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Energy poverty in the Netherlands at the national and local level: A multi-dimensional spatial analysis

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ABSTRACT

The strong increase in energy prices since 2021 has led to a turning point in thinking about energy poverty in the Netherlands, where the concept of energy poverty was thus far neglected in national policy making. Against this background we present the first multifaceted spatial analysis of energy poverty in the Netherlands, which will serve as the analytical foundation to set up a national energy poverty monitor. In doing so, we make a novel contribution to the literature by estimating and systematically comparing a new set of energy poverty indicators for the Netherlands, taking into account the spatial dimension of the energy poverty problem by using georeferenced microdata at the household level, covering nearly 80 % of Dutch households. We measure three dimensions of the energy poverty problem: (i) the affordability of energy, (ii) the energetic quality of houses and (iii) households' ability to participate in the energy transition. Our analysis shows that at 2019 energy prices, approximately 7 % of Dutch households face a combination of high energy costs, inadequate insulation and low income. However, almost half of all Dutch households (48 %) cannot participate in the energy transition in the built environment on their own, because they live in a poorly or moderately insulated house that they are unable to upgrade because they are either tenants, or owners with insufficient financial wealth. About 75 % of energy-poor households live in a dwelling owned by a social housing association. These observations challenge the dominant policy perspective that greening of the housing stock mainly requires providing home-owners limited financial incentives in the form of subsidies. As regards the geography of energy poverty, we find that severe energy poverty is much more spatially concentrated than income poverty, and mainly occurs in peripheral regions of the Netherlands plus some densely populated urban districts. We argue that energy poverty is a symptom of slow diffusion of energy-saving technologies due to a combination of investment barriers, which should be addressed with a balanced mix of additional financial resources, price incentives and home insulation standards.

1. Introduction

In this article we present the first multifaceted nation-wide spatial analysis of energy poverty in the Netherlands. The ultimate goal of our study is to provide the analytical foundations to set up a national energy poverty monitor in the Netherlands, which we believe helps greatly to inform policy makers. In contrast to most other countries in North-West Europe, the Netherlands has until recently neglected the concept of energy poverty in its national policy. At the time of writing, energy poverty is not yet being monitored at the national level – despite obligations to do so from the European Commission – and the problem of an excessive energy bill was until very recently treated an issue related to income poverty and income policy.

But, ever since the pioneering work by Boardman [4] it is known that

even in wealthy countries a combination of low incomes, high energy bills and poorly insulated houses can lead to harmful social effects, including health issues, debt problems and loneliness (see e.g. [2,5–7,27,46]). This fact is obviously at odds with the pursuit of an inclusive and just energy transition, defined as a situation where (i) everyone has access to affordable, reliable and clean energy services, (ii) everyone can participate in decision-making processes regarding changes in the energy system, and (iii) there is recognition of problems arising from energy poverty and unequal opportunities in the transition [11]. Income poverty and energy poverty are of course strongly intertwined, but by no means always coincide: not all households with high energy costs are poor, and conversely there are low-income households that spend relatively little on energy and have no problems paying their energy bills. In the past ten years, many approaches have been proposed

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in the scientific literature to properly measure the multifaceted nature of energy poverty and to distinguish it from income poverty (for overviews, see e.g. [18,35]).

In recent years, raising awareness of the costs and potential inequities related to the transition to a sustainable energy system led to growing attention for the problem of energy poverty in the Netherlands (Van [34,44]). The recent sharp rise in gas prices further exacerbated these concerns, thus bringing the Dutch policy debate more in line with insights from the existing academic literature to date. The publication of a first version of this study in Dutch [30] coincided with the start of several waves of gas price increases. This led the present study, aided by its multidimensional and spatial features, contribute a great deal to a turning point in thinking about energy poverty in the Netherlands. For example, our spatial energy poverty statistics have recently been used by the Dutch Ministry of Internal Affairs to design energy bill compensation schemes and to earmark a few hundred million euro in additional subsidies for insulating homes of energy poor people. Moreover, the Ministry of Economic Affairs and Climate Policy has in the meantime asked the Dutch national statistics institute (CBS, Statistics Netherlands) to set up a (bi-)annual energy poverty monitor on the basis of the energy poverty framework that we present here.

Against this background, we present and justify in this article the analytical foundations of measuring and monitoring energy poverty in the Netherlands, including an assessment of the current energy poverty status. In doing so, we make a novel contribution to the energy poverty literature by estimating and systematically comparing a set of energy poverty indicators for the Netherlands. We consider several aspects of the energy poverty problem, and we explicitly take into account the spatial dimension by using georeferenced microdata at the household level, covering nearly 80 % of Dutch households and including all municipalities and districts in the Netherlands. We measure three dimensions of the energy poverty problem: (i) the affordability of energy, (ii) the energetic quality of houses and (iii) households' ability to participate in the energy transition. Based on a combination of indicators for these three dimensions, we answer three main questions in this study: How many households in the Netherlands are energy poor? What are their socio-economic traits? And where do they live?

Our use of a combination of binary energy poverty indicators of course reflects the multifaceted nature of the energy poverty problem [15,17,20,28,31–33,38–40,43,47]. Rather than adopting or developing one multi-dimensional indicator we choose to develop an energy poverty framework that combines separate indicators that each measure a distinctive feature of the energy poverty problem in the context of the energy transition. An important consideration to opt for this route is that the combination of several indicators in one energy poverty index tends to be conceptually unclear because of the need to aggregate and weight various poverty dimensions with different units of measurement (for discussion see [10,33,35]).

Quantitative research into energy poverty in the Netherlands to date is very limited, and fragmented in terms of regional coverage. An important value added of quantitative data analyses is that they provide insight into the extent and location of the energy poverty problem, which is of particular importance in a policy context where there is a lack of knowledge and awareness of the energy poverty problem. In the Netherlands, previous quantitative studies did not map the energy poverty problem comprehensively: most of the studies are partial analyses in the form of consultancy reports [1,45], mainly focusing on the question of affordability of the energy bill, usually measured in terms of the energy quote (energy costs as a share of income). In a first complete study at national level (Van [34]), the Netherlands Environmental Assessment Agency (PBL) estimated the affordability of energy bills from survey data, in terms of two indicators: the energy quote and the

payment risk. Dalla Longa et al. [12] further extended the framework introduced by PBL and investigated the possibility of using machine learning to estimate and monitor energy poverty in the Netherlands. Besides being based on a limited dataset,¹ these analyses also lacked the geographical dimension. The first geographic or spatial analyses of energy expenditure and energy poverty incidence in the Netherlands have been presented by Mashhoodi et al. [25] and Mashhoodi [26]. Mashhoodi [26] studies the associations between land surface temperature and annual household energy expenditure in urbanized zones of the Netherlands. He concludes that the magnitude of the impact of land surface temperature is comparable to that of well-established determinants of energy poverty, including the presence of privately rented dwellings and building age. Mashhoodi et al. [25] maps energy poverty incidence across Dutch neighborhoods, based on 2014 data on households' energy expenditure as percentage of their disposable income. In contrast, we not limit ourselves, to the affordability aspect of energy poverty.

