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A Deprivation-Based Assessment of Energy Poverty: Conceptual Problems and Application to Germany

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– Abstract –

In this paper, subjective and objective aspects of deprivation are used to derive an aggregated multidimensional measure of energy poverty. The proposed measure is based on deprivation with a direct relation to energy consumption, but it also accounts for excessive financial restrictions due to energy costs, it gives priority to low income households, and controls for economic energy use. Based on logistic regression, we find strong effects of income and energy expenditure on the likelihood of energy deprivation in Germany, but these variables only partially constitute energy poverty. Other aspects, e.g. employment status or housing conditions, play an important role as well.

Keywords: energy deprivation, energy poverty, fuel poverty

JEL-Classification: I32; D63; Q48

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1. Introduction

Energy (or fuel) poverty is currently receiving increasing attention by researchers and policy makers in the European Union and beyond. In developing countries, energy poverty is often characterised by a lack of access to modern and secure energy services (Birol, 2007). In developed nations, the problem usually is characterised by problems to afford adequate energy services, related to insufficient income, high energy costs, and poor energy efficiency (Boardman, 2012). There is an ongoing discussion on what factors contribute to energy poverty at the household level and how energy poverty should be measured. Both aspects are of great importance in order to understand the causes of energy poverty and identify afflicted persons or households.

This article contributes to the literature by discussing a bottom-up approach to the measurement of energy poverty, which is based on objective and subjective problems related to energy affordability and adequate consumption of energy services. The approach is based on the concept of material deprivation. Different "items" of deprivation indicating affordability problems are used to derive a multidimensional energy poverty measure. In order to account for substitution of goods and services under severe budget constraints, a dual approach is used. Under this approach energy poverty is defined by deprivation which is directly related to energy consumption *or* if there is severe material deprivation in other domains of consumption. The approach has several advantages. Most importantly, it reduces the need for exogenous normative assumptions with respect to the definition of energy poverty. The relevant deprivation items, which constitute energy poverty in the proposed approach, are openly observable. Some of the deprivation items furthermore take subjective perceptions of consumption adequacy into account, which allows individual ideas of well-being to enter the assessment. Such individual ideas of well-being can be constrained by second order conditions, such as rational energy use or the restriction of the poverty measure to lower income groups.

The application of the proposed measure to German household data reveals that energy deprivation and, more general, the problem of deprivation are concentrated in the lower deciles of the income distribution. With respect to the "duality" of the measure, we find that general deprivation is highly relevant with regard to the lowest 20% of incomes. This also suggests that low-income households are strongly affected by energy-related deprivation and (simultaneously) by severe general deprivation. Both problems are correlated in this case. In the third, fourth and fifth decile of the income distribution, general deprivation is less relevant and problems in direct relation to energy affordability dominate. With a total energy poverty headcount of 10.9%, the proposed "dual deprivation approach" yields a lower headcount compared to (most) other possible energy poverty measures (Heindl, 2015). Energy poverty furthermore is non-identical to relative income poverty. A regression analysis suggests that there are important contributing factors for energy poverty in addition to household income and expenditure on energy services, such as housing quality and actual indoor temperatures during the winter.

The concept of deprivation-based measurement of energy poverty is discussed in detail in Section 2. In Section 3, German household data are used to apply the concept. This section also contains a detailed description of the poverty headcount differentiated by the components of the multiple poverty measure. Regression analysis is used in Section 4 to investigate factors correlated with energy poverty as represented by the deprivation approach. Section 5 concludes.

2. Conceptual Background

Our approach is based on deprivation-related questions in a representative survey of households on energy consumption in Germany (see Section 3 for a detailed data description). The study of deprivation (shortfall with respect to provision of goods which a person ought to be able to attain) is by now one of the main avenues of research on poverty (Duclos and Gregoire, 2002; Townsend, 1979; Walker and Smith, 2002). It is operationalised in general surveys on deprivation (e.g. EU-SILC)[1], which we partly use or adapt. Some of our questions refer to *objective standards*, such as a track-record of power cut-offs. However, most questions address forms of *perceived insufficiency*. Note that this does not turn them into reports of mere subjective feelings of not having enough, as they relate to intersubjective standards of deprivation (Halleröd, 2006). That is, the questions reveal the self-reported shortfall with respect to a collective standard of what a household should be able to afford. There are, of course, methodological problems of theorising on the basis of subjectively perceived shortfalls, but, as in most of modern poverty research, we would consider it as even more problematic if the perspective of afflicted persons played no role in the measurement of poverty.

[1] The EU statistics on income and living conditions (SILC) comprise a number of questions related to material deprivation which are also used in the present study.

In the case of energy poverty, recourse to self-reported deprivation seems particularly important, as soon as the bare minimum of survival and avoidance of immediately documentable health problems can be taken for granted. With respect to room temperatures and their health effects, this bare minimum may still not be universally attained in advanced OECD countries, as the British example shows (Liddell and Morris, 2010). Yet it would be one-sided to approach energy poverty only via adequate room temperature and neglect other aspects that might be more relevant in countries with a high percentage of adequately insulated housing (see also Healy, 2004, p. 35). Therefore, recourse to less directly measurable factors of what is adequate with regard to energy services cannot be avoided (Waddams Price et al., 2012). The only decision to be made is whether the subjective evaluation of researchers or the self-reported deprivation of the afflicted persons should have priority. Here, we strive to balance both, but assume that the perceived deprivation of afflicted persons is indispensable for an adequate comprehensive calibration of indicators of energy poverty. Moreover, poverty is related to a deprivation of primary goods or minimum capabilities (Brighouse and Robevns, 2010; Rawls, 1971; Sen, 1983). Like other researchers, we believe that 'items' of objectively measured and subjectively reported deprivation can provide meaningful information on basic opportunities or capabilities in relation to energy consumption at the personal level (see e.g. Papadopoulos and Tsakloglou, 2008). Several questions in the survey can be grouped together either to represent energy (service) specific deprivation or forms of deprivation which typically relate more generally to poverty, as for instance some of the EU-SILC deprivation items. We use this distinction to construct a dual indicator that is essentially based on two separate clusters of questions:

The first cluster (A) targets *energy-specific deprivation*. That is, it covers the issues of (i) perceived insufficient ability to attain adequate room temperatures, (ii) perceived imposed limitations concerning electricity consumption or heating, (iii) perceived restriction of general consumption because of (high) energy costs, and (iv) the occurrence of a power cut-off. We assume that one of these limitations alone, if exceeding a threshold of incisiveness, suffices to indicate serious energy-specific deprivation and hence energy poverty (see Table 1).

