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1 Introduction

Fuel poverty has become an increasingly important issue at EU level and in several member states [1,2]. A growing number of policy packages are in place to tackle fuel poverty [1,3] and research into the subject has intensified over the past year. While the UK serves as a pioneer in fuel poverty research, with more than 20 years of experience [4,5], research has only taken place in other European countries in recent years. Analyses exist for France [6,7], Greece [8–10], Slovakia [11], Portugal [12], Austria [13], Belgium [14], Italy [15,16] and Denmark [17], and initiatives such as the Fuel Poverty Network and the European Energy Poverty Observatory (EPOV) facilitate dialogue between relevant stakeholders to identify and resolve fuel poverty issues. Several studies have also been undertaken in Germany [18–24] and the Federal Ministry of Education and Research encourages discussion about fuel poverty as part of its “Research for Sustainable Development” agenda; however, the issue has long been almost a “blank spot” on the German research agenda [25].

There are many reasons why greater attention is being paid to fuel poverty and these reasons differ from country to country. A key issue is the growth in fuel prices; in Germany, for example, household expenditure on heating oil (+ 230%), natural gas (+100%) and electricity (+80%) has increased significantly over the last two decades (1994-2014) [26]. This development not only puts pressure on low income households, those living in energy inefficient homes or with disproportionate energy needs; it also compels policymakers to develop strategies for tackling fuel poverty because fuel poverty creates a number of costs for both the individual and society. Studies indicate that cold and uncomfortable homes negatively affect physical health and mental wellbeing [27] and in the worst cases can cause premature death [28,29]. Fuel poverty reduces living standards and the everyday habits of those living in fuel poor homes and can contribute to social exclusion [13,30].

Consequently, national governments, local authorities and NGOs have implemented policies and programmes to reduce fuel poverty. However, evaluations of such policies and programmes show that they barely reach fuel poor homes [31] or, as Boardman (2010 p.66) concluded, “policy has been poorly targeted, resulting in high levels of misspent money, often more than three-quarters of the money in a fuel poverty policy failing to reach the fuel poor”. Against the background of limited local and national budgets, this finding raises the question of how fuel poor homes can be more effectively identified and targeted to ensure that funds are used to benefit those who most need help. To examine this issue, the author provides an overview of existing fuel poverty measurements and their limitations in targeting fuel poor homes. This study uses an area-based approach, assessing neighbourhoods in terms of their fuel poverty vulnerability. Therefore main driving forces of fuel poverty were identified and their relative impact was assessed using a GIS-MCDA. In contrast to existing policies and programmes, which measure fuel poverty at individual level, this approach assesses the fuel poverty vulnerability of neighbourhoods in terms of their specific characteristics. This not only offers an interesting insight into the spatial distribution of fuel poverty within a city, but also provides the opportunity to tailor policies and actions to those neighbourhoods most in need.

2 Measuring fuel poverty and its limitations

2.1 Macro scale measurements

Measuring fuel poverty is a challenging task. It is a multi-dimensional phenomenon that varies according to time and place, depends on individual household conditions (e.g. household income and characteristics, specific energy needs etc.) as well as external conditions (e.g. energy prices, energy efficiency performance of the building) and is subjectively perceived by individuals [32]. Moreover, measurement metrics depend on the task in hand. At national or EU level, measurement determines the scale and nature of the problem and facilitates the monitoring of progress – but these approaches can be unsuitable for identifying fuel poor homes within streets, neighbourhoods or cities [33].

On a macro scale, there is extensive debate about how to measure fuel poverty [32,34]. There are two main approaches: expenditure-based and consensual-based. Expenditure-based metrics explore fuel poverty as the ratio between household income and energy expenditure and thus measure the affordability of energy services based on objective data. Households whose income/energy expenditure ratio is above a set threshold are considered to be fuel poor. Expenditure-based approaches have been applied and tested in several countries [32]. In contrast, consensual approaches measure fuel poverty based on subjective assessments about a household's ability to adequately warm its home and pay the energy bills on time. Here, self-reported indicators are used to explore perceived fuel poverty, which makes this approach less complex in terms of data collection. Consensual metrics are widely used for pan-European quantification because the EU-SILC survey provides a comparable dataset for EU member states [2,35]. The two approaches have different limitations in terms of both their analytical metrics and their ability to act as guiding principles for the development of policies to identify and target fuel poor homes.

2.2 Metrics-related limitations of the existing measurements

Expenditure-based approaches have several metrics-related limitations. Setting a threshold, for instance, is always normative and results from political negotiations (based on academic recommendations). Moreover, a relative or absolute threshold has different implications for policies. The UK's long-used 10% threshold is a typical example of an absolute threshold, as it measures the absolute amount of household income spent on energy [4]. However, the 10% threshold has been criticised because of its volatility in the face of changes in fuel prices [36]. Recently, England and Wales moved from an absolute threshold to a relative threshold, using the Low Income High Costs (LIHC) indicator. This defines a household as fuel poor if a) it has high energy costs above the national median; and b) it has low household income, which is defined as income below the 60% median poverty line [36,37]. However, this relative threshold has also been criticised because it can mask the impact of increasing energy prices and complicates the monitoring of the effect of political interventions [33]. Another criticism arises from the calculation of energy expenditure. Actual expenditure can be easily collected via household surveys; however, Liddell et al. (2012) [38] pointed out that low income households have a particular tendency to reduce their energy needs in order to cope with limited budgets, energy inefficient homes and increases in fuel prices, which makes actual fuel expenditure a poor indicator [32]. The use of calculated energy costs is, therefore, more appropriate when assessing fuel poverty [33] – but this calculation requires detailed knowledge of the energy efficiency performance of the building stock, which is rarely available anywhere else except in the UK [33,35]. Furthermore, modelling energy consumption always involves assumptions about heating patterns[1] and occupancy[2], which can contribute to incorrect estimations. Finally, the way in which household income is measured is also controversial. Three points must be taken into consideration: firstly, whether income should be adjusted according to household size for the purposes of measurement; secondly, whether income is measured before or after housing costs; and thirdly, whether social benefits (e.g. disability benefits) should be included in household income calculations [27,33].

[1] In Scotland, the average living room temperature for households comprising the elderly and infirm is 23°C, as opposed to 21°C in England [27,33].

[2] Todd (2006) [39] analyses the use of dwellings by households from different cultural backgrounds. The authors demonstrated that different cultural and traditional habits affect the number of rooms regularly used and heated, a fact that is hardly recognised in software calculating energy demand [39].

