

Exploring Energy Deprivation Across Small Areas in England and Wales

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Abstract

Building on a growing field of research on vulnerability to energy poverty, this study focused on addressing the rising energy crisis by examining the issue of energy deprivation in local areas of England and Wales. We developed a classification for energy deprivation using a clustering method to group multiple indicators across various domains. By doing this, we identify spatial disparities of energy deprivation for people living in different neighbourhoods, aiming to provide valuable insights for governments, charities and stakeholders and inform policy making and intervention.

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1 Introduction

The energy market experienced strain in 2021 driven in part by the rapid economic recovery following the COVID-19 pandemic. However, the situation escalated into a global energy crisis, particularly affecting Europe, when the Russian Federation militarily intervened in Ukraine in February 2022 [6]. The crisis has led to a significant increase in living costs, in particular energy costs, resulting in an estimated 6.7 million UK households experiencing energy poverty by November 2022 [8].

Energy poverty or deprivation, as defined by Bouzarovski [1], refers to the lack of access to affordable, reliable, and environmentally friendly energy services, such as heating and lighting, that are adequate in quality and safety [5, 11]. Energy deprivation negatively impacts on health, well-being, social relationships, education, and economic development [1, 7] and poses challenges to the UK government's goal of achieving net-zero greenhouse gas emissions by 2050 [3].

In response to the energy crisis and energy poverty, it is crucial to understand the spatial distribution and characteristics of energy deprivation to inform policy and practice, as well as gaining insights into broader socio-economic and political factors contributing to the

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problem. This study aims to develop a nationwide classification of energy deprivation at small area scale to improve understanding and support evidence-based decision-making by policymakers.

2 Data and Methods

■ **Table 1** Selected variables and their descriptions.

Code	Variable name	Description
V01	Efficient energy	Energy efficiency bands are rated from A (most efficient) to G (least efficient)
V02	Inefficient energy	Efficient energy refers to properties rated as band A and B
V03	Fossil fuels dependency	Inefficient energy includes properties rated as band E, F and G
V04	High CO2 emissions	Fuel type of the property belongs to one of the fossil fuels
V05	Old property	Carbon dioxide emission per square meter of the property is higher than the average
V06	New property	Properties built before 1930
V07	No central heating	Properties built after 2012
V08	Not connected to gas grid	Households with no access to central heating
V09	Prepayment electricity meters	Domestic properties not connected to the mains gas grid
V10	Renewable energy	Households with prepayment electricity meters
V11	Electricity energy	Households with renewable energy access only
V12	Age 0 to 4	Households with electricity access only
V13	Age 75 years and over	Households with young children aged four and below
V14	Lone parent with dependent children	Households with older adults aged 75 years and over
V15	Large household size	A dependent child is any person aged 0 to 15 in a household or aged 16 to 18 in full-time education and living a family with their parent or grandparent
V16	Under occupancy	More than five people living in a household
V17	Retired	Households with at least one bedroom more than required
V18	Long-term sick and disabled	Economically inactive population that aged 16 years and over who did not have a job between 15 March to 21 March 2021 and had not looked for work between 22 February to 21 March 2021 or could not start work within two weeks.
V19	Looking after home or family	Property is not attached to another property but can be attached to a garage
V20	Detached house or bungalow	Property is joined to another property by a common wall that they share
V21	Semi-detached house or bungalow	Property located between two other properties and shares two common walls or is part of a terraced development but only shares one common wall.
V22	Terraced	Property in a purpose-built block of flats or tenement
V23	Flat	Property part of a converted or shared house, including bedsits
V24	Shared houses	Household owns all of the accommodation
V25	Owens outright	Household owns with a mortgage or loan, or part-owned on a shared ownership
V26	Owens with mortgage or shared ownership	Property rented through a local council or housing association
V27	Socially rented	Property rented through a private landlord or letting agent
V28	Privately rented	Percentage of household net income spent on the electricity and gas bills
V29	More income on energy cost	Persons aged 16 years and over who do elementary job as their main occupation
V30	Elementary occupation	Persons that look after, give help or support to anyone who has long-term physical or mental ill-health conditions, illness or problems related to old age
V31	Unpaid care with more than 20 hours	Persons that have not worked in the last 12 months and never worked
V32	Unemployment	Persons who worked 30 hours or less (including paid and unpaid overtime) a week before the Census
V33	Part-time employment	Economically inactive full-time students
V34	Full-time students	Persons who are not English, Welsh, Scottish, Northern Irish, or British
V35	Ethnic minority	Persons who are not English, Welsh, Scottish, Northern Irish, or British
V36	Universal credit	A single payment for each household to help with living costs for those on a low income or out of work

Data are collected from multiple data sources in England and Wales, including Department for Levelling Up, Housing and Communities (DLUHC), Department for Business, Energy and Industrial Strategy (BEIS), Department for Work and Pensions (DWP), and the 2021 UK Census that are available at the property, postcode, and the Lower Layer Super Output Areas (LSOAs) levels, respectively. LSOAs were created as a geographical structure to enhance the collection and presentation of detailed statistical data for small areas in England and Wales. To ensure effective and timely representation, all data are accessed from the most recent years since 2018. 2021 Census LSOA geography in England and Wales are used as the unified spatial granularity to link with data at diverse geographical scales.