A second cluster of questions (cluster B) represents *more general aspects of deprivation*, inter alia motivated by EU-SILC deprivation items, such as (i) perceived insufficiency of income, (ii) lack of provisions for old age, (iii) problems to pay housing-related bills, (iv) inability to cover unexpected expenses, and (v) abstaining from important acquisitions or investments due to a lack of funds (see Table 2 and 3). None of these deprivations need to be caused by energy costs, but it is reasonable to assume a positive correlation for households that face high energy costs. This is the basic assumption behind indirect indicators of excessive imposed energy cost (Boardman, 2012; Hills, 2012). Familiar indirect indicators assume that there is energy poverty if a certain ratio of energy costs relative to income is exceeded (TPR, Boardman, 1991), if excessive (specifically, more than median) energy costs push households into poverty (LIHC, Hills, 2012), or if energy costs push households into poverty (MIS, Heindl, 2015; Legendre and Ricci, 2015; Moore, 2012).

We retain an element of income-based measurement of energy poverty in our treatment of cluster B. Generally, we assume that deprivation passes a poverty-relevant threshold if *three or more* of the income-related deprivation items from cluster B are present. We specifically assume that this income-related deprivation is relevant with respect to energy poverty, if a household's income share of energy expenditure exceeds the TPR-threshold, implying high relative burdens of energy costs. The TPR is preferred to LIHC and MIS for several reasons. Income-related deprivation is likely to be positively correlated to income poverty as used by LIHC and MIS, so that the signal of our deprivation variables might be blurred. Moreover, the TPR has the advantage of being sensitive to losses of real income while energy expenditure is inelastic (Heindl and Schuessler, 2015), a condition that can be expected to contribute to energy poverty in developed countries. On the whole, we presume, in line with the logic of TPR-based studies, that general income-related deprivation tends to be causally linked – or at least strongly correlated – to energy costs if more than ten percent of household income is spent on energy services. Note that the TPR in theory does not relate to actual spending on energy services but to expenses for *adequate* energy services. We capture the aspect of adequacy in a further condition (D) of our indicator as discussed below, and by restricting our indicator to the lower half of the income distribution (cluster C). Inordinately high energy consumption is most likely to be found among well-off households that spend more than ten percent of their income on energy services. Restriction of the TPR to below median households also accounts for analyses of the dynamic behaviour of indicators of energy poverty (Heindl and Schuessler, 2015; Flues and Van Dender, 2017), which for technical reasons (they are best suited for income-based approaches) cannot be repeated for the present indicator.

Overall, a household is counted as 'energy poor' if *at least one* of the two sub-indicators (clusters A or B) is true. This definition requires commenting on the normative justification and the robustness of its assumptions. It is ex ante to be expected that the headcount ratio of energy poverty might vary considerably depending on the choice of the respective thresholds of inclusion. The examination of different thresholds confirms this expectation (Heindl, 2015; Moore, 2012; Waddams Price et al., 2012). Finding an adequate threshold and providing 'bottom-up' empirical evidence for energy-related deprivation is therefore important (Middlemiss and Gillard, 2015; Okushima, 2017), but because there is no obvious natural threshold of relative deprivation, this issue ultimately depends on value judgments. In our normative assumptions, we try to balance three considerations: not to downplay reported deprivation, plausibility, and steering a middle course between possible alternative assumptions. In particular, we include 'strong' instead of only 'very strong' shortfalls into our indicator for cluster A (direct energy-related deprivation), as this can already be interpreted as significant deprivation. However, 'intermediate' (or weaker) responses are not considered a sufficient sign of deprivation, because we expect that respondents might choose this answer as a default option if they feel unsure about their state of deprivation, a worry corroborated by the high incidence of this response.

For the second set of questions (cluster B), two-out-of-five and four-out-of-five might be considered as alternatives to the three-out-of-five threshold we use. The combined headcount for clusters A and B (before further conditions) does not vary too much for these alternatives: from 15.6% for (2/5), to 12.8% for (3/5), and to 11.8% for (4/5). We choose a three-out-of-five threshold because it marks a compromise in this interval of possible assumptions. Of course, as in all studies that posit multi-dimensional poverty thresholds, alternative assumptions concerning thresholds can be pursued in further research.

So far, the proposed dual deprivation-based indicator of energy poverty (DDEP) includes all households which satisfy the outlined criteria regardless of status or income. It might be argued that this is adequate, as even high-status or high-income households can experience deprivation due to high energy costs. However, it is not reasonable in our opinion to extend the notion of poverty to well-off persons who spend a certain percentage of their income on a good they would want to get cheaper, and thus feel dissatisfied. Of course, such persons might even feel financially constrained given their prevailing consumption patterns. But then it is up to them to change these patterns, a decision that is harder to make the less resources a person has (Meier et al., 2013). In consequence, we restrict the notion of energy poverty to lower income households and derive the indicator only for the respective income deciles. The question is where to cut the income distribution. This decision is to some extent conventional because the data do not clearly suggest a suitable cut-off point. Yet the income or cost median has already been used as a threshold for indicators in several studies on energy poverty, and we therefore use the income median as the cut-off point for our indicator (Hills, 2012; Moore, 2012). In consequence, only households from the bottom five deciles of the income distribution count as energy poor (cluster C). With respect to the remaining households, we assume the risk of misrepresentation to be too high to include them into our calculations, that is, the risk of counting households as energy poor whose high energy expenditures result from unforced consumption patterns or from other unforced life-style decisions, such as living in a spacious house. However, to allow for comparison and for an alternative view, we also record the overall values of our indicator for all income deciles (see Table 4).

The last modification we undertake concerns the adequacy of energy services (cluster D). One survey question refers to the importance of economical energy use for a household. It is, of course, not to be expected that all respondents reveal their attitudes honestly in this respect. Those, however, who openly state that economical energy use does not matter to them should, as we think, be excluded from the potentially energy poor, since options to save energy and associated costs are present but are wittingly not used. In this case, a household would be able to (at least partly) improve the own situation autonomously. Therefore, our indicator does not include households which avowedly do not care about economy in energy consumption. In our data analysis below, this modification has very little impact on the overall poverty headcount. We also report results without the restrictions of cluster D for the reason of transparency.