Although consensual approaches require less complex data collection and measurement algorithms, they also have several limitations. Firstly, a household's own assessment is highly subjective. This can contribute to the inclusion/exclusion issues mentioned below if a household *perceives* that it cannot keep its home adequately warm, although it can *objectively* do so (and vice versa). Secondly, the understanding of "adequacy of warmth" as asked in the EU-SILC survey is culturally specific and can differ between regions, countries etc. [2]. Finally, Thomson and Snell (2013) [35] pointed out that the widely used EU-SILC dataset was not originally designed to measure fuel poverty and the indicators used are only binary, which does not allow for a discussion about the severity of fuel poverty.

2.3 Limitations of the existing measurements in terms of their ability to act as guiding principles for identifying and targeting fuel poor homes

A clear definition and an appropriate measurement of fuel poverty are crucial for understanding the dimension of fuel poverty and for monitoring progress [1]. The metrics-related limitations outlined above demonstrate that further research is required, because different measurements can produce very different results. Heindl (2014) [19], for instance, applied several expenditure approaches for Germany , which produced a wide variation in the results – the share of fuel poor homes varied between 2.4% and 29.8%. In the UK, the change from the long-used 10% poverty line to the LIHC indicator significantly reduced the challenge of fuel poverty virtually overnight. Moreover, different metrics not only influence the number of homes identified as suffering from fuel poverty, but also produce different results concerning the characteristics of those households most in need. Palmer et al. (2008:16) [40], using the English Housing Condition Survey from 2005, compared the results of the objective expenditure-based 10% poverty line with the subjective assessment of the household and found little overlap. Only 6% of the households in fuel poverty according to the objective expenditure-based measurement stated that they could not adequately warm their homes in winter because of the cost. Waddams, Price et al. (2007) [41] also compared subjective and objective measurements and found similar results. In their sample, 28% of the households were fuel poor according to the 10% indicator, but only 16% felt subjectively fuel poor. Moreover, only half of the fuel poor households under the consensual approach were fuel poor according to objective expenditure-based measurements.

These results are concerning because measuring fuel poverty should be the first step in developing tailored policies for tackling fuel poverty. According to Sefton (2002: 372) [42], "a well-targeted programme is one that reaches a high proportion of the target group whilst minimizing the number of recipients who do not fall into the target group". Talking about the mismatching of target groups means talking about inclusion and exclusion [43,44]. The former refers to households that are determined as being eligible for subsidies although they are not actually fuel poor (not part of the original target group); the latter refers to households that actually struggle with fuel poverty but are excluded from state support due to the eligibility criteria. Evaluation of British fuel poverty programmes highlight the phenomenon of wrongful inclusion and exclusion [31].

There are many different reasons why the desired target groups are not always reached by the various policies and programmes. The lack of local scale data is one of the main reasons. The discussion above highlights the fact that there can be insufficient data for expenditure-based measurements to be applied at national level. At local level (at least in Germany) the availability of objective income or energy expenditure data for identifying fuel poor households is even more limited, or the available data is restricted due to data security regulations. Household surveys for collecting data on expenditure or consensual measurement are theoretically possible in every local authority area. However, this would require exhaustive surveys, which are time-consuming and costly. Consequently, the complexity of fuel poverty is not adequately reflected in the eligibility criteria of programmes. The criteria only reflect easily available indicators such as welfare benefits or socio-demographic data (e.g. age [7,45,46]). One example of wrongful inclusion and exclusion in the UK is the so-called Winter Fuel Payment (WFP), which is a one-off payment made in winter to all households in which one member was born before May 5th 1953 (for the 2016 payment). However, the programme is not means tested and ignores the financial status of the household. As a result, only 19% of those who received the WFP are actually fuel poor (inclusion) and only 50% of all fuel poor households are eligible for funding (exclusion due to age) [31].

Another aspect is the way in which many programmes are designed. In most cases, people have to apply for support and grants themselves ("self-referral"). This implies that a) households are aware of the existence of a programme; b) they consider themselves to be the target group; and c) they are willing to express their poverty. The last point in particular is a major obstacle for many fuel poor homes, because it is associated with the fear of being stigmatised as poor [6].

2.4 Alternative approaches for identifying and pinpointing fuel poor homes on the local scale

All these limitations result in the fact that the current approaches to measuring fuel poverty and designing policy strategies a) fail to reduce fuel poverty; and b) do not properly address those households most in need. This raises the question about more effective and efficient approaches for identifying fuel poor homes. Dubois (2012:110) [6] proposes the following three alternative approaches, with the aim of using limited financial and human resources more effectively to help and support those most in need:

a) direct identification through database cross-matching
b) decentralised identification
c) geographical identification as a proxy

Theoretically, the simplest way of identifying and pinpointing fuel poor homes is to cross-match existing databases on income and energy costs. Tax and local authorities hold data on income, and energy suppliers have information about household energy expenditure. Expenditure-based approaches could, therefore, be easily applied using this data, given the metric limitations mentioned above. However, these databases are not linked and privacy policy prevents database cross-matching in most cases.

Another option is the identification of fuel poor households by local experts. Actors who work directly within neighbourhoods and who are, therefore, well-connected may be able to detect fuel poverty. However, the success of such a strategy is highly dependent on the experts' knowledge of local circumstances. As local information cannot be both inclusive and objective, such identification will always be heavily biased [47].

Finally, geographical or area-based approaches are another option for pinpointing fuel poor homes. The idea behind area-based approaches is that small spatial units are relatively homogenous in terms of building and household characteristics. Consequently, these approaches do not measure fuel poverty at an individual level, but at a spatial unit level. They identify neighbourhoods, streets, blocks of flats etc. that show a high vulnerability to fuel poverty according to their building and household characteristics. The appeal of this kind of approach is that it does not use primary data (e.g. income, energy expenditure etc.) to identify fuel poor neighbourhoods, but instead uses supporting indicators (e.g. age, household size, building type etc.). This data is locally available and aggregation at spatial unit level avoids data security restrictions. Moreover, these indicators enhance the picture of fuel poverty and help provide a focus for policy actions, as they measure criteria that contribute to fuel poverty without measuring fuel poverty itself [34]. The challenge is to select the proxy indicators that best reflect the vulnerability to fuel poverty and to aggregate the data to an index to minimise inclusion and exclusion effects. Walker et al. (2013) [48] demonstrated the practicability and effectiveness of such an approach. They designed a spatial unit level "Fuel Poverty Index" (FPI) for Northern Ireland[3] and checked the results via door-to-door interviews in some of the identified spatial units: the results showed that in the spatial units identified as having a high fuel poverty risk in the FPI, up to 90% of the households were actually fuel poor.

Area-based approaches appear to be a promising alternative for enhancing the effectiveness of policies for tackling fuel poverty. There are several international examples but hardly any research activity in this area exists in Germany [51], despite the claim to take spatial diversity into account [52].