While the ability to pay energy bills is certainly a fundamental criterion to identify energy poor households, it is by no means the only one. Measuring energy poverty exclusively in terms of affordability, creates a one-sided picture of the issue [5,6] that ignores its main root-cause, i.e. a house with low energy quality. Also, affordability alone does not provide sufficient insight into the extent to which households have (unequal) opportunities to participate in the energy transition by making their homes more sustainable. Households that currently have no payment problems, might still run the risk of lagging behind in the energy transition because they live in an inadequately insulated house that they cannot renovate. These are tenants who depend on the landlord for making their house more sustainable, and homeowners who have insufficient financial means to invest in sustainability. These households often suffer from lack of living comfort (e.g. related to draught, moisture or excessive heat) and associated health problems. Following the approach of Amartya Sen [41], who defined poverty primarily as a lack of capabilities – namely, the capabilities needed to be able to make choices targeted at increasing well-being – we argue that these households should also be seen as energy poor (see also [28]). The latter also underlines the importance to complement quantitative data analyses with qualitative analyses of the lived experience of energy-poor people, drawing on qualitative data on people's everyday lives to document the effects of reduced access to energy services [27].

This article is organized as follows: In Section 2 we present our methodology, define our energy poverty indicators and describe the data used in our study. In Section 3 we present the results of our calculations, quantifying and comparing the various indicators at the national level. In Section 4 and 5 we analyze, respectively, the socioeconomic characteristics of energy-poor households and their spatial distribution. In Section 6 we carry out a sensitivity analysis of the possible impact of an energy price increase on the level and spatial distribution of energy poverty. In Section 6 we discuss how the results of our analysis can be used for qualitative monitoring of energy poverty in the Netherlands. Finally, Section 7 contains discussion of our results from a policy perspective.

2. Methodology

2.1. Energy poverty indicators

As mentioned before, we measure energy poverty from three distinct perspectives: (i) the affordability of energy, (ii) the energetic quality of houses and (iii) households' ability to participate in the energy transition. For each of these three dimension we develop a main energy poverty indicator, as well as several variants. These are summarized in

¹ Up to about 65.000 surveyed households, with detailed energy characteristics of houses available for about 4000 households.

Box 1.

When dealing with the first two dimensions of our analysis – affordability and energetic quality – we only select low-income households as possible candidates for energy poverty. In our view, wealthy homeowners with high energy consumption habits or a poorly insulated home are not to be considered energy-poor, as they possess in principle the means to reduce their energy bills by changing their behavior or by investing in home renovation.² The latter obviously does not apply to the group of owners that live in dwellings of relatively low energetic quality and have insufficient capital or borrowing capacity to invest in making their home more sustainable. Similarly, it does not hold for tenants who depend on the willingness and capacity of the home owners (a housing association or private landlord) to make their home more energy efficient, but who do in the meantime of course pay the energy bills. These two groups cannot independently participate in the energy transition, hence we single them out in our last two energy poverty indicator variants (oLEQ and tLEQ).

The energy quote defines energy poverty as a (too) high share of income spent on energy (i.e. gas and electricity) costs. A high energy quote (HEQ) is not only the best-known but also the most criticized indicator of energy poverty [5,6,9,24,35,42]. On the one hand, this measure underestimates energy poverty because by definition it excludes people who under-consume energy due to financial problems (for example by turning down the heating); on the other hand, it may actually overestimate the problem by including rich households with high energy consumption (for example because they live in a poorly insulated monumental building). As regards the latter, households with a relatively high income that are careless in their use of energy do not have an affordability problem, but rather an overconsumption attitude, which might lead to financial problem in the future and is at odds with the aims of the energy transition. Because this latter group is relatively large in the Netherlands, HEQ leads to significantly overestimated energy poverty shares (See Table 1). This last problem can in principle be corrected by excluding high incomes in the calculation (see e.g. [3,16]), which we do in our analysis using variant 0.1 (LIHEQ).

The Low Income & High Energy Costs indicator (LIHC) is a more accurate measure to identify energy poverty than the HEQ because, unlike the HEQ, it only includes households that have both a low income and high energy costs, i.e. no households with high energy costs but a relatively high income [18]. However, as for the HEQ, the LIHC also fails to identify households that under-consume energy.

The main advantage of the indicator Low Income & house with Low Energetic Quality (LILEQ) is that it no longer reduces energy poverty to an affordability problem, but rather redefines it in terms of households that are vulnerable because they have both a low income and live in a building of relatively low energy quality. This indicator thus paves the way for an analysis of the extent to which households are or are not able to do something about an important cause of energy poverty, namely the quality of their house. The latter requires not only sufficient capital, but also a certain degree of financial and organizational talent, and (usually) ownership. A disadvantage of the LILEQ indicator is of a practical nature: it is not easy to unambiguously measure and compare the energetic quality of houses. In absence of reliable energy label data, in our present analysis we operationalize this indicator in an indirect way (see below). Various initiatives are currently underway (at CBS, TNO and PBL) to provide datasets on definitive energy labels and/or the theoretical energy consumption of houses. Once these data is available, new estimates of the LILEQ can be produced, which will be independent of actual energy consumption data.

We create two variants of the LILEQ indicator to gain some insight

² This is not say that for this group home renovation therefore cannot be difficult, as high income households often have more space to heat or sometimes live in protected monuments that are difficult to renovate due to technical or legal constraints [36].

into under- and overconsuming households – two groups that are often mentioned in studies of energy poverty, but are difficult to identify. The first variant (LILEQ-) measures so-called hidden poverty: households who under-consume energy due to financial problems, for example by turning down the heating or regularly refraining from cooking. We speak of underconsumption if a household, in addition to meeting the LILEQ criteria of low income and low energetic quality, also displays energy costs below the 25th percentile within its housing class. The second variant (LILEQ+) identifies households that consume more energy than others living in a comparable house, for example because they need to maintain high indoor temperature due to health reasons, or because they are careless with their energy consumption. According to LILEQ+, household is energy-poor if, in addition to meeting the LILEQ criteria, it also has energy costs above the 75th percentile within its housing class. The drivers and behavioral patterns that lead a household to under- or over-consume energy are clearly very different, and require targeted policy interventions. The LILEQ- and the LILEQ+ indicators represent a first step towards gaining more insight in these two diverse groups.

Our last indicator, 'House with Low Energetic Quality & inability to invest in renovation' (LEQ), provides insight into unequal opportunities to participate in the energy transition. This indicator singles out home owners with limited financial assets that cannot pay for retrofits (oLEQ) and tenants (tLEQ) who have no control over their home due to lack of ownership. The group of tenants, by definition, also includes middle-income and wealthy tenants, who nevertheless have no influence on the decision whether to renovate the house in which they live. Hence, although most tenants currently are not facing energy affordability problems, they are unable to independently make their homes more energy efficient, for example by improving its insulation, or by installing rooftop photovoltaic panels for electricity self-consumption. This puts part of them at risk of running into payment problems in the future (for example because of rising energy prices), while dealing with lack of comfort and sometimes even health issues due to the poor insulation state of their dwellings. As argued in the previous section, this lack of choices and possibilities in the context of the energy transition is in our view also a form of energy poverty. The main disadvantage of this indicator is the same as that of the LILEQ: due to a lack of reliable and complete data on energy labels (see below), measuring the energy quality of homes is not easy and as yet imperfect.

2.2. Parameters

All the parameters used in the estimation of indicators, are drawn from the household-level microdata database of Statistics Netherlands (CBS). Given the possibilities and limitations of the CBS microdata as well as the desire to link up with existing routines for the use of microdata for policy, we define the various parameters as follows.