To summarize, the dual deprivation-based indicator of energy poverty (DDEP) consists of four clusters or sets:

A) Strong or very strong energy-related deprivation (Table 1).
B) At least three-out-of-five 'general' deprivation items and energy expenditure of 10 per cent or more of disposable income (Tables 2 and 3).
C) Household from lower five income deciles, viz. household income below median.

D) Not intentionally uneconomical energy user (both Table 4).

The indicator can be expressed as: $(A \cup B) \cap C \cap D$.

3. Methodology and Data

3.1 Data Description

The data set used in this paper consists of a representative survey of 1,903 German households. The survey was carried out by the market research company SUZ from March to June 2015. Individuals aged 18 or older were randomly contacted and interviewed. The survey is based on 'computer assisted telephone interviews' (CATI). The interviews took 25 minutes on average. The questionnaire includes the following topics: ownership and frequency of use of electric appliances, deprivation related to energy consumption and income[2], expenditure for electricity, expenditure for heating, housing conditions, type of heating system, and household related variables (size, income, age structure etc., see Table 8 for descriptive statistics). Table 1 summarizes the five deprivation items related to energy consumption (cluster A) which we consider. We see that only few people feel they face 'strong' or 'very strong' restrictions in affording adequate energy services, or have problems to keep their home adequately warm. Electricity supply has been suspended in less than two percent of households. Table 1 also shows the headcount of deprivation items for households with equivalence income below or equal to the median in the sample (figures in brackets).[3]

[Table 1 about here]

Table 2 summarises the results of general or income-related deprivation items (cluster B). Few people state that income is insufficient to cover their necessary expenses (6.83%) or that they face problems to afford housing costs (4.20%); about one fifth of respondents state that they forgo important consumption (19.86%) to afford necessities or that they are unable to cover unexpected expenses up to 900 EUR (19.18%). 28.17% have no private

[2] The deprivation items include items from the EU Statistics on Income and Living Conditions (SILC) (Sikorski and Kuchler, 2011).

[3] In order to make household income and expenditure comparable across households of different size and to account for economies of scale in consumption, equivalence scales are used. The standard procedure, e.g. as used by the European Statistical Office, is to assign a weight of 0.5 to an additional adult person in the household and a weight of 0.3 to each child in the household (Hagenaars et al., 1994). This (so called 'new' or 'modified' OECD equivalence scale) matches income and expenditure of German households well (Kohn and Missong, 2003; Schulte and Heindl, 2017). Let n be the number of adult persons in the household and m the number of children. Equivalence income y_e is derived from disposable income y by $y_e = y\,/(1 + 0.5(n-1) + 0.3m)$.

superannuation, which is highly recommended in addition to public pensions in Germany in order to keep one's living standards after retirement.[4] 25.59% of households in the sample spend ten percent or more of their disposable household income on energy services, which is in line with previous research (Heindl, 2015).

[Table 2 about here]

Please recall the definition of the DDEP indicator, which requires that *at least one* of the items in cluster A must be given (with 'strong' or 'very strong' incidence for A1-A3) or that *at least three out of five* of the items B1-B5 must be true and that households must spend 10% or more of their disposable income on energy services. This, we assume, constitutes deprivation which can be justified as energy poverty because there is either a direct relation of deprivation to energy consumption or there are strong financial restrictions related to high energy expenditure.

Criterion A yields a headcount ratio of 10.88%. In other words, for 10.88% of all households in the sample, at least one of the deprivation items A is true. The additional criterion B requires some attention: About half of the households state that none of the items B1-B5 is true, but for all remaining households, at least one of the items is present (Table 3). Less than one percent of households report that all of the items B1-B5 are true. 8.46% report that at least three out of five items are true. Accounting for the additional ten-percent threshold (B6), criterion B is true for 5.04% of households.

[Table 3 about here]

3.2 The Deprivation Headcount

To derive a headcount for the DDEP indicator, we need to investigate the union of clusters (or sets) $A \cup B$. Table 4 comprises the results in detail, i.e. for the ten deciles of the income distribution. We see that B contributes to A, in particular, in the lower three deciles of the income distribution. B's contribution to A is moderate in the fourth and sixth decile and zero

[4] The problem of missing private superannuation is relevant, since problems of poverty could be shifted over time; i.e. people could take the risk of old-age poverty in the future to afford a certain lifestyle today.

in the remaining deciles. Please recall that the proposed indicator includes two additional conditions:

- Condition C assumes that energy poverty is relevant for households with low income and that high income households should not be regarded as potentially affected by energy poverty.
- Condition D requires economic energy use and in particular that households are willing to save energy if possible.

Regarding condition D, Table 4 shows that most households (91%) state that they use energy economically. If households which regard economic energy use as irrelevant are removed from the headcount, figures decrease slightly by about 0.89 percentage points, which implies that most households captured by clusters A and B do care about economic energy use. The overall non-income restricted headcount of energy poverty is 11.93%. We observe a large headcount ratio in the lower deciles of the income distribution, in particular in the lowest income bracket. The headcount decreases monotonically for the lower eight deciles. Households with adequate income are able to substitute energy consumption or to improve energy efficiency autonomously. Therefore, we opt for an income-threshold below the median (cluster C). If only households in the lower five deciles of the income distribution are considered, the overall headcount ratio of energy poverty decreases by 2.16 percentage points from 11.93% to 9.77%.

[Table 4 about here]

3.3 Group Comparison

When comparing the group of the energy poor to the group of the non-energy poor (Table 5), we find that the energy poor have a significantly lower equivalence income on average. Energy costs show no significant difference. Energy poor households are significantly smaller on average, which inter alia is due to a relatively large share of single households in the group of the energy poor. We observe no significant differences with respect to the share of pensioners in the household. The number of children is somewhat higher in energy poor households. Combined this suggests that single households and households with children are more often affected by energy deprivation, compared to households with two persons. Average room temperatures are about half a degree Celsius lower on average in households affected by energy poverty.

The group comparison reveals some interesting details. First, the proposed indicator in fact takes a 'low income' perspective, but not a 'high cost' perspective. Second, the large share of single households within the group of the energy poor may be reasonable because of strong economies of scale in energy use (Schulte and Heindl, 2017). Third, the significant deviation of average room temperatures can be interpreted as additional evidence for deprivation, in particular with respect to heating. Finally, the share of basic welfare recipients in the group of the energy poor is very high (27%) compared to the non-energy poor (2%). This implies that energy poverty, as captured by the DDEP indicator, has a strong but partial overlap with problems of general income poverty, which is in line with previous studies. Under basic social security in Germany, eligible households receive financial support which also includes payments for electricity. However, the payments often (about half of all cases) do not cover the true costs of electricity consumption (Aigeltinger et al., 2015).