3 An area-based approach for identifying fuel poor neighbourhoods

3.1 Research method

The author used a GIS[4]-MCDA (multi-criteria decision analysis) to identify neighbourhoods with high vulnerability to fuel poverty. A GIS-MCDA is a method "to support a user or group of users in achieving higher effectiveness in decision making while solving a semi-structured spatial decision problem" [53]. Thereby, it is a "procedure that transforms and combines geographic (input maps) and the decision maker's (experts or agent) preferences in a decision (output) map"[53]. MCDA is widely applied to environmental issues such as green investments, energy planning and renewable energies [54–57]. GIS-MCDA is also widely used to solve spatial-related research questions [58]. It is primarily used for location decisions but, in this paper, it is applied as a tool for comparing the fuel poverty vulnerability of urban neighbourhoods and, thus, for pinpointing those spatial units most in need. The neighbourhoods considered are all within the chosen study area, and they are assessed and evaluated according to the defined criteria that affect fuel poverty vulnerability. The GIS part of this analysis is performed with QGIS[5].

To identify vulnerable neighbourhoods an AHP (Analytic Hierarchy Process) is used. AHP was developed by Saaty (1980) [59] and is one of the most frequently used MCDA approaches for solving spatial decision problems [58]. The method can be applied individually or through discussion by a group of experts. The benefit of the latter is that decision-making processes are more transparent and the results are, therefore, more robust because they are based on a consensual assessment of all participating experts in the group. [60].

An AHP consists of the following three main tasks: (1) decomposition; (2) pairwise comparison; and (3) overall assessment.

3.1.1 Decomposition

A literature review was conducted to identify the criteria for fuel poverty. According to Walker et al. (2012:641) [61], three dimensions of vulnerability to fuel poverty can be identified:

- Heating burden vulnerability
- Socio-economic vulnerability
- Building vulnerability

[3] Other examples of similar approaches to data aggregation and index construction exist [15,45,46,49,50].
[4] Geographic information system.
[5] QGIS is a free and open source Geographic Information System, which allows the user to create, edit, visualise, analyse and publish geospatial information.

Heating burden vulnerability relates to absolute energy expenditure and the relative trends of the market, spatial disparities of fuel prices, heating infrastructure and the macro, meso and micro location of a household's dwelling. Fuel costs increased dramatically in Germany over the past two decades (1994-2014); however, the price development differed between energy carriers with a tripling of heating oil prices, while natural gas prices "only" doubled [26]. Moreover, the price of heating oil is very volatile and differs between regions by up to 10%. Similar differences between oil prices can be observed in Northern Ireland [61]. Particularly those areas which are not grid-connected (i.e. for gas or district heating) show the potential for higher vulnerability [45,46,61]. Maritime or continental climate and height conditions influence the heating requirements of a building on a macro scale [7]. A building's location within the urban structure (meso scale) also has an impact because in densely built-up environments the so-called heat island effect may reduce heating demand [62]. Even on a micro scale, the position of a flat within a building affects heating costs – with ground-floor flats requiring up to 42% more space heating than flats on the second/third floor as these are surrounded by other heated flats and benefit from higher levels of solar radiation [21].

Socio-economic vulnerability consists of two aspects. Firstly, households have disproportionate heating demand because of their characteristics (social vulnerability). Secondly, households find it difficult to pay their heating bills due to their income levels (economic vulnerability).

The British fuel poverty strategy identifies "the very young, the oldest pensioners and people with long-term disability or illness" as highly vulnerable to fuel poverty [63]. Elderly people often live in oversized dwellings [64], spend most of their time at home [32,21] and have higher space heating requirements [66,67]. Elderly single person households are even more vulnerable [7,36]. Households with children, in particular those with small children, also have a high risk of becoming fuel poor [7,19,36]. Single parent families are particularly vulnerable, because reconciling family and working life is still a challenge in Germany with the result that single parents tend to work part-time, which limits their household income.

From an economic perspective, Hills (2012) [36] shows that unemployment is a key driver of fuel poverty. 30% of all households in England with at least one unemployed member are fuel poor, while only 10% of households comprising employed members are fuel poor [68]. Legendre and Ricci (2015) [7] find similar results for France.

The building physics, as well as the ownership structure, also plays an important role in fuel poverty vulnerability (**building vulnerability**). The energy performance of buildings differs according to their age, as construction methods and materials change over time. Moreover, until 1977 new residential buildings in Germany were not obliged to meet any minimum energy standards. The German residential building typology sums up these two aspects and shows that, in particular, homes built before and directly after the end of World War II have worse energy performance standards than those built since the 1960s [69]. The building physics of detached houses also contributes to higher fuel poverty vulnerability compared to multi-unit properties because of their surface-heating volume ratio, which (all other factors being equal) is usually worse than for multi-unit properties.

The ownership of a building is a further aspect that affects its energy performance, as it is the owner who decides whether or not to refurbish the building. The literature shows disparities between owner-occupied and rented homes; in Germany, homeowners invest more than landlords in energy renovation projects [70]. Legendre and Ricci (2015) [7] emphasised the fact that the fuel poverty risk for homeowners is significantly lower than for tenants. In the rental market, energy performance differs between different owner groups – particularly between small private landlords (SPL) and common ownership communities (COC) [71]. Overall, the literature shows that fuel poverty is a complex phenomenon and underlines the fact that undifferentiated measurements for identifying fuel poor homes are inadequate.

As a second step, the identified criteria of fuel poverty were operationalised with measurable and locally available indicators. The author cross-matched available data for the case study of Oberhausen (as described below). A total of 12 indicators were determined as the basis for the GIS-MCDA.

3.1.2 Pairwise comparison

The pairwise comparison is a technique where experts compare the relative importance of criteria within a defined hierarchical structure of a decision problem. The advantage is that only two criteria are compared at the same time, which reduces the complexity for the experts. Moreover, the technique allows for a consistency check [60].

In this case, a group workshop (group AHP) was organised comprising three researchers who have been working in the field of fuel poverty and social disadvantage over recent years. The experts were asked to assess the relative importance of the criteria and make a consensual judgement. The experts assessed the criteria on a scale from 1 (equal importance) to 9 (most important). Subsequently, the assessment was converted into criteria weights [59,60] (see Table 1).

