(Dis)United Kingdom? Potential for a Common Approach to Energy Poverty Assessment

Abstract

The UK has an extensive research base in the field of energy poverty, to the extent that other countries have based their policy approaches on the UK model. Despite this, there is no common method for measuring this condition across the UK. Additionally, sustaining meaningful reductions in UK energy poverty remains a challenge. While significant regional differences in UK energy poverty have been identified, it is not possible to draw direct comparisons between devolved countries. This paper explores the causes of these regional differences and contests that a common measurement across the UK countries would be insightful for resource allocation and policy design. The potential for applying a common multidimensional method of energy poverty assessment across the UK countries is investigated, with a strong focus on the value and viability of this process. Findings demonstrate that while there is a high level of data availability for input into a high spatial resolution index, this data is not compatible between countries and would have to undergo a process of data and metrics equivalisation before direct comparisons could be drawn. With increasing interest in the potential of multidimensional indexes to guide EU energy poverty policy, this paper provides useful insights into the practicalities of upscaling indexes between varied socio-political contexts.

Keywords

Fuel Poverty, Energy Vulnerability; Geographic Variation, Multidimensional Energy Poverty Indexes

1. Introduction

Awareness of energy poverty and its impacts is increasing throughout the EU. Schliech [1] identifies that energy poverty has been a prominent issue within the policy arena for approximately 10 years, resulting both from energy price increases and the economic crises. Currently, more than 50 million people are affected by this issue in the EU [2]. These groups are typically unable to maintain an adequate temperature in their homes. The World Health Organization recommends a standard of 21°C for living spaces and 18°C for other household spaces to prevent the numerous health conditions linked to cold homes [3].

In contrast to other regions, in the UK an antiquated and inefficient housing stock brought energy poverty to the attention of academic and political circles as early as the 1970s [4]. The issue has been the subject of academic and policy discourse for a comparatively long period of time, making the UK the country which has made the most intensive efforts to measure and define this condition [5]. A range of responsive policy has since emerged, which has contributed to rises in average indoor temperatures across the country [6]. The expectations of householders in terms of living standards and thermal comfort have changed, with several previous "norms" (*e.g.* ice on the inside of windowpanes in winter) now being widely unacceptable [6]. These changes have not occurred uniformly across Europe. For instance, in Portugal, the population is still experiencing conditions that

were common in the UK during the 1970s (*e.g.* only heating one room) with low consumption levels both for space heating and cooling [7]; whereas in countries like Bulgaria and Poland, the population still uses coal in inefficient residential space heating appliances with direct negative consequences on indoor air quality [8, 9].

Given the improvements in living standards, the UK has been taken as an example by other nations, leading to the proposed adoption of the English definition of energy poverty at a wider scale [10] Despite the valuable experience the UK has gained in mitigating energy poverty, the issue persists, with significant inequalities occurring between devolved UK countries[11]. Although these inequalities have been discussed within wider literature, there is a lack of in-depth understanding of these trends, with no attempt to assess energy poverty at a high level of spatial resolution across the UK as a whole.

In Europe, energy poverty indexes are becoming increasingly refined and widespread. For example, the Multidimensional Energy Poverty Index assesses both the scale and incidence of energy poverty in Poland by combining five dimensions of energy deprivation [9]. The Energy Poverty Vulnerability Index (EPVI) developed by Gouveia *et al* [12] in Portugal provides a high spatial scale insight into energy poverty in the country at civil parish level, assessing both heating and cooling buildings energy performance and socioeconomic indicators. Indexes which facilitate the comparison of energy poverty between EU Member States are now being developed. A composite index using EU SILC indicators has been used to rank the progress of Member states in alleviating both domestic and transport energy poverty [13]. While these developments are encouraging, the scaling of multidimensional indexes to facilitate regional comparisons between different Member States still presents a significant challenge.

In light of the above, this paper uses the UK as a testbed to explore the potential of scaling a multidimensional index across the four UK countries. It carries out a thorough evaluation of data availability in the UK, in order to assess the current viability and future potential for conducting a comparative analysis on energy poverty by using multidimensional indicators. Theoretical datasets recommended by (amongst others) Morrison and Shortt [14], Walker *et al.* [15], and Gouveia *et al.* [12], are a few of the examples used to complete this exercise. The ability to "zoom in" as much as possible in the energy poverty setting enables targeted action and localised policies, therefore the availability of data at high spatial scale is paramount.

The objectives of this paper are: i) to review the status of energy poverty in the UK by country (Scotland, England, Wales and Northern Ireland), in terms of policy, definitions, and indexes, whilst highlighting the differences; ii) identify available data sources and datasets in the devolved countries to assess the potential for a shared UK methodology for energy poverty characterization, iii) to provide input into current energy poverty policy discourse, where debate is rife with regard to the most effective means of measuring, defining and tackling energy poverty. Given that energy poverty is a well-established issue within the UK, a focus has been retained on whether multidimensional index replication would truly add value. Emphasis has also been placed on the "depth" of data attainable by sourcing the highest resolution data possible. This analysis provides useful insights at the European scale, which increasingly values knowledge transfer between Member States [2].

It is worth noting that, while the term "energy poverty" is more widely used in the European context, "fuel poverty" is more often used in the UK, thus both terms have been used within the paper. This paper is organised as follows; Section 2 provides a detailed analysis of the UK energy poverty status, including comparative levels, policy approaches and definitions. The Results and Discussion in Section 3 presents a synthesis of high-resolution work in the UK by country. Section 3 also reviews data

availability for characterizing energy poverty at high-resolution scale within the UK, addressing the viability and value of its application. Conclusions and Policy Recommendations are provided in Section 4.

2. Energy Poverty in the devolved UK countries

Energy poverty is still a relevant issue in the UK, despite its comparatively longstanding recognition [16]. The persistence of energy poverty within the UK is concerning, given the numerous associated negative impacts, felt for instance in the 2003 heat wave, resulting in 2,000 deaths in England and Wales [17]. In the winter of 2017-18, a period of severe cold weather [18] caused significant strain to health services, particularly where infrastructure was poor. Numerous households were without heating in extremely cold conditions due to power failures [18]. Householders were also forced to spend extra funds on making their homes comfortable. There were numerous hospital re-admittances; as patients were released to homes they were unable to heat, putting additional strain on highly taxed health services [19].

In more recent academic discussions, the concept of "energy justice", the right to achieve comfortable conditions in the home has arisen [15], focused on identifying those consumers most vulnerable to energy poverty. Both within the UK and in the EU, debate regarding the most accurate and just methods of defining energy poverty is widespread [20], as are the arguments for and against a common EU definition [21]. It is evident that, although the UK has made significant progress in identifying and designing strategies to tackle energy poverty, it is still a significant problem. This is particularly relevant given that other EU nations have looked to the UK as a leader of energy poverty mitigation. In the following subsections, an overview of energy poverty within the UK is conducted, focusing on the different definitions (subsection 2.1), current status according to the existing metrics (subsection 2.2), and Policy Framework (subsection 2.3).

2.1 Definitions

Following Hills [22], the Low Income High Costs (LIHC) definition was adopted in England, with variations of Boardman's 10% definition being utilised by the remaining countries [23,24,25]. The different approaches have fuelled discussions regarding the definitions of energy poverty, how these affect those identified as energy poor and the design of mitigation policies [26]. Despite this discord, in the UK the 1991 definition paved the way for the development of fuel poverty policy, resulting in a reduction in fuel poverty [6]. Recent research has shown that the lack of a definition can negatively impact mitigation efforts. For example, a recent assessment of energy poverty in Israel and Romania showed that in the case of both countries the lack of a formal definition led to inconsistent data and an inability to identify the energy poor [27]. Definitions do therefore, have a role in reducing energy poverty. A description of the definition employed in each UK country follows.

The LIHC (Low Income High Costs) indicator was implemented in England with the objective of assessing both the extent and depth of energy poverty [22]. According to this indicator, households with low incomes, high energy needs, and high household costs are considered to be fuel-poor [28]. Energy costs are modelled through a calculation combining fuel requirements with correspondent fuel prices, accounting for an adequate level of warmth [28]. Inputs for household details are obtained through the annual English Housing Survey, involving both a physical survey and a qualitative interview [29]. Energy prices are a synthesis of several sources including the Department of Energy and Climate

Change Survey of Domestic Fuels, Office for National Statistics and Sutherland Comparative Domestic Heating Costs Tables [28]. Critics of the LIHC state that the modelling does not account for low income homes with a relatively good level of efficiency; this is particularly the case for small houses with lower energy costs [30]. It is further argued that the LIHC over-values the impacts of energy efficiency measures [31].

The adoption of the LIHC indicator in England was undertaken under consensus that the 10% indicator was overly sensitive to price changes, leading to inappropriate categorisation of energy poor households, including large homes with accordingly high spending rates [22]. Other authors argue that the 10% method was unsuccessful in preventing energy poverty, while its merits include the calculation of modelled rather than actual energy costs [4]. The Hills Review was carried out in austerity conditions and argued that accurate resource allocation was of utmost importance [4]. This justification, however, does not account for the possibility that under austerity, high energy costs would have increased impacts on the population. Both indicators have been criticised for not capturing those households which are energy efficient but in monetary poverty [32].