[Table 5 about here]

An interesting question is how the deprivation-based indicator compares to other indicators of energy poverty (Table 6). Since we are unable to predict or evaluate what a household *would need to spend* on adequate energy services, we need to resort to actual expenditure to calculate LIHC, the TPR, and the TPR5 (the TPR5 is the TPR-measure which is only applied to households with an equivalence income below the median). The tetrachoric correlation between the DDEP, LIHC, and the TPR is positive and significant. We observe a correlation of 0.40 between the DDEP and LIHC, 0.59 in case of the TPR, and 0.66 for the TPR5. This indicates that the measures (partly) identify different households as energy poor.

[Table 6 about here]

For LIHC, the TPR, and the TPR5, we find that equivalence income and energy expenditure is higher in the group of the energy poor when compared to the DDEP. The number of persons in the household is much larger in the case of LIHC. The share of single households is lower for LIHC, the TPR, and the TPR5. Most importantly, indoor temperatures under all three measures, LIHC, the TPR, and the TPR5, are close to the average of 21 degrees Celsius in the overall sample.

4. Regression Analysis and Results

What drives energy-related deprivation as captured by the proposed DDEP indicator? The literature on energy poverty suggests that income and energy costs play an important role, but aspects of energy efficiency are of importance as well (Boardman, 2012; Legendre and Ricci, 2015). The DDEP headcount – which is a binary variable equal to one if deprivation is present – is used as the dependent variable in the regression analysis. Since deprivation is a complex phenomenon, we cannot claim for causality here. The aim merely is to identify variables which are correlated to energy deprivation as captured by the DDEP in order to gain a better understanding of the indicator.

We consider disposable monthly household income after all taxes and benefits in thousand EUR (in1000) and monthly expenditure on electricity and heating in thousand EUR (en1000) as independent variables. Household composition – as an important driver of energy needs (Brounen et al., 2012) – is represented by the number of children of age 0-2, 3-5, 6-15 (chi0_2, chi3_5, chi6_15). Additional adult persons in the household aged 16-59 as well as 60 years and older are included (ad16_59, ad60plus), meaning that the reference category (captured by the constant) is a 'single household'. Households which receive benefits for long-term unemployment or basic social security allowances are included in the form of an indicator variable (alg2), since the literature suggests that energy deprivation occurs frequently in these types of households (Aigeltinger et al., 2015).[5] If a person agrees 'strongly' or 'very strongly' to the statement that the occupied house or apartment needs renovation or if windows are leaky, this statement is captured by an indicator variable (unreno) to provide a proxy for the energy (in)efficiency of the occupied dwelling.

The respondents were asked about actual room temperatures (during the winter month) and room temperatures which are perceived as adequate. Actual room temperatures below the optimum are included in the regression by an indicator variable (tdi).[6] Under-occupation of homes is discussed as a potential source of high energy expenditure (Hills, 2012, p. 51). Therefore, we include an indicator variable that equals one if a person agrees that the home is 'too large' or 'far too large' (underocc). The number of appliances (noappl) and the

[5] The variable 'alg2' covers households which receive basic social security payments under the German laws SGB II (long-term unemployment, 'Arbeitslosengeld 2') and SGB XII (basic security, also at old age, 'Sozialhilfe').

[6] Actual room temperatures refer to the average temperature in often used rooms, such as the living room, during the heating period. Optimal room temperature refers to the temperature which – according to the opinion of the respondents – should (at least) be given.

average age of appliances (avage) are added as explanatory variables to capture additional aspects of the electricity consumption of the households. House ownership is positively correlated with energy efficiency retrofits (Meier and Rehdanz, 2010; Rehdanz, 2007). Consequently, we include an indicator variable for house ownership (own) to capture possible effects related to energy efficiency. Thermal efficiency of houses also correlates with the age of a building. Therefore, we include indicator variables for the period in which the occupied house was built. We distinguish between the pre-war and war period until 1947 (b47), the post-war period of the housing boom from 1948 to 1980 (b14to80), and the period from 1980 to 1995 in which energy-efficiency standards were first enacted in Germany (b81to95). The period from 1996 onwards is the reference category. Since heating costs are contingent on the installed heating system and the prices of used fuels, we control for the most important types of heating systems, namely natural gas (Hgas), light heating oil (Hoil), and district heating (Hdistrict). Finally, we add an indicator variable that equals one if a household lives in the former socialist eastern part of Germany (east). East and West Germany differ in terms of the building structure and with regard to social aspects since unemployment rates and the rates of long-term welfare recipients are higher in the eastern part of the country. See Table 8 for descriptive statistics.

The model is estimated using logistic regression ('logit'). It is selected based on suggestions in the literature but also based on statistical considerations, i.e. statistical tests and information criteria. Box-Tidwell regression is used to test the linearity of the regressors. The analysis shows that the dependent variable 'energy expenditure' (en1000) is non-linear. This implies that the impact of energy expenditure on the likelihood of energy deprivation decreases as energy expenditure increases. Therefore, an additional quadratic term of energy expenditure is added ($en1000^2$). Since income (in1000) and housing conditions (unreno) are correlated, where higher income is associated with better housing conditions, we add an interaction term of the variables 'in1000' and 'unreno' to capture this effect. The variable 'unreno' (p-value: 0.001) and the interaction term of 'unreno' with the variable 'in1000' (p-value: 0.011) are significant, also when tested jointly (p-value: 0.0012).

4.1 Results and Discussion

Table 7 reports the average marginal effects. Column (1) comprises the main results. We find that disposable income (in1000), energy expenditure (en1000), the number of persons in a household (chi3_5, chi6_15, ad16_59), and the indicator variables for basic social security (alg2), required renovation (unreno), and temperatures below the individually perceived adequate temperature (tdi) are highly significant.

[Table 7 about here]

As expected, the marginal effect of income on energy deprivation is negative. We can say that an increase in income by 1000 EUR is associated with a decrease of the risk of energy deprivation (as captured by the DDEP) by about 10%. The effect of energy expenditure is positive, meaning that energy expenditure is associated with a higher likelihood of energy deprivation. A rise in energy expenditure by 1000 EUR increases the risk of energy deprivation by about 40%. Please note, that these effects do not necessarily represent a causal relationship, but merely correlation.