3.1.3 Overall assessment

The overall assessment R_i of the fuel poverty vulnerability of each neighbourhood is arrived at by multiplying the criteria weights with the normalised (score range) criteria values. The results for each criterion were added to form the overall vulnerability:

$$R_i = \sum_k w_k * r_{ik}; \; \sum w_k = 1$$

w_k – weights of the k^{th} criteria of the hierarchical decision problem structure

r_{ik} – normalised values of the i^{th} alternative for the k^{th} criteria

Table 1 Dimension, criteria and indicators of fuel poverty

Dimension	Sub-Dimension	Criteria	Indicator	Source	Criterion Weight
Heating burden		Location	Heating Degree Days	DWD	0.7%
		Energy infrastructure	Share of heating demand covered by oil and storage heater	Heating Atlas	6.6%
Socio-economic vulnerability	Social vulnerability	Elderly people	Share of elderly people above 65 years (%)	Social Atlas	1.0%
		Household with children	Share of households with one or more children (%)	Social Atlas	3.1%
		Single person household	Share of single person households (%)	Social Atlas	1.2%
		Single parent family	Share of single parent households (%)	Social Atlas	10.8%
	Economic vulnerability	Poverty in old age	Share of old-age basic income support (%)	Social Atlas	24.1 %
		Unemployment	Unemployment rate (%)	Social Atlas	24.1 %
Building vulnerability	28.3 %	Heating demand	Specific heat consumption (kWh/m^2)	Heating Atlas	19.9 %
		Ownership	Share of SPL and COC (%)	Census 2011	2.7 %
		Building age	Share of buildings built before 1949 (%)	Census 2011	3.7 %
		Building type	Share of detached houses (%)	Census 2011	2.0 %

Source: own compilation

3.2 Sensitivity analysis

Expert judgements are always subjective and depend on the experience and knowledge of the experts involved. As a result, the weighting of the different fuel poverty criteria as described above would be likely to differ if other experts were asked, or if the same experts were asked at a different time. Therefore, the criteria weights and the results required validation and this was achieved by undertaking two different sensitivity analyses:

a) Involvement of other experts
b) Comparing results with shortlists [72] and average change in ranking [73]

In total, six experts were asked to assess the relative importance of the fuel poverty criteria. The author recruited experts from universities, applied science and NGOs[6]. As in the group AHP workshop, they also used the AHP technique, for which an Excel tool was prepared and e-mailed to all the experts. The experts were asked to use their individual judgement. A comparison between these experts' assessments and the results of the group workshop allowed for validation of the compiled criteria weights: the greater the variation in the results, the less valid the results. It was likely that the criteria weights would differ between experts; the question was how sensitive the results would be in terms of different criteria weights. Two methods were used to answer this question. The first method was adapted from Carver (1991) [72]. Shortlists of neighbourhoods were compared according to their fuel poverty vulnerability R_i. The author defined the shortlist to include neighbourhoods in the top 10% of the ranks (rank 1 to 17). The magnitude of the different results from the group workshop and the other expert judgements was measured by comparing the proportion of neighbourhoods that moved out of the top 10%. The second method measured the average change in rank of the total set of neighbourhoods according to the different expert judgements, in comparison to the reference (i.e. the group workshop results).

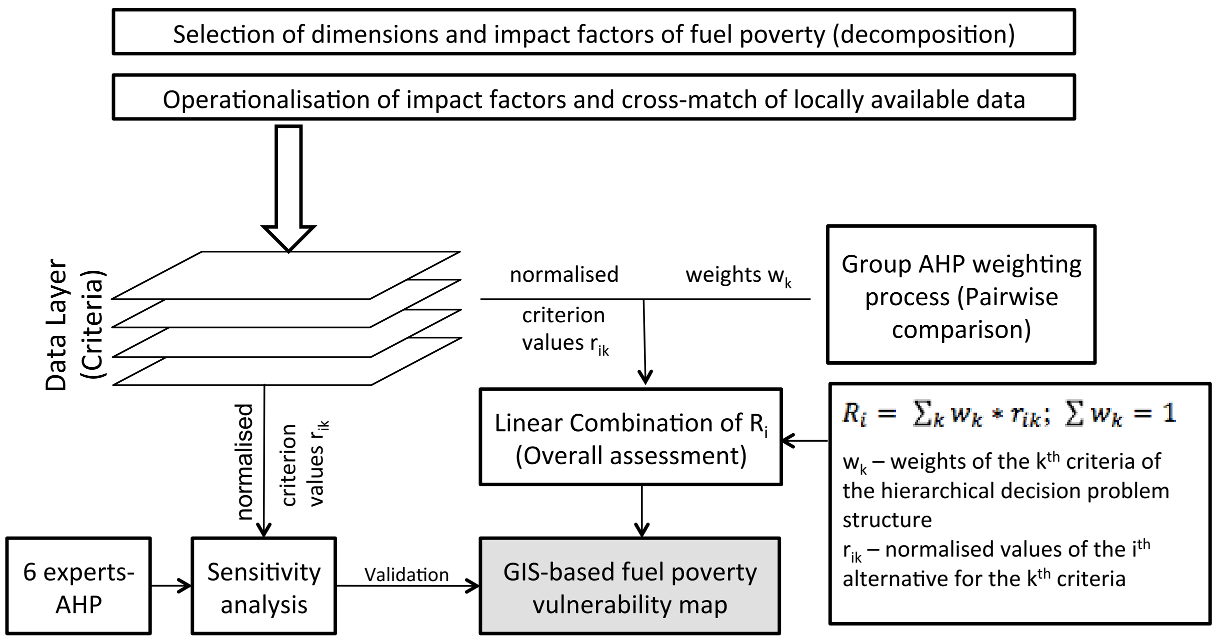


Figure 1 GIS-MCDA conceptual framework for identifying fuel poor neighbourhoods

Source: own diagram

4 Assessing fuel poverty vulnerability: Oberhausen case study

4.1 Case study selection

The area-based approach for identifying fuel poor neighbourhoods was applied to the city of Oberhausen. Oberhausen is a German city in the Ruhr area with approximately 212,000 inhabitants. Oberhausen's development was closely linked to the rise of the coal and steel industries at the end of the 19th century, but the subsequent decline of these sectors (starting in the 1950s) led to enormous socio-economic challenges for the city. Over the last 50 years, the city lost more than 50,000

[6] To ensure their anonymity the author does not name the experts. All the experts have long-standing knowledge of fuel poverty and work in universities, in applied science or in NGOs. All the experts are from Germany and are consequently familiar with the challenges related to the specific situation in Germany. The mix of scientific experts and practitioners provides a comprehensive picture of fuel poverty.

blueinhabitants and today has one of the highest levels of local authority debt per capita of all German cities. Typically for Germany, the building stock is mainly privately owned. Moreover, to tackle the debt crisis, local authority housing stock was largely sold off to private companies and individuals, with the result that local authorities have little influence on the energy performance of the building stock. In addition, the share of owner-occupied homes is low, meaning that residents can only influence their heating costs by behavioural change. Oberhausen residents also have one of the lowest levels of income per capita of all large German cities. These circumstances have created a breeding ground for fuel poverty within the city. However, the general development as outlined above is not representative of the entire city; some areas have developed in line with these trends, but others have followed very different pathways. Therefore, it is reasonable to assume that there are hotspots of fuel poverty vulnerability within the city that should be identified and further investigated.