Following the release of the Fuel Poverty Strategy for Scotland 2018, a revision has been made to the Scottish Fuel Poverty definition [33]. The new definition is shown in Table 1. The 10% fuel cost to income ratio will now be calculated on an After Housing Costs (AHC) basis, whereas previously this ratio was calculated Before Housing Costs (BHC). Additionally, there will be an increase in threshold temperatures for householders adversely affected by cold, damp homes [34]. The Strategy is described as a "landmark" piece of legislation, noting that Scotland is one of the few countries defining energy poverty [24]. Interestingly, the Ministerial Foreword identifies that some elements of energy poverty remain outside the power of the Scottish Government to address; "*there are other drivers of energy poverty we have no control over for example energy prices and polices driven by areas reserved to the UK Government*", [24] p 5. This contrasts with the central Government stance, which advocates separated administration of energy poverty [28]. There are worries regarding the timelines cited, as the document commits to a maximum fuel poverty rate of 5% by 2040, exposing Scottish residents to the impacts of energy poverty for some time [18].

The Welsh energy poverty definition (Table 1) also relies on a 10% indicator, the most recent Welsh Housing Conditions Survey was released in 2018 [35]. Prior to this, the last Welsh Housing Conditions Survey was carried out in 2008. There were concerns about analysis based on 2008 statistics, as a number of energy efficiency projects had since been undertaken [18]. Since 2008 there has been improvement in housing conditions in all tenures, the housing stock in the Welsh private rented sector is both the oldest and the poorest quality. The average energy efficiency band is now Band D, an improvement on the previous Band E [36].

A 10% indicator is also used in Northern Ireland, a private entity (the Building Research Establishment) was employed to model fuel poverty levels for 2017 and 2018. The 2011 Fuel Poverty Strategy defines three key contributors to the problem: income; fuel price and energy efficiency, demonstrating a consistency with the LIHC indicator, the document identifies four key action areas [37]: Targeting of Resources, Improving Energy Efficiency, Achieving Affordable Energy and Building Strong Partnerships.

Table 1. Definitions of energy poverty by devolved UK country

Country	Definition of Energy Poverty
England	"Fuel poverty in England is measured using the Low Income High Costs (LIHC) indicator. Under the LIHC indicator, a household is considered to be fuel poor if: they have required fuel costs that are above average (the national median level) were they to spend that amount, they would be left with a residual income below the official poverty line. There are three important elements in determining whether a household is fuel poor: household income, household energy requirements, fuel prices [28].
Wales	In Wales, a household is defined as being in fuel poverty if they would have to spend more than 10% of their income on maintaining a satisfactory heating regime. Any household having to spend more than 20% is defined as being in severe fuel poverty [38].
Scotland	"The Bill defines a household to be in fuel poverty if more than 10% of its net income (after housing costs) is required to heat the home and pay for other fuel costs – with not enough money left for a decent standard of living. If more than 20% of net income is needed, the household is defined as being in extreme fuel poverty." [33]
Northern Ireland	A household is said to be in fuel poverty if it needs to spend more than 10 per cent of its income on energy costs [25].

2.2 Status

In 2018, in the UK, 18.6% of the population were at risk of poverty or social exclusion [39]. In 2018, a total of 5.4% had arrears on utility bills; 17.8% were living in dwellings with leaking roofs, damp walls, floors or foundation, or rot in window frames or floors; and 5.4% were unable to keep their homes adequately warm during the winter [39]. In 2012, 3.3% were living in a dwelling which was not comfortably cool during summertime [39]. The UK recorded a GINI index of 33.5% in 2018, above the 30.8% for EU28 average [39]. In the first semester of 2019, electricity and natural gas prices for families, with all taxes included, were respectively 1.2% and 22.0% lower compared to the EU28 average [39].

Although the devolved UK countries do not use a common definition for energy poverty, research suggests that rates of energy poverty are highest outside England, as stated by Robinson *et al.* p.80 [5]: "Even within the United Kingdom (UK) there exist significant disparities between the devolved nations (England, NI, Scotland and Wales) with a high prevalence outside England". Comparative levels of energy poverty by UK country are displayed in Table 2, confirming this statement. Statistics were available for both the LIHC and 10% indicators for all UK countries apart from Scotland. These figures (Table 2) demonstrate an interesting level of variation, showing a significantly lower number of households identified as fuel poor under the LIHC in Wales and Northern Ireland but a slightly elevated number of fuel poor households in England compared with the 10%.

Levels in Northern Ireland were the highest in the UK in 2012, at 42% [40]. A strong focus on energy efficiency improvements has resulted in significant reductions of this percentage [41] but has not completely eradicated the issue. Fuel price reductions and income increases were also key contributors to these improvements [42].

In England, energy poverty levels have fluctuated between 10% and 12% since 2003 (retrospectively applying the LIHC indicator), a limited variation which is attributed to the relative nature of the LIHC indicator [43]. Government literature shows that the fuel poverty gap (i.e. the average reduction in fuel bill necessary to remove a household from fuel poverty) and the percentage of fuel poor households can be negatively correlated, i.e. the gap can increase as the number of fuel poor homes

decreases [43]. Academic sources attribute the stabilisation of fuel poverty levels in England to economic austerity, the lack of a "typical" energy poor household and the inadequacy of key policies to address structural energy poverty drivers. Targets for the improvement of private rented stock have also been identified as insufficient [44].

Table 2. Fuel poverty indicators in the devolved UK countries

Country	Number of Fuel Poor Households (10%) indicator	Percentage of Fuel Poor Households (10%) indicator	Number of Fuel Poor Households (LIHC) indicator	Percentage of Fuel Poor Households (LIHC) indicator
England	2,361,400 [45] (2018)	10.4 [45] (2018)	2,460,000 [43] (2019)	10.9 [43] (2019)
Scotland	649,000 [45] (2018)	26.5 [45] (2018)	-	-
Wales	155,000 [38] (2018)	12 [38] (2018)	132,000 [45] (2018)	10 [45] (2018)
Northern Ireland	160,000 [46] (2018)	22 [46] (2018)	55,100 [42] (2016)	7% [42] (2016)

The literature identified a series of inequalities in the manifestation of fuel poverty between the UK countries. Fuel prices are higher in rural areas of the UK, with associated implications for energy poverty [47]. Geographically, Wales, Scotland and Northern Ireland are more rural than England with less energy infrastructure and increased reliance on expensive fuels [48]. Northerly areas have colder temperatures and increased vulnerability to energy poverty. This has particular relevance for Scotland (a country with significant rural area), which experienced minimum temperatures of -10°C during the 2017-18 winter [18].

There are also significant regional differences in energy poverty within the UK countries. The work of Robinson *et al*. [5] identifies lower rates of energy poverty in the South East region of England and elevated rates in the North East and West Midland areas. The South East region of England including London and its surrounding economic belt is generally more affluent. In 2019 median weekly pay in London was £699 compared to £531 in the North East [49]. Despite this, analysis in 2012 estimated that there were 560,000 fuel poor homes in London with 126,000 of these in severe fuel poverty, principally focused in areas of North and South East London [50].

In Wales, both older and more recent assessments have demonstrated a particularly high rate of fuel poverty in South Wales, mostly in deprived urban areas including Cardiff. A moderate but widespread concentration has also been observed in North Wales, with lower rates occurring in more affluent rural areas [51, 52].

In Scotland, a recent assessment showed that higher levels of fuel poverty occurred where homes were not connected to the gas grid, with a prevalence in the Northern Highland area and in several of the Scottish Isles. Furthermore, Morrison and Shortt [14] identified a possible 3150 fuel poor homes previously considered as "low risk" within Stirling Council. The authors highlighted an increased risk of masking smaller areas susceptible to fuel poverty when data is aggregated across larger spatial units. In Northern Ireland, Walker *et a*l. [15] found an increased risk of fuel poverty in open countryside areas and in medium sized towns. Lower levels of risk occurred in small towns and cities.

In summary, clear geographical variations in fuel poverty occur within each UK country as well as across them. The way in which these geographical variations occur is, however, different in each

country. Therefore, the availability of high spatial scale data is paramount for measuring energy poverty as accurately as possible and in the guidance of targeted policy [40].

