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Social outcomes of energy use in the United Kingdom: Household energy footprints and their links to well-being

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ABSTRACT

How energy relates to human need satisfaction, for whom, and with what wellbeing outcomes has remained under-researched. We address this gap by investigating the relationship between household energy footprint and well-being in the UK. Our results indicate that car and air transportation contributed the most to the total energy footprint of high-income and high-energy users. We find significant inequalities in the distribution of energy use and that the top energy users with high well-being are driving excess energy use. A more detailed analysis reveals that individuals with protected characteristics are particularly vulnerable to energy poverty and that their contribution to overall energy demand is negligible. We find that focusing on well-being steers the attention towards questions of sufficiency, overconsumption as well as the context within which we satisfy needs. Tackling the issues of energy poverty and inequalities are important for lowering energy demand and need to be addressed as a matter of climate justice.

1. Introduction

Current energy consumption is too high to maintain global warming within 1.5 degrees without resorting to massive negative emissions (IEA, 2021). Lowering energy demand in the Global North requires changes in how we satisfy our needs and addressing overconsumption (Creutzig et al., 2021). These changes would enable decent living for all through a more equal distribution of energy resources (Grubler et al., 2018; Millward-Hopkins et al., 2020; Millward-Hopkins and Oswald, 2021; Rao and Baer, 2012; Kikstra et al., 2021). How we get there depends on our understanding of how energy demand is distributed now and what purposes it serves.

We know that energy use and carbon emissions associated with it are highly unequally distributed, with the top 10% of income earners (mostly in the Global North) responsible for 49% of all carbon dioxide emissions (Oxfam, 2015; UNEP-CCC, 2021; Bruckner et al., 2022). These findings have highlighted the excess energy use by a minority (Wiedmann et al., 2020) and raised concerns about energy and carbon justice (Jenkins et al., 2016; Shue, 1993; Gore, 2020). The findings also raise questions about how much energy (and carbon) we need to satisfy our needs and to achieve well-being (Walker et al., 2016; Gough, 2017; Darby and Fawcett, 2018; Brand-Correa and Steinberger, 2017). These issues call for recognizing the needs of vulnerable groups in energy transition scenarios (Galvin and Sunikka-Blank, 2018; Büchs et al., 2018; Ivanova and Middlemiss, 2021a), acknowledging and addressing high energy intensity lifestyles stemming from status-seeking, and the need for comparisons to expose inequalities (Wiedmann et al., 2020; Cheung and Lucas, 2016; Luttmer, 2005). We seek to contribute to these debates by profiling the UK households' final energy use and linking it to needs satisfaction. We investigate in detail the distribution, levels, and types of energy use, and identify the most important characteristics of households with low and high well-being.

Research on environmental efficiency of well-being has mostly focused on a country level and considered life expectancy, education, and income (Dietz et al., 2009; Knight and Rosa, 2011; Lamb et al., 2014; Dietz et al., 2012; Steinberger and Roberts, 2010; Steinberger et al., 2012; Jorgenson et al., 2017); yet, distributional analyses are largely missing. In household-level analyses, the most common

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measures of well-being have included life satisfaction (Buhl et al., 2017; Andersson et al., 2014; Verhofstadt et al., 2016; Lenzen and Cummins, 2013) and happiness (Apergis, 2018; Lenzen and Cummins, 2013). Some studies have adopted a broader view of well-being that encompasses mental and physical health (Ambrey et al., 2017), social capital, relative wealth (Claborn and Brooks, 2019), and aspects of multidimensional poverty (Okushima, 2021; Baltruszewicz et al., 2021b, 2021a). Yet most of these studies draw from limited data to operationalize well-being. We address the data limitations by using innovative research methods linking two UK-based household surveys. We adopt a multi-dimensional understanding of human needs. Instead of focusing on individual feelings and wants and one-dimensional indicators (e.g. individual purchasing power) we make a distinction between wants and needs as a way to achieve well-being in a resource constrained word. Further, knowing that after achieving a certain level of human need satisfaction and associated resource use the excess might lead to negative effects on well-being (e.g. via environmental or societal degradation), we consider well-being from a sufficiency perspective. It helps to establish that human needs can be satisfied and beyond their satisfaction the gains may diminish or disappear.

Our analysis and results contribute to better understanding of energy use for needs satisfaction in four key ways. First, we develop a method for linking the UK living costs and food survey (LCFS) of the Office of National Statistics (ONS) and the Understanding Society Survey (USS) of the Institute for Social and Economic Research at the University of Essex, using data from the years 2018/2019. Second, we map the levels, types, and distribution of household energy footprints by income and energy deciles. Third, we link household EF with a well-being index score and analyse the relationships between the components of the index score and energy use. Fourth, we analyse the socio-economic characteristics of clusters of households defined by their levels of well-being and energy use. Furthermore, we discuss lock-ins that prevent people from lowering energy demand while maintaining high levels of well-being. We end by suggesting interventions that could reduce energy demand while improving well-being.

2. Materials and methods

2.1. Calculation of UK household energy footprint using LCFS

The calculate household energy footprints (HEF) based on the USS data. However, the survey does not include detailed household expenditure, which is necessary for calculating household footprints. Below we explain how we overcame this challenge. First, we present a method for calculating household energy footprint using a multiregional input-output model and LCFS data. We derive multipliers (in MJ/£) that are then used to calculate the HEF for UK households. Both the multipliers and HEF calculated using LCFS data are then used to estimate the HEF for USS households.

Calculation of household energy footprints involves several steps. First we need to calculate consumption-based energy use due to household demand in the UK (step 1). For this, we use the UK Multi-regional input-output database (UKMRIO) (Owen et al., 2017; Barrett et al., 2013; DEFRA, 2021) and a dataset of industrial energy use. The UKMRIO database is constructed using UK Supply and Use Tables data produced by the Office for National Statistics for the UK and trade data from EXIOBASE. The data on energy use by industry comes from two sources. For the foreign sectors in the UKMRIO database, we use final energy consumption in terajoules by sector and country from the International Energy Agency (IEA).[1] Final energy use as opposed to primary energy allows us to investigate the households' energy use closer to the purpose for which the energy is used. For domestic energy consumption, we use the National Statistic on Energy Consumption (DEFRA, 2021) which provides more detail on residential heating and power and residential private transport (Owen and Barrett, 2020). To be able to use UKMRIO and IEA data together we need to align the IEA energy use extension vector with foreign sectors in the UKRMIO database.

The calculation of consumption-based household energy footprints requires linking the energy use for the production of goods and services with the household consumption of these products. The method for doing this is based on the Leontief equation, which expresses the inter-industry requirements of each sector to deliver a unit of output of final demand (Miller and Blair, 2009). The Leontief input-output model is based on reported economic data augmented with environmental and energy extensions to help understand the environmental impacts of production and consumption of goods and services. The result from using the Leontief method is a column vector of final energy consumed by all UK households, disaggregated to products categorized by the European Standard Classification of Individual Consumption by Purpose (COICOP). We are able to report HEF by COICOP category because the UK Supply and Use Tables disaggregate household final demand by these categories. This simplifies the next step, which is disaggregating total energy footprints by household types. This is done by first calculating multipliers (step 2). We obtain them by dividing the product footprints (obtained in step 1) by the total annual spend on products by UK households. The latter information is acquired from the Living Cost and Food Survey (LCFS) microdataset (ONS, 2018). LCFS is an annual household expenditure survey of about six thousand households, who are asked to keep a spending diary for two weeks. The survey provides annual weights (used to reduce the effect of non-response bias and produce population totals and means), which when multiplied by household expenditure sum up to the total UK household spending. Having multipliers allows us to move to the next step of calculation: disaggregating household final demand in the UKMRIO model using weighted LCFS household expenditure shares (step 3). The resulting UK household energy footprints (HEF) indicate the total energy use needed to meet the final demand of all goods and services that the households consume. This includes energy directly used by the households (e.g. fuels used to heat and power home and private transportation) and indirect energy embodied in the supply chain of goods such as food or clothing. The UK HEF thus includes energy from both domestic and foreign production.