2.2.1. (Low) Income and insufficient financial assets

We define income as a household's disposable income, plus a correction term that accounts for a household's financial capital. The latter is calculated by annuitizing households' financial assets.³ We include this correction term to properly account for households in our dataset that have no income, but do have capital at their disposal. This

³ The annuitization is based on an estimate of the remaining years of life of the longest living partner in a household, and long-term interest rates from De Nederlandsche Bank (DNB), which are also used for pension calculations by leading Dutch pension funds. Note that this method relies on several assumptions (i.e. interest, life expectancy, no inheritance), which could lead to misclassification of certain households. The choice to only include only financial assets of a household and leave out other types of assets, such as house value, business capital and substantial interest, is because the latter cannot readily be used to pay energy bills.

Box 1

Energy poverty indicators: criteria for a household to be defined as energy poor.

Affordability

- 0. High Energy Quote (HEQ): high energy costs as share of income
- 1. Low Income & High Energy Costs (LIHC)

Energetic Quality

- 2. Low Income & house with Low Energetic Quality (LILEQ)

Ability to Participate in the Energy Transition

- 3. House with Low Energetic Quality & inability to invest in renovation (LEQ)

Variants:

- 0.1 HEQ for low income households (LIHEQ)
- 2.1 LILEQ for under-consuming households (LILEQ-); hidden energy poverty
- 2.2 LILEQ for over-consuming households (LILEQ+); hidden energy poverty
- 3.1 LEQ for owners (oLEQ)
- 3.2 LEQ for tenants (tLEQ)

Table 1

Energy Poverty Incidence in the Netherlands, percentage and number of households.

		% Poverty based on data	# Poor households ^a	% Poverty after correction	# Poor households after correction	# Poor households rounded
0	Low Income (income poverty)	15,1 %	1.194.968	–	–	1.200.000
Affordability						
1.	High Energy Quote (HEQ): energy costs as share of income	8,3 %	660.447	9,6 %	760.770	760.000
2.	Low Income & High Energy Costs (LIHC)	4,0 %	317.171	5,3 %	420.009	420.000
Energetic quality						
3.	Low Income & house with Low Energetic Quality (LILEQ)	3,6 %	283.694	4,9 %	388.310	390.000
3a.	LILEQ for under-consuming households (LILEQ-); hidden energy poverty	1,3 %	102.207	1,8 %	140.223	140.000
3b.	LILEQ for over-consuming households (LILEQ+); hidden energy poverty	0,6 %	47.887	0,8 %	64.718	65.000
Ability to participate in the energy transition						
4a.	Owners of house with Low Energetic Quality & inability to invest in renovation (oLEQ)	21,3 %	1.684.890	–	–	1.700.000
4b.	Tenants of house with Low Energetic Quality & inability to invest in renovation (tLEQ)	26,7 %	2.115.985	–	–	2.100.000
Combination of indicators						
2 and 3	LIHK and LILEK	1,9 %	149.753	3,2 %	253.590	250.000
2 or 3	LIHK or LILEK	5,7 %	451.113	7,0 %	554.728	550.000
1 or 2	HEQ or LIHK	9,4 %	741.451	10,7 %	847.942	850.000
1 or 3	HEQ or LILEK	10,1 %	798.700	11,4 %	903.415	900.000
1, 2, or 3	HEQ or LIHK or LILEK	10,6 %	843.181	11,9 %	943.038	940.000

^a Estimate of actual number of energy poor households: % energy poverty based on data x total number of households.

procedure ensures that many households living in large estates in wealthy neighborhoods – unlikely to incur payment problems – are not incorrectly classified as energy poor. Our low income is based on a standardized threshold of ‘social minimum’ developed by Statistics

Netherlands (CBS) and widely used in Dutch policy making, which is adjusted for the household composition (size).

To identify energy poverty with the energy quote (HEQ), a threshold of 10 % is commonly used – dating back to its introduction more than

thirty years ago [4]. However, with the inclusion of the correction term based on financial assets, adopting the usual 10 % threshold would lead to an underestimation of energy poverty in our data – hence we adopt an energy-quote threshold of 8 % in our calculations.⁴ In the LIHEQ, LIHC and LILEQ indicators we define low income (LI) as disposable income below 130 % of the social minimum – a frequently used metric in Dutch income poverty and social welfare arrangements. To still ensure that wealthy households are not misclassified as energy poor, we also impose the condition that financial assets should be below the national 90th percentile.

To identify home owners with insufficient financial assets to renovate their low energetic quality home (in the first variant of our LEK indicator, oLEK) we define ‘insufficient financial assets’ in terms of falling below a minimum threshold for both savings and home equity. For savings we adopt a threshold of €40,000, assuming an average investment in sustainable home renovation of €15,000–€30,000, and a financial buffer of at least €10,000. For home equity we consider a threshold of €80,000, defined as the difference between a property's actual market price and the associated mortgage debt,⁵ assuming that home equity above this threshold implies sufficient borrowing capacity to finance sustainable home renovation of €15,000–€30,000.

2.2.2. High energy costs

Energy costs entail costs for both gas and electricity, defined as the product of annual consumption levels and the average end-user rates, measured over the year and the various providers. The threshold for high energy costs in the LIHC indicator is chosen as the national median. In contrast to the HEQ, the LIHC indicator is a relative measure.

2.2.3. Low Energy Quality House

For the identification of a property's ‘low energy quality’, one would ideally rely on certified energy labels (for example choosing all houses with an energy label D or lower). However, thus far the registration of energy labels in the Netherlands is still incomplete and partially outdated, hence not suited for our purposes.⁶ We have therefore opted for an indirect definition of energetic quality, which we derive from a combination of house characteristics and the energy consumption. First we divide all houses in the Netherlands into 440 ‘housing classes’, based on 5 housing type classes, 11 construction year classes and 8 home surface classes, following a standard classification system.⁷ For each housing class we then estimate the median energy consumption and subsequently characterize a house as having ‘relatively Low Energy Quality’ if the median energy consumption in the class to which it

⁴ In order to come up with a more appropriate threshold, we initially excluded households with large financial assets from our database, and calculated energy poverty at national level according to the HEQ indicator for a range of threshold values with and without the financial assets correction term. We found that with a threshold of 8 % the difference between the calculation with and without the correction term for this group of households leads to the same level of national energy poverty. Therefore we adopt an energy-quote threshold of 8 % in this study.

⁵ Information on actual property prices is based on its annual appraisal according to a recent valuation reference date by municipalities in the context of the Real Estate Valuation Act (WOZ Act). Information on the actual mortgage debt of a household, based on information from the Tax and Custom Administration Authority.

⁶ By and large, registration of energy labels in the social housing sector is complete and up-to-date, but for the market sector this is not the case: since individual home owners in the Netherlands have yet no incentive to register energy labels after renovation (except in case of sale), a large part of the existing housing stock has only non-certified (preliminary) energy labels that are estimated on the basis of construction year and some rudimentary house features.

⁷ <https://www.cbs.nl/nl-nl/maatwerk/2020/13/energielevering-woningen-naar-energielabel-en-pv-2018>

belongs is higher than the national median. Cross-checking the results of this procedure with the houses that possess a certified energy label, we find that this definition of relatively low energy quality includes all houses with an energy label D or lower, plus roughly half of the houses with an energy label C.