2.4 Policy Framework

Policies to tackle energy poverty are administrated separately by the four UK countries (England, Wales, Scotland and Northern Ireland). Policy shortcomings for addressing energy poverty have been identified by the UK Government and by NGOs [53, 54]. In the words of the National Energy Action charity "*one of the challenges to securing and developing lasting co-operation is the lack of a common definition of fuel poverty across the UK*." p 32. [54]. The same source also referred to differences in support systems between countries, identifying an injustice of energy poverty geographies [55]. Recent discourse (both political and academic) has identified the complexity of tackling the issue, suggesting that a wider range of energy poverty drivers need to be identified and assessed for successful mitigation [56]. Broader drivers are identified in the work of Castãno-Rosa *et al.* [57] Hargreaves *et al.* [58], Middlemiss *et al.* [59] and Longhurst *et al.* [60]. Castãno-Rosa *et al.* [57] outline the importance of behaviour, household structure and dynamics, finances and social activity on energy use, developing an indicator which accounts for these factors. Hargreaves *et al.* [58] explored the impact of social relations on energy demand, describing the impact of two divergent circumstances on energy use, in both cases social circumstances strongly influenced energy consumption. Middlemiss *et al.* [59] explore the impact of social relations on capabilities i.e. how one's social relations can impact access to energy services. In a novel approach, Longhurst *et al.* [60} investigate the role of emotions on energy vulnerability, contesting that emotions such as trust can influence willingness to engage with support programmes. However, this broader perspective on the drivers of energy poverty currently exists mostly at the academic level, with policy still tending to be based on standard objective measures. Given the widespread consensus on the traditional drivers of energy poverty, the analysis also sought to identify how these were addressed through policy.

The central UK Government attributes differences in energy poverty governance to the partially devolved nature of the issue [61]. The various administrations have separate policy targets, with the power to influence particular policies within the respective countries (e.g. energy efficiency programmes) but not the power to influence other aspects, such as income, the market or energy price variations [28]. Whilst this justification has some basis, the lack of a common approach across the devolved countries risks fostering inequalities, as evidenced by the fact that England produces an annual report on energy poverty, while in Northern Ireland there is no statutory requirement on fuel poverty [28].

Analysis of energy poverty policy administration in the UK demonstrates a kind of paradox. Energy poverty is partially attributable to localised characteristics. These include climatic conditions, rurality and particular housing typologies [48]. The individual governments and local Councils have a greater insight into these specificities than central Government, thus it is logical to administrate energy poverty locally. Other factors, such as energy price, are the output of wider influences and therefore need to be addressed centrally. This paradox complicates the administration of energy poverty, and the mixed profile of policy approaches fosters inequality, demonstrated by the varying UK energy poverty levels. These frameworks within the UK provide an interesting platform for the EU approach to the issue, highlighting the challenge of sufficiently accounting for regional specifics without creating regional inequalities.

Following the legal commitment to prevent energy poverty in the UK, the Fuel Poverty Strategy [51] was released in 2001. In response, each country posted interim targets, against the longer-term strategies and targets shown in Figure 1. It is interesting to note that, from the outset, there are differences in the targets designed for each country. These differences were attributed to variations in the nature and scale of energy poverty in each country [61]. Figure 1 demonstrates that previous targets to eradicate energy poverty have been unsuccessful across the UK countries.

Table 3 shows the range of UK energy poverty policies in more detail. The number of different policies shows a strong level of political interest in all four devolved countries, this degree of engagement is unique to the UK. However, Table 3 also highlights a lack of uniformity in policy instruments between UK countries. These inconsistencies are illuminating in the context of the historic policy approach to UK energy poverty. The degree of political resource dedicated to the issue has been attributed to the efforts of lobbying, NGOs and political figures [15]. Analysis of the various policies demonstrates that all three energy poverty drivers – income, energy prices, and energy efficiency- are reflected in the overall policy approach, with each policy targeting at least one of these drivers. With a reduced number of policies targeting income, such schemes include "The Winter Fuel Payment", labelled by some as a blanket payment [15], potentially diverting funds from more targeted policy [34].

Combined energy efficiency and cost agendas proved popular, with policies either combining bill advice with efficiency installations [62, 63] or emphasising the reduced energy costs associated with improved efficiency [43]. This popularity extends to the efficiency-based English fuel poverty target, focused on improving energy performance certificates (EPC) ratings rather than fuel poverty percentages [64]. Efficiency policies also reduce greenhouse gas emissions, an obvious attraction for Government [56]. In the UK housing accounts for 13% of emissions, and the UK's Clean Growth Strategy identifies domestic efficiency upgrades as a target for reducing this figure [65]. Scottish policy pushed this agenda further, directly referring to renewables and publicly owned energy companies as energy poverty mitigation methods [66]. Efficiency-based schemes have been both praised and criticised, with positive examples including the reduced levels of energy poverty in Northern Ireland [41] and Warm Front in England [16]. Critics describe this approach as cost-orientated [15], and as retaining a disproportionate focus on the elderly [67]. The underlying motivations of privately-run schemes have also been questioned, given the desired outcome of efficiency improvements is cost reduction [68]. Significant resource (£640m per annuum) is dedicated this approach through the ECO scheme [69]. There is a strong focus on energy efficiency, which is particularly evident in English political discourse [64]. Whilst efficiency has a critical role to play in energy poverty mitigation, careful administration of these programmes is necessary in order to avoid a continued marginalisation of the most vulnerable. These groups often do not participate in efficiency schemes to the desired extent and are reluctant to take on debts (as required by the Green Deal) [56, 70].

Furthermore, there are very few policies targeting energy costs individually. Where not considered a co-benefit of retrofit, energy costs were principally targeted through supported energy supplier switching schemes and the Energy Price Cap [71]. This reduced focus on energy costs (as a key driver of energy poverty) may partially explain the persistence of the issue, particularly in England where levels have stagnated since 2003 [43]. Switching schemes rely on users to take the initiative, with evidence showing that many consumers rarely switch more than once if at all [71]. The Energy Price Cap does not require any action from the consumer but applies only to consumers on prepayment meters, consumers in receipt of the Warm Homes Discount or consumers on a default tariff [71].

In summary, the UK demonstrates a range of separate policies dedicated to reducing fuel poverty. Within a European context, this level of political engagement is commendable, as many Member State Governments still deny the existence of the problem [72]. This policy approach is, however, fragmented with different approaches resulting in different levels of support between UK countries. Additionally, the incompatibility of UK energy poverty statistics is problematic for identifying where the problem is most serious. Without a more integrated policy approach the UK risks the persistence of the inequalities between devolved countries.