2.2. Statistical matching

The LCFS data include socio-economic household characteristics and the Understanding Society Survey (USS) includes household well-being outcomes we need for our analysis. The USS was started in 1991 as a nationally representative longitudinal survey covering e.g. education, social life, well-being, health, income, and family. While providing expenditure on groceries, restaurants, and residential fuels, the USS lacks detailed information on other household expenditure. We bridge this gap by statistically matching the USS with the LCFS. We use the USS

[1] Given our energy data were obtained from the IEA (IEA, 2004), the final energy from the different sources is aggregated using IEA thermal equivalents. Our method does not however adjust these thermal equivalents to account for energy quality differences across the various energy sources – an adjustment that Cleveland (1992) and Patterson (1993) argue should be undertaken. This is because the lack of readily available exergy data for making such energy quality adjustments.

wave 10 for the years 2018–2020. The challenge of combining the two surveys is that had different samples of the UK population, and thus cannot be merged with a household identifier. Our solution is to extract patterns from both surveys by using common variables. The USS and LCFS surveys were conducted in the same year (2019) and statistical analysis of distributions of socio-economic characteristics such as income, age groups, household types, and location indicate comparable distributions (see Supplementary Materials). These characteristics have been proven as the main drivers of levels and patterns of household energy use (Büchs and Schnepf, 2013, Weber and Matthews, 2008, Wiedenhofer et al., 2013, Donato et al., 2015). This allows the use of statistical tools such as multiple regression and descriptive statistics to estimate HEF for USS households. For several HEF categories, for which we did not have USS expenditure, we estimate values using multiple regression. Examples include footprint for rail, bus and other public transport, communication, recreation and education (Table 1). When possible, we used additional information to restrict estimation to only those who report activity associated with a given HEF category. For example, respondents in the USS reported what type of public transport they used and how often. Similarly, we have information on who is enrolled for education.

We use multipliers calculated from the UKMRIO model and LCFS data for estimating the consumption reported by USS households. For example, USS households reported their yearly expenditure for house fuels. We multiplied the expenditure with multipliers expressed in MJ/£ to obtain the total MJ used by a household in 2019. In the case of electricity and gas consumption depending on the type of payment (e.g. smart meter or direct debit) and location, we adjusted the household expenditure using regional price differences in 2019. A total of 14% of USS households did not report expenditure on electricity or electricity and gas combined. We assumed that these households are connected to electricity without reporting spending. Since the majority of households report spending on electricity and gas in one bill, we imputed spending on electricity using this form of payment. For this calculation, we used an iterative form of stochastic imputation, and only data from the USS survey (see Supplementary Materials).

For the direct energy use linked to private transportation, we calculated energy use from reported mileage and type of car (engine size) driven by the USS households and multiplied it with multipliers from HEF in LCFS. We have information about the number of purchased vehicles and their condition (new/used) and used it to calculate in the LCFS survey the average energy footprint per purchased vehicle and applied it to USS households. For leased cars, we used the average energy footprint per owned vehicle. For air transport, we used the average footprint per flight reported by LCFS households and applied it to the number of flights taken by the USS households. In both surveys, we could differentiate between the footprints for domestic and international flights.

We were challenged by the lack of information or a weak regression model for certain consumption categories. Here we assigned an average footprint based on the LCFS households categorized by income deciles to the USS households. For example, within each income decile, the USS households are assigned the same energy footprint for clothing and shoes. Although this limits nuanced comparison between specific footprint categories, those estimates are useful for the calculation of the total energy footprints.

2.3. USS energy footprints – Comparison with LCFS and limitations

The LCFS and USS surveys differ in their representativeness. The LCFS scales up to the UK population (27 million households) and the USS survey represents population patterns. Thus, the HEF for the LCFS sum up to the final household demand in 2019, whereas the USS HEF sums up to around half of it. When comparing LCSF and USS energy footprints, we find similar energy use distributions by income deciles, as well as when regional and household type groups are compared (Supplementary Materials).

When comparing the contributions of different consumption

Table 1
Final energy use per category and its share in total energy use for the UK. Based on footprints calculated using USS (2018/2019) or LCFS (2019) data.

	Category	LCFS (GJ)	(%)	USS (GJ)	(%)	Method for USS	USS-LCFS	Comment
Food and non-alcoholic beverages:	Food and alcohol	274,426	4.7%	178,967	4.8%	Multiplier	0.1%	Missing exp. in USS imputed
Clothing and footwear:	Clothing	43,041	0.7%	24,524	0.7%	Avg by income decile	-0.1%	
	Shoes	20,175	0.3%	11,497	0.3%	Avg by income decile	0.0%	
Housing, water, electricity, gas and other fuels:	Housing, water	220,632	3.7%	100,518	2.7%	Estimated (R2=0.36)	-1.1%	Pred. based on regression using LCFS footprints as a base
	Coal and coke & wood and peat	134,343	2.3%	65,333	1.7%	Multiplier	-0.5%	
	Oil, gas, electricity	1,628,962	27.6%	611,766	16.2%	Multiplier	-11.4%	Missing exp. in USS imputed
Furniture:	Furniture	217,294	3.7%	123,814	3.3%	Avg by income decile	-0.4%	
Health:	Health	84,872	1.4%	48,348	1.3%	Avg by income decile	-0.2%	
Transport:	Purchase of vehicles	59,130	1.0%	29,612	0.8%	Multiplier	-0.2%	Avg GJ per vehicle purchased
	Vehicles: leasing, other	275,960	4.7%	132,959	3.5%	Multiplier	-1.1%	Avg GJ / No. of vehicles in the household
	Fuel	970,425	16.5%	605,006	16.1%	Multiplier	-0.4%	Includes difference in car fuel and engine
	Other transport	121,847	2.1%	69,439	1.8%	Avg by income decile	-0.2%	
	Public transport rail/tube	18,121	0.3%	21,221	0.6%	Estimated (R2=0.62)	0.3%	Estimated only for users of transport
	Public transport: bus	41,349	0.7%	94,349	2.5%	Estimated (R2=0.28)	1.8%	Estimated only for users of transport
	Public transport other	281,974	4.8%	160,704	4.3%	Avg by income decile	-0.5%	Avg. only for users of transport
	Transport air domestic	44,095	0.7%	80,765	2.1%	Multiplier	1.4%	Avg GJ / flight
	Transport air international	643,665	10.9%	1,045,183	27.8%	Multiplier	16.8%	Avg GJ / flight
Communication:	Communication	32,774	0.6%	14,611	0.4%	Avg by income decile	-0.2%	
Recreation:	Recreation, package holidays	285,782	4.8%	119,744	3.2%	Estimated (R2=0.28)	-1.7%	
Education:	Education	32,532	0.6%	11,767	0.3%	Estimated (R2=0.39)	-0.2%	Only for those reporting being in education
Restaurants and hotels:	Restaurants and hotels	214,237	3.6%	72,836	1.9%	Multiplier	-1.7%	Missing exp. in USS imputed
Miscellaneous:	Miscellaneous	251,222	4.3%	143,156	3.8%	Avg by income decile	-0.5%	
	Total	**5,896,860**	**100%**	**3,766,121**	**100%**			

Note: Match between USS and LCFS is highlighted as follows: green – multiplier method and low difference, yellow – multiplier method and high difference, blue other method and low difference categories to the total, the biggest differences lie in international air transport (+17% for USS) and oil, gas and electricity (−11% for USS) (Table 1). These discrepancies originate to differences in reported usage by households in the LCFS and the USS. In the USS, more households reported flying internationally than in the LCFS. Differences in the footprints may also be due to calculation method: for private transport, we based energy footprints on self-reported mileage (see previous section), while for public transportation we used available information about the frequency of travel when restricting the number of households for which energy use was estimated using a regression model. We employed regression to estimate energy footprint for education. Although the adjusted R^2 was moderately strong (0.39), only 260 households reported spending on education in the LCFS survey. This is due to the free education system in the UK and the low percentage of households sending their children to independent schools. Hence, we expect estimated values using regression models for USS to be somewhat inflated.

We highlight that 75% of the USS footprints are **not** estimated with regression models, but calculated based on reported spending or quantity used. Of the remainder, 16% is based on using the average HEF of income deciles and the remaining 9% are estimated on using regression models.

2.4. Reporting total energy footprints per adult equivalent

We calculated the HEF as GJ/household, and to calculate individual footprints we divide household footprints with household sizes using the Organisation for Economic Co-operation and Development (OECD) equivalence scale. The energy footprint (EF) per adult equivalent (ae) distributes HEF among adults and children assuming children contribute less to the footprint. We use detailed USS information to examine EF related to air transport as reported by individuals in the survey instead of having total air travel footprint divided by adult equivalent.