4.2 Data

In Germany, local scale data is rare and there is no single database containing all the relevant data. Official statistical offices only compile data at local authority level, which does not allow for comparison between neighbourhoods. Existing surveys, e.g. SOEP (Socio-Economic Panel), EVS (Income and Consumption Survey) and the German micro census collect much of the data required to measure fuel poverty vulnerability, but these surveys are designed to produce representative findings at national or regional level. There is not a culture of local scale surveys like there is in Great Britain (e.g. the UK Housing Survey). Therefore, neighbourhood data is only collected by local authorities and the principles of such data collection differ from local authority to local authority, which makes comparisons between cities difficult. In the case of Oberhausen, data from the local "Social Structure Atlas" is used to operationalise the residential structure of each neighbourhood. In addition, the city has compiled a "Heating Atlas", which includes information on heating demand and energy carriers used. Data on buildings was collected by a census in 2011, while climate data is produced by the German Meteorological Service (DWD). All this data is available for 2011 and aggregated in this study to represent 168 statistical units/neighbourhoods.

4.3 Results

The results of the analysis show that the neighbourhoods suffer from different levels of fuel poverty vulnerability (see Figure 2[7]). The overall risk index R_i is particularly high for neighbourhoods in the south, southeast and east of Oberhausen. In contrast to other parts of the city, where high vulnerability can be observed selectively, here there are "hotspots" of fuel poverty. On the one hand, these areas are characterised by a high unemployment rate, a high share of old people living in poverty, single parent families and households with children, building stock that was mainly built before 1949 and ownership dominated by small private landlords and common ownership communities – all aspects which contribute to high fuel poverty vulnerability. On the other hand, these neighbourhoods are mainly supplied by district heating, multi-unit properties are the dominant building type and heating consumption is below the city average – all aspects which contribute to low fuel poverty vulnerability.

This demonstrates the two limitations of this analysis. Firstly, the overall assessment R_i produces a general overview of a neighbourhood's vulnerability. However, it is based on the aggregation of the three fuel poverty dimensions, which may lead to overlaps between those criteria that create a tendency towards fuel vulnerability and those criteria that inhibit it. Secondly, it is obvious how important the weighting of these criteria is for effectively distinguishing areas with high vulnerability from those with lower vulnerability. Consequently, the validity of the results and their usefulness in

[7] All maps share a five class quantile classification scheme. This method was used because it places an equal number of neighbourhoods into each class, which allows for a suitable visual comparison between the different maps [74].

designing tailored policies is limited by the lack of sensitivity of the aggregated data, on the one hand, and the subjectivity of the experts' assessment on the other hand.

To tackle the first limitation, it is useful to analyse R_i in relation to the three defined dimensions of fuel poverty (heating burden, socio-economic vulnerability and building vulnerability) (see Figure 3). A separate perspective for each dimension offers a more comprehensive understanding of fuel poverty. In doing this, the results show a different spatial distribution of fuel poverty vulnerability depending on the dimension analysed. In terms of heating burden and building vulnerability, the distribution is quite similar (with high risks in the north and north-east areas of the city), while in terms of social vulnerability the neighbourhoods in the south/south-east and east show high vulnerability.

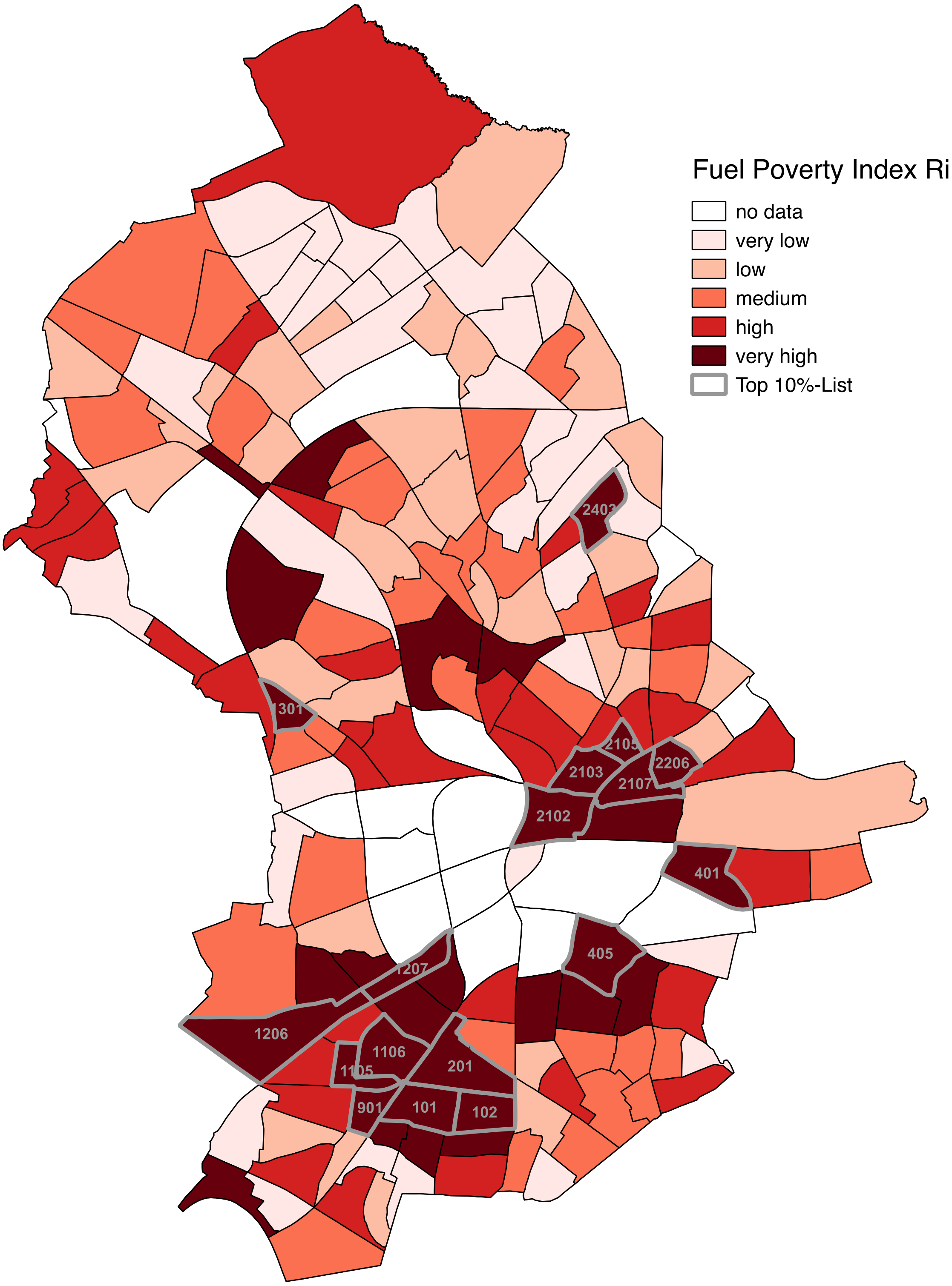


Figure 2 Fuel poverty vulnerability R_i based on Group AHP Workshop[8]