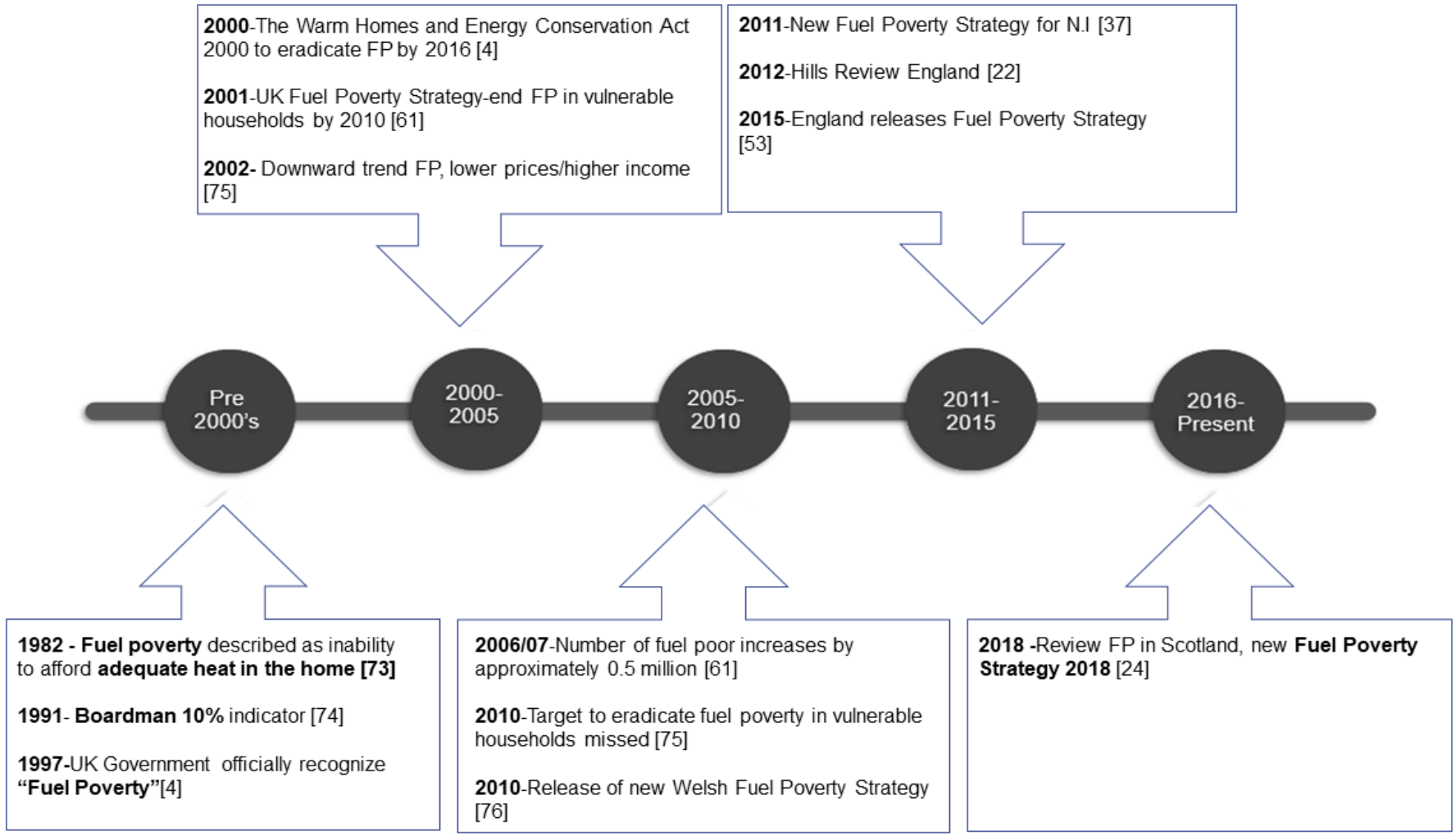

Figure 1 - UK Energy Poverty Policy timeline

Table 3. Key energy poverty policies in UK devolved countries

Policy name	Country		Summary	Driver Targeting
Winter Fuel Payment [77]	U.K.		Automatic payments between £100-300 if born before Nov 1953	Income
Cold Weather Payment [78]	G.B (equivalent scheme for N.I.)		Payment if temperature is 0° or less for 7 consecutive days. £25 for each 7 day period between 1 Nov and 31st Mar	Income
Warm Homes discount [79]	G.B.		Single payment £140 to energy supplier as a discount to energy bill.	Income
Green Deal [80]	G.B.		Household improvements funded by loan paid through energy bills or meter.	Energy efficiency
Energy Company Obligation (ECO),[69]	G.B.		Energy efficiency improvements in households funded by energy companies. Now "ECO 3" a lower cost version	Energy efficiency
Warm Homes Programme Nest & Arbed [62,63]	Wales	Nest	Energy bill advice and energy efficiency improvements (managed by British Gas)	Energy efficiency/ Energy costs
		Arbed	Funding energy efficiency measures in deprived communities	
The Domestic Private Rented Property Minimum Standard [81]	England and Wales		Minimum efficiency levels for private rented property in England and Wales. Minimum level EPC E grade, if under this band cannot rent to new tenants after April 2018 or continue to rent after April 2020	Energy efficiency/ Energy costs
Decent Homes Programme [82]	England		Household improvements including central heating systems	Energy efficiency/ Energy costs
Fuel Poverty Target- (Based on Fuel Poverty Strategy 2015), [43]	England		"To ensure that as many fuel poor households as reasonably practicable achieve a minimum energy efficiency rating of Band C by 2030, with interim targets of Band E by 2020, and Band D by 2025"	Energy efficiency/ Energy costs
Scotland's Energy Efficiency Programme [83]	Scotland		Cut levels of fuel poverty so that no more than 5% of the population are affected by 2040. Includes the Scottish Government Home Energy Efficiency Programme, offering free energy advice	Energy efficiency/ Energy costs
Warmer Homes Scotland [84]	Scotland		Delivered regionally by the Energy Savings Trust. Provide a range of efficiency measures, now including renewables for remoter communities	Energy efficiency/ Energy costs
Home Energy Scotland [85]	Scotland		Managed by Energy Saving Trust, network of local advice centres covering all Scotland. Provides free, impartial advice on improving energy efficiency and reducing costs	Energy efficiency/ Energy costs
Affordable Warmth Scheme [86]	N.I.		Scheme targeting fuel poverty in the private sector through the installation of energy efficiency measures	Energy efficiency
Welsh Government Housing Quality Standard [87]	Wales		Requiring all social landlords to improve their housing stock by December 2020 [31]	Energy efficiency
The Clean Growth Strategy [65]	U.K.		Improving UK homes by focusing on two areas: Improving energy efficiency, Rolling out low carbon heating	Energy efficiency/ Energy costs
Energy Price Caps [71]	G.B.		Ensuring fairer energy prices and protecting consumers against overcharging, caps applied to energy supplier on charges per kWh	Energy costs
The UK's Draft Integrated National Energy and Climate Plan [66]	U.K.		U.K. (England same target) Upgrade fuel poor homes to an energy performance certificate EPC rating of C or better by 2030 Wales-Wales-Warm Homes programme £104 m further investment Scotland-Public energy company and bioenergy to reduce fuel poverty in Scotland N.I-Affordable Warmth Scheme (as above)	Energy efficiency/ Energy costs

3. Results and Discussion

The following sections discuss a range of recent studies and assess the viability and value of conducting a regional high-resolution multidimensional assessment of energy poverty across the UK, where a range of energy poverty indexes and indicators have previously been developed.

3.1 Implemented Metrics

Despite several sources arguing that the 10% indicator was no longer fit for purpose, the significantly lower number of homes categorised as fuel poor under the LIHC definition in England has proved controversial [30]. The difference in groups identified by each UK definition remains divisive [5], and a similar debate is now occurring more widely at an EU level, where a series of indexes and indicators to measure energy poverty are emerging [32]. Producing an index that could offer a UK-wide perspective would potentially add a further dimension to the debate which is currently lacking. By exploring the potential for scaling a regional index, this exercise generates insights to both UK specific and wider EU discourse. In this section, a review of recent energy poverty measurement and high spatial resolution work within devolved UK countries is conducted, summarising methodologies employed and relevant spatial scales. In this context, the advantages and disadvantages, as well as the viability of a multidimensional high-resolution approach for the UK are discussed.

The range of sources shown in Table 4 indicate the high profile of energy poverty in the UK. The Table refers to key recent works, presenting several high spatial resolution scale studies for UK countries. Existing high-resolution studies have focused on the individual UK countries, with high spatial scale assessments identifiable for each country. A higher number of these assessments were available for England, this coincided with more regular reporting on the issue of fuel poverty.

The first high spatial scale resolution assessment of energy poverty in the UK was the “Fuel Poverty Indicator”, developed by the Centre for Sustainable Energy and The University of Bristol, predicting rates of energy poverty by electoral ward, combining data from the 2001 Census, the 2003 English House Condition Survey and a national property database Residata for England [88]. With the increased popularity of geographic information systems (GIS), such approaches have been more widely replicated within the UK, and often feature an energy poverty map. Studies with an accompanying map are identifiable for all four devolved countries [5, 14, 40, 51, 52, 88, 89, 90,91, 92,93,94, 95]. Studies without mapping outputs, were also found [96]. The sources fell into three broad categories, country level assessments of the relevant UK country, adaptable tools which combined national and local datasets and local tools based on local authority data.

Country level assessments provided an overview of energy poverty in the relevant administration [5, 51, 52, 91, 92, 93]. These studies typically combined Index of Multiple deprivation, Census and EPC data [51, 92, 93], or employed government fuel poverty data to map fuel poverty accordingly [5, 52, 91]. An outlier of this group was “The Fuel Poverty Look-up Tool” which allows users to compare rates of fuel poverty in different areas of England at high resolution scale. Although a country level assessment, the tool provides comparative percentages rather than a visual representation of energy poverty. Generally, these assessments provided an instant “snapshot” of energy poverty in each country, where users can make regional comparisons and identify where severity is greatest. These sources have the shared disadvantage of being based on mass data which masks pockets of energy poverty [14]. Another disadvantage of these tools is that their integration into policy (either national or local) was not clear.

Adaptable tools had the capacity to be refined through liaison with local authorities, providing data such as SAP values or data on poor housing [88, 89]. Interestingly, despite being developed in 2003 the Centre for Sustainable Energy FPI [88] was designed specifically to combine English national statistics with local authority data. More recently, sources which combine country level data with local knowledge are the FRESH vulnerability project [89], Scottish charity Changeworks [90} and Assessment Tool for Low Income High Costs [94]. FRESH combines English and Welsh income data with local health and housing data. FRESH is clearly linked to policy with maps used as an evidence base for grant applications and to implement a regional community energy programme [89]. Changeworks produced a fuel poverty map of Scotland, also providing free local "overview" maps on request to local authorities. Detailed maps are chargeable and incorporate local authority databases, to date in depth reports have been developed for City of Edinburgh, Fife, Scottish Borders and Dumfries and Galloway [90]. The Assessment Tool for Low Income High Costs allows users to apply the LIHC definition in combination with local data on vulnerability and health. The tool developers noted some discrepancies in the English Housing Survey (an LIHC input) which affected the accuracy of fuel cost calculations. The tool is freely accessible on the National Energy Action website, primarily aimed at advice agencies and researchers [102]. Overall, these tools demonstrated a clear application in fuel poverty policy, however, their capacity to be used in regional comparisons of fuel poverty levels was less evident.

Finally, the local London Fuel Poverty Risk Indicator [95] combined a series of local vulnerability indicators to guide strategic targeting of high-risk wards. Basing the tool on local data facilitates the pinpointing of fuel poor households. The disadvantage of this approach is once again that comparison with other UK regions is not possible. The key advantage of the tool was its clear utility for local policy, where users could select specific indicators to identify which mitigation measures are likely to be the most impactful in a particular area.

Collectively these sources have the potential to contribute to policy in different ways such as, highlighting regional variations [5, 40, 51, 52, 92], improving monitoring and targeting [88, 90] or by resource prioritisation [89]. Despite this, their integration into policy is somewhat sporadic, taken up by some local authorities but not others, demonstrating that spatial data is not central to UK fuel poverty policy.