2.5. Well-being

We characterize well-being with well-being outcome measures related to mental and physical health, financial situation, material deprivation, fuel poverty, and loneliness (Table 2). The approach is informed by an eudaimonic understanding of well-being based on the Theory of Human Needs (Doyal and Gough, 1991). Doyal and Gough (1991) explain that the achievement of basic human needs requires mental and physical health that allows us to participate in society and to have the autonomy to do so. These basic needs do not change with time, place, or culture. How we satisfy our basic needs is dependent on social (e.g. law, culture) and physical (e.g. infrastructure, sanitation) provisioning systems and individual choice. We use these variables to generate a well-being score (WBS). Each component of WBS is scored on a scale of 0 to 10 and the whole index has a minimum score of zero and a maximum of 70. We define an individual with a high level of well-being as one that achieves at least the average well-being score. We restricted the high well-being (HWB) outcomes to include only those who are above the poverty line and reported being able to heat the house during winter. Individuals with low well-being (LWB) have below average well-being scores.

The limitations of our analysis include missing responses to questions included in the WBS. The WBS is available for 90% of the weighted sample, leaving 10% of individuals without a score. However, we find that for the majority of socio-economic characteristics the sample is representative (see Supplementary Materials).

3. Results

3.1. Energy footprints – Levels and composition

We first compare the levels and compositions of energy footprints

Table 2
Variables chosen for the construction of well-being score.

Variable	Well-being outcome	Type	Definition
Mental Health Index (MHI)	Mental health	c	On a Likert scale: 0 “All of the time” 1 “Most of the time” 2 “Some of the time” 3 “A little of the time” 4 “None of the time”. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)? 1) Mental health meant accomplished less;2) Mental health meant worked less carefully; 3)Felt calm and peaceful; 4)Had a lot of energy; 5) Felt downhearted and depressed
Physical Health Index (PHI)	Physical health/ Autonomy	c	On a Likert scale: 0 “All of the time” 1 “Most of the time” 2 “Some of the time” 3 “A little of the time” 4 “None of the time”. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health? 1) Physical health limits the amount of work; 2) Physical health limits the kind of work; 3) health limits moderate activities 4) pain interfered with work 5) health limits several flights of stairs
Loneliness index (LI)	Mental Health/ Participation	c	On a Likert scale: 0 “Often” 1 “Some of the time “2 “Hardly ever or never “How often feels: 1) lack of companionship; 2) left out; 3) isolated from others 4) lonely
Subjective well-being Index (SBW)	Mental Health/ Participation/ Autonomy	c	On a Likert scale: 0 “not at all “, 1 “no more than usual “2 “rather more than usual “3 “much more than usual” Have you recently … 1) been able to concentrate on whatever you’re doing? 2) lost much sleep over worry? 3) felt that you were playing a useful part in things? 4) felt capable of making decisions about things? 5) felt constantly under strain?6) felt you couldn’t overcome your difficulties? 7) been able to enjoy your normal day-to-day activities? 8) been able to face up to problems? 9) been feeling unhappy or depressed? 10) been thinking of yourself as a worthless person? 11) been feeling reasonably happy, all things considered?
Subjective financial situation (SFS)	Economic security	c	How well would you say you yourself are managing financially these days? Would you say you are: 0 “Finding it very difficult” 1 “Finding it quite difficult “2 “Just about getting by “3 ‘Doing alright’ 4”Living comfortably”
Energy poverty	Protective housing/ adequate heating	d	

(*continued on next page*)

Table 2 (*continued*)

Variable	Well-being outcome	Type	Definition
			In winter, are you able to keep this accommodation warm enough?
Above the poverty line	Autonomy/ Economic security	d	Based on Index from the Social Metrics Commission

'd' corresponds to dichotomous, and 'c' to categorical variable type.

(EF) by income and EF deciles. All footprints are presented in GJ per adult equivalent (ae) per annum. There is a nine-fold difference in energy use between the lowest and top EF decile (panel b in Fig. 1). This increase from 47 GJ/ ae to over 405 GJ/ae mostly arises from higher energy use for car and air transportation, which makes up the majority of the total EF (between 70 GJ/ae and 275 GJ/ae) for the top four energy deciles (6–10). International air EF increases rapidly from 19 to 23 GJ/ ae for the bottom 40% of income earners to 92 GJ/ae for the top 10% of income earners (panel '*a'* in Fig. 1). The tenth income decile has higher private transport (car and air) EF than the total EF of 60% of the population. If the top decile just stopped flights, their total EF would be reduced by over one-third – around 103 GJ/ae – the level of the total energy use of the bottom 20% of the income earners (sic).

Whereas private transport is responsible for most of the total EF of the top 50% earners and energy users, housing EF contributes the most to the total EF of the bottom 50% of energy users (panel bin Fig. 1). When considering the differences between EF by income and energy (Fig. 1), we observe similar energy compositions in each decile with the exception of international flights EF. Income and EF are highly correlated (Table 3), a common result in foot-printing studies (Ivanova et al., 2017; Oswald et al., 2020; Wiedenhofer et al., 2013; Cohen et al., 2005). Much larger ranges in energy deciles rather than income deciles call for analysis of the reasons behind the large spread in energy use. Therefore, in the following sections, we mainly use energy deciles.

Inequalities in energy use are further pinpointed when considering the distribution of energy use (Fig. 2). The bottom 10% of energy users

Table 3
Correlation: Energy footprint vs income for British households in 2018/2019, energy footprint vs well-being; well-being vs income. Input values are log-transformed.

Pairwise correlations						
Variables	Income (£/ae)	EF (GJ/ ae)	WBS	Car-transp. EF (GJ/ ae)	Air-transp. EF (GJ/ ae)	Housing EF (GJ/ ae)
Income (£/ae)	1.000					
EF (GJ/ ae)	0.43***	1.000				
WBS	0.27***	0.27***	1.000			
Car-transp. EF (GJ/ ae)	0.25*	0.52*	0.22*	1.000		
Air-transp. EF (GJ/ ae)	0.32*	0.87*	0.22*	0.22*	1.000	
Housing EF (GJ/ ae)	0.06*	0.27*	0.02*	0.06*	0.02*	1.000

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Gross household income divided by adult equivalent, Total energy footprint (EF) in GJ per adult equivalent, well-being score (WBS) with min 0 and max 70 score.

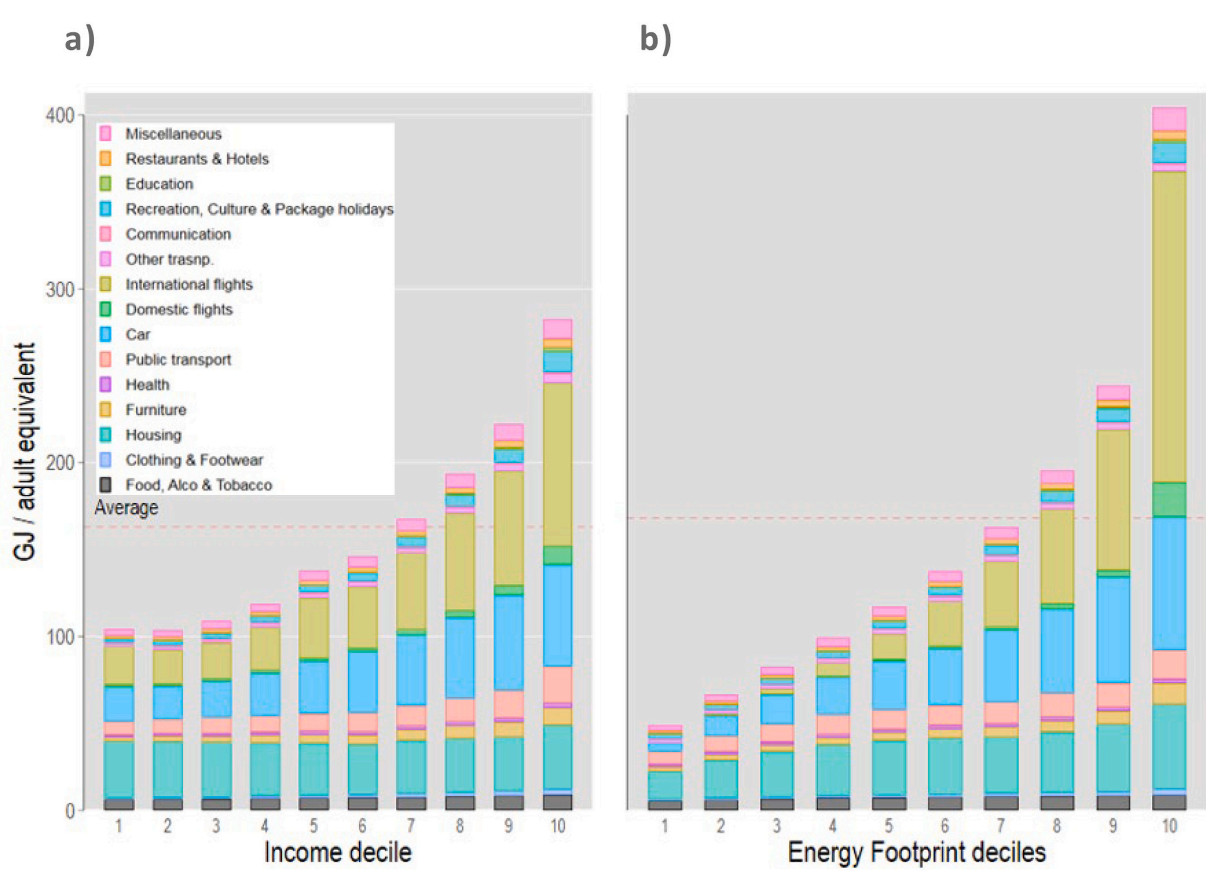


Fig. 1. Energy footprints of British households– levels and composition by income deciles (panel a) and by Energy footprints deciles (panel b). Calculated using USS (2018/2019) and LCFS (2019) data.

