Energy Research & Social Science 95 (2023) 102915

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Distributing less, redistributing more: Safe and just low-energy futures in the United Kingdom

Joel Millward-Hopkins [*], Elliott Johnson

Sustainability Research Institute, School of Earth and Environment, University of Leeds, UK

ARTICLE INFO

Keywords:
Climate change
Decent living standards
Energy justice
Energy poverty
Energy demand
Inequality
Just transitions

ABSTRACT

Low energy demand pathways may be essential for the transition to net zero. However, to date, the distributional impacts of these futures have been neglected, leaving open crucial questions about living standards and inequality. Using the lens of 'decent living energy', this article begins to piece together the puzzle by providing a distributional analysis of a recent low-energy-demand, net-zero scenario for the UK. We find that if the UK succeeded in following a low-energy pathway, but income and energy inequality continued increasing at the current rate, 9 million people could lack sufficient energy for meeting decent living standards in 2050. Theoretically, this can be mitigated either by achieving considerable reductions in income inequality, or by ensuring highly energy-efficient technologies are available at all income levels as this reduces the energy required to meet decent living standards. Reviewing various specific policies that could forge a low-energy-demand future, we find some are inherently equitable and others can easily be designed to be so. However, policies could also prove regressive in numerous ways. We thus argue that an equitable, socially-just, low-energy-demand policy pathway would need to be responsive and dynamic, bold and targeted, and joined-up with respect to both policy implementation and assessment.

1. Introduction

In recent years, low energy demand scenarios have been proposed as alternative mitigation pathways [1,2]. These have been developed in response to both the inadequate pace of carbon mitigation to date [3] and the heavy reliance of 2-degree-consistent climate scenarios on negative emission technologies; technologies suggested to be infeasible at large scale [4,5]. Low energy demand scenarios go beyond tradition technological energy efficiency measures to challenge patterns of energy and material consumption [6]. This includes shifting consumption towards less intensive forms – e.g. shifting travel from domestic aviation to high-speed rail – or entirely avoiding consumption where feasible – e.g. reducing the need to travel by increasing homeworking. The research also adds weight to the broader message emerging from environmental sciences that climate change and other ecological challenges cannot be addressed without fundamental changes to the global economy, and the growth-dependency and mass inequality that underpin it [7–9].

A low energy demand scenario developed as part of the Positive Low Energy Futures work in the UK has suggested a ~50 % reduction in energy demand is possible while improving social outcomes, which compares to the essentially flat UK energy demand seen over the past 50 years [2]. Moreover, Barrett et al. [2] found that at least a 40 % energy demand reduction is needed to meet the 2050 net-zero target committed to by the government, without relying upon mass deployment of unproven negative emissions technologies such as BECCS. Previous work at the global level found that a ~60 % reduction on current final energy use would be possible by 2050 while also providing decent living standards for all [10]. However, even moderately large inequalities could double the required energy use if *decent living energy* of ~15 GJ cap^{-1} year^{-1} were retained as the minimum consumption for the lowest consumers [11].

Returning to the UK, assuming the net-zero commitment survives the pressure of escalating energy prices, looming recession, and changing national and international political landscapes, the obvious question is: how can the country move towards this climate-safe, low-energy future? By providing detailed sectoral pathways describing the required changes in terms of technological deployment and activity levels, Barrett et al. [2] offer the vital first step. The challenge is how to deliver these changes – politically, economically and socially – and here the issue of inequality is crucial. Government statistics indicated 13 % of the UK

---

* Corresponding author.
E-mail address: joeltmh@gmail.com (J. Millward-Hopkins).

https://doi.org/10.1016/j.erss.2022.102915
Received 28 August 2022; Received in revised form 5 December 2022; Accepted 7 December 2022
Available online 15 December 2022

population were in fuel poverty in 2020,[1] and in reality the situation may be much worse [12]. Given that income inequality is a strong predictor of the prevalence of fuel poverty at the national level [13,14], it is imperative that these relationships are explored in future scenarios.

Low energy demand futures do not assume that any kind of deprivation exists, as the activity levels they presuppose are defined to exceed the *decent living standards* that underpin decent living energy [1]. However, these scenarios have so far focused upon regionally-averaged activity levels and energy consumption, and hence they are, in a sense, blind to inequality. Moving from the assumption that average consumption exceeds decent living, to the assumption that these standards are available to all, implicitly assumes a certain degree of equality [15]. But it remains unclear how much inequality could be 'permitted' within low energy demand futures before deprivation occurred, despite some valuable early work at the European level [15]. This issue is certainly not exclusive to low energy demand work – mitigation pathways frequently overlook questions of inequality, especially those relying on Integrated Assessment Models [16]. However, distributional impacts are particularly pertinent to scenarios that explore radical reductions in energy consumption. Overall then, while low-energy-demand scenarios describe specific pathways from today's high, inefficient energy use to low-energy futures, they do not describe pathways from today's high inequalities to the lower levels necessary to eliminate deprivation. A low-energy-demand future where a significant number of people lacked decent living standards would thus be a low-energy-demand future gone astray, but it's a possible future nonetheless.

These gaps are the motivation for our current work, where we explore interactions between low-energy-demand futures, living standards, and income & energy inequality in the UK. We ask four key questions: If the UK succeeded in following a low-energy-demand pathway but failed to reduce income inequality, how many could lack access to *decent living energy*? Could this be mitigated by decoupling energy inequalities from income inequalities? How much equality in income & energy use is needed to ensure *decent living energy* is available for all within a low-energy-demand future? Are low-energy-demand policies likely to alleviate or exacerbate income & energy inequalities?

2. Background

2.1. A low energy demand future in the UK

The global work of Grubler et al. [1] set the agenda for low energy demand (LED) work, and the recent UK study of Barrett et al. [2] presented the first comprehensive national-level analysis. Barrett et al. develop four scenarios – progressively more ambitious – from a baseline drawing upon current and planned policies to one assuming fundamental technological, social, infrastructural and institutional changes aimed at both reducing energy demand and fostering social and environmental co-benefits (*Transform*). We focus here upon the *Transform* scenario, which reduces UK final energy demand to 2.9 EJ in 2050 – a 52 % reduction on the 1990 level of 6.2 EJ. This is a per-capita reduction from 108 to 41 GJ (62 %). Notably, the *Transform* scenario is the only one that manages to achieve net-zero in 2050 without substantial carbon capture in the electricity generation sector. The scenario data are shown in Fig. 1 and 2050 values listed in Table 1.

The basis of the UK LED model is a sectoral, bottom-up assessment of pathways for activity levels (e.g. passenger kilometres cap^{-1}; food kcal cap^{-1}) derived after applying demand-side strategies. These activity levels are then input into an integrated modelling framework to explore the implications on both energy supply and carbon capture & removal technologies. Here, the TIMES modelling framework is used [17], which optimises supply-side energy systems in order to meet at the lowest-cost the (exogenous) energy service demands previously defined. The model takes a territorial perspective on energy use, thus omitting embodied/imported energy.

Finally it should be noted that, like the decent living energy models described below, the LED models of Grubler et al. [1] and Barrett et al. [2] consider final, rather than primary energy demand. For analysing the relationship between energy use and human well-being – and hence for the current work – final energy is a much more appropriate measure, as it's a step closer to useful energy services [18].

2.2. Decent living energy estimates

Conceptually, LED scenarios present technically feasible pathways for reducing energy demand to aid meeting mitigation targets. In contrast, *decent living energy* (DLE) models are more theoretical, and they estimate the minimum energy required to provide a material basis sufficient to support human well-being. Consumption in LED scenarios thus remains above sufficiency levels, while DLE models fix activity levels at *decent living standards*. The standards used are assumed to be a prerequisite for fulfilling basic human needs – thus are built upon needs theories [19] – and they are specified as an inventory of culturally-universal material requirements [20,21]; *pre*requisite, as they do not themselves guarantee social and physical well-being. Similarly to LED work, existing DLE models utilise bottom-up modelling built upon activity-levels and energy intensities.

Two DLE model estimates are available that are appropriate for the current UK work. The global model of Millward-Hopkins et al. [10] offers a UK-specific estimate. However, it should be noted that the model was developed primarily to make high-level estimates of the global energy required for decent living, so the national data comes with uncertainties. Kikstra et al. [22] developed another global model and offered regional estimates, including for Western Europe. This *WEU* data is relatively well suited to estimating decent living energy requirements for the UK, but the imperfect geographical match, along with some necessarily simplified assumptions in the model itself, leads to a degree of uncertainty here as well. Values are summarised in Table 1.