For instance, the English 2015 Fuel Poverty Strategy identifies a policy of helping the "worst first", developing a supporting "non-gas map" and identifying "non-gas" homes as at particular risk of fuel poverty [53]. Despite this, the main target of the strategy focuses on improving EPC grades, with little evidence of spatial targeting of fuel poverty in subsequent Annual Fuel Poverty Reports. Without a clear focus on spatial targeting in the central government strategy there is a risk that the use of spatial data will be applied inconsistently, depending on the interpretation of the relevant local authority, each with their own political priorities. England, however, is the only country where Governmental sources spatially representing energy poverty are identified [91].

This wider strategic under-representation of spatial data is reflected in the remaining UK countries. For example, the Scottish 2018 Fuel Poverty Bill recognises increased energy demand and costs in rural areas, yet the strategy does not appear to be guided by spatial data [33]. In Wales a revised fuel poverty strategy is due to be released in 2020, its 2010 predecessor does not draw upon spatial data, despite observing that price variations in oil and LPG prices in rural areas impacted customer vulnerability [76]. The 2011 Fuel Poverty Strategy for Northern Ireland identifies that rural dwellings

are more exposed to the weather and face limited fuel choices, yet spatial data is not used to guide the strategy [37]. In the case of Wales and Scotland spatial assessments existed at the time of strategy publication [51, 90], which could have been drawn upon to support strategy design. While in Northern Ireland there is evidence that reductions in fuel poverty have been achieved as a co-benefit of other schemes such as the NISEP energy efficiency programme [97], rather than through spatial targeting. In fact, collectively the UK fuel poverty strategies showed a far stronger focus on energy efficiency than on spatial targeting.

Efficiency improvements are undeniably important, however these schemes, involve a trade-off between trying to reach the greatest proportion of fuel poor homes possible, while avoiding the allocation of funds to homes which are not fuel poor. Given the persistence of fuel poverty in the UK, better integration of spatial data into strategic targeting has the potential to mitigate this "coverage vs leakage" effect [98]. Table 4 presents a range of high spatial scale work including not only a broader selection of fuel poverty drivers, but also showing *where* the most vulnerable are likely to be. Better integration of this data into strategic policy will progress the approach to mitigating fuel poverty [60], adding depth to efficiency-based targets which to date have only gone *so far* in reducing fuel poverty [99].

Overall there are a range of impressive attempts to represent the spatial manifestation of UK energy poverty, with the potential to support fuel poverty policy and improve targeting. However, currently these sources present a "mixed bag" of results which do not allow a direct comparison of energy poverty levels between and sometimes within UK countries. For example, when comparing country scale assessments, the scales measuring the severity of energy poverty differ within and between UK countries. In England the most severe range of energy poverty observed by Robinson *et al.* [5] was between 22%-56% (10% indicator), compared with 17%-51% (LIHC indicator). In Wales the most severe range measured by Kelly [52] was 23%-31%, and Gordon and Fahmy [51] between 32%-43%. The most severe ranges observed in Scotland and Northern Ireland were significantly higher, with a range of 61%-92% in Scotland [90] and 75%-95% in Northern Ireland [40]. In the Scottish case this is consistent with the highest rate of energy poverty observed across the four countries. In Northern Ireland this coincides with the second lowest level of energy poverty. These differences demonstrate the discrepancies which arise from the application of different methodologies to assess energy poverty. While each method will have its benefits and drawbacks, these varied approaches make it difficult to identify where severity is greatest. Gaining a UK wide perspective on energy poverty is therefore important in ensuring that those most in need are identified and targeted.

Recent academic and NGO representations identify clear regional variations in the UK countries respectively [5, 40, 51, 52]. A number of spatial representations of energy poverty in the UK have been undertaken, yet integration of this data into government strategy is limited. Additionally, there is there is no study assessing energy poverty at high spatial scale resolution across the UK. While some limits occur as a result of variances in statistical data collection methods between different UK countries (e.g. Census data) [100] and policy devolution [28], the sources identified are currently an under-used resource in the UK which should be better integrated into government policy. Building on these sources to create a means of assessing energy poverty at a UK wide scale would deepen the current understanding of regional inequalities and avoid the limits of either the 10% or the LIHC definitions discussed early in this paper.

Table 4. Recent energy poverty high resolution projects in devolved UK countries

Source Name	Source type	Relevant country	Summary	Spatial scale
'Getting the measure of fuel poverty': The geography of fuel poverty indicators in England [5].	Academic	England	Aim of study was to determine how the distribution of fuel poverty using the new LIHC indicator compares to the formerly used (in England) 10% indicator.	LSOA Lower Layer Super Output Area
FRESH Vulnerability Mapping (Foundation Data for Robust Energy Strategies for Housing) [89]	Community interest company	Wales	Community interest company which takes big data on poor health and poor income and matches with street level maps of poor housing.	Street level
Mapping Fuel Poverty Across Northern Ireland [40]	Academic	Northern Ireland	Area based approach based on Census Output Areas, from 2011 Census. Data on housing was extracted from the Land and Property Services. Heating burdens calculated by accounting for winter temperatures and fuel types.	Census Output Area
Estimating Percentage of Households in Fuel poverty by Data Zone in Scotland [90]	NGO	Scotland	Maps represented either at country or street level to identify areas in fuel poverty. Generated using data from the Scottish House Condition Survey and paired with 2011 Census and Energy Performance Certificate data.	Data Zone
Fuel Poverty in Scotland: refining spatial resolution in the Scottish Fuel Poverty Indicator using a GIS based multiple risk index [14]	Academic	Scotland	Uses a GIS framework to integrate census data with georeferenced energy efficiency data on local housing.	Census Output and individual dwelling
A Small area fuel poverty indicator for Wales [51]	Academic	Wales	2008 report estimating number and percentage of households likely to be in fuel poverty, based on 2001 census data	MSOA Middle Lower Layer Super Output Area
Investigating a New Way of Delivery Energy to Tackle Fuel Poverty using Case Studies in Wales and Scotland [52]	Academic	Wales	A Masters thesis project which uses data supplied by the Welsh Government to map fuel poverty in Wales	LSOA
Fuel Poverty Indicator [88]	Academic	England	Now no longer updated-aimed to efficiently identify fuel poor households, designed to help meet the 2016 target	English Electoral Ward
Parallel [91]	Governmental	England	Online tool which uses 2016 Government/BEIS data to create interactive fuel poverty map for England	LSOA
Mapping Energy Vulnerability in England [92]	Academic	England	Online look up tool allowing users to look up energy vulnerability categorises four groups which lead to energy poverty, a group is identifiable for each LSOA	LSOA
Energy Poverty and Gender in England: A spatial perspective [93]	Academic	England	Academic assessment of energy poverty by gender in England	LSOA
Fuel Poverty Statistics in England – Lookup tool [96]	Governmental	England	A tool which allows access to data on fuel poverty levels and rates	Constituencies, Local Authorities and Regions
Fuel Poverty Assessment Tool for Low Income High Costs [94]	NGO	England	Tool to help energy sector workers (both corporate and governmental) assess whether households are in fuel poverty. Aim to create a free online assessment tool.	LSOA
London Fuel Poverty Risk Indicator [95]	Governmental	England	Tool to guide strategic targeting of wards at high risk of fuel poverty	Wards

3.2 Viability of a Common Approach

The complex range of drivers which cause energy poverty were discussed previously in this paper. In an attempt to account for these, the works of Gouveia *et al.* [12], Besagani *et al.* [101], Pérez-Fargallo *et al*. [102], and Martín-Consuegra *et al.* [103] are used to devise a set of criteria and corresponding datasets for analysis. Based on the outputs of this analysis, the viability of assessing energy poverty across the UK is explored, by assessing the availability and variations in national data sources. An inventory of data types, indicators and sources was performed, and data availability is assessed, with a focus on collecting data at the highest spatial scale possible.

Table 5 outlines the Data Types and Required Inputs for the criteria identified through the works cited above. A total of 23 Required Inputs were assessed across the 7 Data Types. A full analysis of the availability of data for each criterion is provided in the Annex, Tables A.1 to A.5. Data is not available in standard "UK" datasets, instead several different country groupings are identified. Figure 2 shows the number of sources for each data type, date (pre and post 2016), per country grouping and per spatial scale. For the purposes of analysis, in Figure 2 spatial scales were amalgamated into three categories, small scale data (Household, Lower Layer Super Output Area (LSOA), Data Zones, and Small Areas), medium scale data (Electoral Ward, Local Council, NUTS 3, Council Area and Local Authority) and large scale data (Regional, Sub-national, Country, National). A summary of the different spatial scales found within the sources is presented in Table 6. This analysis highlights that the geographic administration of the UK is complex, which is attributed to two factors, divergent administrative structures between UK countries and the fact that boundaries within hierarchical layers are subject to amends [100]. These complexities filter down to the relevant sources for assessment of data availability.