2.3. Data

Our calculations are based on a dataset for the year 2019 (the most recent we could use), comprising 6,149,385 households spread over 355 municipalities and 3018 districts. This means that the dataset includes 78 % of the nearly 8 million households in the Netherlands in 2019, all municipalities and 97 % of the districts. This makes it the most comprehensive energy poverty dataset developed to date in the Netherlands, and also the first to include this level of spatial detail across the whole country.

The group of households not included in our analyses can be divided into two sets. Together, these two sets amount in total to about 1.7 million households, >22 % of the total. The first set contains households for which no energy consumption data is available, for example because they are connected to a district-heating network. The second set comprises households for whom no reliable estimates of income, capital or housing data are available in the database. This includes households sharing the same address, households residing in buildings that are intended as business premises, households living in unusual dwellings – such as boats and housing units – and households with an exceptionally low or temporarily low income – such as students and entrepreneurs who had a particularly bad year. Underlying data from Statistics Netherlands (CBS) show that around 10 % of people registered as entrepreneurs deal with (risk of) poverty. Most of these people work in the sectors delivery services, transport, catering industry and agriculture. As regards the group of students, over 320,000 students registered in the Netherlands, with an average monthly income of €500. Recent research shows that students frequently live in energy poverty while they are often an under-reported and under-supported group when it comes to energy poverty policies [23].

In order to properly estimate how many of these households are affected by energy poverty, further research is needed, for example by means of surveys. As regards our present analysis, the omission of this group of households implies that our calculations most likely underestimate actual energy poverty levels. This is because most households in this group are expected to have relatively low incomes, hence be more likely to incur energy poverty, compared to the national average. To compensate for this effect we assume that in this group the energy poverty share is 10 %, i.e. similar to the highest (uncorrected) energy poverty levels found in our dataset, as will be shown below. This entails, for indicators LIHC and LILEQ, a correction factor of approximately 1.3 percentage points at the national level (the full calculation can be found in Appendix A). We apply this 1.3 percentage points correction to all our energy poverty indicators; for the two variants LILEQ- and LILEQ+ we apply the correction pro rata as they are subsets of LILEQ.

In order to assess the spatial distribution of energy poverty, we create summary statistics of our indicators at national, municipal and district level. To this end we apply the official definitions of municipal and district boundaries from Statistics Netherlands (CBS, 2019). To guarantee privacy and prevent disclosure of individuals or companies, the CBS applies strict conditions for the use and publication of the data. This means that for some areas, for which we only have a limited number of data points, we are not allowed to show district-level results. We can, however, still use those data points for calculations at the national and municipal level.

3. Quantifying energy poverty in the Netherlands

In this section we address the question of how many Dutch households are energy-poor by estimating our various indicators at national

level, and by assessing their overlap and coherence. The results are presented in Table 1. We show the share and the total number of energy-poor households for each indicator (as well as for some meaningful combinations of indicators), with and without the aforementioned correction factor of 1.3 percentage points. In the last column of Table 1 we report the totals as rounded numbers, so as to emphasize that our results should always be interpreted as estimates.

According to the classical HEQ indicator, 9.6 % of households in the Netherlands is energy-poor. This estimate is well-aligned with prior results that were also based on a measure of households' energy quote (e. g. Van [34]). The more accurate LIHC and LILEQ indicators, however, yield significantly lower estimates for national energy poverty shares: 5.3 % and 4.9 %, respectively, for LIHC and LILEQ. The difference between the results for HEQ versus LIHC and LILEQ is attributed to the above-mentioned shortcomings of the HEQ indicator. If we exclude high-income household from the calculation (variant 0.1 LIHEQ), the resulting national energy-poverty share decreases to 6.5 % (not shown in Table 1). This value is more in line with the one obtained using the LIHC indicator – which, like HEQ, also tackles the affordability dimension of energy poverty. With variants LILEQ- and LILEQ+ we identify the shares of, respectively, hidden energy poverty (1.8 %) and overconsumption (0.8 %). These energy poverty levels seem to be, to the best of our knowledge, still relatively low as compared to other European countries.⁸

Two particularly interesting groups can be identified by considering households that satisfy the energy poverty criteria for both LIHC and LILEQ, or for *either* of them. The former yields the LIHC & LILEQ indicator: the number of low-income households that have both high energy cost and a house of relatively low energetic quality. This group of about 250.000 households (3.2 % of the total) incurs a very high energy poverty risk, both from the standpoint of affordability and that of house quality. If we consider all households that are identified as energy-poor by either LIHC or LILEQ, we get a total corrected energy poverty share of 7 %. This corresponds to about 550.000 low-income households that either have high energy costs, or live in a house with relatively low energetic quality. This indicator combination accounts simultaneously for both affordability and house quality, hence we consider it our main measure of energy poverty. For comparison, as reported in the first row of Table 1, the share of households below the poverty line is about 15 %, or a total of 1.2 million. In other words, energy poverty in the Netherlands affects about half as many households as income poverty.

Finally, considering indicators oLEQ and tLEQ we observe that nearly half (48 %) of the households in the Netherlands inhabit a dwelling of relatively low energetic quality and are not immediately able to independently invest in sustainable renovation. Indicator tLEQ identifies the tenants in this group (26,7 % of all households in the Netherlands), who depend on their landlord, hence do not have the authority to decide about rendering their house more energy efficient. With indicator oLEQ we distinguish the homeowners who do not have sufficient (access to) financial capital to invest in sustainable renovation (21,3 % of the national total). While the set of energy-poor households according to LILEQ is by definition included in this group, the majority of households that are selected by either tLEQ or oLEQ at the moment does not experience affordability problems. They are however at risk of not being able to participate in the energy transition by being forced to forego the opportunity to improve the energetic quality of their house.

⁸ Although exact cross-country comparisons are difficult due to use of different definitions and lack of consistent data, in terms of most energy poverty indicators for which cross-countries comparisons are available – ‘inability to keep home adequacy warm’ and ‘arrears on utility bills’ – the Netherlands scores relatively low and comparable with Scandinavian countries. An exception may be the share of household expenditure on energy among the lowest income quintiles seems, which seems relatively high in the Netherlands (see e.g. [13]).

This may ultimately lead to affordability problems, especially if energy prices continue to raise.

To conclude this section, in Table 2 we present an overview of the average energy use in the different types of energy-poor households, and compare it with the national mean. Depending on the chosen indicator, energy poor households spend between 13 % and 20 % of their income on energy, against an average of 5 % for all Dutch households. The relatively higher costs for energy-poor households are mainly a consequence of their higher gas consumption. This is apparent if considering the affordability indicators HEQ and LIHC. According to HEQ, energy-poor households use 43 % more gas than average, while ‘only’ consuming 10 % more electricity. For LIHC households consumption of gas and electricity is, respectively, 32 % and 8 % higher than the national average. In the other energy poverty categories, gas usage is also typically higher (10–12 %), while electricity consumption is lower (7–13 %) than the national average.

4. Socio-economic traits of energy-poor households

In this section we present a socio-economic characterization of energy-poor households in the Netherlands. We analyze the distributions of housing characteristics, household composition and income situation for energy-poor households – according to the various indicators – and compare these with national averages for all households.