Both DLE models are conceptually similar, in that they propose consumption-based, final energy thresholds for providing decent living standards for all by 2050, with activity levels across the full population fixed to these living standards. Both also provide high and low estimates. The Millward-Hopkins et al. model offers an estimate that assumes state-of-the-art technologies based upon a mix of the most highly efficient available today and improvements that may be expected in the coming decades (referred to herein as *MH-low*). It offers another using less advanced, but still efficient, technologies (*MH-high*). The Kikstra et al. model assumes current technological efficiencies, thus is more comparable with the *MH-high* model. But it also provides two scenarios: one with an increased share of public transport and one without (referred to herein as *Kikstra-low* and *Kikstra-high*, with low & high referring to energy use, not the public transport share). The *Kikstra-low* threshold thus forms a better comparison herein, as the LED *transform* scenario assumes high levels of public transport. A more crucial point – one returned to below – is that the efficiency of energy services assumed in the *MH-low* model is most similar to the *Transform* LED model, while the *MH-high* and both *Kikstra* models assume negligible efficiency improvements relative to today.

3. Methods

3.1. Modelling energy inequality and decent living energy shortfalls

The energy demand outputs from Barrett et al. [2] are nationally averaged, but in reality energy use – like income and wealth – varies substantially across populations. In the UK, Owen and Barrett [23] report that the energy footprint of the (income-based) top 5 % is nearly five times that of the lowest consumers. Footprints of the highest consuming subset of this top 5 % will be much higher, but data for the

---

[1] See: www.gov.uk/government/collections/fuel-poverty-statistics.

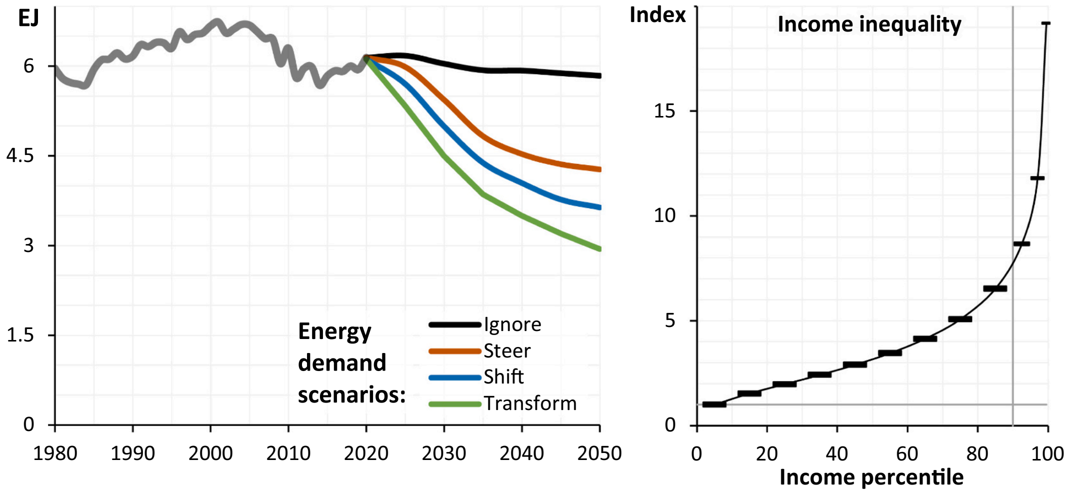

Fig. 1. Historical final energy consumption in the UK and the scenarios of Barrett et al. [2] (left). The parameterisation of current income inequality used in the current work (right), indexed to that of the first decile, and with the data-bar widths scaled to the size of the quantiles considered.

Table 1
Summary of the final energy values proposed by two Decent Living Energy studies, and that estimated in the highest- and lowest-energy scenarios of Barrett et al. [2]. The original names of the Decent Living Energy models are listed, with the names used in the current work in brackets.

Study	Model type	Scenario name	Region	2050 data (cap^{-1} yr^{-1})
Millward-Hopkins et al. (2020)	DLE	DLE (*MH-low*)	UK	15.3 GJ
		LAT (*MH-high*)		26.0 GJ
Kikstra et al. (2021)		MobInc (*Kikstra-low*)	WEU	27.9 GJ
		MobCon (*Kikstra-high*)		29.9 GJ
Barrett et al. (2022)	LED	Ignore	UK	81.7 GJ
		Transform		41.2 GJ

super-rich is extremely poor [24]. Here we aim to estimate how the proportion of people at risk of falling below decent living energy varies with the magnitude of income – and hence energy – inequality, in a low-energy-demand future.

Following previous work on income redistribution and climate mitigation [25], our approach involves first parameterising current income inequality – measured as disposable (post-tax) income – using a lognormal distribution indexed to the lowest income group. We calculate the lognormal distribution for which the income of the top 10 % is ten times that of the bottom 10 % – approximately matching the ratio of the 2016 income data reported in Owen and Barrett [23]. From this lognormal, we extract income for population deciles up to the top 10 %, which we split further into three groups: the 90–95 %, 95–99 %, and top 1 %. The result is the curve shown in Fig. 1, where the indexed income of the top 1 % is now 19.2 and the income Gini coefficient 0.37. This Gini matches the current values reported in the World Inequality Database and officially by the UK government. The advantages of using a lognormal model, rather than the raw income data, is that it allows for this further disaggregation of the highest decile and associated estimate for the top 1 %, and it makes modifying the level of inequality a simple process. Note, however, that checking the accuracy of our model for the top 1 % is not possible given a severe lack of data [24].

Second, we convert this income distribution into an energy distribution using income-energy elasticities (detailed in the following subsection). These describe the percentage increase in energy use for every 1 % increase in income. Here we consider six key sectors from the LED scenario – domestic buildings, non-domestic buildings, materials & products, and mobility split into air travel, surface travel, and freight. After elasticities have been combined with the income inequality curve of Fig. 1 to calculate sectoral energy distributions, the energy distributions are rescaled so that average consumption matches the sectoral values of the LED scenario. Summing across sectors thus gives a total energy use distribution consistent with both current energy inequality and the future (reduced) energy demand of the LED scenario. Finally, from these quantiles, we estimate energy use for each percentile via a simple interpolation (*interp1* in Matlab), which gives an approximately linear slope between each quantile. Note that the ratios of the energy use of low consumers relative to the mean are close to the empirical data of Owen and Barrett [23], confirming the validity of our approach; energy use of the lowest percentile (quintile) in our model is 41 % (54 %) of the mean, while data from Owen and Barrett puts the lowest ventile (quintile) at 45 % (55 %) of the mean. Nonetheless, our focus only upon lognormal energy consumption distributions rules out the possibility of different future distributions [26], which could, for example provide a firmer 'floor' on energy use while demanding more reductions from those are the very top. Note also that the energy use data for materials & products is upscaled to include embodied emissions, thus making the LED scenario comparable with the consumption-based perspective of DLE models. The calculation, political and ethical questions this raises, and results without the adjustment are included in Section 4 of the Supplementary materials.

Third, we calculate the population consuming below decent living energy, using different thresholds from the DLE models. This involves a simple count of how many percentiles are below each threshold. What this implies for living standards is discussed in Section 3.3 below.

Finally, we repeat these steps across a reasonable range of income inequality while ensuring average energy use matches the LED transform scenario. We vary income inequality so the Gini ranges from 0.1 to 0.45, recalculate energy use distributions, and then estimate the population below DLE.

3.2. Modelling technological (in)equality

Our quantitative analysis is reported in two parts, both of which follow the four steps described above to produce a high-level picture of how much of the UK population could fall under decent living energy in a low-energy-demand future.

The first part (Section 4.1) assumes that current relationships between income and energy inequality remain unchanged. Elasticities are thus used that capture current inequalities in both activity-levels and technological access. These are derived from Owen and Barrett [23], as summarised in Table 2 and described in the Supplementary information.

Table 2
Summary of energy & activity-level elasticities. Energy-income elasticities are derived from the data of Owen and Barrett [23], while activity-income elasticities are derived from the data shown in Fig. 3. Values in the energy-income column are used in part 1 of the quantitative analysis, and those in **bold** used in part 2.

Consumption sector	Energy-income elasticity	Comparable activity-level	Activity-income elasticity
Domestic buildings			
Gas & electricity	0.21	Space per person	**1.09**
Non-domestic buildings			
All direct energy	**0.58**	–	–
Mobility			
Air travel	1.01	Flights per person	**1.00**
Non-air travel	0.77	km per person	**0.56**
Car travel	–	km per person	0.57
Rail travel	–	km per person	1.13
Bus travel	–	km per person	−0.43
Freight travel	**0.68**	–	–
Materials & products			
Consumer goods	**0.68**	–	–
Nutrition			
All food	0.56	Meat consumption	~0

For example, the elasticity of domestic energy use is low (0.21; Table 2), because although wealthier households are larger they also tend to be better quality, thus requiring less energy for thermal comfort [12,27]. A similar phenomena is evident for household appliances [28]. In contrast, the elasticity of energy use for surface travel is high (0.77) because wealthier people tend to travel more, via more intensive modes, and using larger cars [29].