The majority of sources are available post-2016, with pre-2016 data found only in the Socio-economic sector, primarily Census data (2011), as shown in Table A.5. Less data was available for the G.B and U.K. groups than for the countries individually or the England and Wales group. Not unexpectedly cross referencing with Table 5 shows that a higher number of sources corresponds to those data types with more required inputs. The presence of data sources for one country grouping (i.e. for England and Wales jointly) did not mean that data would not be available for the same country in another grouping (i.e. for England and Wales separately). There is a high level of variation in the spatial scale in which data is collected and presented between devolved countries. When considering the results shown in Figure 2 with the Annex A tables, it is evident that most datasets are available at a high scale of spatial resolution. Generally, the most refined data is available by Lower Layer Super Output Area (LSOA) for England and Wales, [104], by Data Zones for Scotland [105], and by Small Areas for Northern Ireland [100]. These scales are consistent with those employed by recent high-resolution UK energy poverty assessments (Table 4). Data availability by country grouping and spatial scale is shown in Tables A1-A5 (Annex A). These tables demonstrate the differences occurring between the spatial scales at which the data is collected by the different countries.

In general there is a high level of data availability for each criterion assessed. "Energy Consumption" and "Climate Data" are the datasets with the least variation in country grouping. The Annex tables also list datasets for each data type, showing that EPC data, housing surveys and deprivation data are key data sources. The employment of housing surveys is a highly developed tool to collect data for energy poverty studies in the UK. The English Housing Survey has been widely acclaimed, generally

being more regularly carried out than the housing surveys of the remaining countries [18]. Surveys from all countries are, however, a highly useful source for many of the criteria assessed. It should be noted that without the 2019 Welsh Housing Condition Data Survey, a number of the sources for Wales would have been outdated (as the previous survey was completed in 2008), compromising the reliability of this data.

Another key data source is the "Indexes of Multiple Deprivation", modelling for the presence of hazards such as excess cold in homes (Annex A.6). In most instances, these datasets supersede the data from the 2011 Census with more recent data, whilst still maintaining a high level of spatial resolution. Exceptions occur in the "Socioeconomic" sector, where in the case of Northern Ireland, datasets for "Education", "Elderly and Young People", "Housing Tenure" and "Occupancy Rate" are available at Small Area level only from the 2011 Census. This limitation also occurs for the "England and Wales" country grouping- alternative sources are available for England and Wales separately, but only at country level (except income data available at LSOA). For Scotland datasets for "Income", "Elderly" and "Young People" and "Occupancy Rate" are available at Data Zone level. Recent Scottish education data is available only at Council Area level and Building Conservation Status and Tenure are available only at Local Authority level. Further sources useful for the Socioeconomic section (specifically for Education and Income) are available in the U.K. grouping but these were available only at National and NUTS 3 levels.

Two other criteria which present complications were the "Other Indicators for Benchmarking" and "Building Typology" areas, with particular reference to the sub-criteria of "Construction years" and "Social Housing". In the case of "Construction Years", data is sourced from housing surveys and it is available only at Local Authority level for Scotland, Country level for England and Wales and Council Areas for Northern Ireland. For "Social Housing", data is available at Council Area for Scotland, Local Authority for Wales, and at Country level for England and Northern Ireland. The work of Morrison and Shortt [14] as well as the Changeworks [90] and FRESH [89] projects demonstrate that high resolution data for these criteria can be obtained through liaison with local authorities. However, implementing this kind of liaison across the UK would be very resource intensive and would present challenges in terms of data protection [103], as previously identified this would also depend on the willingness and or ability of the relevant local authority to engage. Therefore, a trade-off arises between sustaining a focus on high resolution data and the potential for scaling the index across the UK.

The theoretical datasets assessed in this analysis sought to add to depth to current approaches to energy poverty measurement in the UK. Reference to Table 5 and the Annex tables shows a broad range of datasets available at high resolution scale, including some which are not included in current UK energy poverty metrics. Specifically, the analysis showed the availability of data for the "Heating and Cooling" criteria and for "Education". The UK is typically associated with cold winters, however, given current climate change projections it may be prudent to consider including cooling datasets in the development of energy poverty metrics [17, 66]. Education is considered to impact awareness of and access to energy poverty support schemes [12], the analysis demonstrated a range of educational datasets which could be built into future energy poverty assessments.

To summarise, data is available for each criterion evaluated, although these are not available in a consistent format but in different country groupings depending on the dataset in question. This data is generally available at a high scale of spatial resolution. Exceptions occur in the "Socioeconomic"

sector where data at this level was mostly only available from the 2011 Census, raising questions about the representativeness of this data for current analysis. In the other sectors it is possible to supplement data that would otherwise have been available from the Census with Housing Condition or EPC data, with EPC data being particularly valuable given its ability to provide data about individual households. While EPCs are highly valuable sources of data some concerns have been raised about their accuracy, where discrepancies have occurred in EPCs generated for similar building types. This has been attributed to differences in assessor expertise and the requirements of accreditation body [106]. Supplementing Census data can imply a lower level of spatial resolution.

Finally, a broad range of spatial scales are observed in the datasets investigated, these vary between countries and are not directly comparable, therefore any attempt to generate a UK wide index at high spatial scale resolution would have to develop a method to standardise these datasets. With the datasets in their current format, it would be necessary to carry out separate indexes for each country, or possibly for Scotland, Northern Ireland and then Wales and England jointly. In line with the assertions of Gouveia *et al.* [12] when referring to the Portuguese case study, this approach would provide a barometer of vulnerability, rather than a strict street level identification of energy poverty.

Table 5. Data types and required inputs for an energy poverty vulnerability index

Data Type	Required inputs
1.Climate/region: [12], [15]; [26]; [101], [102], [103], [107]	1.1 Heating degree days
	1.2 Cooling degree days
	1.3 Outdoor temperature
2.Building typology: [12],[26]; [94] [101], [102], [103], [108]	2.1. Apartment/house, no of floors
	2.2. Construction years
3.Building characteristics: [12], [14], [15], [22] [26], [32] [101], [102], [103] [107], [108]	3.1. Walls
	3.2. Pavement
	3.3. Ceiling/Roof
	3.4 Glazing
	3.5 Ventilation
4.Other indicators for benchmarking: [12],[101], [102], [103], [109], [110], [111]	4.1. Social tariff support
	4.2. EU SILC indicators
	4.3. Social housing
	4.5 Non-conventional dwellings
5.Energy consumption: [12], [26]; [101], [102], [103]	5.1. Per end use
	5.2. By region
6.Climatisation equipment: [12], [21], [70]; [95] [101], [102], [103], [108], [109] [111]	6.1. Levels of ownership
	6.2. Type
	6.3. Efficiency
7.Socio-economic data: [12], [14], [15], [26], [70], [94], [95], [101], [102], [103], [107], [108],[112]	7.1. Educational level
	7.2. Average income
	7.3. Elderly and young people
	7.4. Conservation status of the building
	7.5. Tenure of the house
	7.6 Occupancy rate