Tables 3 and 4 show an overview of the housing characteristics of energy-poor households. The category of multi-family dwellings in Table 3 includes flats, gallery, porch, ground floor and upstairs dwellings, apartments and dwellings above commercial spaces. Remarkably enough, energy poverty in the Netherlands is not concentrated in these homes. If we define energy poverty in terms of high energy costs (HEQ, LIHC), we see that roughly only one third of energy poor households live in multi-family houses. If, on the other hand, we define energy poverty in terms of a lower energetic house quality (LILEQ, eLEQ, hLEQ), we see that 80–90 % of energy poverty can be found in households in a terraced house, a corner house or a semi-detached house. No <16 % of homeowners with a house of relatively low energetic quality and insufficient financial capacity to renovate it (oLEQ) live in a detached house. This observation anticipates the conclusion that energy poverty in the Netherlands is mainly concentrated in sparse and non-urban areas outside the Randstad⁹ conurbation, as thoroughly discussed in Section 5.

Table 2
Energy consumption characteristics.

	Average annual gas consumption		Average annual electricity consumption		Energy quote ^a
	M ³	Index	kWh	Index	%
All households	1177	100	2749	100	5 %
Energy poor households					
HEQ (affordability)	1687	143	3011	110	16 %
LIHC (affordability)	1555	132	2958	108	13 %
LILEQ (energetic quality)	1314	112	2400	87	20 %
LILEQ- (underconsumption)	865	73	1560	57	32 %
LILEQ+ (overconsumption)	2071	176	4007	146	19 %
eLEQ (ability to participate)	1314	110	2400	87	20 %
hLEQ (ability to participate)	1296	110	2545	93	6 %

^a Energy costs as share of income.

⁹ The Randstad conurbation is located in central-western Netherlands and consists of the cities Amsterdam, The Hague, Rotterdam and Utrecht and their surroundings.

Table 3
House characteristics (I).

Sample	Type of house				Ownership		
	Detached house	Semi-detached house	Terraced house	Apartment	Privately owned	Social rent	Other ^a
	%	%	%	%	%		
All households	10	25	35	30	60	30	10
Energy poor households							
High Energy Quote (HEQ)	14	25	26	34	31	56	13
Low Income & High Energy Costs (LIHC)	5	28	34	33	11	75	13
Low Income & house with Low Energetic Quality (LILEQ)	7	48	41	3	14	75	12
Owners of house with Low Energetic Quality & inability to invest in renovation (oLEQ)	16	41	41	1	100	–	–
Tenants of house with Low Energetic Quality & inability to invest in renovation (tLEQ)	6	46	44	4	–	75	25

^a Private rent, unknown.**Table 4**
House characteristics (II).

Sample	Construction year house						Average living area <i>m</i> ²	Average house value €
	<1950	1950–1975	1975–1990	1990–2000	2000–2010	>2010		
	%	%	%	%	%	%		
All households	20	30	25	10	10	5	117	245.981
Energy poor households:								
High Energy Quote (HEQ)	26	43	21	5	3	1	112	206.260
Low Income & High Energy Costs (LIHC)	20	48	22	5	3	1	101	180.151
Low Income & house with Low Energetic Quality (LILEQ)	19	55	21	4	1	0	117	186.358
Owners of house with Low Energetic Quality & inability to invest in renovation (oLEQ)	22	37	26	10	5	2	134	233.289
Tenants of house with Low Energetic Quality & inability to invest in renovation (tLEQ)	18	53	23	4	1	0	117	199.483

Table 3 also shows that – taking LIHC and LILEQ as reference indicators – approximately 75 % of energy-poor households are to be found in the social housing sector, i.e. renting their home from a social housing corporation – considerably more than the national average of 30 %. About 11–14 % of energy-poor households are home owners and a comparable share rents privately.

Table 4 shows that energy poverty is most common in houses built between 1950 and 1975: about 50 % of energy-poor households have a house in this segment, compared to 30 % on average in the Netherlands. <10 % of energy-poor households live in a house built after 1990. House size does not correlate significantly with energy poverty, except perhaps for the LIHC indicator, which shows slightly smaller living areas than average. House value, on the other hand, is considerably lower than average for energy-poor households, according to all indicators except for homeowners with a house of relatively low energetic quality and insufficient financial capacity to renovate it (oLEQ). This is consistent

with the notion that oLEQ partly concerns detached (monumental) buildings that are poorly insulated.

Table 5 provides an overview of household composition of energy-poor households, again compared to the average for all households. Single-person households and single-parent families are strongly over-represented in the group of energy-poor households. Depending on the indicator and counting oLEQ and tLEQ as one single group, 17–22 % of energy-poor households consist of single-parent families, while they constitute only 5 % of all households in the Netherlands. In total, families with children (both one- and two-parent families) make up about 30 % of the households that are currently energy-poor and about 60 % of the subgroup of home-owners that has insufficient financial capacity to make their relatively energy-inefficient home more sustainable (oLEQ) – especially two-parent families with children are overrepresented in the latter group.

As can be seen in Table 6, about 40 % of energy-poor households

Table 5
Household composition.

Sample	Household composition					Average # persons
	Single person	Couples without children	Couples with children	Single parents	Other multi-person	
	%	%	%	%	%	#
All households	30 %	30 %	30 %	5 %	5 %	2,3
Energy poor households						
High Energy Quote (HEQ)	61 %	18 %	9 %	10 %	1 %	1,6
Low Income & High Energy Costs (LIHC)	38 %	21 %	17 %	22 %	2 %	2,2
Low Income & house with Low Energetic Quality (LILEQ)	46 %	23 %	13 %	17 %	2 %	2,0
Owners of house with Low Energetic Quality & inability to invest in renovation (oLEQ)	13 %	26 %	54 %	5 %	2 %	3,0
Tenants of house with Low Energetic Quality & inability to invest in renovation (tLEQ)	33 %	29 %	21 %	15 %	2 %	2,2

Table 6
Source of income.

Sample	Income				
	Job or business	Social assistance benefit	Pension	Social benefit unemployment or illness	Average annual income ^a
	%	%	%	%	€
All households	60 %	10 %	30 %	0 %	49.274
Energy poor households					
High Energy Quote (HEQ)	27 %	36 %	36 %	1 %	21.496
Low Income & High Energy Costs (LIHC)	21 %	44 %	35 %	0 %	20.568
Low Income & house with Low Energetic Quality (LILEQ)	20 %	36 %	44 %	0 %	20.307
Owners of house with Low Energetic Quality & inability to invest in renovation (oLEQ)	–	–	–	–	56.243
Tenants of house with Low Energetic Quality & inability to invest in renovation (tLEQ)	49 %	17 %	34 %	0 %	35.637

^a Including estimated income from financial assets.

receive income from social assistance or from pension. The average annual income of energy-poor households (HEQ, LIHC and LILEQ) is less than half of the national average. Interestingly, elderly people with a pension income make up for a relatively large group of the homeowners with a house of relatively low energetic quality and insufficient financial capacity to renovate it (oLEQ).