For part two (Section 4.2), we adjust the elasticities in order to remove technological inequalities and hence consider *technological equality* – where equally efficient technologies are available to all irrespective of income level. We do this to explore how income inequality may influence access to decent living energy when efficient technologies are available to all. Elasticities are thus adjusted so they describe the relationship between activity-levels and income only (Fig. 3). This is done for domestic and mobility energy only, as for non-domestic buildings, materials & products, and freight, it is not clear how to implement technological equality. Indeed, there may already be a degree of equality: the efficiency of thermal comfort and appliances in budget and high-end supermarkets may be similar; luxury and basic goods may be transported in the same freight vehicles. For domestic energy the elasticity changes dramatically (Table 2), as energy inequality is much smaller than inequality in floor space (Fig. 3, top-left). The top 10 % use only twice as much domestic gas and electricity as the bottom 10 % (in final energy), but house size is nearly 7 times larger and roughly proportional to income. Therefore, if housing were of the same quality across income levels, so energy use per m^2 of floor-space were equal, inequality in domestic energy use may be much higher than today. Note that existing data on housing space inequality is specified as rooms per person [30], and in Fig. 3 this is converted to m^2/person using average dwelling size from the 2020–2021 English Housing Survey.

For air travel the elasticity changes only negligibly, as inequality in energy use is almost identical to the inequality in annual number of flights per person (Fig. 3; bottom-left) [31]. However, neither the models used to estimate energy inequality, nor the survey data recording number of flights, account for different classes of business flights (economy, business, first, etc.). There are thus some uncertainties here, but digging further is beyond our scope.

For surface mobility, the change in elasticity is smaller and in the opposite direction with respect to domestic energy, as inequality in energy use is larger than inequality in activity-levels (Fig. 3; top-right). Energy use of the top 20 % is 4.3 times that of the bottom 20 %, but the former travel only 2.2 times as far. This is due largely to those on higher incomes travelling more by car and in larger cars. However, there is more inequality in rail than car transport, with the top 20 % travelling 5 times more distance by rail than the bottom 20 %, but only 2.3 times more distance by car (Fig. 3; middle- and bottom-right). Bus travel, in contrast, reduces with income, thus leading to the only negative elasticity in Table 2. Consequently, by modifying the elasticity of surface travel to simply describe inequality in total distance travelled, we effectively assume that technologies *and* mode share are the same across the income distribution. Only the total distance travelled increases with income, which we consider an appropriate assumption for the high-level analysis we aim to undertake.

Finally, note that food is listed in Table 2, but due to the negligible contribution of the sector to total energy use (~1 %) it is not included in the quantitative analysis. Food is, however, included in the qualitative analysis of Section 4.3, as it would be a focus of carbon mitigation policy and thus the implications for inequality are important to consider; these elasticities are hence referred to there. The sources and assumptions underlying Fig. 2 are fully described in the Supplementary materials.

3.3. Interpreting decent living energy shortfalls

It's important to understand what we can and can't say about the deprivation of those that fall below decent living energy in our analysis. The inventory of material requirements that form decent living standards, which themselves underpin DLE models, are specified precisely across eight dimensions. These include nutrition, shelter, mobility, healthcare, education, hygiene, clothing, and communication & information [10]. Because we compare total energy consumption at different income levels to DLE thresholds, we can't say anything about shortfalls in each sector. So when we estimate that a certain share of the UK population is below DLE, we can't say specifically that these people's homes are too small, or too cold, or they don't have sufficient mobility. What our results do say is that – given the efficiency of technologies available to them – these people can't access sufficient energy to provision all the things they need for a decent life. This may mean they have sufficiently large homes but lack the energy to heat them; or they have sufficiently warm homes but they're overcrowded; or they're not able to travel sufficiently much to reach necessary services; or some combination of the above along with other shortfalls in decent living.

We abstain from an assessment of decent living shortfalls in specific sectors for a number of reasons. First, any transition to an unequal low-energy-demand future would likely be non-uniform: regressive home-energy policies could increase inequality in home energy use while higher aviation taxes decreased mobility inequalities; highly-efficient technologies may penetrate more widely in some sectors than others. Further, sectoral analysis would ideally use disaggregate estimates of household needs. Decent living standards as currently operationalised in DLE models don't distinguish, say, the mobility needs of childfree urban couples that work largely from home, and rural families who don't. Of course, this also applies to total energy, but sectoral analysis would potentially magnify the issues. Given these many complexities, we adopted our top-down approach focusing upon total energy use in comparison to aggregate decent living energy.

We have also abstained from framing decent living shortfalls as describing energy poverty, for two reasons. First, energy poverty is an amorphous concept with no standardised definition [32] and we did not wish to foster further confusion by conflating it with DLE shortfalls. Second, energy poverty is underpinned by energy access and affordability concerns, whereas DLE shortfalls only reflect the former. Consequently, while there is undoubtedly overlap between the two concepts, the difficulty in meaningfully aligning them made it inappropriate for us to interpret DLE shortfalls in this way.

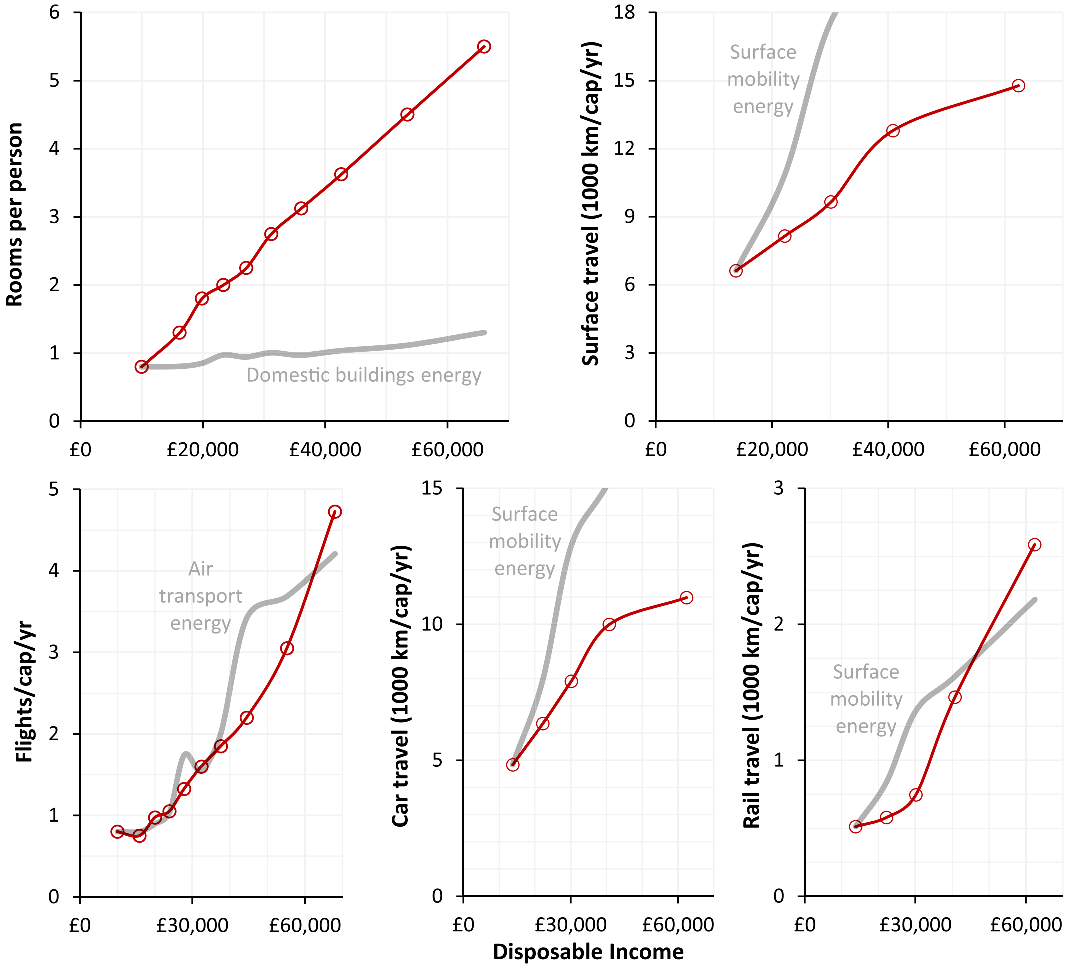

Fig. 2. Activity-levels plotted against disposable (post-tax) income for residential floor space (top-left), total surface mobility (top-right), flights per person per year (bottom-left) and distance travelled by car (bottom-middle) and rail (bottom-right). To visualise whether energy or activity-level inequality is higher, energy consumption per capita for comparable sectors is also shown as grey lines, indexed to the activity-level of the lowest quantile. Specifically, plotted are domestic gas and electricity energy (top-left), energy for all surface transport (top-right, bottom-middle and bottom-right), and energy use for air travel (bottom-left).