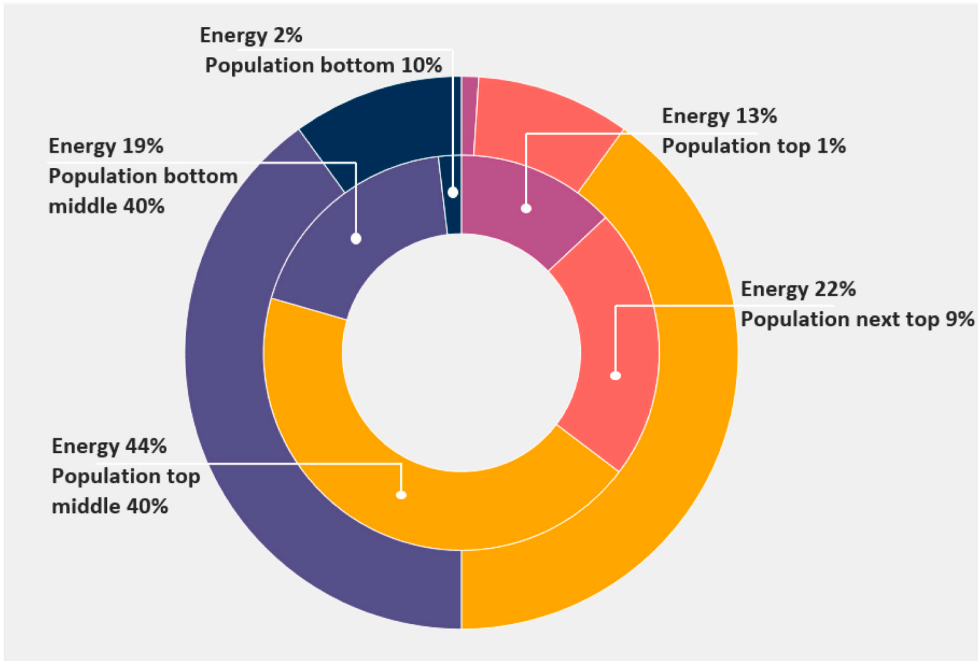


Fig. 2. Distribution of Energy footprint in British population (%). The shares of population calculated on the energy footprint basis. Calculated using USS (2018/2019) and LCFS (2019) data.

contribute only 2% to the total energy use, and only 5% of the top 10% users' usage. The bottom half of energy users are responsible for just one-fifth of total energy use. This is less than the share of the top 10% of energy users, which is over a one third of total energy use (Fig. 2). But are those high-energy users living better than low energy users and why do they use so much energy? In the next sections, we seek to address these questions.

3.2. Footprints vs well-being score

We now examine energy footprints in relation to well-being. We begin with an analysis using a well-being score (WBS) (section 3.2) and end with an analysis of the main characteristics that increase the odds of having high or low well-being (sections 3.3 and 3.4).

The WBS vs EF statistics (Fig. 3) shows a saturation trend common in international comparisons (Steinberger and Roberts, 2010; Martínez and

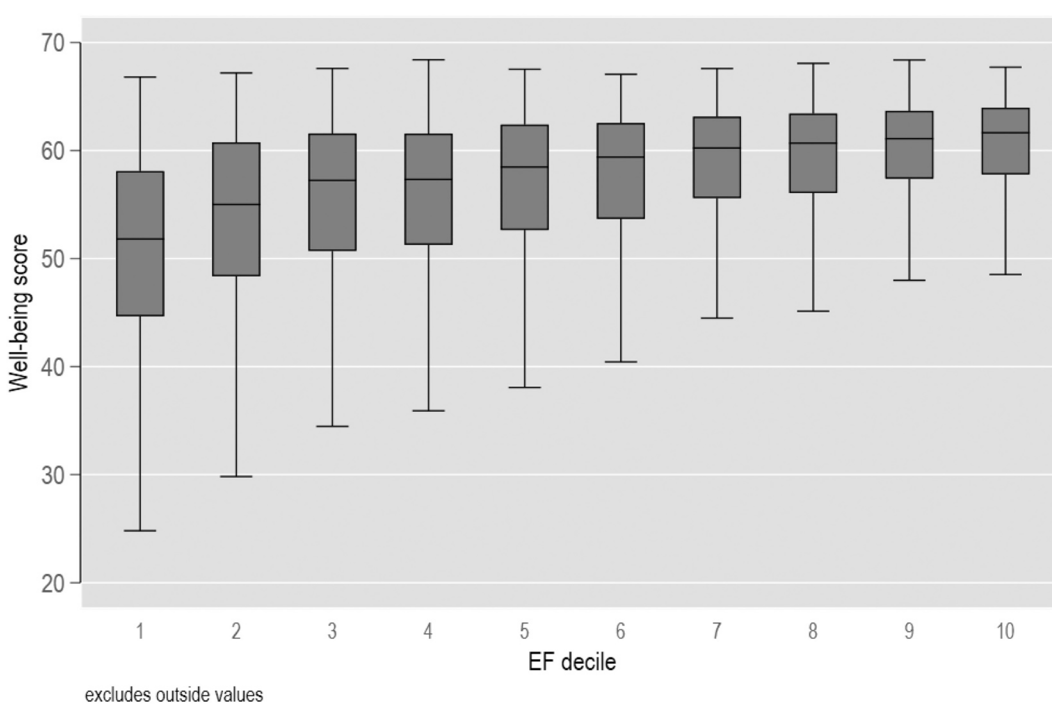


Fig. 3. Box plot for well-being score by energy footprint decile. Data based on UK household surveys: USS (2018/2019) and LCFS (2019).
The top of the box is 75th percentile, the middle line corresponds to the median, the bottom line of the box is the 25th percentile. The top and bottom of whiskers correspond to upper and lower adjacent values (the most extreme values within the 1.5 interquartile range of the nearer quartile).

Ebenhack, 2008); increments in energy at low EF levels are associated with large well-being increases but with diminishing or no returns when EF grows, similar to prior findings by Lenzen and Cummins (Lenzen and Cummins, 2013).

There is a monotonically increasing relationship between WBS and energy footprint (Fig. 3). The large range of WBS indicates that each Ef decile includes households with varied WBS scores. It is possible to have a high WBS with as little as 50 GJ/ae or with ten times as much, 400 GJ/ae (Fig. 1). It is thus difficult to establish an energy threshold for high WBS. Other factors, such as socioeconomic characteristics and provisioning systems, are important for understanding the role of energy in the attainment of well-being. This relationship is further confirmed when taking into account the weak correlation between WBS and EF (Table 3).

Next we analyse the relationships between WBS components (Table 2) and EF (Table 4) to understand how they are linked to energy demand for specific services, and where decoupling of well-being from energy is possible. The role of the regression analysis presented in Table 4 is to show associations, not causality. In what follows we analyse the relationships between well-being components and energy footprints, and the direction and significance of those associations. The aim is to test hypotheses about the effects of the variables of interest and not to predict specific outcomes. The magnitude of the coefficient and the large goodness-of-fit parameter $R^2$are thus not crucial to the analysis. Small R^2 are counterbalanced by large sample sizes, which are important for hypothesis testing.