We follow a typically geodemographic classification method framework to build an energy deprivation classification. First, a list of variables is selected based on the large amounts of review of energy vulnerability and poverty [1, 7, 9, 10, 12, 13]. 36 variables are selected to reflect the energy deprivation and can be summarised into five domains: energy efficiency, energy access, energy demand and service, housing and financial vulnerability. Figure 1 depicts the chosen variables and their descriptions. All variables are measured using percentages to reduce the potential data bias of various estimation size available at individuals, households, or properties.

Prior to clustering, transformation and standardisation are conducted to enable equal variable contribution and more interpretable results. Additionally, correlation analysis is implemented to avoid certain types of variables with a high degree of association skewing

the cluster result. We exclude variables that exhibit correlation coefficient values larger than 0.8 (either positively or negatively) with more than one other variables. Five variables, specifically high carbon dioxide emissions, prepayment electricity meter, under occupancy, retired, and universal credit, are identified and excluded. Lastly, a widely used k-means clustering method [2, 4, 14] is conducted to group all LSOAs in England and Wales. To determine the optimal number of clusters (k), a Clustergram is utilised to help identify the point of diminishing returns, where increasing the number of clusters does not significantly improve the clustering quality. K=6 finally generates robust results after multiple iterations.

3 Results and Discussions

Figure 1 displays the spatial disparities of six groups of energy deprivation at LSOAs in England and Wales, representing Energy Efficient Suburbs, Energy Periphery, Energy Density, Energy Inefficiency, Energy Constraints, and Energy Precarity (Group A to F). For better interpretation, we calculate index scores of each variable and create Figure 2 to help us explain the energy deprivation characteristics for each group.

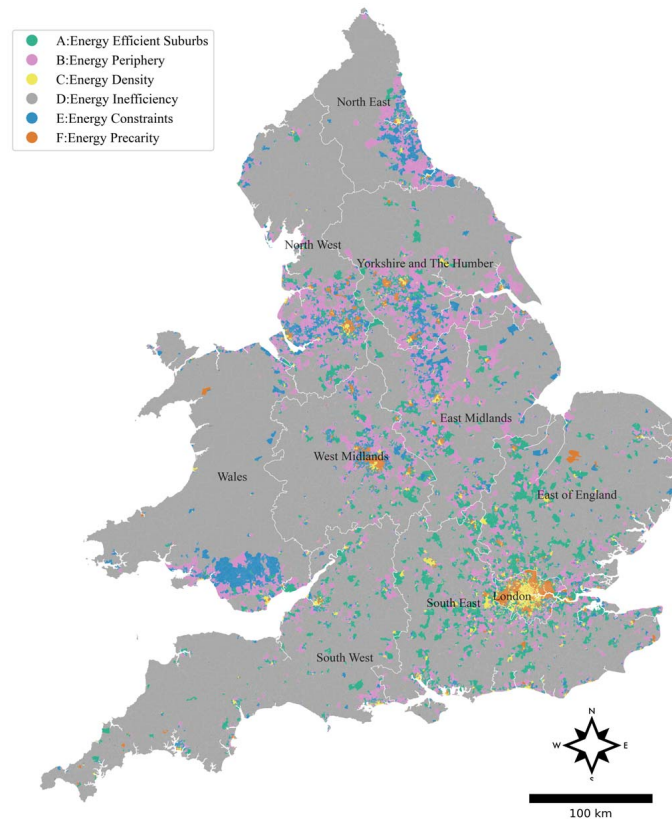
Residents of Group A, Energy Efficient Suburbs, typically live in relatively new houses with the highest energy efficiency and lowest carbon footprints compared to other groups. They tend to own these houses financed using a mortgage, loan or shared ownership scheme. Properties in the group are typically well-connected to the gas grid. There is a higher proportion of families have very young children below four years old. The group is found throughout suburban areas in England and Wales, especially in the southeast and southwest regions of England.

Group B, Energy Periphery, is characterised by residents of retirement age and who are mostly white British, own their detached or semi-detached property either outright, or with a mortgage or via shared ownership. Properties are typically well serviced by energy, including central heating and are well-connected to mains gas. However, properties tend to be under-occupied and hence their occupants consume more energy than they might in smaller homes. This group is pervasive in urban outskirts, and towns close to cities.

For Group C, Energy Density, many individuals are economically inactive full-time students and ethnic minority, concentrating in high-density neighbourhoods of privately rented flats or shared houses. They rely heavily on electricity as gas grid access is often limited. Additionally, residents may reside in either older properties without central heating or properties with high energy efficiency ratings A or B. The group is concentrated in the city centres of England and Wales.