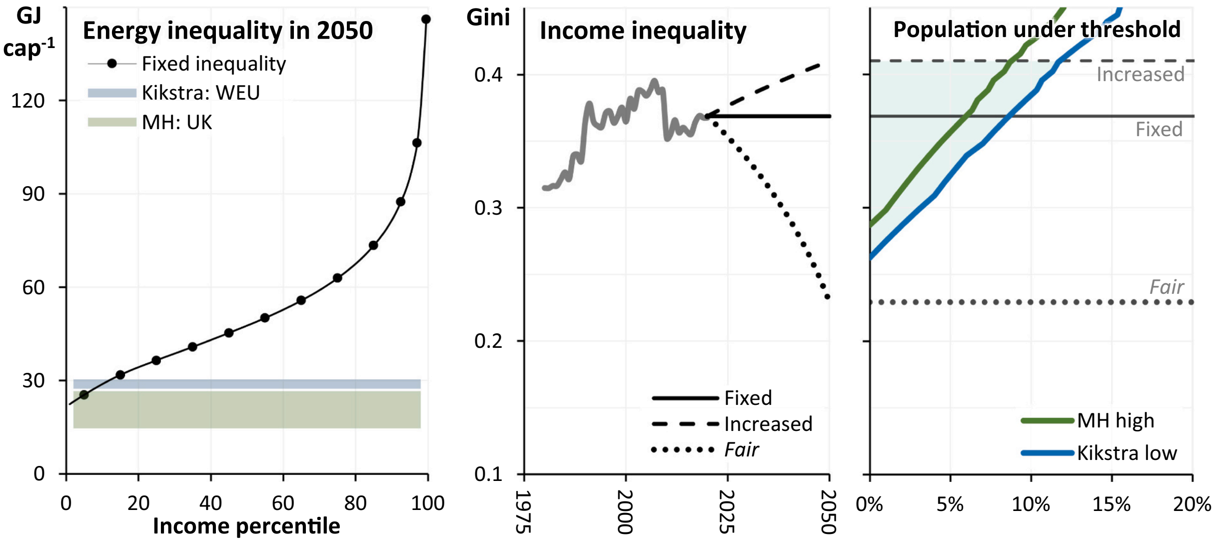

Fig. 3. Energy inequality in 2050 using the *transform* scenario of Barrett et al. [2] with income inequality fixed at its current level, compared to the DLE thresholds of Table 1 (left). UK income inequality historically, assuming an *increased* linear continuation of this trend, and a reduction to *fair* levels (middle). The population using less energy than DLE for different thresholds, as a function of the income Gini coefficient (right) – the green shaded area highlights the population at risk of falling below DLE. Historical Gini data is from the World Inequality Database (https://wid.world/).

4. Results

4.1. Decent living shortfalls under persistent technological inequalities

Combining 2050 energy consumption from the LED transform scenario with current income inequality and elasticities, leads to the energy consumption distribution shown in Fig. 3 (left). The average footprint of the top 1 % is ~150 GJ cap^{-1}, so ~6 times the ~25 GJ cap^{-1} of the bottom 10 % and ~10 times the *MH-low* threshold of 15.3 GJ cap^{-1}. This leaves the bottom 10 % close to the *MH-high* threshold, but below both *Kikstra* thresholds. For broader comparison, the top 20 % in the USA and UK currently consume ~300 and ~150 GJ cap^{-1}, respectively [26,33]. (Note, due to the inefficiency of energy services delivery today, particularly heating in low-income housing, it is not meaningful to compare current energy consumption with the DLE thresholds.)

We then produce the same data with income inequality varied broadly, but consider reasonable upper and lower limits, namely, the *increased* and *fair* levels as shown in Fig. 3 (middle). The former assumes a simple linear extrapolation of the income Gini, which has risen from 0.31 to 0.37 over the past four decades, thus giving a 2050 income Gini of 0.41. The latter assumes the income ratio between the highest and lowest earners matches that people in the UK consider to be ‘fair’ (a ratio of ~6), following previous work [25,34]. Fig. 3 (right) is then obtained, which shows the percentage of the UK population falling under the *MH-high* and *Kikstra-low* thresholds as a function of the income Gini.

From this, we estimate that by 2050, if income inequality continued increasing at the rate it has since 1980, around 9 million people would fall under the *Kikstra-low* threshold and 7 million under the *MH-high* threshold (~12 % and ~9 % of the United Kingdom population, respectively). Reducing income inequality to *fair* levels is more than sufficient to eliminate these DLE shortfalls, highlighting the powerful influence of inequality upon access to decent levels of energy, notwithstanding the uncertainties in the specific numbers above.

In contrast, even under increased income inequality none fall under the *MH-low* threshold, which assumes highly efficient technologies are used to meet decent living standards (thus why it's so low). But by using current income-energy elasticities, the analysis in Fig. 3 assumes technological inequalities remain fixed, with the lowest consumers lacking access to the efficient technologies underpinning the *MH-low* threshold, particularly in sectors like housing. Whether such inequalities persisted would depend upon the particular policies used to achieve a low-energy demand pathway – questions we return to in Section 4.3. In any case, in order for the *MH-low* threshold to be a valid comparison, we must consider energy inequality under technological equality.

4.2. Decent living shortfalls under technological equality

After modifying the relationship between and domestic and mobility energy and income via the elasticities listed in Table 2, a new relationship between income inequality and inequality in total energy use is obtained. These new elasticities are used to reproduce Fig. 3, but with a heuristic estimate of technological equality for domestic buildings and mobility.

Modelled energy use is more unequal after these adjustments – the increased inequality in domestic energy use outweighs the reduced inequality in surface mobility energy, and changes for air travel are negligible (Fig. 4). Consequently, more people are under each DLE threshold (Fig. 5; right). However, as those on lower incomes are now assumed to have access to efficient technologies, the *MH-low* threshold is the most appropriate comparison. Using this, none would be under DLE if income inequality remained at today's levels. But if income inequality increased, a gradually higher number of people would be at risk of falling below DLE, potentially exceeding 2 million if inequality increased at the historical, post-1980 rate.

These results thus highlight the pivotal roles of economic and technological inequalities for achieving universal access to decent living energy. But we reiterate that this is an explicitly high-level analysis, with inherent uncertainties in the quantitative results. There are important questions about how the energy required for decent living varies from the DLE model estimates for individuals and households with differing

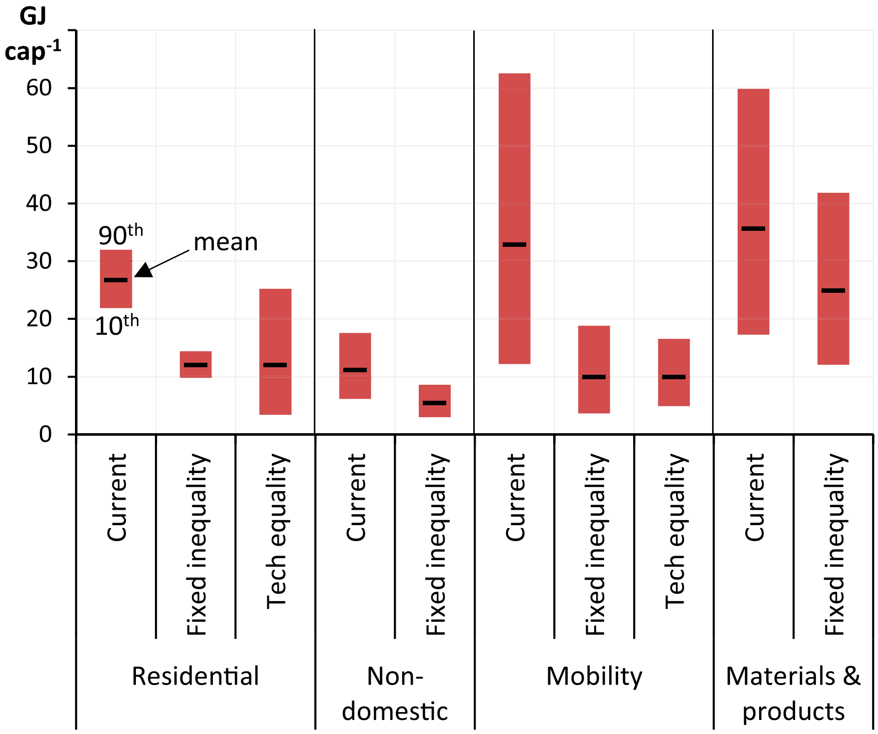

Fig. 4. Energy consumption of the 10th to 90th percentiles, disaggregated across four sectors. *Current* energy consumption refers to the 2020 data from our model; *fixed inequality* is the 2050 LED case with inequalities fixed at present levels (thus corresponding to Fig. 3, left); *tech' equality* is the 2050 LED case with inequalities based upon activity only (thus corresponding to Fig. 5, left). Black bars indicate mean energy consumption for each sector.

