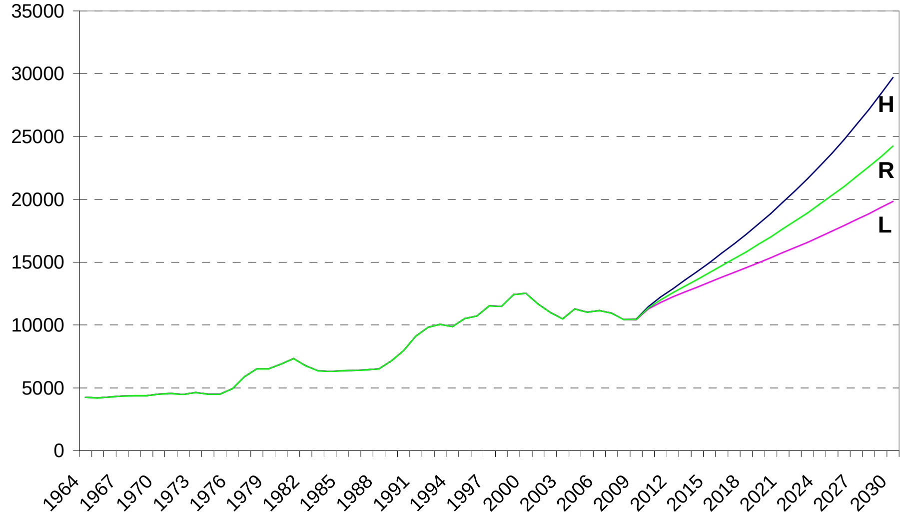


Communication

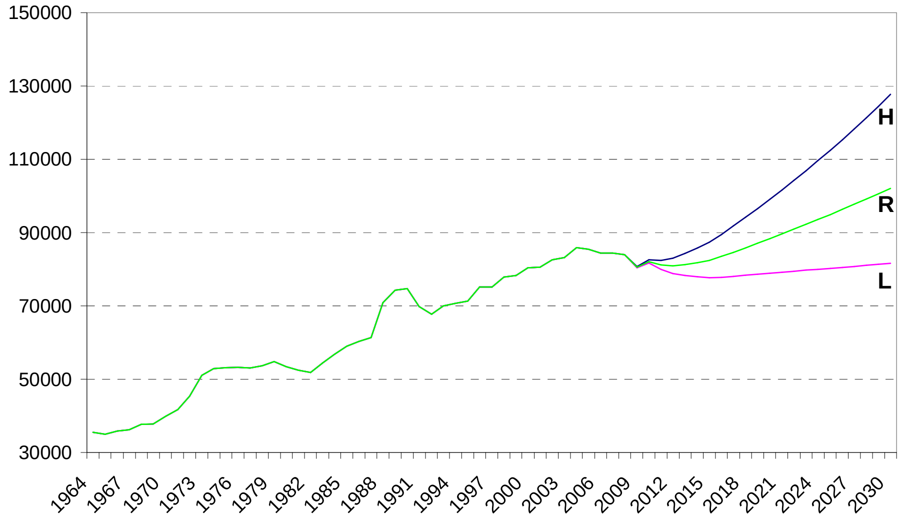
Figure 1 (continued): Household expenditure (million pounds) 1964-2030 (H: 'high', R: 'reference', L: 'low')



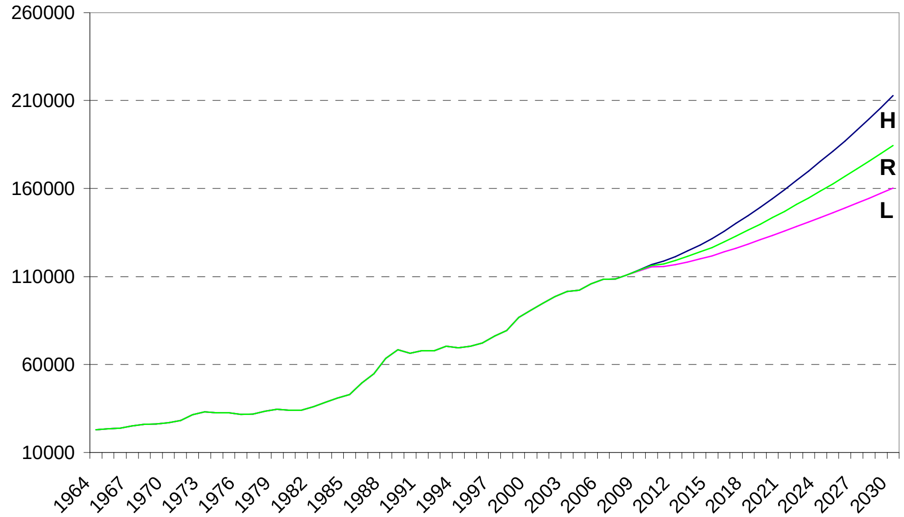
Recreation and culture



Education



Restaurants and hotels



Miscellaneous goods and services

Figure 1 (continued): Household expenditure (million pounds) 1964-2030 (H: ‘high’, R: ‘reference’, L: ‘low’)