Source: own calculation and visualisation

[8] Numbers within the highlighted neighbourhoods represent neighbourhood IDs

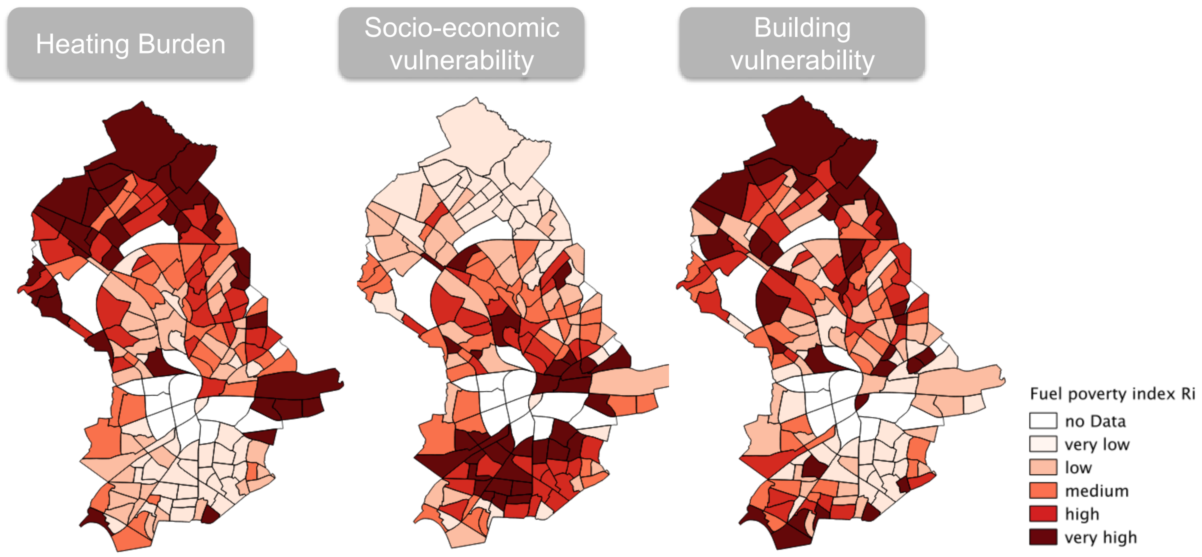


Figure 3 Fuel poverty vulnerability, differentiated by the three fuel poverty dimensions

Source: own calculation and visualisation

In terms of the second limitation, the author conducted the sensitivity analysis as described above. A comparison between the criteria weights produced by the group AHP workshop and the judgement of the other experts produces similarities but also differences. This is shown in Figure 4. The “0% line” represents the results of the group AHP. Bars above the “0% line” mean that the experts rated the importance of the criteria higher than in the group AHP model. Consequently, bars below this threshold indicate that the criteria were considered to be less important. For example, Expert 6 rated the relevance of the criterion “Energy Infrastructure” 23.6 percentage points higher than the group AHP. Thus, “Energy Infrastructure” explains 30% of the fuel poverty vulnerability of a neighbourhood for Expert 6 (6.6% group AHP rating plus 23.6% individual expert rating). As the sum of all weights must total 100%, Expert 6 clearly considers some criteria to be less relevant than the group AHP does, such as “Unemployment”[9] and “Heating demand”. The results can be classified into three groups: very similarly weighted criteria by all experts (location, single-person households, building type, building age, elderly people), comparable weightings of criteria by most of the expert assessments (energy infrastructure, households with children), and highly volatile weightings (single parent families, poverty in old age, unemployment, ownership and heating demand)[10]. The variation in weights of some criteria by the experts emphasises the difficulties of reaching a common understanding of fuel poverty. Additionally, it underlines the importance of careful expert selection.

[9] Given a weight of 2.8%, it is 21.4% less important for Expert 6 than for the group AHP.

[10] As the experts completed the Excel tool by themselves, the author is unable to explain the differences in expert judgement. One possible explanation, however, might be the different qualifications of the experts because it became obvious that economists rate economic criteria higher than social scientists do. Improvements could be achieved through a second contact (e.g. interview, delphi method), but this was beyond of the scope of this paper.

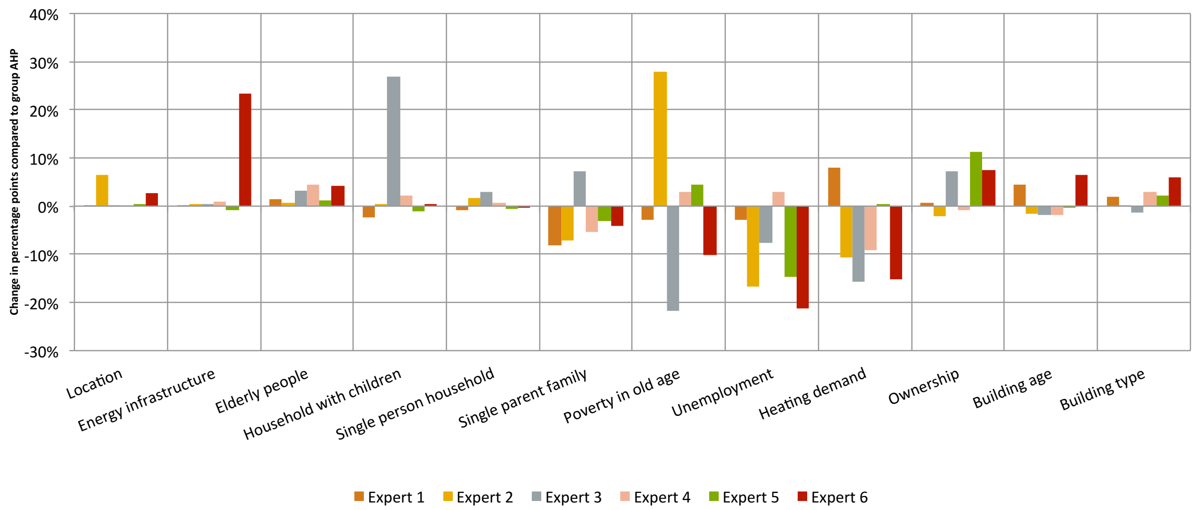


Figure 4 Criteria weights by different experts compared to group AHP weights (0%-line)