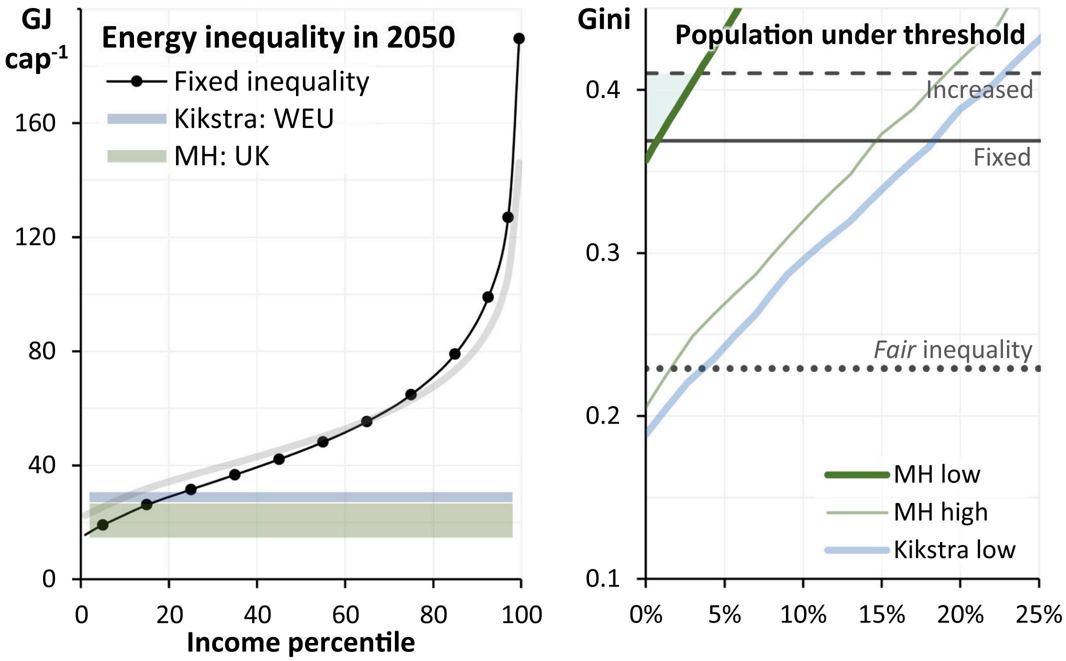

Fig. 5. Energy inequality in 2050 using the *Transform* scenario from Barrett et al. [2] with income inequality fixed at its current level and elasticities adjusted to assess technological equality (left). The light grey line represents energy inequality based upon the unadjusted elasticities (i.e. that from Fig. 3 left). The DLE thresholds are shown for comparison. Right shows the population using less energy than DLE as a function of the income Gini coefficient, plotted for different thresholds – again the green shaded area highlights the population at risk of falling below DLE, based upon the most appropriate threshold.

needs such as disabilities [35,36], and with spatial factors such as access to schools, medical centres, and essential services [37]. We return to these questions in the discussion.

4.3. Policies for low-energy-demand and (in)equality

So far we've shown that a low-energy-demand future in the UK accompanied by current trends in inequality – in income, technological access, and energy use – could leave ~10 % of the population lacking sufficient energy for meeting decent living standards (7–9 million people). A substantial reduction in income inequality to *fair* levels could eliminate this outcome, as could an increase in technological equality accompanied by a flattening of the current rise in income inequality.

We now move from these high-level findings to the details: are the specific demand-side policies being proposed likely to alleviate or exacerbate income and energy inequalities? What policies can be expected to push towards a just, equitable low-energy future? What are the risks of policies having the opposite effect (unintended or otherwise)? A lack of understanding about how an unequal low-energy future may come about was one reason we abstained from making sectoral estimates of decent living shortfalls (Section 3.3). The policy analysis of this section thus paves the way for more disaggregate future work along those lines. We discuss policies across housing, mobility and food. These include the two sectors in which technological equality was modelled in the previous section, and together are arguably the areas most central to well-being and social life.

A number of the low-energy-demand strategies assumed in the UK Transform scenario for domestic buildings are listed in Table 3, alongside associated policies and potential impacts of these on socio-economic inequalities, many taken from Eyre et al. [38]. Some of the policies for lowering energy demand have strong potential to reduce inequalities – and could help achieve the technological equality we modelled above. For example, as household space is currently highly correlated to income, policies encouraging living in smaller homes could be progressive. And as low-income houses are far more likely to be poorly insulated and inefficiently heated and illuminated, grant schemes would have to be targeted at such households to most effectively reduce energy demand – and such schemes can be funded progressively. However, there are also various ways in which policies could prove regressive. For example, incentives for homeworking (or costs avoided by doing so) would mostly be captured by those on higher incomes, as the ability to work from home is strongly correlated with income. And blunt policies designed to increase household occupancy (rather than decrease space per person) could be highly regressive and increase overcrowding, as household occupancy isn't correlated with income and smaller rental properties are, in any case, often not available for those on lower incomes.

Low-energy-demand strategies, policies and impacts for the mobility sector are listed in Table 4. As for domestic energy, available policies for lowering energy demand have the potential to either reduce or exacerbate inequalities. For surface transport, policies such as clean air zones and investment into active travel networks could prove progressive, as lower-income households tend to be subject to more air pollution and obesity. Additionally, investments into active travel and public transport networks could help alleviate car dependency, which is felt most acutely by those on low incomes (despite being more common for higher-income households). In contrast, policies incentivising electric vehicles will continue to be regressive while the upfront costs remain out of reach for low-income households. Further, if transport policy continues to be dominated by support for (cleaner) private vehicles, this may leave public transport neglected, and hence UK rail transport – for one – may continue to be highly costly and unequally distributed while also hampering our ability to reach net-zero targets [47].

Compared to surface travel, policies to reduce air transport energy use are likely to be inherently more progressive, as air travel is highly correlated with income. Frequent flyer taxes and fuel taxes, for example, would both be progressive. However, there are risks even here. Migrants and non-white UK residents fly more than white British residents, often due to family commitments and other social ties. Further, given the lower incomes of many (but not all) UK ethnic minorities, many may currently be *under-consuming* with respect to social needs. This raises difficult questions about what constitutes legitimate reasons for

Table 3
Various low demand strategies for domestic energy use from the Transform scenario of Barrett et al. [2], alongside potential policies for achieving then and the consequent implications for inequalities.

	Strategy	Potential policies	Implications for socio-economic inequalities
Home-use practices	More home-working, video conferencing & 4-day weeks	Employment legislation	↓ A four day working week could potentially address structural inequalities in the labour market (if implemented without a reduction in pay) as working hours can be redistributed among those who experience working-time insecurity [39] ↑ There is a strong correlation between hybrid working and income, aside from some exceptions like paramedics and firefighters[a], so any incentives for (or costs saved from) homeworking will be captured largely by those on higher incomes
	Smaller homes & increased occupancy	Occupancy taxes; Incentives for housing lodgers/ exchange students; Rental relocation schemes for homeowners; Mandate the building of smaller new homes	↓ Housing *space* inequality is currently considerable [30], so policies aimed at increasing occupancy of large, low-to-medium occupancy homes could decrease this ↑ The number of people per household isn't correlated with income[b], so blunt policies aimed at increasing occupancy could further increase overcrowding in low-income homes [40] ↑ When smaller homes are unavailable, occupancy taxes can create additional burdens for lower-income households [41] ↑ Rental relocation policies for owners of large homes may bolster inequalities in inherited wealth
Technologies	Installation of heat-pumps; Phasing out gas boilers; Fabric improvements; Onsite renewables	Funding via energy taxes or revolving funds; Building regulations; Product standards	↓ Low-income groups should benefit the most from deployment of energy-efficient technologies, as they are far more likely to be in poor quality housing while also currently lacking the capacity to change this [27,42] ↑ Consumption-based home energy taxes are regressive, as lower income households spend a far higher proportion of their incomes on home energy bills [23] ↑ Funding schemes that do not address split-incentives between landlords & renters could further entrench technological inequalities
	Efficient lighting & appliances	Product standards & labelling; Taxes on low-efficiency goods and vice versa; Energy company obligations	↓ Revolving funds and tax-funded grants schemes can be designed such that funding is targeted at low-income households [43] ↑ Funding schemes can be regressive if funded via energy companies such that costs are simply passed onto consumers ↑ Similarly, taxes on inefficient appliances may be burdensome for low-income households that lack the financial means to replace them ↑ Rebate schemes still require households to have access to significant upfront capital
	Smart-meters & controls and demand response	Installation obligations on energy suppliers; Marketing and educational campaigns	↓ Smart controls may allow low-income households, including those on prepayment meters, to better manage payments and credit[c] ↑ There may be barriers to many low-income households engaging with smart controls [44] and they may be among the latest adopters when adoption is not mandatory [45] ↑ Vulnerable households with less flexible energy use patterns (e.g. home medical equipment) may not be able to benefit from flexible tariffs [46]

[a] See the ONS, *Which Jobs can be done from Home?* www.ons.gov.uk/employmentandlabourmarket/peopleinwork/.