Additional persons in a household between three and 59 years increase the likelihood of energy deprivation. This effect is stronger for children between the age of three to five (+4.8%) when compared to children aged six to 15 years (+3.3%), and when compared to a person aged 16 to 59 years (+2.5%). For infants (zero to two years) and elderly persons (60 years or older), no significant effect on energy deprivation is found.

Households which receive basic social security (alg2) are more likely to face energy deprivation (+8.2%). If a household occupies a house or apartment which requires renovation or has leaky windows (unreno), the likelihood of energy deprivation increases as well (+3.1%). Finally, indoor room-temperatures below the individually perceived optimal temperature during the heating period (tdi) are positively correlated with energy deprivation (+4.6%).

So far the regression analysis revealed four types of variables with correlation to energy deprivation: i) income, ii) energy expenditure, iii) household composition, and iv) the 'quality' of the occupied house or apartment (whether it needs renovation), which is related to the energy efficiency of the building. Since most energy poverty indicators primarily focus on income and energy expenditure, we examine the importance of these two variables.

Figure 1 depicts the probability of being affected by energy deprivation, dependent on monthly disposable household income and monthly energy expenditure. We see that the likelihood of energy deprivation is not only contingent on income and energy expenditure, but also the *change in the likelihood of being deprived* is dependent on income and energy expenditure, all other things equal. For example, an increase in the energy expenditure of a low-income household has a larger impact on the probability of being deprived when compared to a household with higher income. This intuitively makes sense, since low income is associated with more severe budget constraints. We observe a similar effect for a change in income: Such a change causes less pronounced alteration in the probability of energy deprivation when energy expenditure is low compared to when energy expenditure is high. We can express this as an elasticity derived from the average marginal effects. If monthly disposable household income is equal to 1,000 EUR – roughly above the 'risk of income poverty' threshold – and if energy expenditure equals 100 EUR per month, a one percent change in income is associated with a 1.15 percent decrease in the probability of being deprived. Similarly, a one percent increase in energy expenditure is associated with a 0.7 percent increase in the probability of being deprived. While these effects do not necessarily represent a causal relationship, we nevertheless see that the correlation of income and energy deprivation is stronger when compared to the effect of energy expenditure.

The 'quality' of the occupied house or apartment is correlated with energy deprivation as the regression suggests. We can examine this effect by predicting the probability of energy deprivation contingent on housing quality. For this purpose we keep income fixed at 2,000 EUR and predict the likelihood of energy deprivation based on average marginal effects. A single household with an income of 2,000 EUR living in a house or apartment of good quality (unreno=0) has a rather low probability of being affected by energy poverty as captured by the DDEP (4.4%). If the occupied house or apartment requires renovation (unreno=1), we observe a higher probability of energy deprivation (7.4%). This illustrates that poor housing quality, which also is related to low energy efficiency, shows important correlation to energy poverty as captured by the indicator.

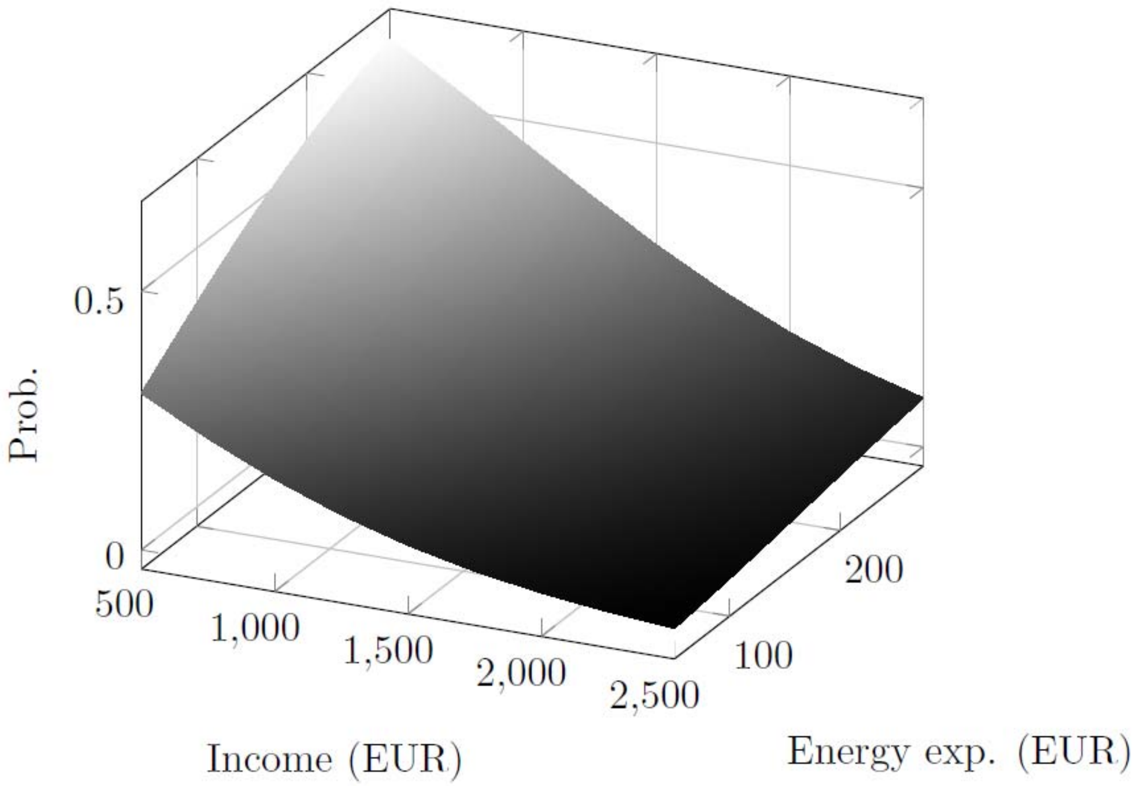

Figure 1: Predicted probability of energy deprivation (average marginal effects) plotted over monthly disposable household income and monthly energy expenditure.

Finally, the regression analysis reveals a strong correlation of basic social security allowances (alg2) and energy deprivation. Households which receive such payments are more likely to report energy deprivation.[7] If we compare the likelihood that a household reports energy-related deprivation for households which receive basic social security payments (alg2=1, solid line) and other households with low income as depicted in Figure 2, we see that basic social security is strongly correlated with energy deprivation. Since payments for electricity consumption in basic social security allowances do not cover the actual expenses of a majority of eligible households, deprivation can be expected (Aigeltinger et al., 2015).