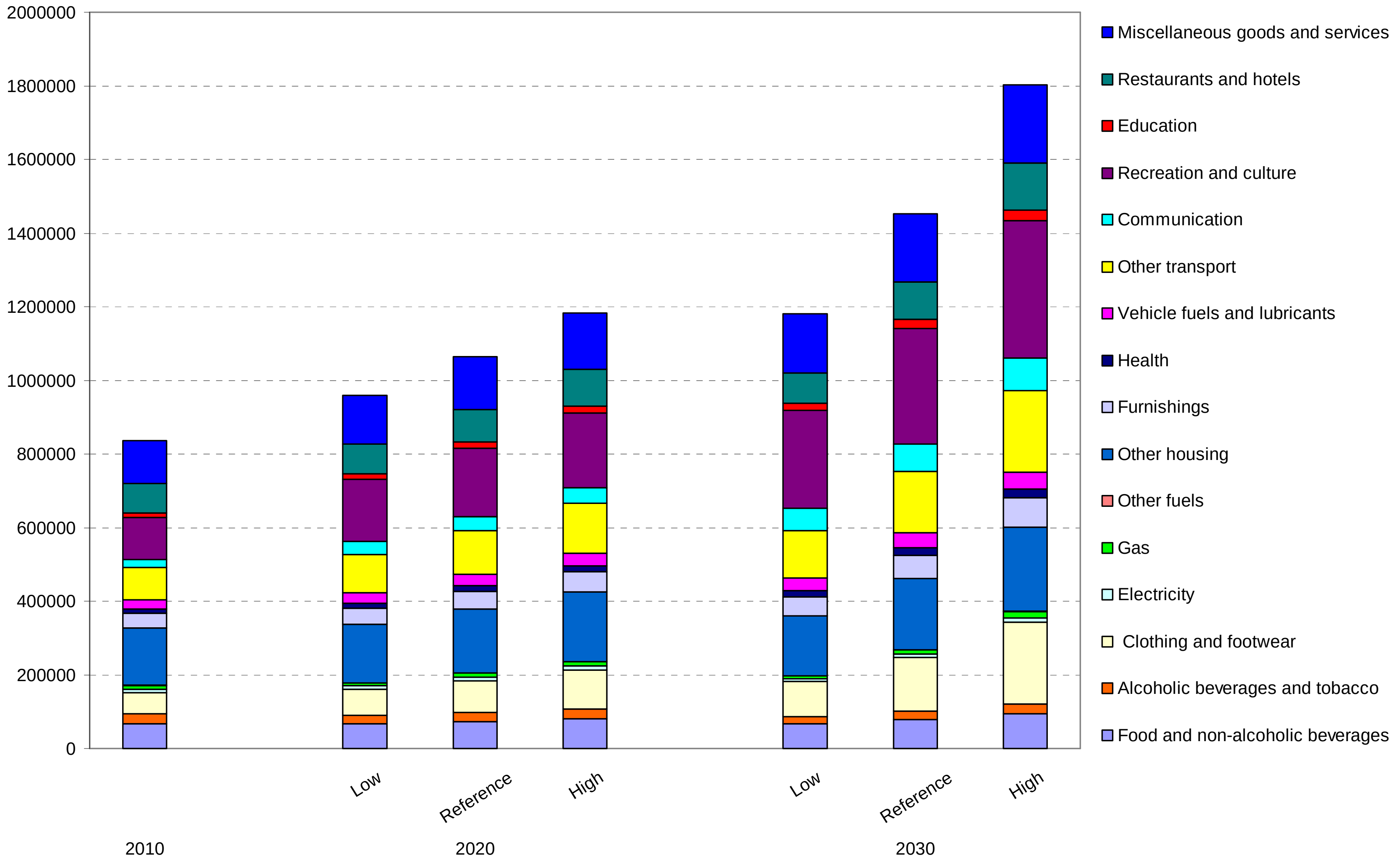


Figure 2: Household expenditure (million pounds) 2010, 2020 and 2030

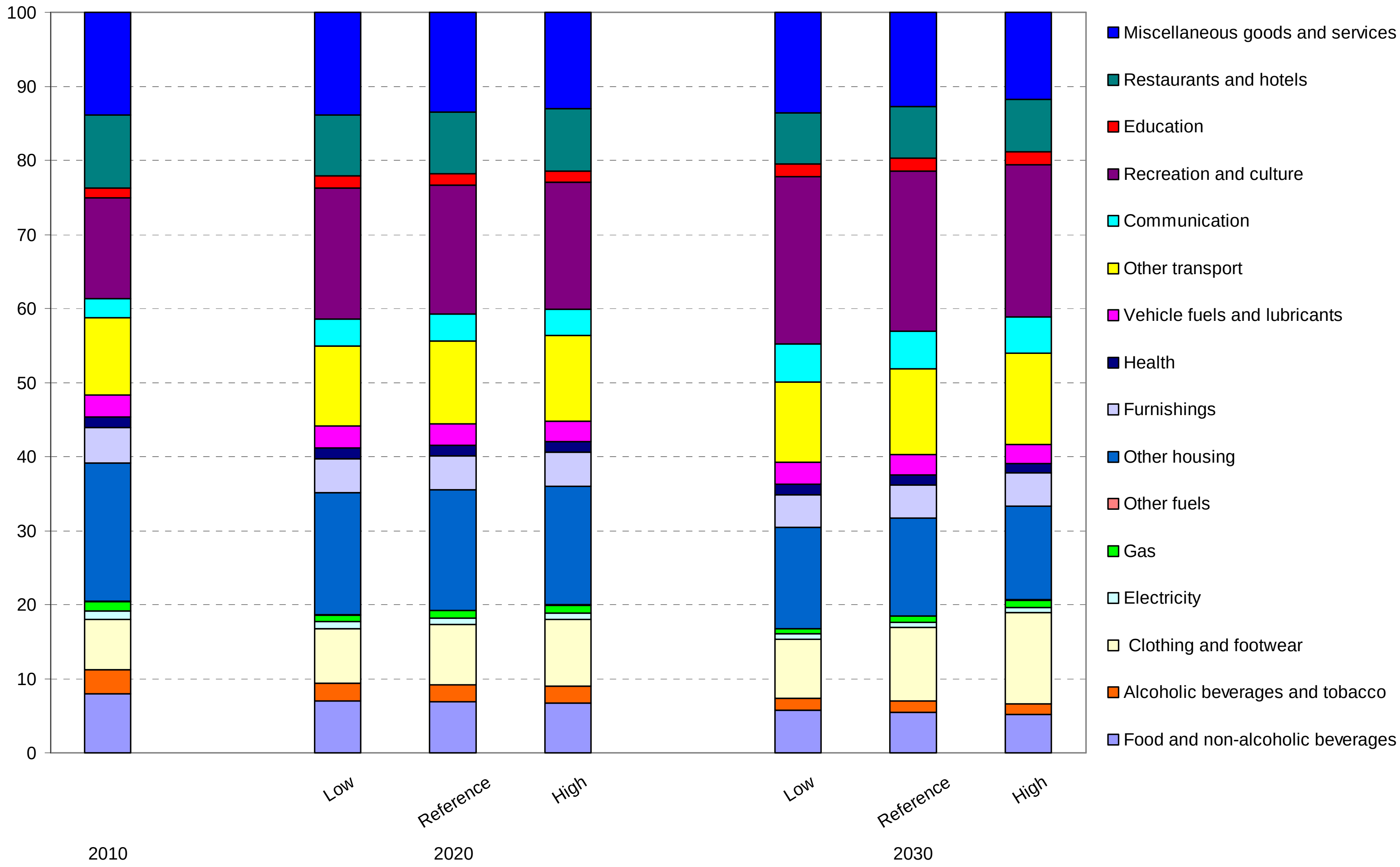


Figure 3: Household expenditure