[b] See the English Housing Survey, www.gov.uk/government/collections/english-housing-survey.

[c] www.gov.uk/guidance/smart-meters-how-they-work.

undertaking activities as high-impact as flying. So, while a frequent flyer levy may reduce the frequency at which people fly in a highly progressive way, migrants may be negatively affected – in the absence of administratively-difficult mitigating policies [59]. But to make things yet more complicated, taking this stance positions the social needs of UK citizens (say, the need for a UK Bangladeshi to maintain family relations)

Table 4
Various low demand strategies for mobility energy use from the Transform scenario of Barrett et al. [2], alongside potential policies for achieving then and the consequent implications for inequalities.

	Strategy	Potential policies	Implications for socio-economic inequalities
Surface transport	Lower car ownership & mileage; More car sharing	Vehicle, fuel & road use taxation; Car-free & low traffic zones; Employment legislation; Infrastructure investment & disinvestment	↓ Low income urban households are currently subject to more air pollution, so should benefit most from clean air zones [48] ↓ Car dependency and *in*efficiency are positively correlated with income in the UK [29], so policies aimed at reducing car ownership and use may, on balance, be inherently progressive
	Full switch to electric vehicles	Fuel & differential vehicle taxation; Product standards	↑ Electric vehicles have been purchased almost exclusively by high-income households, which is difficult to tackle given, e.g., the large gap between the cheap, old vehicles low-income households typically buy and their lack of access to off-street parking for home charging points [49] ↑ A dominant focus on electric vehicles may bolster car-dependent infrastructures, thus locking low-income households into expensive mobility patterns
	Expansion & integration of active travel and public transport	Infrastructure investment; City planning	↓ Obesity is more prevalent among low-income groups[a], so active travel policies may be able to narrow these health inequalities, provided they target low income areas & populations ↓ A focus on public and active travel may reduce car-dependency, thus reducing mobility costs for low-income households
Aviation transport	Reduction in total demand	Carbon/fuel taxes; Frequent flyer levies; Elimination of subsidies	↓ Air travel is strongly correlated with income, so demand-reduction policies should be inherently progressive [31] ↑ Migrants and non-whites travel more than white British nationals [50], and given the generally lower incomes of these groups they may still be under-consuming, thus demand-reductions policies could regressively impact migrants' with respect to *social* needs

[a] See NHS Digital, *Health Survey for England 2019*, https://digital.nhs.uk/data-and-information/publications.

against those of others (the need for Bangladeshi citizens to not be displaced by rising sea levels). It is beyond our scope to answer these (potentially unanswerable) questions.

While food is a minor contributor to UK energy use, agriculture makes up a significant portion of UK emissions. Given that low-energy-demand strategies are primarily motivated by carbon mitigation goals, the implications for inequality of demand-side strategies in the food sector are well within our scope. Therefore, policies for reducing demand in the food sector and their impacts are listed in Table 5. In contrast to housing and mobility, demand-side strategies in the food sector appear to have less risk of regressive impacts. This is largely because obesity is more prevalent among low-income groups, and hence policies disincentivising consumption of low-quality, unhealthy animal products and overconsumption of calories more broadly could benefit these groups the most. Of course, this is only true if healthier substitutes are available at no greater cost. However, the costs of meat substitutes are now competitive with meat (see Supplementary information). Plant-based alternatives can also be healthier [60] and the costs are forecast to continue to fall [61]. Nonetheless, policies need to be designed so as not to push those on low incomes towards refined carbohydrates, processed sugary foods, and the cheapest, lowest quality meats. Also of importance here is that, unlike other high-impact forms of consumption such as flying, meat consumption – the highest impact food category – doesn't increase with income [62]. This means that in order to meaningfully reduce meat consumption strategies must be aimed at the full income distribution.

5. Discussion and conclusions

We can now offer tentative answers to the questions we proposed in the introduction. First, if the UK succeeded in following a low-energy, net-zero pathway – but without addressing income and energy inequality, such that they continued to increase at the current rate – then 9 million people could lack sufficient energy for meeting decent living standards in 2050. Attempting to avoid this outcome by decoupling energy inequality from income inequality is made difficult by the fact that technological equality – making efficient technologies available at all income levels – would lead to higher coupling of domestic energy use to income inequality, which would offset reductions in energy inequality in other sectors. However, provided income inequality did not rise above current levels, technological equality could drastically reduce the energy required for providing decent living standards, thus allowing these standards to be available to all (despite the large energy inequalities that would remain). Without such technological equality, income inequality would have to decrease considerably for the lowest energy consumers to remain above decent living energy.

Finally, moving beyond this high-level analysis of energy inequality to specific strategies for lowering energy use and carbon emissions, we find that many prospective policies have large potential to reduce socio-economic inequalities and could help to achieve precisely the technological equality explored in our high-level analysis. However, as others have argued [63,64], mitigation policies could also prove regressive in numerous ways, if, for example, they were designed such that they primarily cater to the interests of landlords and private car owners; required upfront costs only available to the middle- and upper-classes; or did not take into account the specific social and material circumstances of vulnerable households or migrants. By worsening energy poverty across Europe, the recent aggressive spike in energy prices has exposed how poorly-designed climate policies can exacerbate existing inequalities if financial burdens are unfairly distributed [65].

An equitable, socially-just, low-energy-demand policy pathway would thus need to be: responsive and dynamic – by continually reflecting upon and mitigating the distributional impacts of policies; bold and targeted – by directing large investments towards necessary infrastructures and technologies and the people most in need, rather than merely ushering in a preferred direction those existing markets that only serve households with sufficient financial resources; connected in implementation – e.g. by joining up obesity and agricultural policies; and connected in assessment – e.g. by accounting for the (lowered) risk to geopolitical shocks, such as the energy crisis spurred by the Russian invasion of Ukraine, when funding retrofits of low-quality housing or investing in active travel networks.

Reflecting upon both parts of our work, we can suggest a future research agenda for distributional analysis of low-energy-demand, net-zero futures. First, in our quantitative analysis, we assessed deprivation using thresholds that represented *decent living energy*, and applied these thresholds across the UK population. However, in practice, decent living energy will vary spatially – depending upon, for example, the accessibility of essential services – as well as being influenced by factors such as poor health or disability or the number of dependents in a household.

Table 5
Various low demand strategies for food energy use from the Transform scenario of Barrett et al. [2], alongside potential policies for achieving then and the consequent implications for inequalities.

Strategy	Potential policies	Implications for socio-economic inequalities
Dietary change	Taxes on high-impact foods and removal of subsidies (largely meat & diary); Subsidies and R&D for further developing meat substitutes; Mandatory environmental labelling; Procurement standards for food in public institutions	↓ Health benefits of price-policies tend to be largest for low-income groups, who respond strongly to price changes, provided healthy substitutes are available [51] ↓ Costs of meat substitutes are already competitive with meat, and as prices of the latter rise and the former continue to fall, healthy and sustainable protein sources will become more easily available to lower income households. Moreover, while healthy foods are more expensive [52], following dietary recommendations for meat reduces dietary costs [53] ↑ Price policies can lead to regressive taxation, although this can be mitigated by directing the (substantial) revenues towards the needs of low-income groups [53] ↑ Meat-taxes may push poorer people towards more unhealthy diets: refined carbohydrates, processed sugary foods, and the cheapest and lowest quality meats [54]
Reduced calorie intake	Taxes on unhealthy foods; Subsidies for healthy, low-impact foods; Planning regulation for siting of fast food outlets	↓ Obesity is more prevalent among low-income groups[a] and inequality is projected to widen [55]. In addition, causality goes both ways [56], so policies aiming to reduce food overconsumption may be able to narrow both health and income inequalities ↑ 'High-agency', population-wide interventions may increase inequalities as higher income groups have more cognitive, psychological, time, and material resources, thus enabling more engagement [57], and such policies have dominated obesity policy in the UK [58]

[a] See NHS Digital, *Health Survey for England 2019*, https://digital.nhs.uk/data-and-information/publications.