[7] Basic social security payments in Germany are defined on a per-capita basis. Housing costs and heating expenses of eligible households are reimbursed by the social security agency. Households receive direct payments for the remaining needs, which are defined with reference to the expenditure of households belonging to the lower two deciles of the equivalised income distribution.

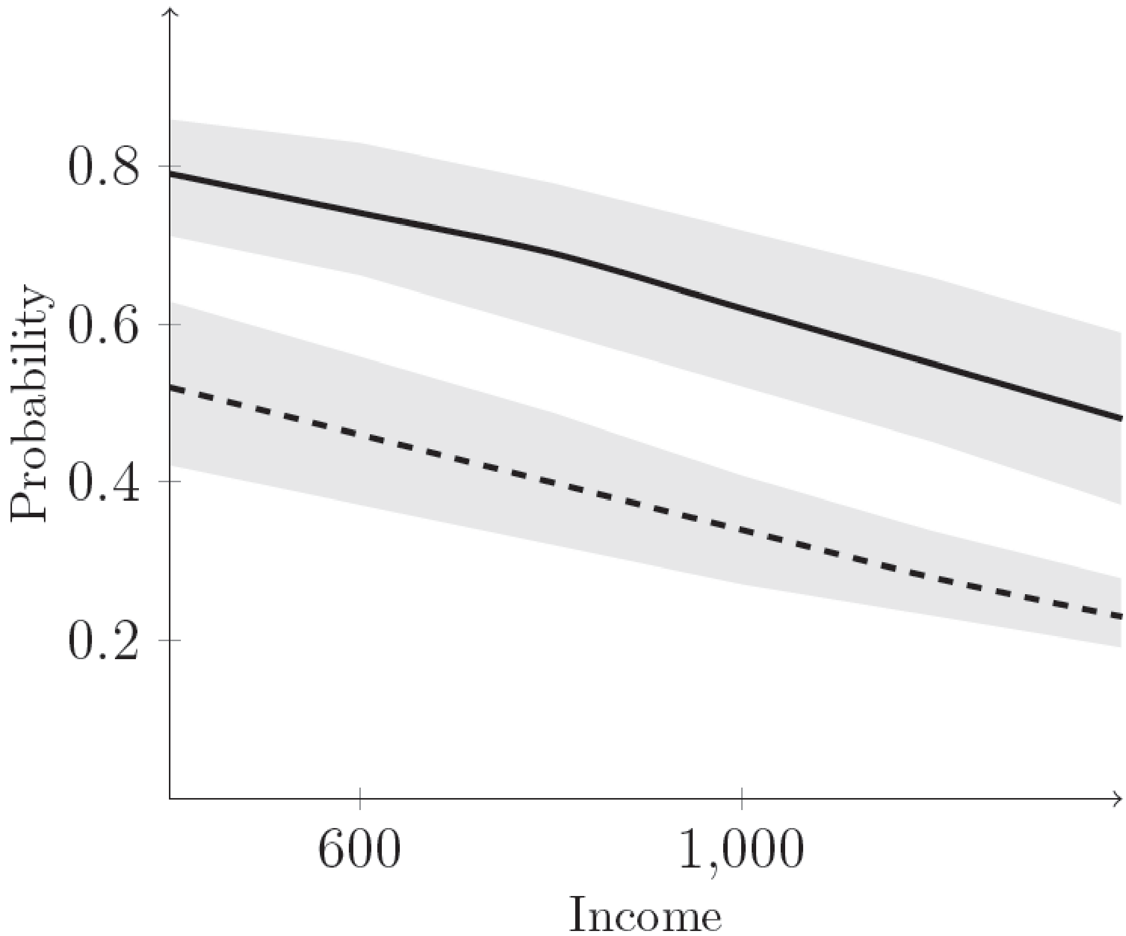

Figure 2: Estimated probability (average marginal effects) of energy deprivation in low-income households, grouped by recipients of basic social security (alg2=1, solid line) and the remaining households (dashed line) depending on their monthly disposable household income. The grey areas indicate 95% confidence intervals.

4.2 Alternative Specifications and Robustness

Column (1) of Table 7 includes a number of additional independent variables which were omitted in the previous discussion because their marginal effects and regression coefficients are not significantly different from zero. We nevertheless include these effects in the regression, since the literature suggests that these effects might be of relevance, either to explain energy poverty, or to explain energy consumption of households (Boardman, 2012; Brounen et al., 2012). Column (2) of Table 7 shows marginal effects if the ancillary variables are omitted. We see that the effect of energy expenditure is lower in (2) compared to (1) while the effect of income is stronger. We further see that the variable 'unreno' (whether a house or apartment needs renovation) has a more pronounced effect if the additional variables are omitted. It is likely that variables such as the age of the building or the heating system capture some variation in the data. This is important for avoiding biased estimates, as these variables help to explain the energy efficiency of buildings or behavioural aspects in energy use. Thus, it seems advisable to focus on the model presented in column (1) rather than the one in (2) even if statistical tests, for example model selection based on the BIC criterion or joint parameter tests, yield no clear result.

Column (3) of Table 7 shows a modified version of the model displayed in column (1). In column (3), disposable income and energy expenditure are transformed to 'equivalised' figures (ein1000 and een1000) using the 'new OECD equivalence scale'.[8] As can be seen in column (3), all average marginal effects related to the size of households become smaller when compared to column (1) and they are not significantly different from zero. At the same time, the remaining marginal average effects do not change considerably. This indicates that using the new OECD equivalence scale to transform income and expenditure does partly 'absorb' the effect of household composition on energy-related deprivation.

5. Conclusions and Policy Implications

In this paper, we propose a (dual) deprivation-based measure of energy poverty (DDEP), which is based on i) deprivation items which are directly related to energy consumption and ii) on items related to severe material deprivation in general, which concur with spending a high share of income on energy services. Naturally this definition, like any definition of poverty, includes normative aspects (e.g. the weighting of deprivation items or the question of which items are to be considered) and is non-exclusive. However, we have tried to make our assumptions as transparent and our results as accessible as possible and hope that this work will contribute to a better understanding of energy poverty and the driving forces behind it. Such an approach is not necessarily a substitute for existing energy poverty measures, e.g. those based on household income and energy expenditure. It rather compliments existing measures by linking the assessment of poverty to observable shortcomings in relation to energy consumption. This may also help to improve the empirical foundation of existing measures by means of recalibration of the implied energy poverty line(s).