share (%) 2010, 2020 and 2030

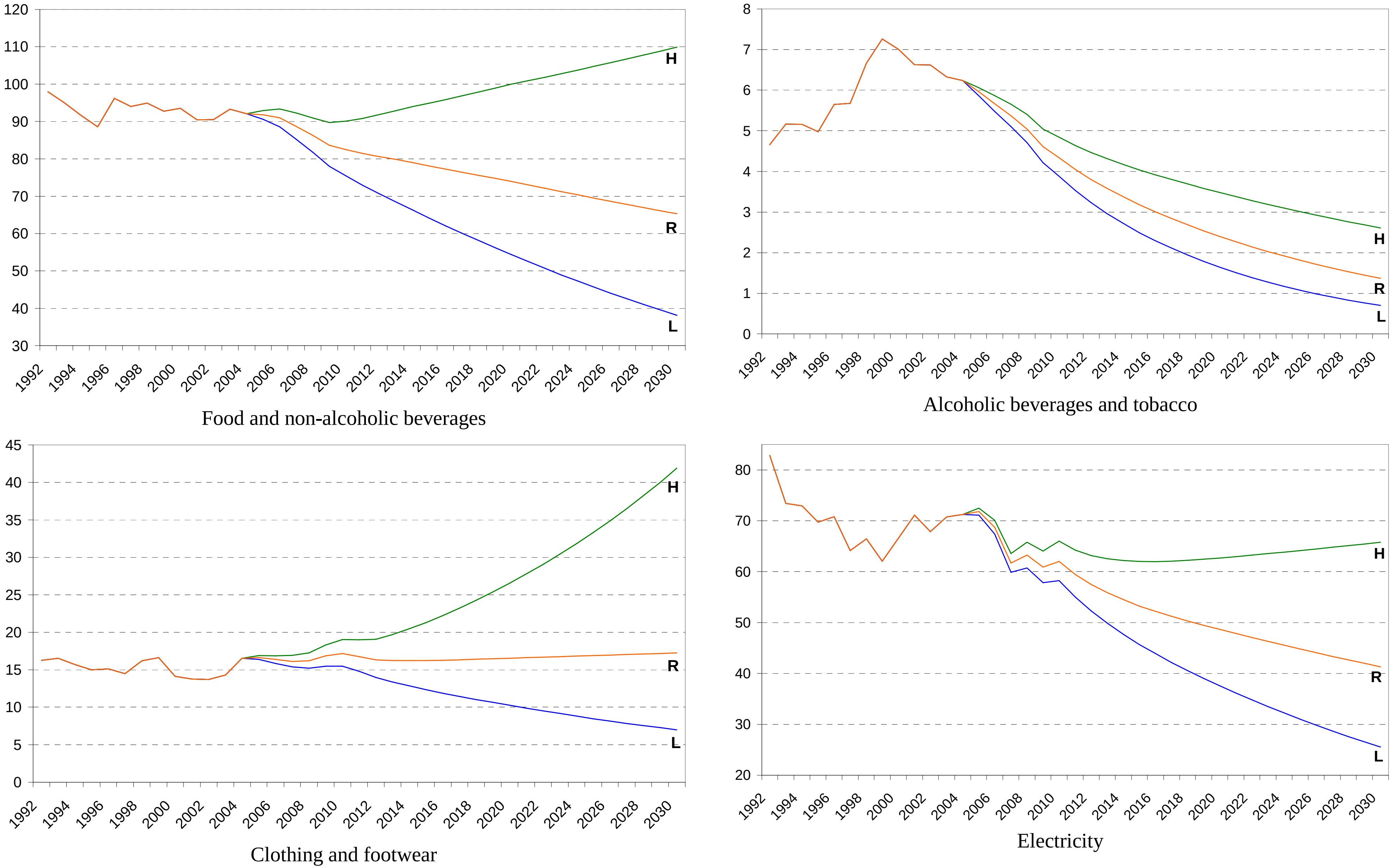


Figure 4: GHGs associated with household expenditure ($mtCO_2$) 1992-2030 (H: 'high', R: 'reference', L: 'low')