For high-level analysis like ours, these differences can reasonably be assumed to average out at the national-scale. But issues of spatial justice [37] and vulnerability [27] highlight the inability of our results to pinpoint the particular demographics at risk of deprivation, and should be central to future distributional work. Second, in our policy review, we summarised the range of distributional outcomes that may accompany different low-energy-demand policies. This could be used to inform a quantitative assessment of how transitions to a low-energy-demand scenario in the UK may look, in terms of inequalities in activity levels and technological access in different sectors. Future distributional work could therefore aim to:

(1) Estimate how decent living standards vary across subnational demographics;
(2) estimate how activity-level and technological inequalities within different sectors may evolve under specific packages of low-energy-demand policies (ranging from regressive to progressive), taking into account different trajectories of income inequality;
(3) assess deprivation by comparing these activity-level distributions directly with decent living standards, with sectoral and demographic disaggregation;
(4) quantify energy inequalities from the bottom-up, by combining activity-level distributions with the inequalities in technological access.

There remain, however, open questions relating to the notion of decent living standards themselves. These standards are grounded in philosophical theory from basic human needs and capabilities to ethics and justice; as well as in human rights and international law [21]. They were forwarded as an alternative or complementary measure to assess serious deprivation, alongside indicators such as the *Human Development Index* [21]. The notion of decent living energy should thus be understood in the context of development and living standards *globally*. Therefore, in many respects, the material basis underpinning DLE represents a reduction in consumption relative to the consumer-culture that most are used to in wealthy Global North countries such as the UK. In practical terms, living at the level of DLE would mean living in much warmer, dryer, and healthier homes than the majority of lower-income UK residents currently do, but with much less fast fashion and cheap meat (among other things). Such reductions in conspicuous consumption and every-day luxuries would likely arise what psychologists refer to loss aversion [66], meaning 'decent' living standards may not be received as such, irrespective of their broader benefits. This raises familiar questions regarding the political and social feasibility of such changes to patterns of consumption. That said, even in the cases where we estimated some would fall under DLE, most are well above it. For example, with income inequality fixed at current levels alongside technological equality – i.e. the curve of Fig. 5 (left) – 3 % of the UK population are below DLE, but 50 % of the population are consuming three times the DLE level.

We finish by highlighting the other half of the economic equation, namely, that of work. The analysis above has focused upon consumption – the material and energy basis of decent living standards. This begs the question: what is required of a person to secure access to decent living energy? One can imagine a future where those on the lowest incomes are only able to secure what we've referred to as decent living standards by balancing multiple precarious jobs and with no hope of ever being able to afford a house, while others were able to consume many times that level through passive incomes such as renting second homes. Our high-level analysis would conclude here that decent living standards were being met. However, in such a context, the word decent feels highly misplaced.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The contributions of both authors were supported by the Centre for Research into Energy Demand Solutions, award EP/R035288/1.

References

[1] A. Grubler, C. Wilson, N. Bento, B. Boza-Kiss, V. Krey, D.L. McCollum, N.D. Rao, K. Riahi, J. Rogelj, S. De Stercke, J. Cullen, S. Frank, O. Fricko, F. Guo, M. Gidden, P. Havlík, D. Huppmann, G. Kiesewetter, P. Rafaj, W. Schoepp, H. Valin, A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies, Nat. Energy 3 (6) (2018) 515–527.

[2] J. Barrett, S. Pye, S. Betts-Davies, O. Broad, J. Price, N. Eyre, J. Anable, C. Brand, G. Bennett, R. Carr-Whitworth, A. Garvey, J. Giesekam, G. Marsden, J. Norman, T. Oreszczyn, P. Ruyssevelt, K. Scott, Energy demand reduction options for meeting national zero emission targets, Nat. Energy 7 (2022) 726–735.

[3] IPCC, Climate change 2022: mitigation of climate change. contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change, in: J.S.P.R. Shukla, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley (Eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022.

[4] P. Smith, S.J. Davis, F. Creutzig, S. Fuss, J. Minx, B. Gabrielle, E. Kato, R. B. Jackson, A. Cowie, E. Kriegler, D.P. van Vuuren, J. Rogelj, P. Ciais, J. Milne, J. G. Canadell, D. McCollum, G. Peters, R. Andrew, V. Krey, G. Shrestha, P. Friedlingstein, T. Gasser, A. Grübler, W.K. Heidug, M. Jonas, C.D. Jones, F. Kraxner, E. Littleton, J. Lowe, J.R. Moreira, N. Nakicenovic, M. Obersteiner, A. Patwardhan, M. Rogner, E. Rubin, A. Sharifi, A. Torvanger, Y. Yamagata, J. Edmonds, C. Yongsung, Biophysical and economic limits to negative CO2 emissions, Nat. Clim. Chang. 6 (1) (2016) 42–50.

[5] S. Fuss, J.G. Canadell, G.P. Peters, M. Tavoni, R.M. Andrew, P. Ciais, R.B. Jackson, C.D. Jones, F. Kraxner, N. Nakicenovic, C. Le Quéré, M.R. Raupach, A. Sharifi, P. Smith, Y. Yamagata, Betting on negative emissions, Nat. Clim. Chang. 4 (10) (2014) 850–853.

[6] F. Creutzig, L. Niamir, X. Bai, M. Callaghan, J. Cullen, J. Díaz-José, M. Figueroa, A. Grubler, W.F. Lamb, A. Leip, E. Masanet, É. Mata, L. Mattauch, J.C. Minx, S. Mirasgedis, Y. Mulugetta, S.B. Nugroho, M. Pathak, P. Perkins, J. Roy, S. de la Rue, Y. du Can, S. Saheb, L. Some, J. Steg, D.Ürge-Vorsatz Steinberger, Demand-side solutions to climate change mitigation consistent with high levels of well-being, Nat. Clim. Chang. 12 (1) (2022) 36–46.

[7] J. Hickel, P. Brockway, G. Kallis, L. Keyßer, M. Lenzen, A. Slameršak, J. Steinberger, D. Ürge-Vorsatz, Urgent need for post-growth climate mitigation scenarios, Nat. Energy 6 (2021) 766–768.

[8] L.T. Keyßer, M. Lenzen, 1.5 °C degrowth scenarios suggest the need for new mitigation pathways, Nat. Commun. 12 (1) (2021) 2676.

[9] T. Wiedmann, M. Lenzen, L.T. Keyßer, J.K. Steinberger, Scientists' warning on affluence, Nat. Commun. 11 (1) (2020) 3107.

[10] J. Millward-Hopkins, J.K. Steinberger, N.D. Rao, Y. Oswald, Providing decent living with minimum energy: a global scenario, Glob. Environ. Chang. 65 (2020), 102168.

[11] J. Millward-Hopkins, Inequality can double the energy required to secure universal decent living, Nat. Commun. 13 (1) (2022) 5028.

[12] L. Middlemiss, A critical analysis of the new politics of fuel poverty in England, Crit. Soc. Policy 37 (3) (2016) 425–443.

[13] R. Galvin, Letting the Gini out of the fuel poverty bottle? Correlating cold homes and income inequality in European Union countries, Energy Res. Soc. Sci. 58 (2019), 101255.

[14] R. Bardazzi, L. Bortolotti, M.G. Pazienza, To eat and not to heat? Energy poverty and income inequality in Italian regions, Energy Res. Soc. Sci. 73 (2021), 101946.

[15] I. Jaccard, P.-P. Pichler, J. Toebben, H. Weisz, The energy and carbon inequality corridor for a 1.5°C compatible and just Europe, Environ. Res. Lett. 16 (2021), 064082.

[16] N.Rubiano Rivadeneira, W. Carton, (In)justice in modelled climate futures: a review of integrated assessment modelling critiques through a justice lens, Energy Res. Soc. Sci. 92 (2022), 102781.

[17] R. Loulou, A. Lehtilä, A. Kanudia, U. Remme, G. Goldstein, Energy Technology Systems Analysis Programme, International Energy Agency, Paris, France, 2016.

[18] L.I. Brand-Correa, J.K. Steinberger, A framework for decoupling human need satisfaction from energy use, Ecol. Econ. 141 (2017) 43–52.

[19] I. Gough, Climate change and sustainable welfare: the centrality of human needs, Camb. J. Econ. 39 (5) (2015) 1191–1214.

[20] N.D. Rao, P. Baer, "Decent living" emissions: a conceptual framework, Sustainability 4 (4) (2012) 656–681.

[21] N.D. Rao, J. Min, Decent living standards: material prerequisites for human wellbeing, Soc. Indic. Res. 138 (1) (2018) 225–244.