Neighbourhoods classified in group D, Energy Inefficiency, are predominately located across rural parts of England and Wales. Residents are typically older, retired and tend to live in detached houses that they own outright. Properties are typically built before 1930 and some lack a gas grid connection due to their rurality. Most properties have low energy efficiency, leading to higher carbon dioxide emissions per square meter. Some properties only use renewable energy resulting in lower carbon footprints.

Group E, Energy Constraints, is typified by residents who are white British and have constrained access to energy services, predominantly concentrated at urban edges and suburbia of the north and midlands of England and southern Wales. Residents typically reside in rented semi-detached or terraced social housing, and are employed in elementary occupations. They often receive welfare payments to cover essential living costs. Many energy precarious households are lone parents with dependent children below four years old, or have



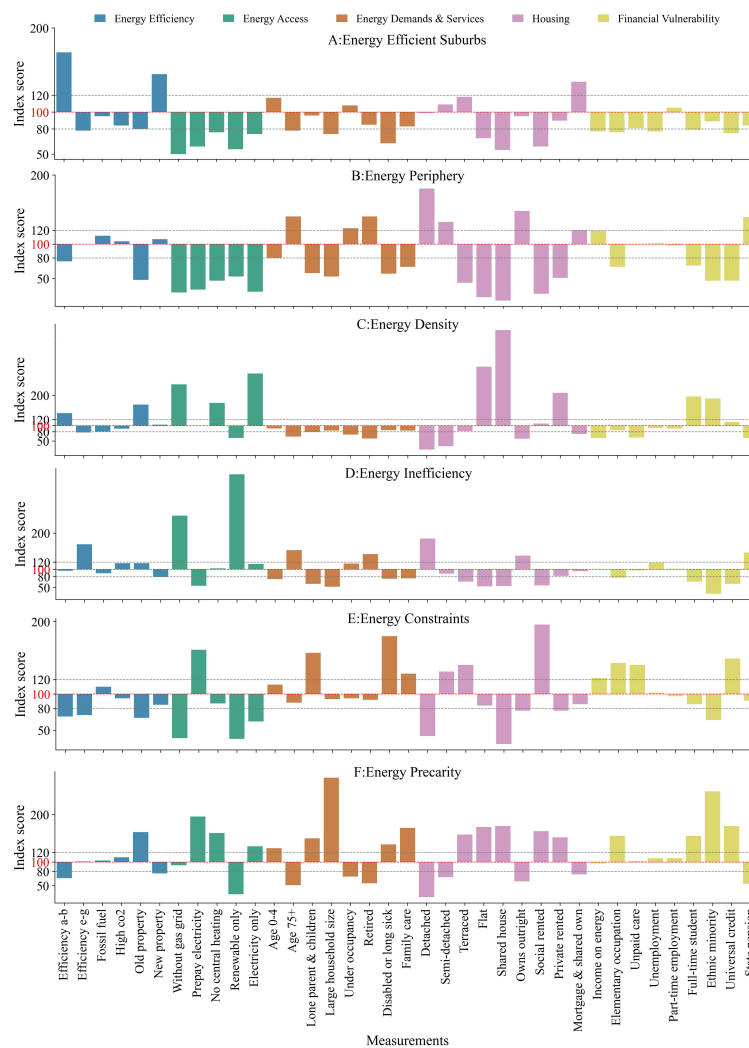
■ **Figure 1** Spatial patterns of energy deprivation in England and Wales at LSOA scale.

residents who provide unpaid care or have long-term sick or disability. Residents often use prepayment electricity meters to manage their energy bills, which are more expensive than other payment ways, and thus, higher proportions of their income are spent on energy.

Residents of Group F, Energy Precarity, are the most energy-deprived compared to other groups. Neighbourhoods offer a mix of rented terraced, flats and shared older properties, that often have constrained energy access, including no central heating, dependent on electricity only and prepayment electricity meters. These low-income areas have a high proportion of ethnic minorities, lone parent households and dependent children. They are more likely to live in overcrowded properties. The group is prevalent in outer parts and less desirable neighbourhoods of cities and towns.

4 Conclusion

This research collected and measured multiple indicators related to energy deprivation. By examining the spatial distribution and contextual characteristics of cluster results, we identify the most and least energy deprived areas in England and Wales and the characteristics of individuals living in those areas. Some future works are required to mitigate the limitations. First, there is no best method to determine the number of optimal k and k -means clustering has some embedded limitations such as sensitive to outliers, exploration with other methods may assist in more accuracy and reliability in methodology. Furthermore, the selection of variables may not cover all factors that influence the energy poverty of households due to



■ **Figure 2** Index score for each group of energy deprivation.

the data limitation of small area statistics. Further survey data can be used via small area micro-simulation to supplement more variables for the classification. Lastly, this study mainly focus on the description of energy deprivation classification, further policy implications should be provided for future work.

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