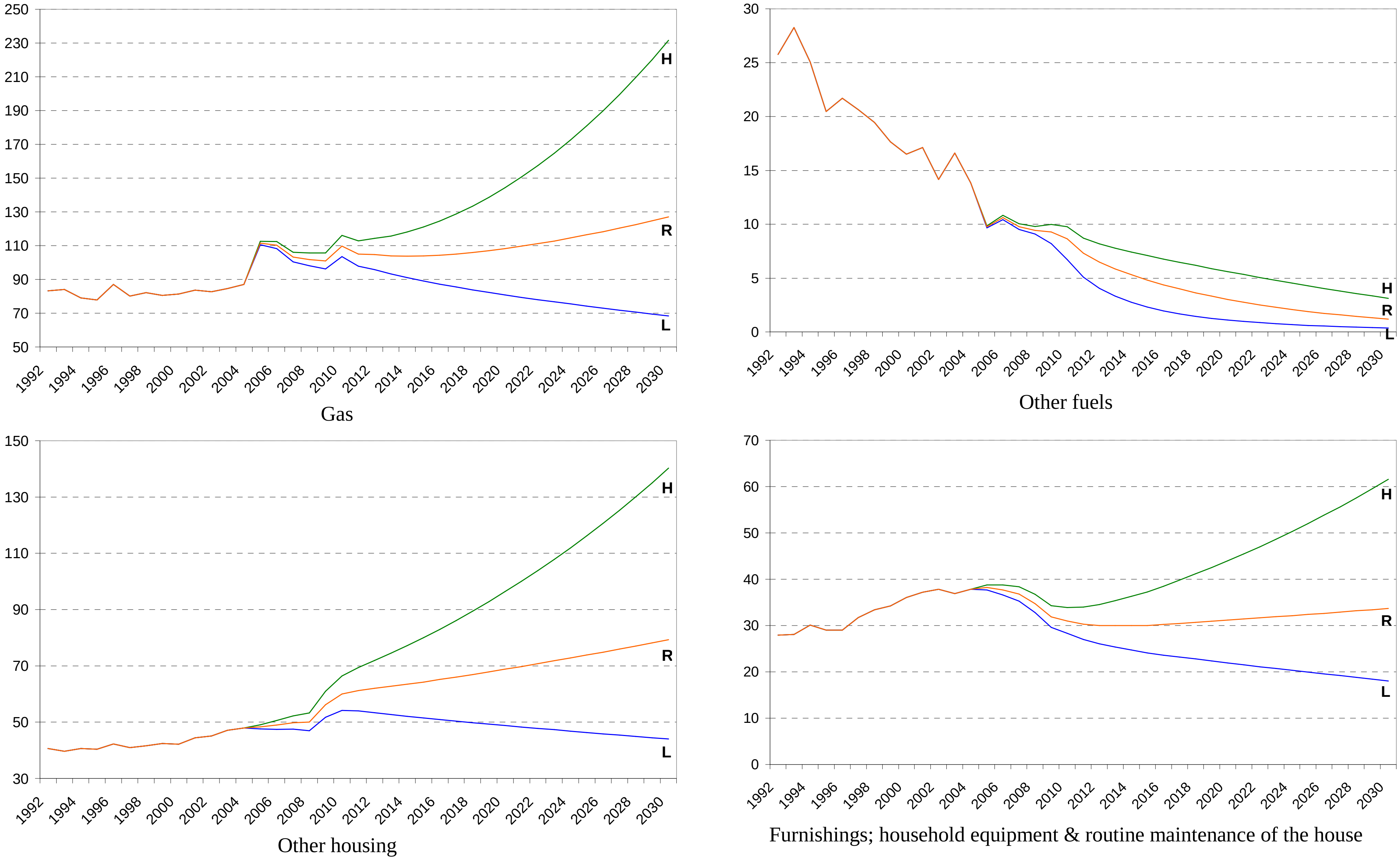
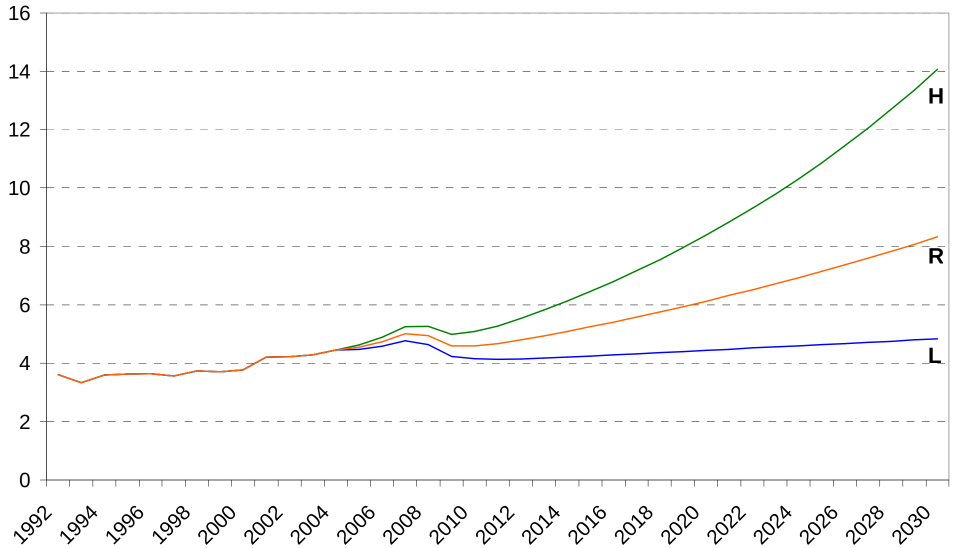
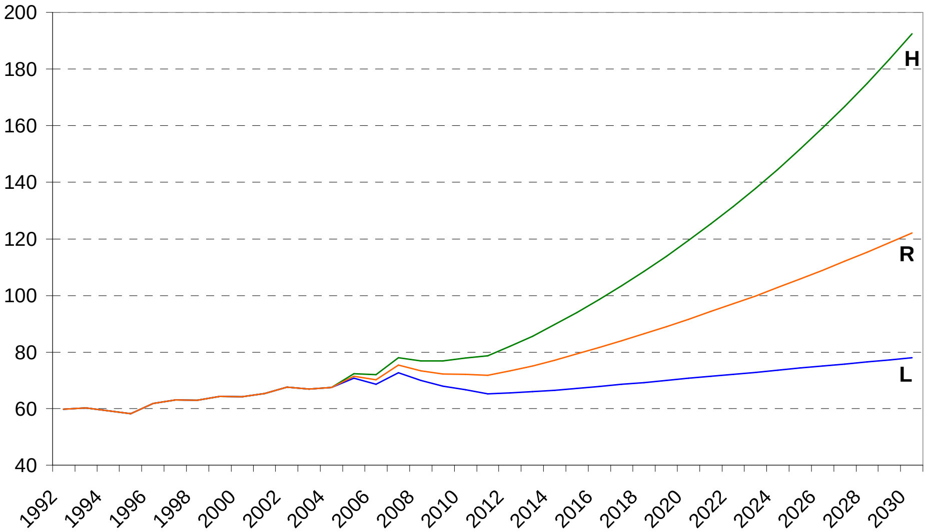