Source: own calculation and visualisation

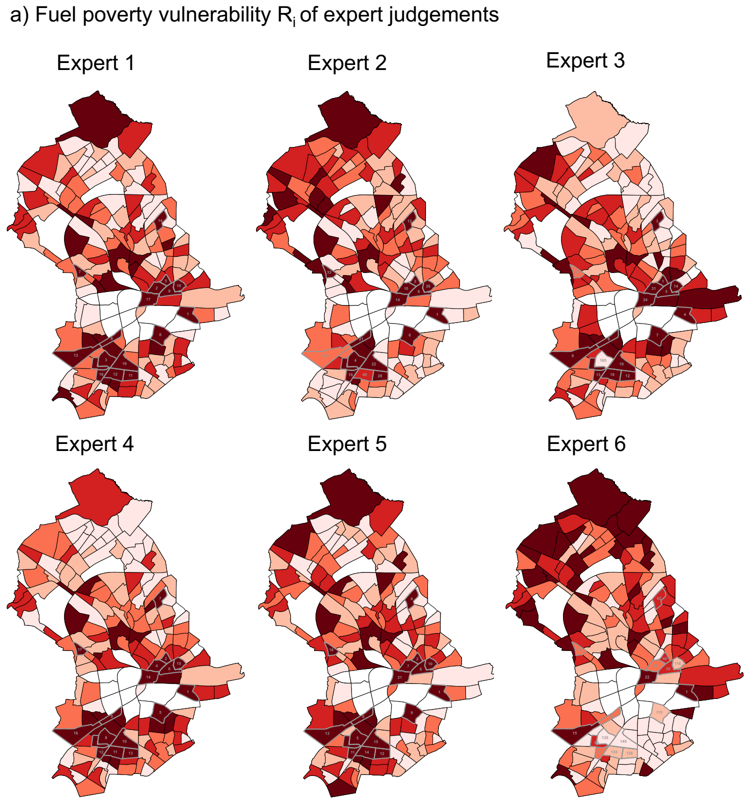
Variation in criteria weighting may also lead to quite different findings. Therefore, the second part of the sensitivity analysis consisted of a comparison between the results of R_i for the different expert judgements of fuel poverty criteria. The analysis emphasises two points. Firstly, the design of the index as an additive sum leads to an offset of criteria values that increase or reduce fuel poverty vulnerability. Consequently, the interquartile range (IQR)[11] of R_i is low, which contributes to a high average change in ranks (Figure 5 b/c). Secondly, the range in the lower quartile, and more importantly in the upper quartile, is much higher and the structure of neighbourhoods within the top 10% of the group AHP remains relatively stable compared to the average rank change of all neighbourhoods. Except for Expert 6, all other experts show a consistency of more than 50% with the top 10% list of the group AHP, with Expert 1, Expert 5 and Expert 4 having a consistency of over 90%. This means that almost all the neighbourhoods with very high fuel poverty vulnerability in the group AHP model remain highly vulnerable within the additional expert judgements, despite the above-mentioned changes in criteria weights. Neighbourhoods no. 401, 2105, 1105, 405, 2107 and 2403 all rank in the top 10% list in all judgements except in that of Expert 6[12]. The judgement of the Consumer Advocacy Centre North Rhine-Westphalia (Expert 6) varies significantly from all other expert assessments. As this organisation focuses on fostering energy efficiency in electricity use and gives legal advice for consumers affected by power cuts, the author assumes that this focus on energy in the form of electricity may have had a significant impact on the expert's judgements, as this expert gives a much higher rating than any other expert to energy infrastructure and the share of heat storage (which is significantly greater in the north than in the south of Oberhausen).

The robust results in terms of the top 10% list are also visible in Figure 5a. High or very high fuel poverty vulnerability can be observed in all maps in the south/south-east and east of the city (except in the judgment of Expert 6). Moreover, the maps show that even according to the judgements by Expert 2 and Expert 3 (who demonstrate low consistency with the top 10% list), these neighbourhoods are likely to remain highly vulnerable, which means they still rank within the upper quartile.

[Insert Figure 5 File]

[11] The IQR is the 1st quartile subtracted from the 3rd quartile

[12] This does not mean that significant changes do not exist. For example, neighbourhood no.1106 ranks 6 according to the group AHP weighting, but ranks 165 according to the judgement of Expert 3.



b) Consistency Top 10% list and average change in rank of expert judgements

No.	Field of Research	Institution	Consistency of 10 %	Average change in rank
Expert 1	Applied Science	Wuppertal Institute	94.1%	17
Expert 2	Applied Science	Centre of European Economic Research	52.9%	35
Expert 3	Research	University of Siegen	64.7%	28
Expert 4	Research	University of Applied Science Erfurt	100%	8
Expert 5	NGO	German Caritas Association	94.1%	24
Expert 6	NGO	Consumer Advocacy Centre North Rhine-Westphalia	11.8%	59

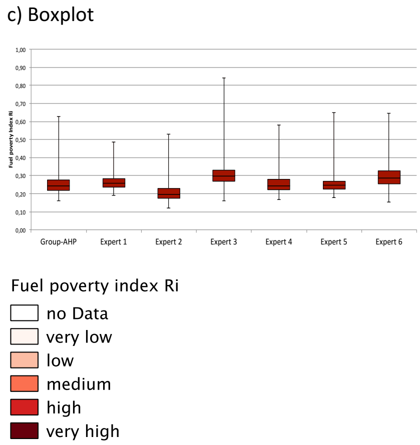


Figure 5 Results of sensitivity analysis of fuel poverty vulnerability R_i[13]

Source: own calculation and visualisation

5 Discussion

The analysis enhances the understanding of the complexity of fuel poverty and is, consequently, a first step towards the development of more effective spatially and content-adapted strategies and policies for tackling fuel poverty. It is difficult to draw clear policy recommendations based on a single case study; however, the selection of the city of Oberhausen was not incidental. It is representative of a number of similar cities suffering from economic decline. Such cities exist in the Ruhr area, in Saarland, in parts of East Germany and also in other European countries. Moreover, the neighbourhoods are heterogeneous, including a mix of middle-class detached properties and socially neglected areas etc. Therefore, the analysis enables the formulation of some initial thoughts for policy needs and improvements.

First, many European countries such as Germany have neither an official definition nor an official way of measuring fuel poverty. This is concerning because every discussion and every policy design requires a clear definition of the subject, as policies cannot be tailored if the target group remains unclear.

Second, many European countries lack the required data for measuring fuel poverty on the macro scale, nor do they have local scale data. The discussion about measurement metrics is essential, but while data availability on the local scale remains poor, supporting indicators are a good compromise for identifying and pinpointing the fuel poor. Here the evaluation of existing policies emphasises the

[13] Numbers within highlighted neighbourhoods represent the rank of each neighbourhood according to the respective expert judgement.

fact that simple indicators, such as being in receipt of welfare benefits, age etc., are inadequate for explaining the complexity of fuel poverty. Therefore, more comprehensive proxy indicators are required. Several authors have produced multivariate statistics from macro scale datasets to assess the impact of proxy indicators. This requires a) that the proxy variables on the macro scale are also available on the local scale; and b) that there is an official definition of fuel poverty in order that it can be measured as a dependent variable. If these conditions are not met, the approach presented in this study can offer a pragmatic alternative.