The subjective financial situation, physical health, and being above the poverty line are linked to income and material services and thus to increased energy use (Table 4). But the improvement of non-material needs linked to mental health and subjective well-being does not increase energy demand (Rao and Wilson, 2021; Stillman et al., 2012). EF of car transport is an important needs satisfier, as its relationship with each WB component is positive, significant, and inelastic, with the exception of subjective well-being, for which the relationship is negative (Table 4). This might be because living in areas with high car ownership decreases subjective well-being (Lenzen and Cummins, 2013). Better physical health and adequate heating are associated with lower Housing EF, which indicates that high heating requirements might be a sign of poor quality of dwelling and higher energy needs due to sickness or disability (Büchs et al., 2018; Ivanova and Middlemiss, 2021a). It might also suggest the unaffordability of switching to more clean and efficient fuels or investing in thermal insulation, which can be out of reach for poor households who often rent.

Air travel - EF increases with better physical health and financial situation. This is not surprising, as income and air travel - EF are correlated (Table 3) and long-distance traveling might require good physical health (Ivanova and Middlemiss, 2021b). WBS and air travel - EF are, however, weakly correlated (Table 3). There is no association between air travel and improved mental health, loneliness, or subjective well-being – reasons for traveling are more likely lifestyle related, and flying having become a default to reach holidays destinations. Cohen et al. confirm this result, with their research spotlighting increasing feelings of guilt and denial of air transport's climate impacts, which lead to a cognitive dissonance of habit and conscience (Cohen et al., 2011; Gössling et al., 2020a).

3.3. *Energy footprint vs high and low well-being index*

We compare the level and composition of EFs for those with low and high well-being using a binary variable. High well-being (HWB) is defined as having at least an average WBS, as well as being above the poverty line and having adequate heating. Low well-being (LWB) means having a below average WBS. Those with HWB constitute 59% of the sample and are responsible for two-thirds of total energy demand (Fig. 4). Energy use within the HWB group is highly unequally distributed, as few (7.8%) are responsible for a disproportionate amount of energy demand (25%), and half of those with HWB (51%) use less than their share (43%) (Fig. 4). Among those with LWB, a few high-energy users (2.2%) are responsible for one-tenth of the total energy (Fig. 4). The rest with LWB (39% of the sample), contribute less than one-quarter (23%) of the total energy demand. Those with larger EF have a higher chance for well-being: among the top 10% of energy users, almost three-quarters have high well-being (72%), whereas, among the lowest 10% of energy users, fewer than one-third have high well-being 29% (Table 5).

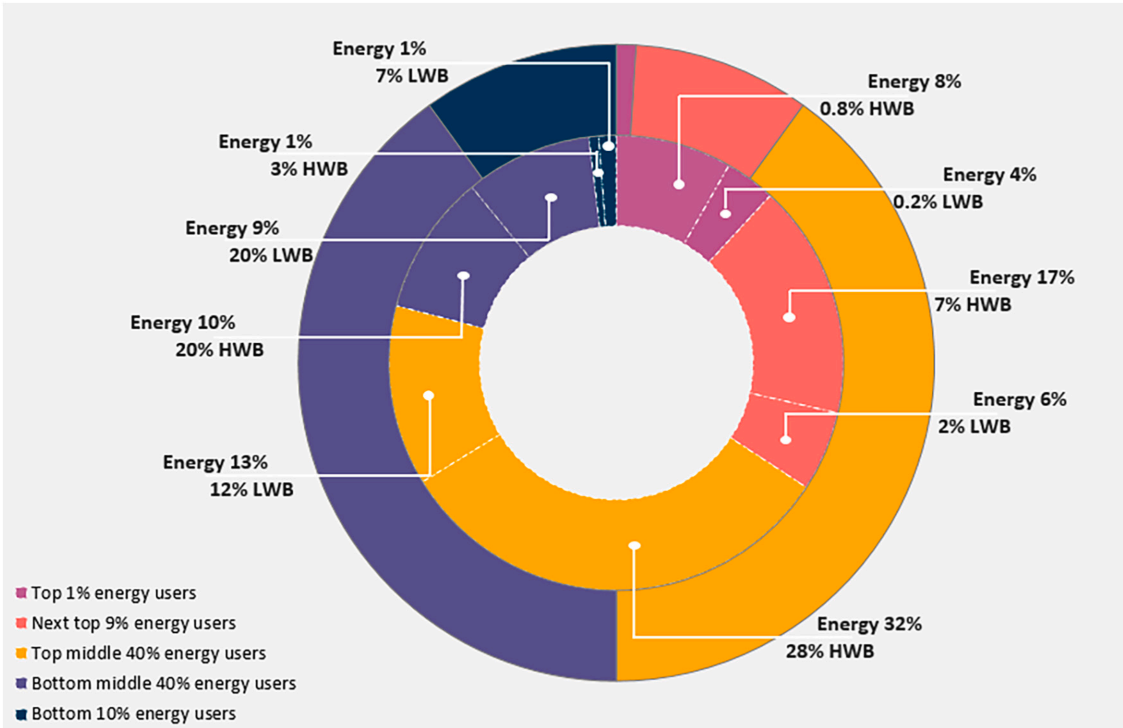
Next, we delve into levels and types of energy use by energy groups and well-being status. There is little change between the energy use of high WB and low WB energy users for all energy use levels (Fig. 5). It is not obvious what makes a difference between having or not having high levels of well-being. The reasons come to light when examining the contribution of each energy category to overall EF (Fig. 6). In LWB groups, housing and public transport EF make a larger proportion of the total EF. For those with HWB, private transport in the form of car and air travel - EF is responsible for a high proportion of their total EF (between 18 and 73%). The majority with HWB and low EF reported having holidays and savings, which indicates that they are not deprived of leisure but obtain it at lower energy intensity than those with HWB and high total EF (Table 5).

A small share (3%) of the sample achieved high WB at a very low EF of 50 GJ/ae (Figs. 4 and 5), but at the same time, top 10% with HWB used more than ten times that amount of energy (∼400–800 GJ/ae).

Table 4
OLS regression results of the natural logarithm of energy footprints in GJ per adult equivalent by Total EF (1), type of transport: Car transportation EF (2), air transportation EF (3), and Housing EF (4). Data based on UK household surveys: USS (2018/2019) and LCFS (2019).

	(1)		(2)		(3)		(4)	
	Total EF (log)	|t|	Car transp. EF (log)	|t|	Air-transp. EF (log)	|t|	Housing EF (log)	|t|
MHI (log)	−0.04	(−1.21)	0.12*	(2.26)	−0.10	(−1.61)	0.09**	(2.59)
PHI (log)	0.39***	(29.33)	0.45***	(17.46)	0.12***	(3.73)	−0.20***	(−13.16)
Subj. WB (log)	−0.08***	(−6.00)	−0.13***	(−5.07)	0.04	(1.24)	0.07***	(4.29)
Lon. Ind (log)	0.12***	(7.38)	0.09**	(3.15)	0.05	(1.62)	0.07***	(4.05)
Subj. fin.sit (log)	0.29***	(21.95)	0.20***	(8.04)	0.52***	(18.83)	0.08***	(5.42)
Has Adeq. heat.	0.11***	(6.27)	0.15***	(4.18)	0.12**	(2.74)	−0.12***	(−5.74)
Above Pov.	0.34***	(34.49)	0.47***	(25.33)	0.34***	(16.25)	0.08***	(6.89)
constant	3.07***	(54.60)	1.25***	(11.65)	2.44***	(20.03)	3.08***	(47.56)
N	24,417		21,651		14,571		24,407	
R^2	0.15		0.06		0.06		0.01	

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results are weighted. Footprints with zero home energy and transport energy were excluded. We interpret the coefficients (βi) as elasticities of energy demand in relation to their well-being component score. For example, a 1% increase in the PHI results in a 0.39% increase in Total EF. If βi = 1, the relationship is proportional, if βi < 1, the relationship is inelastic, and if βi > 1, the relationship is elastic. If -βi indicates inverse of the independent variable.



Note: Outer ring corresponds to the energy group: top 1%, next top 9% top middle 40%, bottom middle 40% and bottom 10%. Inner ring corresponds to energy distribution by well-being group. HWB – high well-being; LWB – Low well-being.

Fig. 4. Distribution of energy footprints of British households in GJ per adult equivalent by high and low well-being groups. Calculated using USS (2018/2019) and LCFS (2019) data.

However, the majority of those with HWB use little more than the national average amount of energy (180 GJ/ae vs 163 GJ/ae). A full quarter of the sample with HWB uses less than half the average EF, between 50 and 100 GJ/ae. However, this is still more than what is modelled as sustainable in scenarios such as Low Energy Demand or Decent Standards of Living (Millward-Hopkins et al., 2020; Rao et al., 2014; Kikstra et al., 2021) (around 55 GJ for Global North).