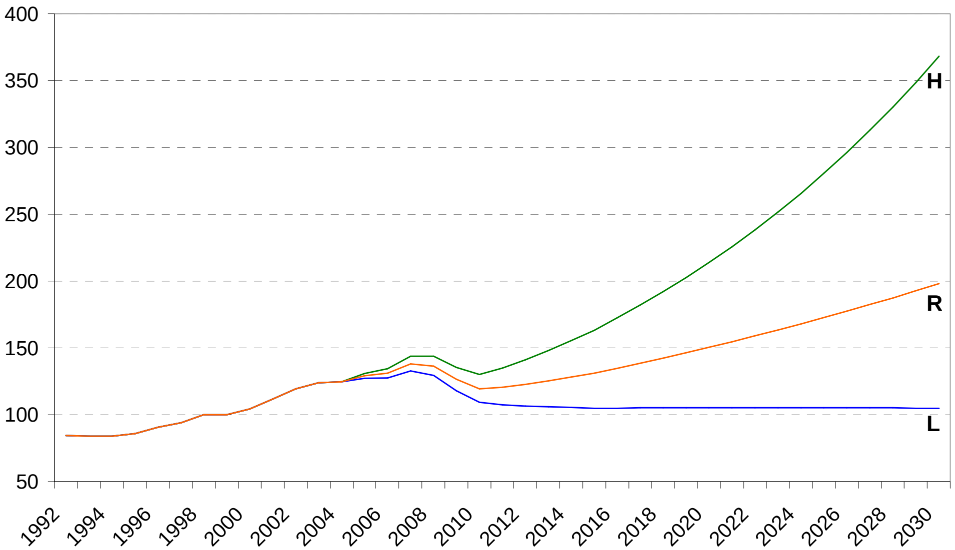
Figure 4 (continued): GHGs associated with household expenditure (mtCO_2) 1992-2030 (H: ‘high’, R: ‘reference’, L: ‘low’)