5. Spatial distribution of energy poverty

In this section we present and discuss the spatial distribution of energy-poor households in the Netherlands. Fig. 1 shows the regional distribution of energy poverty in the Netherlands at municipality level. We measure energy poverty as ‘LIHC or LILEQ’: the share of households with a low income that have either high energy costs or a house with an low energetic quality. By comparing the amount of energy-poor households (height of the bars) with their relative share (color of the bars), the map shows a sharp spatial dichotomy in the Netherlands. A strong concentration of municipalities with relatively high energy poverty shares is found in the rural north and (south-) east of the country, whereas relatively low shares are observed in the Randstad conurbation. Due to their high population density, however, municipalities in the Randstad host on balance more energy-poor households than municipalities in the rest of the country.

In Fig. 2 we provide a more detailed overview by inspecting the

distribution of all the various indicators at district level.¹⁰ The maps reveal the presence of energy-poor districts in all parts of the Netherlands, including in the Randstad, where a few energy-poor districts can be found amidst a background of low energy poverty. The tLEQ indicator is an exception to this pattern, as tLEQ-energy-poor households are uniformly spread across the country. A comparison of the maps in Fig. 2 reveals that, while there is a large district-level overlap between the various indicators, there are also clear differences as to which districts are identified as energy-poor depending on the definition utilized. This phenomenon is a consequence of the complex multifaceted character of energy poverty: some indicators are more sensitive to specific energy poverty drivers than others. This underscores that it is paramount to measure energy poverty by means of different indicators in order to include all household affected by this problem. Also, it implies that the severity of energy poverty in a districts can be gauged by whether it is identified as energy poor by multiple indicators – along with its energy poverty shares according to any specific indicator being higher than the national average.

Underlying data confirm that HEQ, LIHC and LILEQ are relatively strongly correlated, with a slightly stronger correlation between LIHC and HEQ than between LIHC and LILEQ. Most notably is that LIHC correlates much stronger with oLEQ than tLEQ – i.e. energy poverty in terms of Low Income and High Costs (LIHC) is more frequently observed among owners energy inefficient homes with limited financial capital (oLEQ) than among renters of energy inefficient homes (tLEQ).

In Fig. 3 we explore the correlation between energy poverty and urbanization. The x-axis of the various panels in Fig. 3 represents the degree of urbanization, from high (1) to low (5), while the y-axis measures energy poverty shares. The line-connected dots in the plots are the average energy poverty shares, calculated at districts level, for a particular degree of urbanization. Each color represents a particular energy-poverty definition, and each panel presents a group of indicators (note that some indicators appear in multiple panels to allow comparisons). In the legend we also report the Pearson correlation coefficient ρ . Because the urbanization scale is plotted from high to low, a negative value of ρ indicates a positive correlation between energy poverty and the degree of urbanization. Most energy poverty indicators, with the exception of LIHC, correlate negatively with urbanization (positive ρ), indicating that – unlike income poverty – energy poverty is not a problem that primarily occurs in big cities. The correlation is particularly strong for tLEQ. We speculate that this may partly be due to the fact that in recent decades the majority of urban renovation projects have

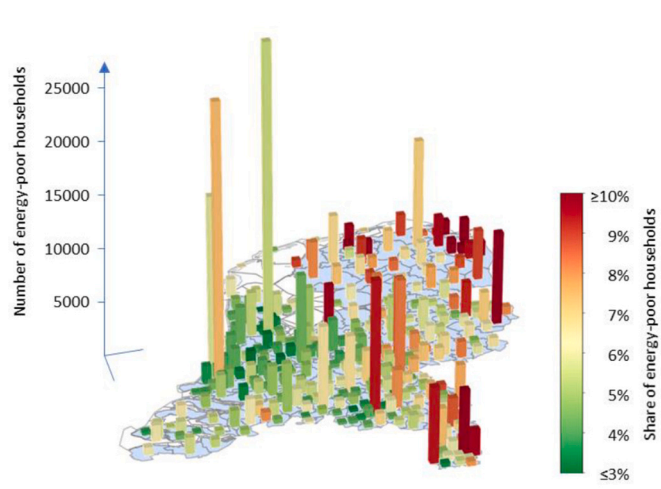


Fig. 1. Energy poverty* per municipality: percentage (bar color) versus number of households (bar height).

*Municipalities with <3 % energy poverty have been omitted for the sake of legibility of the figure.

¹⁰ For many districts LILEQ values are very low, affecting less than a dozen houses. For this reason we have chosen to present LILEQ data at municipality level, so as to avoid disclosing potentially sensitive information regarding a small share of the population.

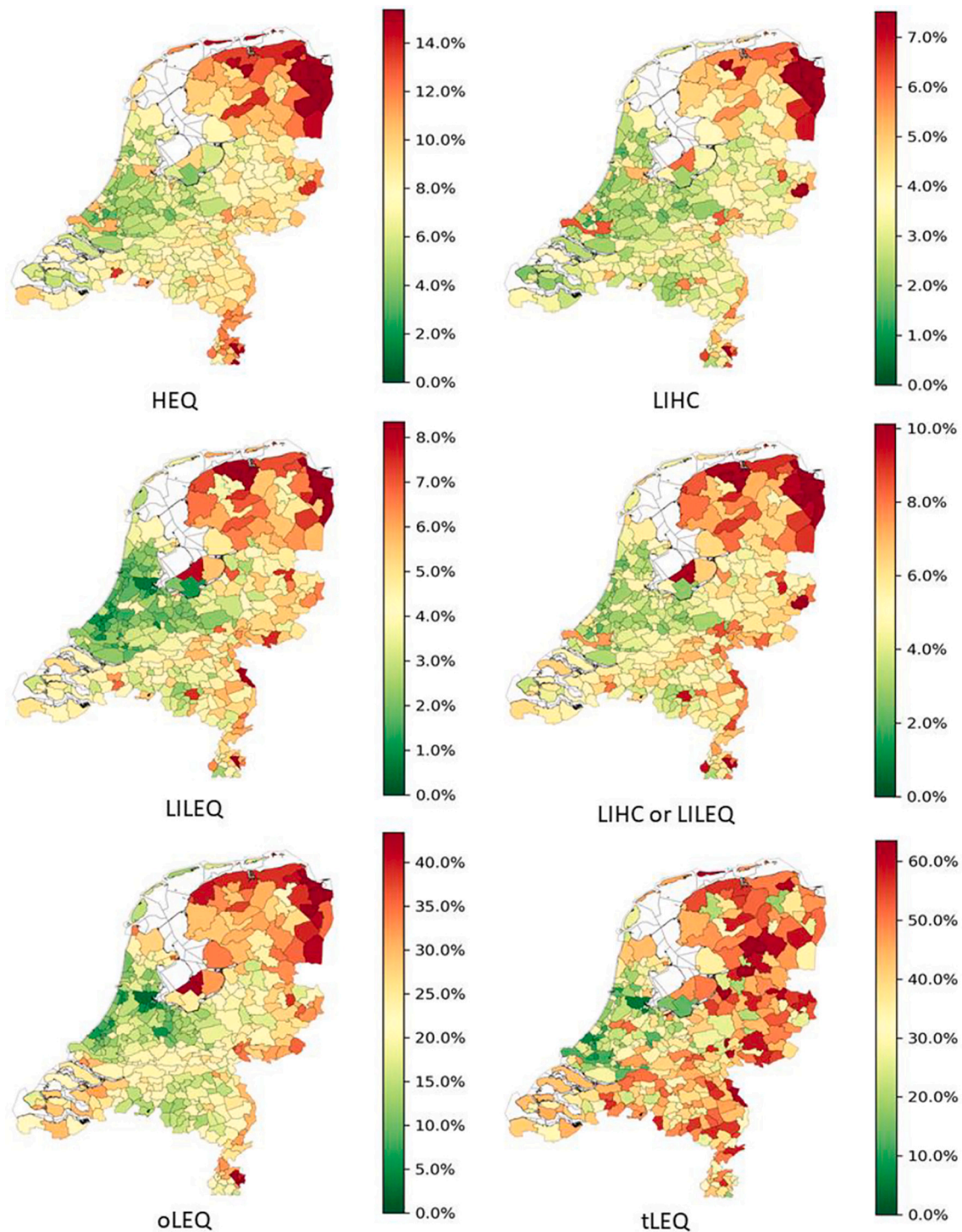


Fig. 2. Energy poverty incidence at district level.