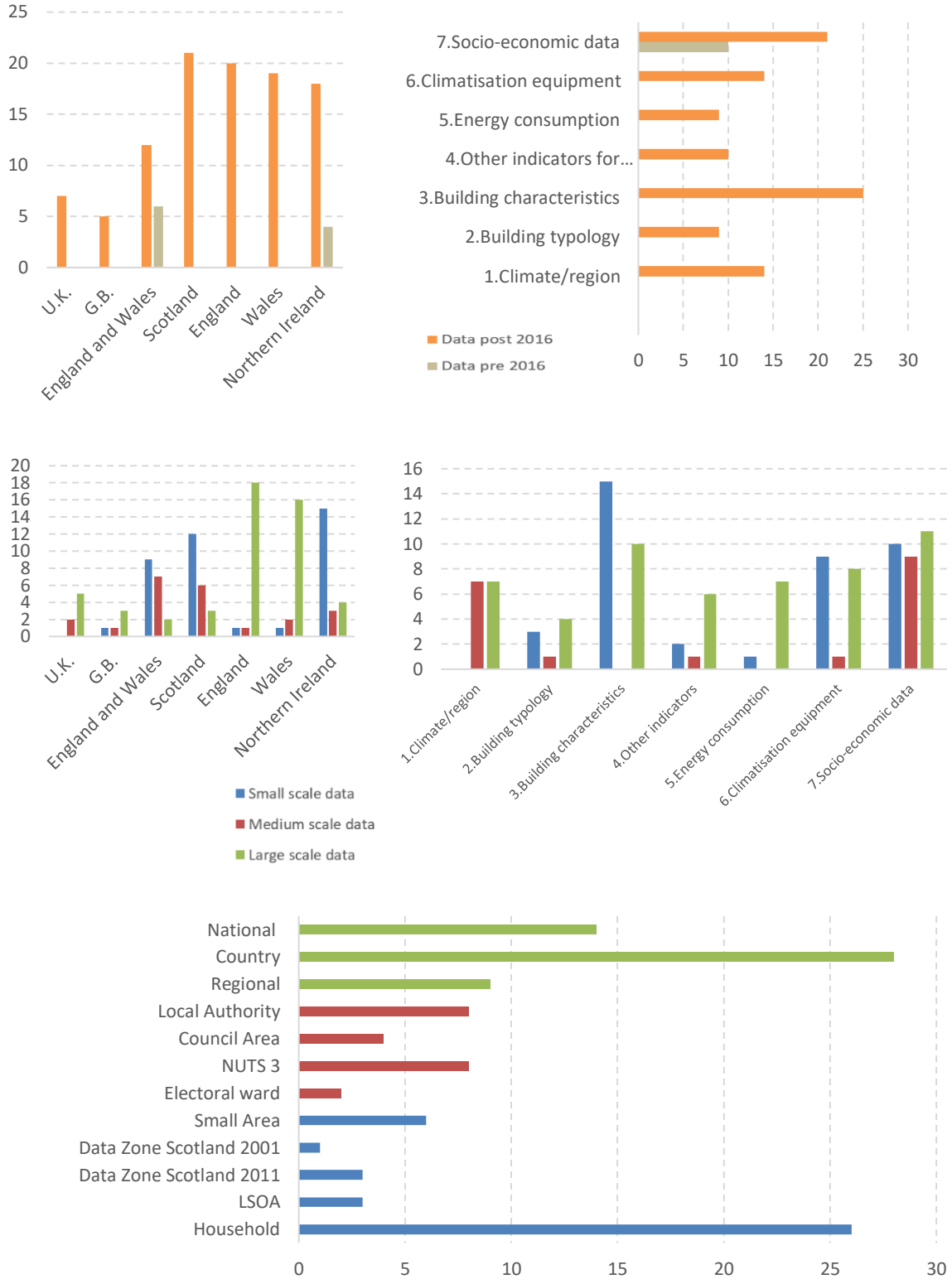

Figure 2. Number of sources by UK country grouping, data source, spatial scale and date

Table 6. Spatial scale definitions UK administrative geographies

Spatial scale	County/ countries applies to	Definition
Household	UK	Data available at individual household level
Lower Layer Super Output Area (LSOA)	Great Britain	The average number of households within LSOAs in England and Wales on 27 March 2011 was 672 [100].
Data Zone Scotland 2001/2011	Scotland	Data zones are grouped Output Areas with between 500 and 1,000 residents. Defined as the key geography for small area statistics in Scotland [105]
Small Area	Northern Ireland	Small areas were introduced after the 2001 Census to produce areas which fit into the SOAs [100]
Electoral ward	UK	Spatial unit used to elect local Government of statistical purposes all of the UK is considered as having electoral wards. In 2015 the UK had 9,196 [113]
Local Council	Northern Ireland	11 Local Council areas in Northern Ireland [114]
NUTS 3	All	A European statistical measure used for specific diagnoses, there are 1348 NUTS 3 regions [115]
Council Area	Scotland	Scotland divided into 32 Council Districts [116]
Local Authority	England and Wales	Local Authority may refer to; a County Council, a District Council, a London Borough Council, the Common Council of the City of London the Council of the Isles of Scilly, a Unitary Authority in Wales [117]
Regional	UK	Used to refer to wide areas within the UK. E.g. North West, South East [118]
Sub-national	England	In the datasets studied sub-national was used to refer to the North, South East, Rest of England.
Country	Devolved U.K. administrations	The term “Country was used to refer to datasets available for the Wales, Scotland, Northern Ireland or England separately
National	UK	The term "National" was used to categorise datasets applying to the UK as a whole

3.3 Value of Application

Considering the preceding analysis collectively, a high spatial scale approach for the UK is broadly feasible, however, this task requires political commitment to agree on a common pathway. This approach would account for a broader range of vulnerability criteria, the need for which is identified in a range of recent sources [5,57, 58, 59,60, 119,]. A common multidimensional approach could offer an innovative insight into the extent and depth of energy poverty across the UK where currently spatial assessments only offer a perspective on the UK countries individually. Section 3.1 highlighted an under-use of spatial data in UK energy poverty policy, therefore this approach also has the potential to guide resource allocation and the address of regional inequalities. A balance must be struck between mitigating the impacts of “masking” associated with index scaling [14], and the resource intensity involved with the inclusion of local data [89, 90, 95].

There is a growing drive for an EU approach to energy poverty which allows for inter-comparison between Member States [120]. Presently, the EU is a long way from understanding the individual national drivers of energy poverty, as inter-State comparison is in its infancy and indexes are based on general, not specific drivers [13]. The Openexp report identified a need to develop regional work, requiring refinement of current EU statistical collection processes. Furthermore, inconsistencies in the availability of key datasets presented a barrier for index development [13]. The works of Gouveia *et al* [12], Martin-Consuegra *et al.* [103] and Besagani *et al.* [101] at multiple scales represent a

comprehensive and innovative progression for inter-country comparison but the scope of what is being addressed also varies (only heating energy poverty, both heating and cooling, or a wider inclusion of energy services). Nevertheless, these assessments are based on centralised political systems (be they at local or national scale) as opposed to the diverse range of political systems which operate within the EU. Clearly facilitating regional inter-state comparisons within countries requires an advancement of data equivalisation methods between divergent political systems. The use of proxies could be applied in order to achieve this equivalisation.

With its devolved political nature, high level of data availability and an extensive research background, the UK could be a useful testbed for developing cohesive European energy poverty assessments. The complexities uncovered within the UK are therefore a useful insight into the transferability of energy poverty index methodologies at a European scale. The outputs of this process would feed into methodologies for scaling up indexes while accounting for a range of vulnerability indicators, facilitating knowledge transfer and policy development. This work identified that a trade-off arose between the availability of recent data and the availability of data at high spatial scale. Access to recent datasets (held by local authorities for instance) is limited due by data confidentiality restrictions. While acknowledging the rationale for these restrictions, it is not possible to fully account for data availability without this information. Future work should therefore focus on contacting the relevant bodies in order to overcome this obstacle.

Another limit of this work is related to energy poverty drivers and the data sources included in the analysis. The authors citied several works highlighting the importance of including broader drivers within the assessment of energy poverty, while some of these were included in the index, emergent social drivers such as those explored by Hargreaves [58], Middlemiss [59], Longhurst [60] and were not. The justification for this is that there is comparatively little evidence of how these drivers influence energy poverty and policy at a greater scale, future work should consider how these drivers could be integrated into a quantitative index.

4. Conclusions and Policy Implications

This assessment investigated the potential of producing a multidimensional high-resolution spatial scale energy poverty index for the UK case study. Findings demonstrate that, while from both a perspective of value and viability this approach is broadly feasible, some key datasets were not collected regularly, with implications for the representativeness of the results. In some cases, this data could be supplemented, but this generally implied a reduced level of spatial resolution.

The complexity of the UK administrative system also presented several key challenges. Firstly, the necessary datasets for input into an index are not available at a consistent level of spatial resolution. Secondly, the collection of these datasets is not uniform across the devolved countries, showing variations in the countries which these datasets refer to. These issues, whilst not insurmountable, would have to be carefully considered in the analysis conducted. Perhaps most critically, this analysis demonstrates that although a series of efforts have been made to assess energy poverty within the individual UK countries, these have not been used to gain an overall perspective of UK energy poverty. Although high spatial scale assessment of energy poverty is becoming increasingly refined, in the UK, a country which has made consistent efforts to tackle energy poverty, its potential for supporting policy has not been fully explored.

The value of a high-resolution spatial scale multidimensional approach is the opportunity to apply a common UK standard, highlighting inequalities and introducing consistent monitoring. The current UK policy approach to energy poverty is fragmented, making accurate inter-country comparisons difficult. Decision making is not based on a sound understanding of how energy poverty manifests across the UK but is instead based on how the issue manifests in the separate countries. This inconsistent overview of energy poverty risks decisions being based on information which is misrepresentative. Future UK policy must therefore be informed by measures which are inter-comparable between the devolved countries, highlighting the importance of developing appropriate methodologies, such as the approach discussed in this paper.

Additional research is needed into how UK policy administration and levels of energy poverty are linked. Levels of energy poverty in England are lowest - this coincides with more regular energy poverty reporting. Hence, the English administrative approach may have useful insights for the remaining UK countries. Key UK energy poverty policy recommendations are listed below: 1) Use existing data to guide the “help the worst first strategy”. Comparative statistics demonstrated that levels of energy poverty were greatest outside England. Several existing studies identified the areas in each country where energy poverty was most severe, yet there is little evidence of how this data is being applied in UK energy poverty policy. 2) Standardise assessment energy poverty policy across the UK countries. This would require all four countries to have similar legal obligations in terms of energy poverty and conducting key activities such as Housing Conditions Surveys with the same regularity in each UK country. 3) Increase data availability for energy poverty assessment. Some datasets were not available at the requisite scale for analysis, such data would be held by local Councils, obtaining this data would be resource intensive and potentially limited by data protection. Strategies need to be devised for the release of this data without compromising confidentiality. 4) Reliable and accessible EPC data. Given the importance of EPCs to this kind of analysis, it is critical that EPC data is of a standard high quality. 5) Broaden the range of criteria and scope used to assess energy poverty. Recent academic discourse has highlighted the importance of diversifying the range of indicators used to assess energy poverty and including space cooling vulnerability.