[22] J.S. Kikstra, A. Mastrucci, J. Min, K. Riahi, N.D. Rao, Decent living gaps and energy needs around the world, Environ. Res. Lett. 16 (2021), 095006.

[23] A. Owen, J. Barrett, Reducing inequality resulting from UK low-carbon policy, Clim. Pol. 20 (10) (2020) 1193–1208.

[24] I.M. Otto, K.M. Kim, N. Dubrovsky, W. Lucht, Shift the focus from the super-poor to the super-rich, Nat. Clim. Chang. 9 (2) (2019) 82–84.

[25] J. Millward-Hopkins, Y. Oswald, 'Fair' inequality, consumption and climate mitigation, Environ. Res. Lett. 16 (2021), 034007.

[26] Y. Oswald, J. Steinberger, D. Ivanova, J. Millward-Hopkins, Global redistribution of income and household energy footprints: a computational thought experiment, Glob. Sustain. 4 (2021) 1–24.

[27] N. Simcock, K.E.H. Jenkins, M. Lacey-Barnacle, M. Martiskainen, G. Mattioli, D. Hopkins, Identifying double energy vulnerability: a systematic and narrative review of groups at-risk of energy and transport poverty in the global north, Energy Res. Soc. Sci. 82 (2021), 102351.

[28] BRE, Report 9: Domestic Appliances, Cooking & Cooling Equipment, BRE & the Department of Energy and Climate Change, 2013.

[29] G. Mattioli, I. Philips, J. Anable, T. Chatterton, Vulnerability to motor fuel price increases: socio-spatial patterns in England, J. Transp. Geogr. 78 (2019) 98–114.

[30] B. Tunstall, Relative housing space inequality in England and Wales, and its recent rapid resurgence, Int. J. Hous. Policy 15 (2) (2015) 105–126.

[31] M. Büchs, G. Mattioli, Trends in air travel inequality in the UK: from the few to the many? Travel Behav. Soc. 25 (2021) 92–101.

[32] K. Mahoney, J.P. Gouveia, P. Palma, (Dis)United Kingdom? Potential for a common approach to energy poverty assessment, Energy Res. Soc. Sci. 70 (2020), 101671.

[33] Y. Oswald, A. Owen, J. Steinberger, Large inequality in international and intranational energy footprints between income groups and across consumption categories, Nat. Energy 5 (2020) 231–239.

[34] S. Kiatpongsan, M.I. Norton, How much (more) should CEOs make? A universal desire for more equal pay, Perspect. Psychol. Sci. 9 (6) (2014) 587–593.

[35] D. Ivanova, L. Middlemiss, Characterizing the energy use of disabled people in the European Union towards inclusion in the energy transition, Nat. Energy 6 (12) (2021) 1188–1197.

[36] C. Snell, M. Bevan, H. Thomson, Justice, fuel poverty and disabled people in England, Energy Res. Soc. Sci. 10 (2015) 123–132.

[37] S. Bouzarovski, N. Simcock, Spatializing energy justice, Energy Policy 107 (2017) 640–648.

[38] N. Eyre, Y. Bobrova, J. Rosenow, J. Barrett, C. Nolden, New times, new policies? Policies to change energy use in the context of zero carbon, in: European Council for an Energy Efficient Economy proceedings, 2022.

[39] H. Chung, A social policy case for a four-day week, J. Soc. Policy 51 (3) (2022) 551–566.

[40] A. Kearns, Housing space and occupancy standards: developing evidence for policy from a health and wellbeing perspective in the UK context, Build. Res. Inf. (2022) 1–16.

[41] G.M. Huebner, D. Shipworth, All about size? – The potential of downsizing in reducing energy demand, Appl. Energy 186 (2017) 226–233.

[42] L. Middlemiss, R. Gillard, Fuel poverty from the bottom-up: characterising household energy vulnerability through the lived experience of the fuel poor, Energy Res. Soc. Sci. 6 (2015) 146–154.

[43] S. de la Rue, G. du Can, A. Leventis, A.Gopal Phadke, Design of incentive programs for accelerating penetration of energy-efficient appliances, Energy Policy 72 (2014) 56–66.

[44] B.K. Sovacool, P. Kivimaa, S. Hielscher, K. Jenkins, Vulnerability and resistance in the United Kingdom's smart meter transition, Energy Policy 109 (2017) 767–781.

[45] C. Wilson, T. Hargreaves, R. Hauxwell-Baldwin, Benefits and risks of smart home technologies, Energy Policy 103 (2017) 72–83.

[46] P. Calver, N. Simcock, Demand response and energy justice: a critical overview of ethical risks and opportunities within digital, decentralised, and decarbonised futures, Energy Policy 151 (2021), 112198.

[47] C. Brand, J. Anable, I. Ketsopoulou, J. Watson, Road to zero or road to nowhere? Disrupting transport and energy in a zero carbon world, Energy Policy 139 (2020), 111334.

[48] D. Fecht, P. Fischer, L. Fortunato, G. Hoek, K. de Hoogh, M. Marra, H. Kruize, D. Vienneau, R. Beelen, A. Hansell, Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherlands, Environ. Pollut. 198 (2015) 201–210.

[49] C. Mullen, Fairness in transitions to low-carbon mobility, One Earth 4 (2) (2021) 168–171.

[50] G. Mattioli, J. Scheiner, The impact of migration background, ethnicity and social network dispersion on air and car travel in the UK, Travel Behav. Soc. 27 (2022) 65–78.

[51] F. Sassi, A. Belloni, A.J. Mirelman, M. Suhrcke, A. Thomas, N. Salti, S. Vellakkal, C. Visaruthvong, B.M. Popkin, R. Nugent, Equity impacts of price policies to promote healthy behaviours, Lancet 391 (10134) (2018) 2059–2070.

[52] N.R.V. Jones, A.I. Conklin, M. Suhrcke, P. Monsivais, The growing price gap between more and less healthy foods: analysis of a novel longitudinal UK dataset, PLOS ONE 9 (10) (2014), e109343.

[53] N.R.V. Jones, T.Y.N. Tong, P. Monsivais, Meeting UK dietary recommendations is associated with higher estimated consumer food costs: an analysis using the National Diet and Nutrition Survey and consumer expenditure data, 2008–2012, Public Health Nutr. 21 (5) (2018) 948–956.

[54] T. Garnett, Plating up solutions, Science 353 (6305) (2016) 1202–1204.

[55] L. Keaver, C. Pérez-Ferrer, A. Jaccard, L. Webber, Future trends in social inequalities in obesity in England, Wales and Scotland, J. Public Health 42 (1) (2019) e51–e57.

[56] T.J. Kim, O. von dem Knesebeck, Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis, BMJ Open 8 (1) (2018), e019862.

[57] J. Adams, O. Mytton, M. White, P. Monsivais, Why are some population interventions for diet and obesity more equitable and effective than others? The role of individual agency, PLoS Med. 13 (4) (2016), e1001990.

[58] D. Theis, M. White, Is Obesity policy in england fit for purpose? Analysis of government strategies and policies, 1992–2020, Milbank Q. 99 (1) (2021) 126–170.

[59] M. Büchs, G. Mattioli, How socially just are taxes on air travel and 'frequent flyer levies'? J. Sustain. Tour. (2022) 1–23.

[60] F. Hashempour-Baltork, K. Khosravi-Darani, H. Hosseini, P. Farshi, S.F.S. Reihani, Mycoproteins as safe meat substitutes, J. Clean. Prod. 253 (2020), 119958.

[61] H. Ritchie, D.S. Reay, P. Higgins, Potential of meat substitutes for climate change mitigation and improved human health in high-income markets, Front. Sustain. Food Syst. 2 (2018).

[62] C. Stewart, C. Piernas, B. Cook, S.A. Jebb, Trends in UK meat consumption: analysis of data from years 1–11 (2008–09 to 2018–19) of the National Diet and Nutrition Survey rolling programme, Lancet Planet. Health 5 (10) (2021) e699–e708.

[63] B.K. Sovacool, P. Newell, S. Carley, J. Fanzo, Equity, technological innovation and sustainable behaviour in a low-carbon future, Nat. Hum. Behav. 6 (2022) 326–337.

[64] B.K. Sovacool, B. Turnheim, A. Hook, A. Brock, M. Martiskainen, Dispossessed by decarbonisation: reducing vulnerability, injustice, and inequality in the lived experience of low-carbon pathways, World Dev. 137 (2021), 105116.

[65] F. Belaïd, Implications of poorly designed climate policy on energy poverty: global reflections on the current surge in energy prices, Energy Res. Soc. Sci. 92 (2022), 102790.

[66] D. Kahneman, Thinking, Fast and Slow, Macmillan, 2011.