been carried out in the large cities in the Randstad area, implying that the geographical center of gravity of the energetically less good houses shifted to the less densely populated areas in the north and east of the country. An additional hypothesis is that house quality in these latter regions is relatively low on average, because these regions have traditionally been poorer than the urbanized western part of the Netherlands (the Randstad area). Clearly, these hypotheses require further investigation. For example, based on a comparison of the level and dynamics of fuel poverty in rural and urban areas of the UK, Roberts et al. [37] find that, on average, urban fuel poverty is more persistent than rural fuel

poverty but that rural fuel poor are more vulnerable to energy price shocks. More research is needed to assess whether these conclusions also hold for the Netherlands. Such research is valuable to assess whether and policy effectiveness may differ across rural and urban space and to what extent spatial targeting of energy poverty policies is a good strategy (cf. [8]).

In Fig. 4 we present kernel density plots for all indicators. These show the cumulative normalized frequency of districts (y-axis) that exhibit a certain level of energy poverty (x-axis). If the levels of energy poverty were uniformly distributed across all districts, these plots would show as

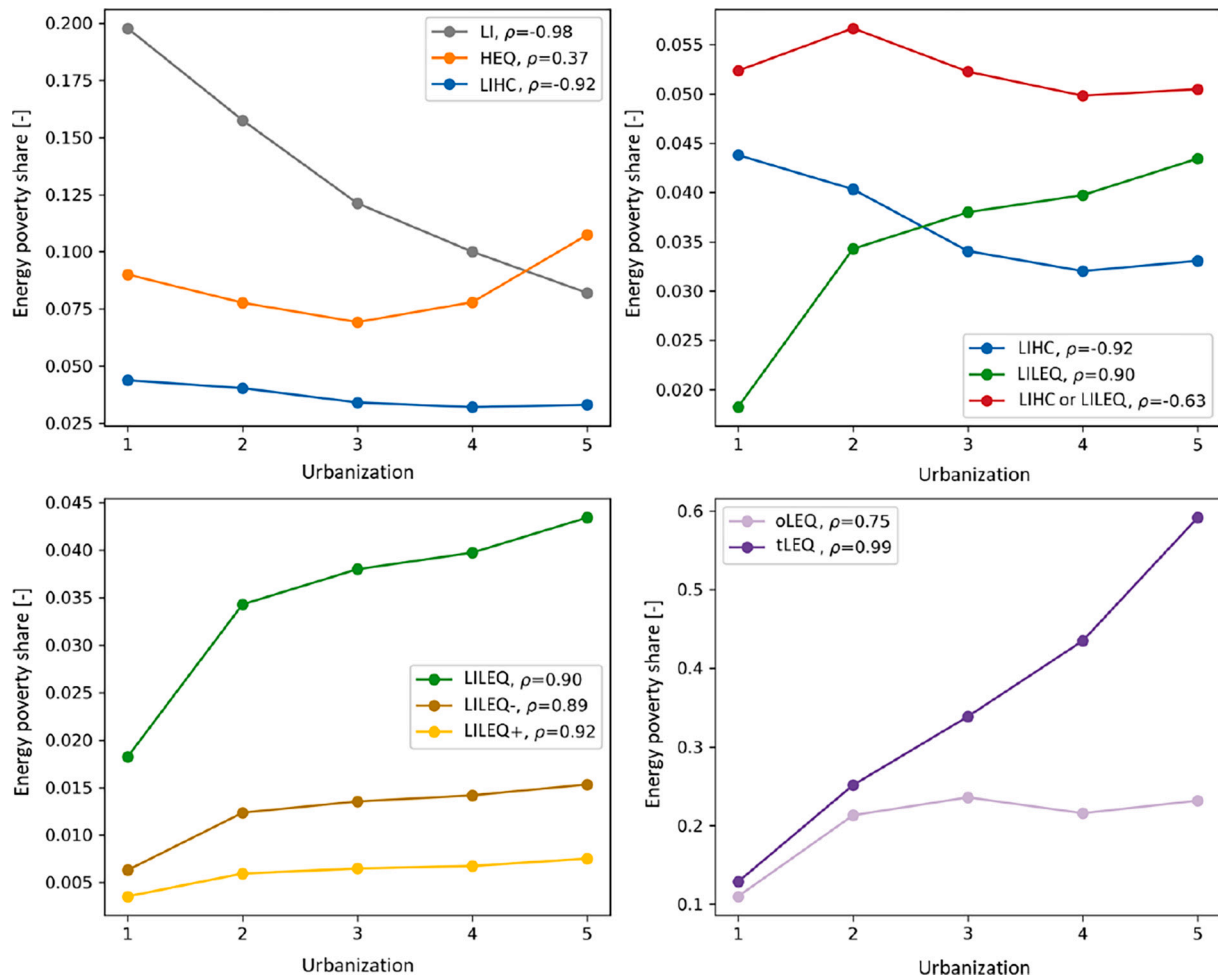


Fig. 3. Correlation between energy poverty and degree of urbanization at district level.
1: very strongly urban; 2: strongly urban; 3: moderately urban; 4: slightly urban; 5: rural.

straight lines (with a 45° slope if the x-axes were normalized to 1). The fact that most lines in Fig. 4 have a steep gradient before flattening out at the top indicates that, according to our set of indicators, high energy poverty levels are concentrated in only a few districts. A comparison of the lines in the top-left panel reveals that income poverty (LI) is more uniformly distributed than energy poverty measured in terms of LIHC, while HEQ lies somewhere in between. In the top-right panel one can see that LIHC and LILEQ are very similar, while “LIHC or LILEQ” – their sum along the horizontal axis – present a slightly more uniform distribution. In the bottom-left panel, the steep slope of the LILEQ- and LILEQ+ lines confirms that energy poverty related to under and over consumption of energy is a very concentrated problem. The underlying data show that the spatial concentration of severe energy poverty is very high: there are approximately 400 districts (13 % of the total) in the Netherlands where the energy poverty share is at least twice the national average. In other words, severe energy poverty is highly concentrated in a relatively small amount of districts. In these districts the level of energy poverty is sometimes a factor 3 or 4 higher than the national level, even reaching shares as high as 10 % and 80 %, respectively, for LIHC and tLEQ. Finally, the bottom-right panel in Fig. 4 shows that oLEQ and especially tLEQ are an exception to the general patterns of highly concentrated energy poverty. The tLEQ kernel density plot approaches a 45° line, indicating that this form of “choice poverty” is evenly distributed across all Dutch districts.