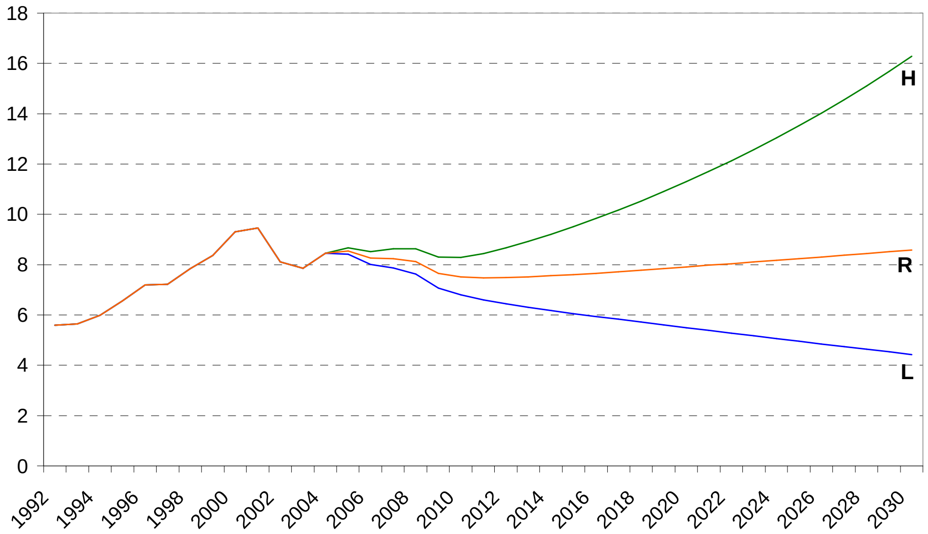
Health



Vehicle fuels and lubricants

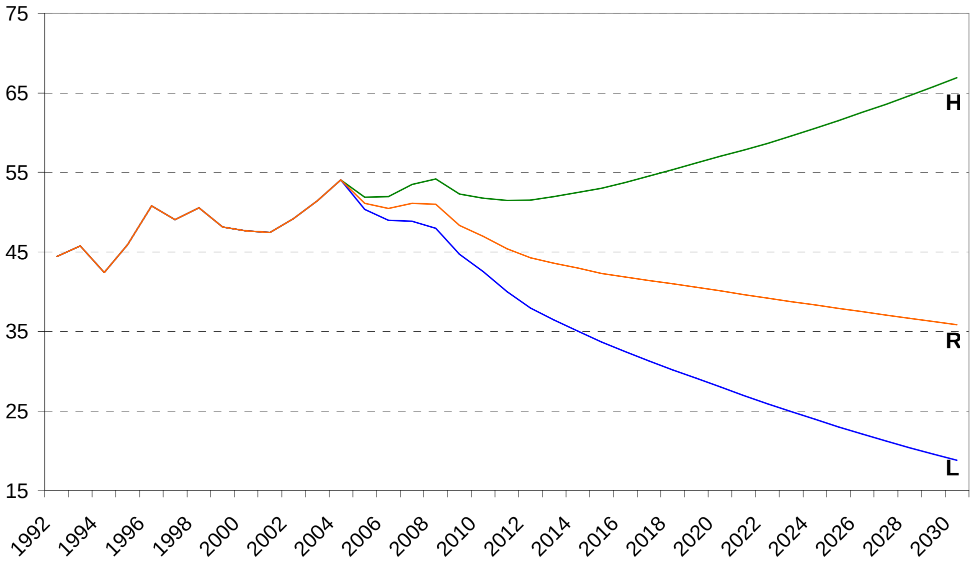


Other transport

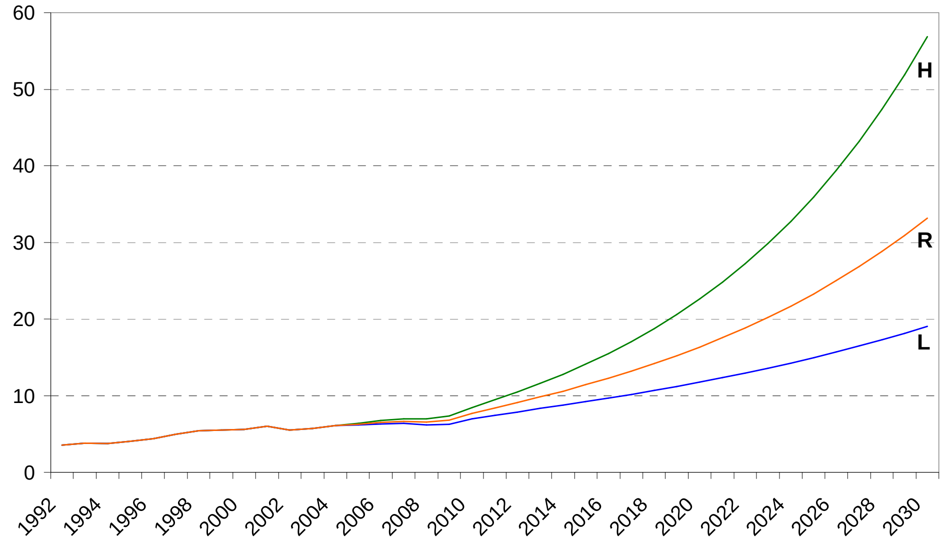


Communication

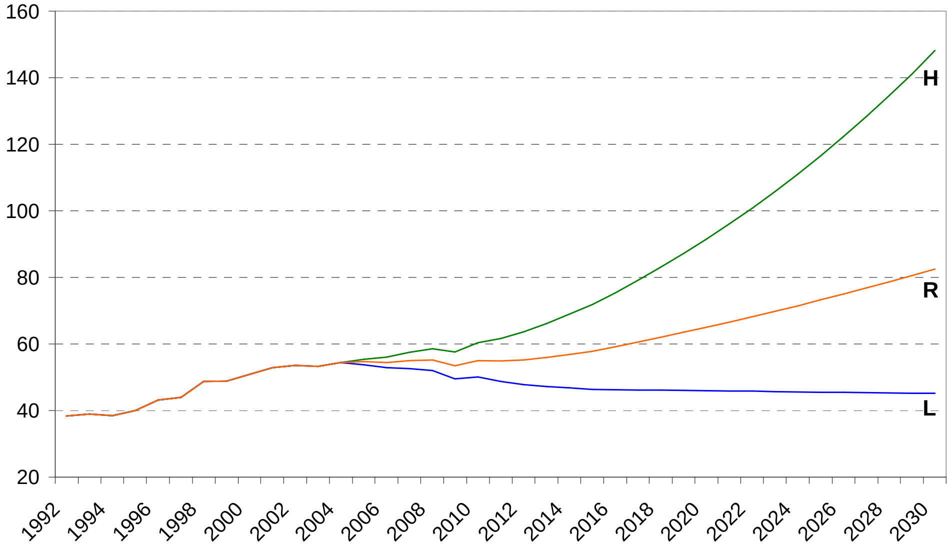
Figure 4 (continued): GHGs associated with household expenditure (mtCO_2) 1992-2030 (H: ‘high’, R: ‘reference’, L: ‘low’)