Third, fuel poverty is not equally distributed in individual areas. “Hotspots” and “coldspots” exist and these require different policy solutions. With regard to the “hotspots”, Boardman (2010:222) [75] proposes the introduction of Low Carbon Zones (LCZ) focusing on the worst housing and poorest people. The establishment of such zones, e.g. based on the top 10% list, offers several advantages. Policies can be developed to specifically target these zones, or these zones can receive more help than other areas based, for example, on the differences in fuel poverty vulnerability rankings as presented in this paper. In particular in terms of energy efficiency improvements to the building stock, an area-based approach reflecting fuel poverty vulnerability could be more cost-effective [61]. Such zonal approaches could also be integrated into the existing CO_2 Building Rehabilitation Programme by providing higher grants for building owners whose buildings are located in such zones. This would also prevent households who are narrowly above a fuel poverty threshold becoming fuel poor. On an individual household level, these zones do not solve the inclusion and exclusion problem. However, they help to ensure that human resources and finances are concentred on highly vulnerable neighbourhoods. They also enable fuel poor households to be proactively targeted via home visits, campaigns or local multipliers (e.g. associations, churches etc.), which reduces the barrier of “self-referral”. The latter could also be a strategy for “coldspots”.

Fourth, splitting fuel poverty into three dimensions allows for the development of a more comprehensive perspective on fuel poverty. This underlines the fact that tackling fuel poverty requires the balancing of political interests, as a trade-off between ecological and social targets may be necessary. What does this mean? In contrast to the situation in Great Britain, this study does not demonstrate a positive correlation between fuel poverty and the energy inefficiency of homes. Compact building environments characterised by multi-unit properties and district heating lead to a lower specific heating demand in the south/south-east and east of Oberhausen. The north/northwest and west of the city are characterised by a high share of detached single-family houses built in the 1960s and 1980s and heated with oil, which leads to a higher heating demand and higher potential for energy efficiency. Therefore, the north has greater potential for climate mitigation policies. These areas also benefit from current KfW and BAFA funding schemes for energy modernisation [76]. From an ecological perspective, existing German Energiewende[14] policies target precisely those neighbourhoods with high energy efficiency potential. Neitzel (2014) [79] also shows that, in these areas, efficiency potential can be more easily tapped because the houses are occupied by the comparatively wealthy middle classes. Moreover, many houses are owner-occupied, meaning there is no landlord-tenant dilemma [80]. However, from a social welfare perspective, energy efficiency policies should focus on the vulnerable neighbourhoods in the south/southeast and east of the city, because even small energy efficiency improvements in these areas could balance socio-economic disadvantages.

[14] The term ‘German Energiewende’ denotes the transition from the current fossil fuel-based energy system towards a low carbon, environmentally sound, reliable and affordable energy system by the means of renewable energies, energy efficiency and energy conservation [77]. The term is rooted in the anti-nuclear movement of the 1970s [78], but has been used as a synonym for the energy transition in Germany since the Fukushima nuclear disaster.

Fifth, the design of this area-based approach could be easily replicated in other local authority areas because data for each of the criteria are available for almost all local authority areas in Germany, and the weights from the group AHP workshop are universally applicable. This would help to validate the robustness and the practicability of this approach. This approach could also be used to evaluate existing fuel poverty programmes.

These five initial thoughts invite policymakers to reflect more deeply on existing policy frameworks and requirements for new policies. Equally, the paper also invites scientists to undertake further research, because it demonstrates clear limitations. The expert judgements of fuel poverty criteria are subjective and merely a snapshot of current social and political debates and trends. With the help of the sensitivity analysis, the author attempts to put the group AHP assessment into a broader context, but it is obvious that the spatial distribution of fuel poverty vulnerability differs according to the different expert judgements. However, except for one expert judgement (Expert 6), the spatial distribution remains comparable – detecting vulnerable areas in the south/southeast and east of the city. It would also be valuable to compare the analysis with different MCDA methods such as outranking approaches (ELECTRE, PROMETEE etc.) or to validate the approach by using it in other local authorities. Moreover, the results should be validated by on-site visits to selected neighbourhoods. Both these methods of validation were unfortunately beyond of the scope of this paper. The selection of experts was pragmatic and only served to demonstrate the feasibility of the approach. In terms of policy design, the expert selection process is crucial and needs to be transparent to gain political and social legitimacy. It is necessary to bring political parties, NGOs, research institutes and local authorities together to develop a mutually agreed definition of fuel poverty criteria. The sensitivity analysis shows that this is highly challenging because the experts selected must represent a range of different points of view in order to avoid a few aspects of the complex phenomenon of fuel poverty dominating the whole picture.

The process of weighting criteria should be repeated regularly as the assessment may differ over time. For example, the expert judgements presented in this case study were undertaken during a period of very low heating oil prices (early 2016). At the same time, Germany was involved in an ongoing debate about poverty in old age. Both issues could have affected the subjective assessment. Additionally, neighbourhoods are in a constant state of change due to general societal trends. Currently, for example, the northern neighbourhoods of Oberhausen comprise a high share of elderly but relatively wealthy people, but the demographic forecast estimates that its population will further age. Similarly, heating prices change constantly depending on the markets, the German pension scheme is regularly under discussion, the rate of inflation varies and so on. Consequently, the vulnerability of the northern neighbourhoods may change dramatically over time.

6 Conclusion

It is essential to have a clear understanding of fuel poverty and its measurement to design policies that are effective in tackling fuel poverty and reaching those who are most in need. To date, the evaluation of international and national programmes shows that the target groups are not effectively reached and this must be improved if fuel poverty is to be addressed. Reasons are manifold and lie in the measurement metrics, data availability and the design of policies and programmes. One way of creating more tailored policies is by applying a so-called area-based approach to identify spatial units (e.g. neighbourhoods) with high fuel poverty vulnerability due to their specific characteristics. To this end, a GIS-MCDA was developed using an AHP approach, which was able to pinpoint fuel poor neighbourhoods in a German city. This approach does not measure whether a household is in fuel poverty, nor does it predict the absolute number of households in any neighbourhood that may be fuel poor. Instead it measures the fuel poverty vulnerability of neighbourhoods and, therefore, allows for funding and support to be channelled to high risk areas. Despite the methodological limitations discussed in this paper and the need for further research, the area-based approach presented offers interesting insights into the complex structure and spatial distribution of fuel poverty and invites policymakers to develop more tailored policies to target those most in need. In particular, it may help to overcome the “self-referral” dilemma from which many of the existing policies suffer. The author hopes that this approach will give a new impetus to the German and international debate.

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