Overall, excess energy use is implicated to a small minority with HWB. Therefore, it is possible to reconcile maintenance of high WB and energy demand reduction.

3.4. *Characteristics of those with high and low well-being*

Out of the maximum of 70 points, those with high well-being (HWB) score on average 13 points higher than those with low-wellbeing (LWB) (62 points vs 49 points) (Table 5). When examining differences between energy groups, clusters with LWB score lower for all WB components with the highest disparities for loneliness and subjective financial situation (average two points difference for the maximum score of 10 points per component). The difference in WBS between the lowest 10% energy users with HWB and the highest 1% with HWB is only 1 point (Table 5), but the difference in their energy use is over 800 GJ/ae, a seventeen-fold increase (Fig. 5). As already noted, energy footprints weakly correlate with WBS and give an incomplete picture of the differences between those with high and low well-being. For that reason, we use additional information detailed in microdata on various socio-economic characteristics to obtain a more nuanced account (Table 5). We describe them below.

3.4.1. *Protected characteristics*

Protected characteristics such as gender, ethnicity, or age reduce the probability of having HWB. The bottom 50% of energy users with LWB is disproportionally female, single, without work, and dedicating two hours more than the high energy users to un-paid housework. In contrast, the top energy users (9% and 1%) with HWB are on average middle-aged, white, male, working long hours, having two cars but no children. This cluster contains the highest 25% of income earners in the UK with an average gross monthly income of £4100–6400 per person (Table 5) (ONS, 2022b). Being non-white also reduces the chances of having HWB (Table 5). Overall, 14% of respondents belong to a non-white group, but twice as many of them have LWB rather than HWB (5% and 9% respectively). But the older a person is, the higher the chance of having HWB, possibly due to material aspects of well-being and greater chance of having accumulated wealth or receiving regular pensions (ONS, 2022a).

3.4.2. *High share of housing energy*

Among the bottom 50% of energy users, housing EF contributes the most (28–34%) to the total EF, particularly among those with LWB (Fig. 6). Higher share of house fuels does not mean higher absolute EF as the lowest 10% of energy users consume a mere 17GJ/ae of housing fuels while already the bottom middle 40% consumes almost twice as much (30 GJ/ae). Higher share of house fuels does not translate to warmer houses as lack of adequate heating among LWB groups is the norm (Table 5): they are likely living in poorly insulated dwellings. Groups with LWB often lack authority to renovate their homes, as they are disproportionally rentees (48% compared with 17% for those with HWB).

Over a third of households in the lowest 10% with LWB have a prepayment meter, which is an expensive payment method. With a small income of 1100£ per person and the majority living below the poverty line (62%), these households have to choose between energy services to fulfil their needs. They may need to choose between eating, warming up their houses or buying petrol for their car (Table 5) (Mattioli et al., 2018). These characteristics make those with low EF and LWB vulnerable to energy poverty and to be unable to decide about their living

Table 5
Socio-economic characteristics of individuals grouped by energy users group and well-being status. Data based on UK household surveys: USS (2018/2019) and LCFS (2019).

		Avg.	HWB	L WB	|t|	OR	L 10% HWB	L 10% LWB	BM 40% HWB	BM 40% LWB	TM 40% HWB	TM 40% LWB	T 9% HWB	T 9% LWB	T 1% HWB	T 1% LWB
Location	Number of obs.	28,614	16,863	11,751			673	1,647	5,248	5,235	8,081	3,751	2,296	852	565	266
	Share of population	100%	59%	41%			3%	7%	20%	20%	28%	12%	7%	2%	0.8%	0.2%
	Urban	58%	**52%**	**67%**	***	▼	**70%**	**81%**	**59%**	**70%**	**47%**	**57%**	**43%**	**51%**	49%	57%
	Suburban	24%	**30%**	**16%**	***	▲	**16%**	**8%**	**26%**	**14%**	**33%**	**23%**	32%	28%	28%	21%
	Rural	18%	**18%**	**16%**	***	▲	14%	11%	15%	16%	19%	20%	25%	21%	23%	22%
Dwelling	Number of bedrooms	3.0	**3.2**	**2.8**	***	▲	2.4	2.5	**2.9**	**2.7**	**3.3**	**3.1**	**3.5**	**3.4**	3.6	3.6
	Renting	30%	**17%**	**48%**	***	▼	**45%**	**76%**	**24%**	**52%**	**11%**	**30%**	**9%**	**26%**	10%	15%
HH size	Number of kids	0.5	**0.4**	**0.6**	***	▼	**0.3**	**0.9**	0.5	0.6	0.4	0.5	0.3	0.4	0.4	0.5
	Share of single hh	41%	**33%**	**52%**	***	▼	**55%**	**61%**	**37%**	**54%**	**29%**	**45%**	**26%**	**45%**	**21%**	**49%**
	Household size	2.8	**2.7**	**2.9**	***	▼	**2.3**	**3.1**	2.7	2.8	**2.7**	**2.9**	**2.6**	**2.9**	2.7	2.6
Ind. char	Age	50	**52**	**47**	***	▲	**62**	**47**	**54**	**48**	**50**	**45**	**50**	**43**	**49**	**44**
	Male	47%	**51%**	**42%**	***	▲	45%	43%	**51%**	**41%**	**51%**	**43%**	**52%**	**41%**	**64%**	**46%**
	Non-white	6%	**5%**	**9%**	***	▼	6%	8%	**5%**	**9%**	**4%**	**9%**	**5%**	**11%**	8%	14%
Education	16 > yrs edu	40%	**45%**	**32%**	***	▲	16%	16%	**34%**	**28%**	**52%**	**42%**	62%	56%	69%	55%
	12 to 15 yrs edu	21%	**21%**	**22%**	*	▼	18%	20%	21%	21%	**21%**	**25%**	**19%**	**25%**	14%	23%
	<= 11 yrs edu	39%	**34%**	**46%**	***	▼	67%	63%	**45%**	**51%**	**27%**	**33%**	19%	19%	17%	22%
Work	Not working	43%	**39%**	**49%**	***	▼	71%	70%	**46%**	**52%**	34%	35%	29%	29%	16%	21%
	Working h/w	37.2	**38.1**	**35.7**	***	▲	34.7	31.0	**35.8**	**34.0**	38.6	38.1	40.7	38.9	44.9	43.1
	Housework h/w	9.4	**9.0**	**10.0**	***	▼	**9.7**	**10.0**	**9.6**	**10.4**	8.7	9.6	8.2	8.7	7.3	7.9
Travel	No. of cars	1.5	**1.7**	**1.3**	***	▲	0.6	0.6	**1.3**	**1.1**	**1.8**	**1.6**	2.0	1.7	1.7	1.5
	No. of dom. flights	0.2	0.2	0.1		NA	0.0	0.0	0.0	0.0	**0.1**	**0.1**	0.8	0.7	5.1	2.5
	No. of EU flights	0.8	**1.1**	**0.5**	***	▲	0.0	0.0	0.1	0.1	1.1	1.0	3.0	2.8	**8.3**	**9.5**
	Number. of int. flights	0.3	0.4	0.2		NA	0.0	0.0	0.1	0.1	0.4	0.3	**1.2**	**1.2**	4.4	3.3
	Cannot afford holidays	23%	**10%**	**38%**	***	▼	**30%**	**56%**	**17%**	**46%**	**7%**	**21%**	**4%**	**16%**	1%	4%
Income & poverty	Gross mthly inc. (£ ae)	2,300	**2,700**	**1,800**	***	▲	**1,300**	**1,100**	**1,900**	**1,600**	**3,000**	**2,300**	**4,100**	**3,100**	**6,400**	**3,600**
	Below poverty line	18%	0%	43%	**NA**	NA	0%	62%	0%	45%	0%	33%	0%	25%	0%	34%
Income & poverty	No adqt heating	5%	0%	11%	NA	NA	0%	16%	0%	12%	0%	8%	0%	12%	0%	2%
	Pre-payment meter	14%	**7%**	**24%**	***	▼	**12%**	**34%**	**11%**	**27%**	**4%**	**15%**	3%	10%	**0%**	**5%**
Well-being	Avg. well-being score	57	62	49	**NA**	NA	61	46	62	49	**62**	**51**	62	52	62	54
	Mental Health index	7.1	**7.4**	**6.8**	***	▲	**7.4**	**6.7**	**7.4**	**6.8**	**7.4**	**6.8**	**7.4**	**6.8**	**7.3**	**6.9**
	Physical Health index	8.4	**9.1**	**7.4**	***	▲	**8.3**	**7.0**	**9.0**	**7.3**	**9.2**	**7.8**	**9.2**	**8.1**	**9.4**	**8.2**
	Loneliness index	8.4	**9.2**	**7.3**	***	▲	**9.2**	**7.3**	**9.2**	**7.3**	**9.2**	**7.2**	**9.2**	**7.3**	**9.1**	**7.7**
	Subjective well-being	6.9	**7.5**	**6.0**	***	▲	**7.6**	**6.0**	**7.6**	**6.1**	**7.5**	**6.0**	**7.5**	**5.9**	**7.4**	**6.0**
	Subjective financial sit.	7.9	**8.7**	**6.8**	***	▲	**8.4**	**6.4**	**8.4**	**6.7**	**8.7**	**7.1**	**9.0**	**7.2**	**9.2**	**6.4**
Energy footprint (GJ/ae)	Total EF	160	**183**	**128**	***	▲	**50**	**47**	**97**	**92**	**194**	**183**	364	362	863	792
	Housing EF	32	**32**	**31**	***	▲	17	17	**26**	**30**	**34**	**38**	47	50	58	63
	El,, oil, and gas EF	25	**25**	**25**	**	▲	13	14	**22**	**25**	**26**	**29**	**33**	**33**	31	35
	Biomass fuels EF	2.8	**3.0**	**2.4**	**	▼	0.0	0.0	**0.6**	**0.7**	**3.1**	**4.5**	9.1	12.7	19.3	21.6
	Car EF	35	**41**	**27**	***	▲	**5**	**4**	**23**	**18**	**48**	**45**	76	78	**102**	**82**
	Air –travel EF	53	**67**	**33**	***	▲	5	3	14	13	**73**	**58**	176	155	459	401