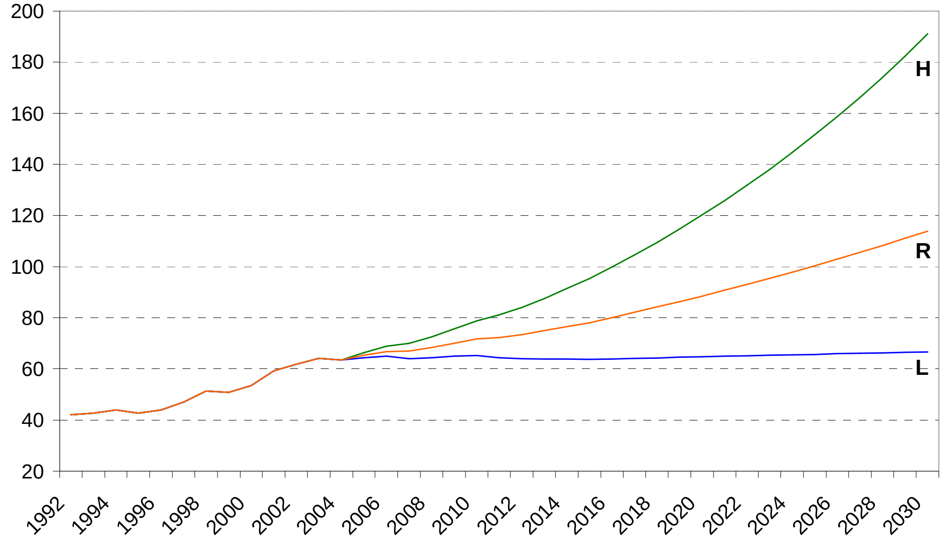
Recreation and culture



Education



Restaurants and hotels



Miscellaneous goods and services

Figure 4 (continued): GHGs associated with household expenditure (mtCO_2) 1992-2030 (H: ‘high’, R: ‘reference’, L: ‘low’)