The UK has been at the forefront of addressing energy poverty in the past and remains highly advanced in this field, with a unique range of Governmental policy targeted specifically at this condition. Despite this advanced status of policy response, the impacts of the UK’s exit from the European Union present a series of uncertainties for future manifestations of UK energy poverty, some with specific relevance to this evaluation. The identified dataset for “Heating and Cooling Degree Days" was part of an EU database, and several SILC data were unavailable for the UK for 2018, presumably as a result of the UK’s impending exit. Furthermore, while EPC data is collected within the UK, the implementation of EPCs was a result of wider EU legislation. Should similar legislation be implemented in the future, the UK will not be a participant and therefore risks stagnation within the field. Finally, the potential for Member State knowledge transfer has been highlighted as critical to the resolution of energy poverty. The upcoming “looser” relationship between the UK and the EU signifies that the UK is less likely to participate in EU wide energy poverty discourse, representing not only a loss to the remaining EU 27, but also to the UK.

Notwithstanding this complication, the UK is a useful case study for the development of energy poverty policy given the comparative maturity of UK policies within a European context. By assessing the viability of a high-resolution multi-dimensional approach to energy poverty in the UK, this analysis proved to be insightful from a more general perspective regarding the transferability of energy

poverty assessments. Political unity is necessary in UK energy poverty mitigation for the creation of comparable datasets as well as consistent measures and policies. The root of the current varied status of UK energy poverty lies within the policy response to the issue. Nationally devolved policy has led to the devolution of energy poverty policy, with the result that energy is not measured in a consistent way across the country. While there is a call within European debate to reflect individual national characteristics in the assessment of energy poverty, this analysis raises questions about the extent to which separate policies can impact energy poverty levels.

The outputs of this process show that common approaches will have to be suitably flexible to allow for the specifics of each Member State in order to be both accurate and informative. They will also need to be scalable for comparison purposes. Nations at a developmental stage of energy poverty policy should therefore take care that assessment methods allow for transparent comparisons between different regions of the same country, facilitating the logical distribution of resource. This could be particularly relevant for nations such as Germany where federal states have a high level of authority. Further policy development could then focus on creating common datasets to allow for inter-European comparison, both at the regional and national level. This would allow knowledge transfer and potentially reduce the timeframes involved in mitigating energy poverty. The challenges encountered in this analysis are consistent with the challenges which apply to creating common European methods for assessing energy poverty at a regional scale.

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Annex-A Data source review-Characterisation of data sources for the UK Countries

Table A.1. Climate region and Building Typology data sources

Data Type	Required inputs	Availability of Data by Country Grouping													
		U.K.		G.B.		England and Wales		Scotland		England		Wales		Northern Ireland	
		Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res
1.Climate/region	1.1 Heating degree days	EUAGRICAST [12]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3
	1.2 Cooling degree days	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3	EUAGRICAST [121]	NUTS 3
	1.3. Outdoor temperature	Met Office UK & Regional series [122]	Regional	Met Office UK & Regional series [122]	Regional	Met Office UK & Regional series [122]	Regional	Met Office UK & Regional series [122]	Regional	Met Office UK & Regional series [122]	Regional	Met Office UK & Regional series [122]	Regional	Met Office UK & Regional series [122]	Regional
2.Building typology	2.1. Apartment/house, nº of floors	N/A	N/A	N/A	N/A	Domestic EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland Domestic EPC Register [127]	Household
	2.2. Construction years	N/A	N/A	N/A	N/A	N/A	N/A	Scottish House Condition Survey 2017 [128]	Local authority	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland House Condition Survey 2016 [129]	Council areas

Table A.2. Building characteristic data

Data Type	Required inputs	Availability of Data by Country Grouping													
		U.K.		G.B.		England and Wales		Scotland		England		Wales		Northern Ireland	
		Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res
3.Building characteristics	3.1. Walls	N/A	N/A	N/A	N/A	Domestic EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland Domestic EPC Register [127]	Household
	3.2. Pavement/floor area	N/A	N/A	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland Domestic EPC Register [127]	Household
	3.3. Ceiling/Roof	N/A	N/A	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland Domestic EPC Register [127]	Household
	3.4 Glazing	N/A	N/A	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland Domestic EPC Register [127]	Household
	3.5 Ventilation	N/A	N/A	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland Domestic EPC Register [127]	Household

Table A.3. Other indicators and Energy consumption data

Data Type	Required inputs	Availability of Data by Country Grouping													
		U.K.		G.B.		England and Wales		Scotland		England		Wales		Northern Ireland	
		Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res
4.Other indicators for benchmarking	4.1. Social tariff support	N/A	N/A	Quarterly benefits summary 2018 [130]	National	N/A	N/A	Economic Activity, Benefits and Tax Credits [131]	Data zone 2001	English Housing Survey 2017-18 [125]	Country	National survey for Wales 2018 [132]	Country	Northern Ireland Benefits Statistics Summary [133]	Small Areas
	4.2. EU SILC indicators	SILC ESQRS UK 16 [134]	National	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	4.3. Social housing	N/A	N/A	N/A	N/A	N/A	N/A	Local Authority Housing Council Housing [135]	Council areas	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Local authority	Northern Ireland House Condition Survey 2016 [129]	Country
5.Energy consumption	5.1. Per end use	Energy consumption in the U.K. 2019 [136]	National	Energy consumption in the U.K. 2019 [136]	National	Energy consumption in the U.K. 2019 [136]	National	Energy consumption in the U.K. 2019 [136]	National	Energy consumption in the U.K. 2019 [136]	National	Energy consumption in the U.K. 2019 [136]	National	Energy consumption in the U.K. 2019 [136]	National
	5.2. By region	N/A	N/A	Lower and Middle Super Output Area electricity consumption & Lower and Middle Super Output Areas gas consumption [137], [138]	LSOA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Sub-national electricity consumption in Northern Ireland & Sub-national gas consumption statistics in NI: 2019 [139], [140]	Council areas

Table A.4. Climatization equipment data

Data Type	Required inputs	Availability of Data by Country Grouping													
		U.K.		G.B.		England and Wales		Scotland		England		Wales		Northern Ireland	
		Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res
6.Climatisation equipment	6.1. Levels of ownership	N/A	N/A	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Country	N/A	N/A	Northern Ireland Domestic EPC Register [127]	Household
	6.2. Type	Energy Consumption in the U.K. 2019 [136]	National	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	Household	English Housing Survey 2017-18 [125]	Regional	Welsh Housing Conditions Survey 2018 [126]	National	Northern Ireland Domestic EPC Register [127]	Household
	6.3. Efficiency	N/A	N/A	N/A	N/A	EPC bulk data [123]	Household	Domestic Energy Performance Certificates [124]	National	English Housing Survey 2017-18 [125]	Regional	N/A	N/A	Northern Ireland Domestic EPC Register [127]	Household

Table A.5. Socio-economic data

Data Type	Required inputs	Availability of Data by Country Grouping													
		U.K.		G.B.		England and Wales		Scotland		England		Wales		Northern Ireland	
		Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res	Relevant source	Spatial Res
7.Socio-economic data	7.1. Educational level	Education and Training Statistics for the United Kingdom: 2018 [141]	National	N/A	N/A	2011 Census [142]	Electoral Ward	Education, Skills and Training [143]	Council areas	N/A	N/A	National survey for Wales [132]	National	2011 Census [144]	Small Areas
	7.2. Average income	Regional gross disposable household income, UK: 1997 to 2017 [118]	NUTS 3	N/A	N/A	2011 Census [142]	Electoral Ward	Scottish Index of Multiple Deprivation (SIMD) 2016 [145]	Data Zone	The English Indices of Deprivation 2019 [146]	LSOA	Welsh Index of Multiple Deprivation 2019 [147]	LSOA	Northern Ireland Multiple Deprivation Measures 2017 [148]	Small Areas
	7.3. Elderly and young people	N/A	N/A	N/A	N/A	2011 Census [142]	Local authority	Children and Young People & Population [149], [150]	Data Zone 2011	English Housing Survey 2017-18 [125]	Country	National survey for Wales [132]	Country	2011 Census [144]	Small Areas
	7.4. Conservation status of the building	N/A	N/A	N/A	N/A	2011 Census [142]	Local authority	Scottish House Condition Survey 15-17 [128]	Local authority	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	Northern Ireland House Condition Survey 2016 [129]	Country
	7.5. Tenure of the house	N/A	N/A	N/A	N/A	2011 Census [142]	N/A	Housing [151]	Local authority	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	2011 Census [144]	Small Areas
	7.6 Occupancy rate	N/A	N/A	N/A	N/A	2011 Census [142]	Local authority	Housing [151]	Data Zone 2011	English Housing Survey 2017-18 [125]	Country	Welsh Housing Conditions Survey 2018 [126]	Country	2011 Census [144]	Small Areas