HWB – high well-being; LWB – Low well-being, BM – bottom middle, TM – Top middle; T – Top. Blank space in |t| and OR indicates no significant relationship, NA means not applicable for the variable, and stars relate t: t statistics expressed at significance levels * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The significance levels are for the odds ratios of the probability that the individual will have HWB to the probability that the individual will have LWB given the increase/the achievement of the independent variable. Each of the independent variables is considered in turn. Red and green triangles correspond to odds ratio: one indicates no effect, positive effects are greater than one (green) and negative effects are between zero and one (red triangle). For example, the odds ratio of having HWB depending on living in an urban area are <1 (red triangle), meaning living in urban area decreases odds of having HWB. Data based on USS, wave 10.

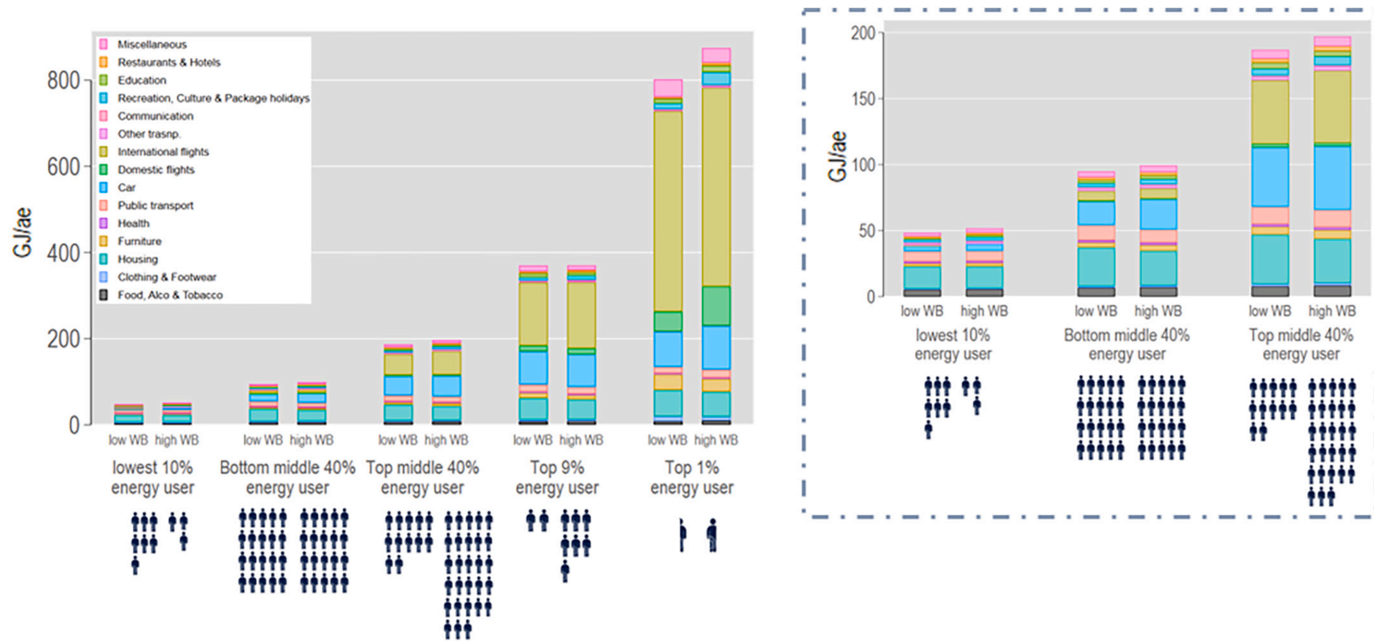


Fig. 5. Energy footprints of British households– levels and composition by high and low well-being and energy group. Calculated using USS (2018/2019) and LCFS (2019) data.
The right side of the figure shows the magnification of the left side figure for the lowest 10%, bottom middle 40%, and top middle 40% of energy users.

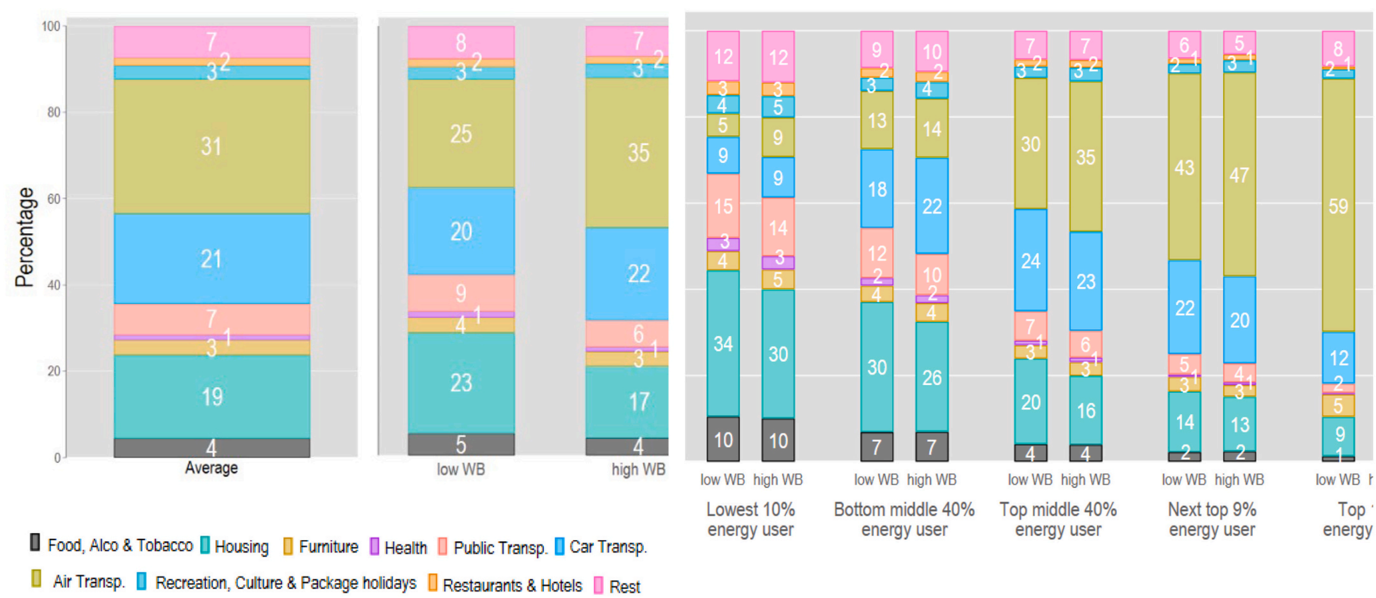


Fig. 6. Contribution to overall energy footprint of British households by energy footprint categories. Calculated using USS (2018/2019) and LCFS (2019) data.

conditions.