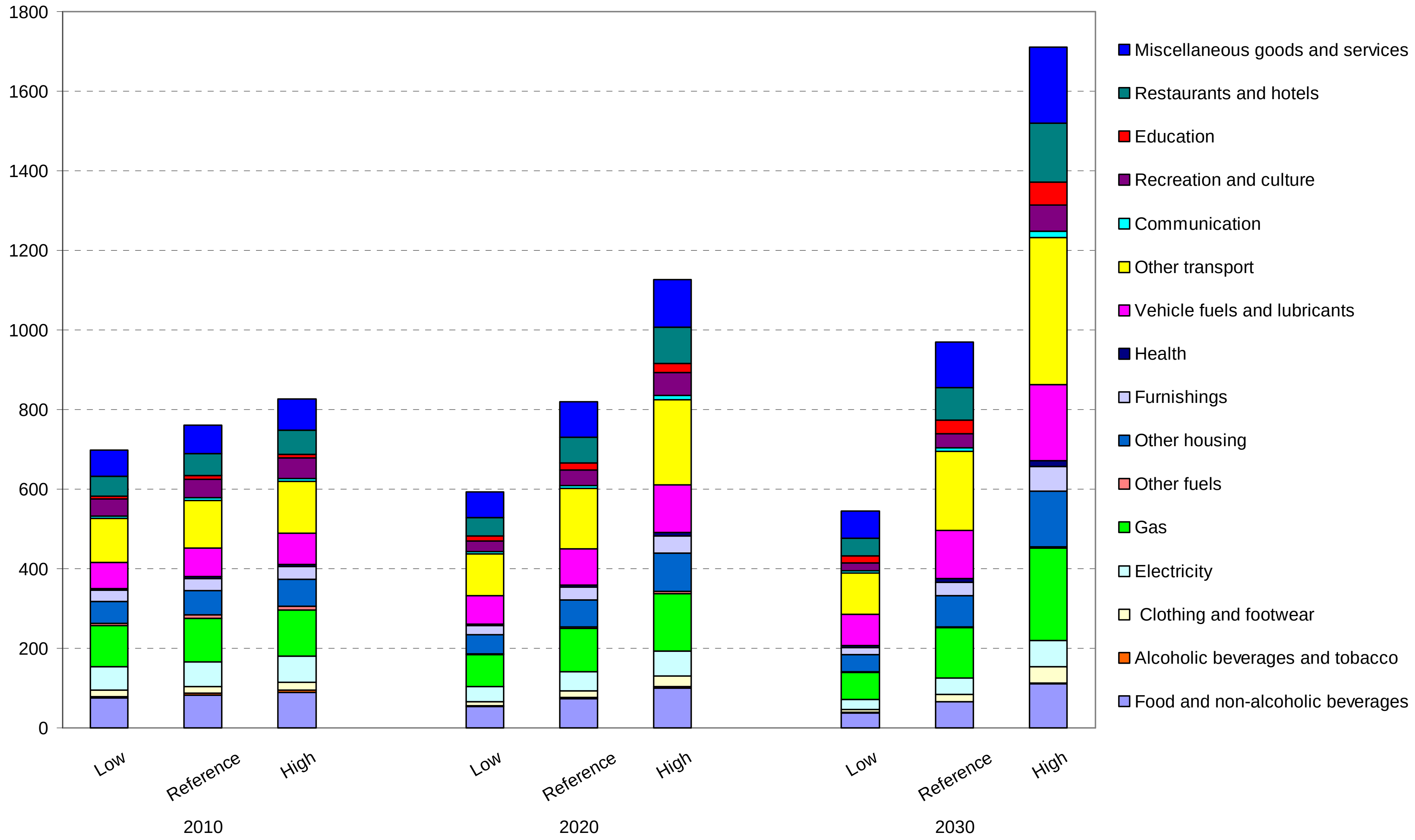


Figure 5: GHG emissions associated with household expenditure (mtCO_2) 2010, 2020 and 2030
Note: The last available data for GHG emissions used in ELESA is for 2004. Therefore, there is a difference between forecast scenarios in 2010.

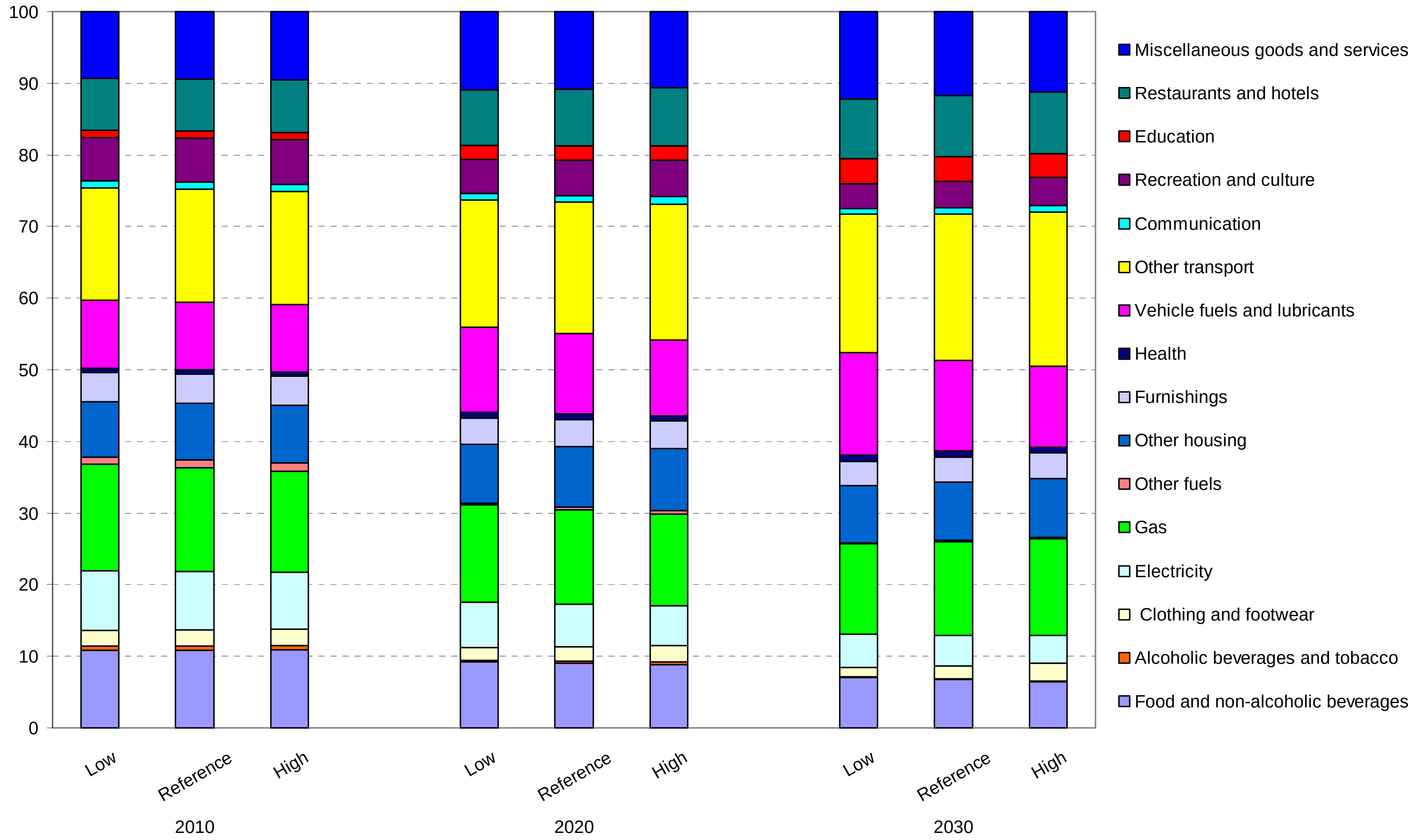


Figure 6: GHG emissions share associated with household expenditure (%) 2010, 2020 and 2030
Note: The last available data for GHG emissions used in ELESA is for 2004. Therefore, there is a difference between forecast scenarios in 2010.