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[8] Hills (2012), for instance, suggests using equivalised figures to account for household size. This technique is a commonly used technique to generate 'per capita' figures of income. The new OECD equivalence scale assigns a weight of 1 to the first adult person in the household. Additional adults are weighted by a factor equal to $\gamma = 0.5$. Each child in the household (0 to 15 years) receives a weight of $\delta = 0.3$. With disposable household income y, equivalised ('per capita') income y_e is given by $y_e = y\frac{1}{1+\sum\gamma+\sum\delta}$.

Based on the DDEP, we find that energy-related deprivation occurs frequently among low-income households, in particular in the lowest decile of the income distribution. General deprivation combined with a high share of income spent on energy services – the second attribute of the measure – contributes little to the overall DDEP headcount, but general deprivation often (not always) is associated with energy-related deprivation (Table 4). This is most relevant with regard to the lowest two deciles of the income distribution. Households identified as energy poor by the indicator have a low-income on average, close to the 'risk of income poverty line' in Germany. Expenditure of these households on energy services is lower than in the group of non-energy poor households. This effect likely is related to substitution patterns, i.e. unwanted restriction of energy consumption in order to afford other important things. Energy poor households also exhibit significantly lower average room temperatures and the share of welfare recipients in this group is high (Table 5). When compared to alternative energy poverty measures which are defined based on income and expenditure (i.e. the ten-percent rule and the low income/high cost measure), there are strong differences in the group of the poor: Energy-related deprivation as reflected by the DDEP is present in households with low equivalised income *and* low equivalised energy expenditure (Table 6).

Finally, logistic regression shows that (per capita equivalised) income, energy expenditure, and the condition of the occupied house or apartment (if it needs renovation or if windows are leaky) are significantly correlated with the likelihood of being affected by energy-related deprivation. However, the effect of income on the likelihood of energy-related deprivation is stronger than the effect of expenditure on energy services. The observed effect of the condition of the occupied house or apartment is moderate, but households affected by energy-related deprivation exhibit lower room temperatures, which could be due to individual reasoning to save heating costs but could also be influenced by poor energy efficiency of the occupied buildings.

Overall, the results confirm that energy costs and energy efficiency play an important role with respect to energy-related deprivation and hence energy poverty as a broader problem. However, the results also show that income apparently plays the most important role as a 'risk factor' for being deprived (according to the proposed DDEP measure). This has important implications for possible policies which aim at reducing energy-related deprivation: First such actions should focus on the poorest households as the prevalence of energy deprivation is highest in this group. Second, actions which aim at reducing energy costs or improving energy efficiency can help to reduce energy deprivation, i.e. in low-income households. Examples are ‘soft’ measures to raise awareness of the costs associated with appliance usage or the benefits of energy efficiency investments. From this perspective, low income plays an important role not only as a factor which is correlated to deprivation, but also as barrier to energy efficiency investments. Therefore, energy poverty appears to have a strong overlap with ‘general’ poverty and the related problems, but there are specific aspects, such as ‘energy literacy’ and the removal of investment barriers with respect to (economic) energy efficiency investments, which should be addressed in order to reduce problems of energy deprivation. ■

[Table 8 about here]

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Table 1: Summary of deprivation items (cluster A) related to energy consumption (categories “not at all” and “moderately affected” are omitted for A1-A3 for convenience). Figures in brackets show results for households with equivalised disposable monthly income below or equal to the median in the sample.

A1: Do you need to restrict electricity consumption to afford necessary things in life?		
Intermediate	Strong	Very strong
12.05% (17.47%)	2.84% (4.60%)	1.47% (2.41%)
A2: Do you restrict space heating to afford necessary things in life?		
Intermediate	Strong	Very strong
11.09% (16.00%)	2.21% (3.35%)	0.89% (1.57%)
A3: Do you restrict the consumption of other important things to afford adequate energy services?		
Intermediate	Strong	Very strong
9.80% (15.58%)	2.74% (4.84%)	0.69% (1.26%)
A4: Has the supply of electricity been suspended (present or past)?		
No	Announced	Actually present
93.58% (90.99%)	4.63% (5.87%)	1.79% (3.17%)
A5: Do you have trouble keeping your home adequately warm?		
No	Yes	
96.64% (94.66%)	3.36% (5.34%)	

Table 2: Income-related deprivation items (cluster B)

Item	True (in percent)
B1: Income sometimes insufficient to cover all necessary expenses	6.83%
B2: No private superannuation	28.17%
B3: Problems paying housing costs	4.20%
B4: Problems covering unexpected expenses (up to 900 EUR)	19.18%
B5: Forgoing important consumption to afford necessary things	19.86%
B6: Energy expenditure exceeds 10 percent of disposable income	25.59%

Table 3: Combined occurrence of B1-B5

Items B1-B5	**Percent of sample**	**Cumulated**
Five out of five true	0.95%	0.95%
Four out of five true	2.57%	3.52%
Three out of five true	4.94%	8.46%
Two out of five true	9.72%	18.18%
One out of five true	28.95%	47.13%
None is true	52.86%	100%

Table 4: Headcount ratio for clusters A, B, D, and the overall headcount for the dual deprivation-based indicator (DDEP).

Criterion	Headcount in percent										
	Overall	Deciles of the income distribution in ascending order									
		1	2	3	4	5	6	7	8	9	10
A: ‘energy-related deprivation’	10.88	36.65	17.24	12.62	10.44	9.20	6.88	5.67	2.63	5.47	0.58
B: ‘general deprivation’	5.04	35.08	9.36	3.40	1.10	0.00	0.53	0.00	0.00	0.00	0.00
$A \cup B$	12.82	49.21	21.67	13.59	10.99	9.20	7.41	5.67	2.63	5.47	0.58
D: ‘economic energy consumer’	91.07	92.15	91.13	91.75	92.86	92.53	91.53	88.14	91.58	90.55	88.44
$(A \cup B) \cap D$	11.93	45.03	20.69	12.14	9.89	8.62	7.41	5.15	2.63	5.47	0.58
Overall DDEP headcount: $(A \cup B) \cap C \cap D$	**9.77**	**45.03**	**20.69**	**12.14**	**9.89**	**8.62**	**-**	**-**	**-**	**-**	**-**
Energy exp. Share (%)	8.53	19.09	10.62	9.56	9.16	6.88	6.54	6.91	6.20	5.50	4.22
Equiv. income (EUR/month)	1,901	689	1,038	1,272	1,445	1,623	1,819	2,034	2,347	2,794	4,169

Table 5: Comparison of energy poor vs. non-energy poor households according to the DDEP (all values are mean values, stars indicate significance level of the difference between the two groups based on t-tests).