Among high energy users with HWB, average housing EF is well above the mean (47–58 GJ /ae compared to a mean of 32 GJ/ae). Location matters here: rural living gives more space, more than three bedrooms, which for the top 1% with HWB results in nearly two times higher house fuel use than the sample average (Table 5). While the top 10% use about a quarter more electricity and gas compared to the top middle 40%, they use three to six times more wood and coal because fireplaces and wood burners are more common in rural settings. Within this group of high earners and energy users is a small sub-group that struggles (2% of the weighted sample population). The top 9% of energy users with LWB includes a higher number of single households (45%) and non-white individuals (11%). Poor mental and physical health, loneliness, and financial problems might contribute to their low well-being score. One-fourth is below the poverty line and those not having adequate heating are twice as common as the sample average.

3.4.3. *Private vs public transport – Needs satisfier escalation vs needs satisfaction*

While private transport dominates the HWB group, public transport may be important for those with LWB. Car transport EF increases almost twenty-fold from the lowest 10% to the top 1% of energy users with HWB (Table 5). This might partly be related to suburban or rural living and the fact that affluent households travel longer distances by car regardless of public transport availability. In contrast, low energy users with HWB mostly live in urban areas (70%) and have low ownership of

0.6 cars per person. We cannot examine the quality of public transport accessible to rural and suburban dwellers in our sample. However, the literature highlights lack of affordability, reliability, and flexibility of rural public transport which can lock people into car-dependent lifestyles (Mattioli, 2017; Mattioli et al., 2020; Local Government Association, 2022; Urban Transport Group, 2019; Department for Transport, 2021a). While these factors could partly explain dependence on private transportation, it does not justify all of it. In the UK, common purposes of car trips include commuting, escorting children, shopping and carrying heavy goods, which are related to satisfying needs for education, sustenance, or economic security (Mattioli et al., 2016; Department for Transport, 2021b). But the cluster with the highest car transport EF, the top 10% of energy users with HWB, is middle-aged, male, and without children.

The concepts of needs escalation, negative satisfiers, and car dependency can help explain excess private transport use. Needs escalation occurs when a specific product or technology "escalates in terms of overall use, and thus, in its environmental impact" (Brand-Correa et al., 2020). Environmental impact is often linked with negative needs satisfiers, which car use is via its contribution to air pollution, upkeep costs (possibly leading to having to choose between eating or driving (see Mattioli, 2017) and sedentary lifestyles (Brand-Correa et al., 2020). The escalation of car use is possible due to induced demand, relocation to car-dependent areas, and prioritisation of investment in infrastructure for private transport, all political-economic factors behind car dependence (Mattioli et al., 2020). Our results indicate that a car is important for satisfying needs, but that the context within which this dependency occurs is created. This leads to a situation where those with the lowest energy use and LWB might need more energy for car use and those with HWB and high energy use, utilise private transport for all activities, although more energy-efficient cleaner alternatives exist.

4. Discussion

This research addresses a gap in the foot-printing literature by going beyond the drivers and barriers of household footprints to examine the social outcomes of energy use, in terms of needs satisfaction and well-being. We contribute to the foot-printing literature the first analysis of the direct and indirect energy demand in the UK, focusing on final energy use and linking it to well-being outcomes. Our results highlight issues of energy poverty as well as excess energy use. As a result, this analysis goes to the core of energy justice: some households use so little energy that they cannot achieve high well-being, while others use over ten times more.

We found that high well-being is possible to achieve with 50-100GJ/ae, which is less than the national average energy footprint (EF), and is achieved by 3%–23% of the population. This is an encouraging result as it shows that living well within limits is already possible in present context. However, half of the households (25%) with low EF (<100 GJ/ae) have low well-being and are vulnerable to energy poverty. Earlier studies have found that fuel poverty often leads to a "heat or eat" dilemma experienced by low-income families, older people, and the disabled (Ivanova and Middlemiss, 2021a; Walker and Day, 2012; Frank et al., 2006). Buchs highlights that those who are "sick and stuck at home" require *more* housing energy to stay warm (Büchs et al., 2018). Our results resonate with this: households with low well-being and poor physical health have higher EF related to electricity, oil, and gas than those with high well-being. Energy poverty is currently framed in terms of resource scarcity or efficiency and not in terms of inequality, income poverty, and austerity (Middlemiss, 2019). Not recognizing that households' poverty is multidimensional may lead to a lack of comprehensive response, or missing those who need the help the most (Gillard et al., 2017; Rosenow et al., 2013; Sovacool, 2015; Middlemiss and Gillard, 2015). A comprehensive governmental response such as strong incentives for retrofitting is needed. The pressure for change often comes from protest groups such as Insulate Britain, which fight for retrofit programs that would help reduce energy demand and improve lives of the most vulnerable and often invisible groups.

Another issue of energy poverty relates to transport poverty. We found that among those with high well-being private transportation EF is substantially higher. Mattioli and colleagues (Mattioli et al., 2018) have demonstrated how access to affordable car transportation matters for the achievement of well-being within existing provisioning systems because of the absence of alternative means of transportation to get to work or access essential services or social activities. Lower-income households on low energy budgets spend a larger share of their expenditure on car fuel and they often need to reduce other energy expenditure to afford a car (Mattioli et al., 2018, Mattioli, 2017, Martiskainen et al., 2021). These lower-income households are often pushed to car ownership because alternatives do not exist, especially in rural setting (Mattioli, 2017). High-income and high-energy users also heavily rely on private transportation but their car use often also sustains a highly energy-intensive lifestyle. Using a car to walk a dog, gardening and pet care, and disposal of waste are examples of the escalation of need (and want) satisfiers (Brand-Correa et al., 2020; Mattioli et al., 2016). The reliance on cars for needs and wants satisfaction is created and maintained by the political economy of car dependence. The difficulty to escape the dependency stems from land-use plans serving a car-oriented lifestyle and undermining public transport, and the creation of car culture by the automobile industry (Mattioli et al., 2020; Brand-Correa et al., 2020). When private transport accounts for most of the footprint of high income and high energy groups, more stringent energy or emission taxation and regulations limiting the health and environmental impacts of private transport are needed (Boyle et al., 2021).

Our most striking findings relate to flying. Among the top 10% of energy users, flying contributes over half of the total EF and the air travel - EF is many times larger than the sample average total EF. Flying is increasingly considered an excess contributing to the climate crisis (Gössling et al., 2020b). Public policies in the UK and internationally have omitted to tackle emissions from aviation. With new subsidies on domestic flights (GOV.UK, 2021), the UK government is promoting energy-intense lifestyles of income elites. Excess energy use due to flying could be addressed by frequent flyer levies which would also help distribute flying more equally. The purpose of flying should be considered though when designing interventions as there is a difference between weekend shopping trips to Paris and trips to reconnect and care for family abroad.

Our detailed analysis of energy distribution among UK households in relation to well-being is an important element that is missing from the existing energy demand scenarios for the UK (Barrett et al., 2021). With the need to understand distributional impacts of energy reduction scenarios, our study highlights characteristics of those most vulnerable in society and those living in unabated excess energy. Our results emphasize the need for more energy demand research through a gender and racial lens. We observed the importance of disaggregating data by ethnicity, as we find that those most vulnerable to energy poverty are often non-white and female, whereas those who most often overshoot energy use are white, wealthy middle-aged men. Taking into consideration the historical context of colonialism in the UK the issue of energy demand is also a justice issue. New ideas of how to tackle energy demand reduction include personal carbon or/and energy allowances. Equal distribution of allowances can risk not meeting people's needs and could have regressive distributional effects. Equity principles such as sufficiency, understood as to everybody according to their needs (but not wants), might help bring about more equal outcomes for all.

Realizing the 1.5-degree scenario pathway entails significant changes to the way in which we travel, work and live. It also requires reducing social inequalities. Growing income and pursuit of rural living have locked many into energy-intensive lifestyles. Those living in urban areas have lower EF but are not immune to energy-intense lifestyles, as flying to distant destinations has become an expected and affordable way of holidaying (Wiedenhofer et al., 2018). Without policies aiming for sufficiency, we will not be able to mitigate the effects of our lifestyles. Living a sufficient lifestyle does not doom us to 'go back to caves' (Millward-Hopkins et al., 2020). Our analysis suggests that more efficient energy services such as the provision of public transport and improvements in housing could substantially lower energy demand without adversely affecting well-being outcomes. However, this will not be enough, interventions must also target high energy users whose energy excess can undermine efforts to reduce energy consumption (Wiedmann et al., 2020). Sufficiency can mean flourishing for all but sustaining the status quo of unchecked energy-intensive lifestyles of a few rich can be also disastrous for all.

Declaration of Competing Interest

None.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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