Variable	Overall sample	Not energy poor	Energy poor
Equiv. income (monthly, EUR)	1900	2000	974***
Equiv. energy expenditure (monthly, EUR)	131	132	122
Number of persons in household	2.43	2.45	2.21**
Share of single households	0.22	0.20	0.41***
Number of children in household	0.40	0.39	0.46
Share of pensioners	0.28	0.28	0.28
Av. room temperature (in C°)	21.00	21.05	20.51***
Share of basic welfare recipients	0.05	0.02	0.27 ***

*** p-value < 1%, ** p-value 1%

Table 6: Comparison of energy poor households based on the proposed dual deprivation-based DDEP measure, the LIHC, the TPR, and the TPR5 (all values are mean values).

Variable	DDEP	LIHC	TPR	TPR5
Headcount	9.77%	11.61%	25.59%	21.18%
Equiv. income (monthly)	974	999	1,237	1,023
Equiv. energy expenditure (monthly)	122	180	193	161
Number of persons in household	2.21	3.22	2.19	2.27
Share of single households	0.41	0.10	0.32	0.31
Number of children in household	0.46	0.66	0.28	0.32
Share of pensioners	0.28	0.21	0.38	0.36
Av. room temperature (in C°)	20.51	20.90	20.86	20.82
Share of basic welfare recipients	0.27	0.09	0.13	0.15

Table 7: Marginal average effects (from logistic regression), dependent variable: energy deprivation headcount ratio.

Variables	(1)	(2)	(3)
in1000	-0.0987***	-0.105***	
	(0.00860)	(0.00845)	
en1000	0.391***	0.277***	
	(0.0931)	(0.0876)	
chi0_2	0.0278	0.0302	0.00833
	(0.0196)	(0.0202)	(0.0186)
chi3_5	0.0483***	0.0488***	0.0240
	(0.0182)	(0.0179)	(0.0153)
chi6_15	0.0326***	0.0291**	0.0110
	(0.0116)	(0.0115)	(0.0101)
ad16_59	0.0249***	0.0181***	-0.00631
	(0.00723)	(0.00672)	(0.00731)
ad60plus	0.0151	0.00580	-0.0182
	(0.0110)	(0.0104)	(0.0114)
alg2	0.0824***	0.0875***	0.0723***
	(0.0282)	(0.0298)	(0.0261)
unreno	0.0308**	0.0387***	0.0287**
	(0.0124)	(0.0123)	(0.0123)
tdi	0.0459***	0.0456***	0.0441***
	(0.0163)	(0.0162)	(0.0161)
underocc	0.00276		0.00572
	(0.0159)		(0.0161)
noappl	-0.00365*		-0.00390**
	(0.00190)		(0.00189)
avage	-0.00758		-0.00530
	(0.00925)		(0.00923)
east	0.0103		0.00970
	(0.0140)		(0.0141)
own	-0.0249*		-0.0211
	(0.0149)		(0.0146)
b47	0.0208		0.0229
	(0.0238)		(0.0238)
b48to80	0.0245		0.0265
	(0.0208)		(0.0206)
b81to95	-0.00344		-0.000355
	(0.0247)		(0.0246)
Hgas	0.0161		0.0144
	(0.0162)		(0.0159)
Hoil	0.0318		0.0265
	(0.0214)		(0.0207)
Hdistrict	0.0377		0.0344
	(0.0257)		(0.0257)
ein1000			-0.157***
			(0.0129)
een1000			0.693***
			(0.141)
Observations	1,903	1,903	1,903
Pseudo R^2	0.3634	0.3464	0.3787

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 8: Descriptive statistics of variables used in the logistic regression.

Variable	Variable description	Mean	St. dev.	Min.	Max.
DDEP	Headcount ratio of the dual deprivation-based indicator of energy poverty (binary dependent variable)	0.098	0.297	0	1
in1000	Income in thousand euros per month after all taxes and benefits	3.056	2.023	0.2	50
ein1000	Equivalence income calculated based on the 'new OCED equivalence scale'	1.900	1.168	0.14	27.78
en1000	Energy expenditure (electricity, space heating, and water heating) in thousand euros per month	0.206	0.141	0.03	2.62
een1000	Equivalence energy expenditure calculated based on the 'new OECD scale'	0.131	0.092	0.025	1.31
chi0_2	Number of children (0 to 2 years)	0.054	0.255	0	3
chi3_5	Number of children (3 to 5 years)	0.076	0.302	0	3
chi6_15	Number of children (6 to 15 years)	0.270	0.628	0	4
ad16_59	Number of additional adult persons (16 to 59 years) in the household	1.440	1.178	0	7
ad60plus	Number of additional elderly persons (60 years and more) in the household	0.591	0.819	0	5
alg2	Recipient of basic social security allowances (binary variable)	0.048	0.213	0	1
unreno	House or apartment requires renovation or leaky windows are present ('strong' or 'very strong' agreement to this statement, binary variable)	0.309	0.462	0	1
tdi	Stated indoor room temperatures are below individually perceived adequate room temperatures during the heating period in often used rooms, i.e. the living room (binary variable)	0.135	0.342	0	1
underocc	House or apartment is 'too large' or 'far too large' (binary variable)	0.232	0.422	0	1
noappl	Number of electric appliances in the household	13.491	4.774	3	42
avage	Average age of electric appliances in discrete categories (1: 0-2 years; 2: 3-5 years; 3: 6-10 years; 4: 10 years or older)	2.415	0.597	1	4
east	Household located in Eastern Germany (binary variable)	0.189	0.392	0	1
own	House or apartment owned by the household (binary variable)	0.598	0.491	0	1
b47	House built before 1947 (binary variable)	0.231	0.421	0	1

b48to80	House built between 1948 and 1980 (binary variable)	0.421	0.494	0	1
b81to95	House built between 1981 and 1995 (binary variable)	0.175	0.380	0	1
Hgas	Main heating system: natural gas (binary variable)	0.503	0.500	0	1
Hoil	Main heating system: light heating oil (binary variable)	0.223	0.416	0	1
Hdistrict	Main heating system: district heating (binary variable)	0.085	0.278	0	1

Overall number of observations for all variables: n=1,903, numbers are rounded to the third decimal place.

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