In Fig. 5 we present again the energy poverty distribution at district level, according to the various indicators, this time visualized as violin plots. The height of the violins represents the entire distribution, while

their width indicates the probability of a certain level of energy poverty. The widths are normalized to allow a better comparison of the various distributions. Inside the violins one can see the distributions as box-plots, with the median shown as a white dot. Most distributions are asymmetric, often starting with large widths at the bottom and ending with long thin tails at the top (i.e. high energy poverty shares). The HEQ distribution is closest in shape to the low income (LI) distribution. In contrast, energy poverty measured as either affordability (LIHC) or house energetic quality (LILEQ) displays distributions that are much more flattened at the bottom. Energy poverty as “choice poverty” (oLEQ and tLEQ) is incomparably greater and more evenly distributed than energy poverty in terms LIHC and/or LILEQ.

The insights presented above do of course not yet fully identify and quantify the drivers and causes of energy poverty. This topic is broad and complex, and would deserve a separate dedicated study. As a first step we present below the results of a logistic regression that helps to understand the energy poverty patterns we described above, including the spatial dimension. As regards the latter, the East and North East of the Netherlands – the areas with highest average energy poverty incidence levels – have more severe cold and warm seasons (as measured for example by the heating and cooling degree days – which we refer to collectively as HCDD¹¹). These are however, also the regions where urbanization levels are lower. Higher levels of energy poverty in these

¹¹ To create the HCDD variable, we coupled NUTS3 level HDD and CDD data from Eurostat for the year 2019 to our household-level database.

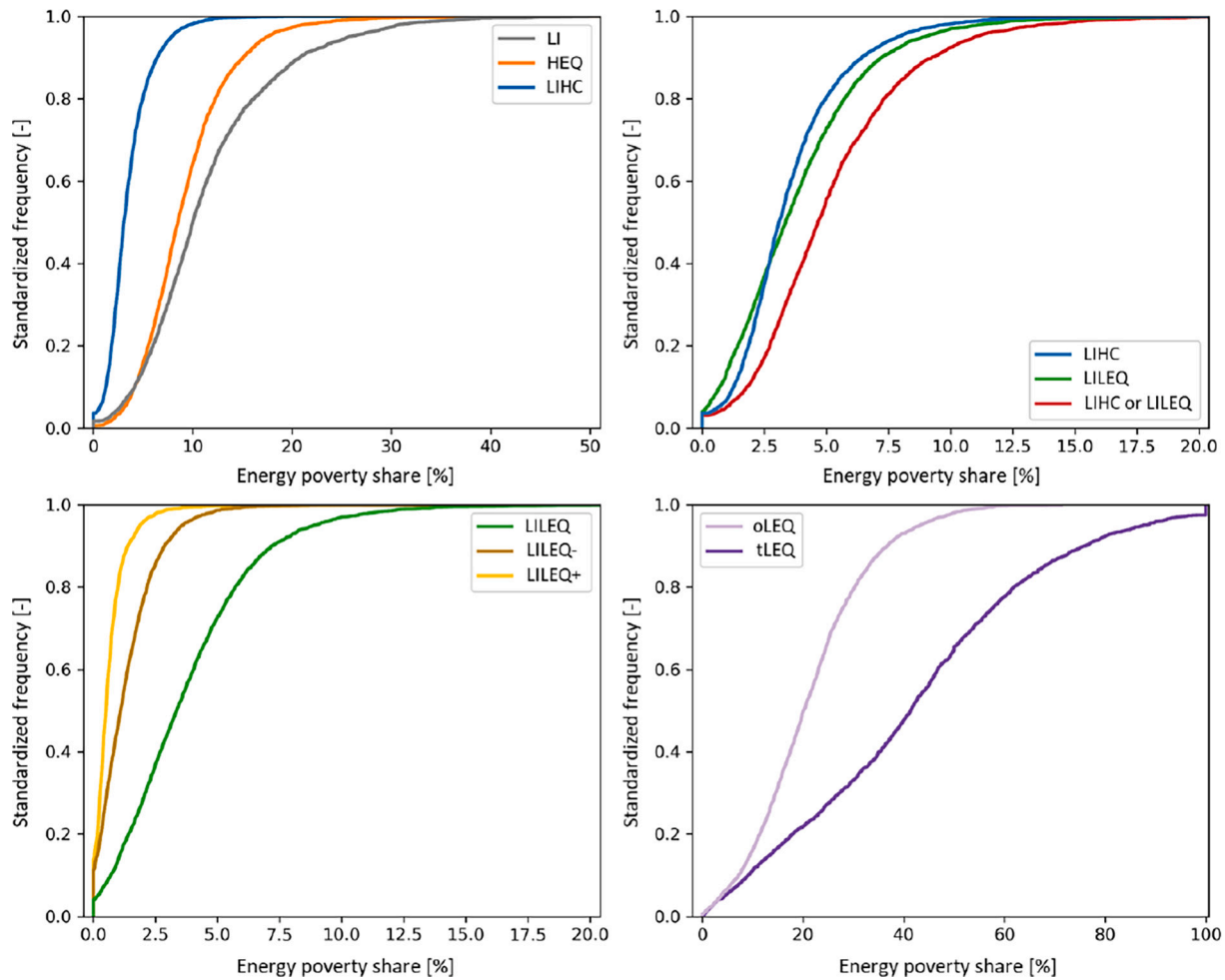


Fig. 4. Standardized frequency distribution of energy poverty incidence levels across districts (each panel uses a specific x-axis scale to emphasize the differences among the various curves within).

areas might be due to either climate or urbanization, the underlying hypotheses being, respectively: (i) higher HCDD would trigger higher energy consumption for heating and cooling, which in turns would enhance the risk of energy poverty, and (ii) lower levels of urbanization means more sparsity of dwelling, which typically correlates with higher energy usage (especially in winter). To test these hypotheses we created three logit models, whose specifications and results are reported in Table 7.

In Fig. 6 we present the regression coefficients for the various models in graphical form to facilitate comparisons. Model 1 reveals that higher HCDD are associated with higher levels of energy poverty across the three selected indicators. The highest odds ratio is that of LILEQ (1.4), which makes intuitive sense since houses with low energetic quality are more susceptible to extreme climate events. The results of Model 2 are broadly consistent with the data presented in Fig. 3, top right panel. Higher urbanization corresponds to higher LIHC (odds ratio 1.15) and lower LILEQ (odds ratio 0.81), while the combined indicator LIHC or LILEQ is only slightly positively correlated with urbanization level (odds ratio 1.05). The coefficients and odds ratio essentially remain unchanged in Model 3 where we consider urbanization and HCDD simultaneously. This suggests that climate and urbanization both affect energy poverty, but they do so in an independent manner.

The coefficients of Models 1–3 are in general very small (below ~ 0.5 in absolute value), which raises the question of whether the dependency of energy poverty on HCDD and Urbanization implied by our simple regression exercise is robust. This question clearly requires a more thorough analysis, which is beyond the scope of this study. As a

rudimentary test, we developed two additional models, in which we consider urbanization and HCDD together with two variables that are very strong predictors of energy poverty: whether or not a household lives in a rented dwelling, and whether or not they receive some form of subsidy income. These two variables are added in Models 4 (variable Renter) and 5 (variables Renter and Subsidy). The results of these two models are broadly in line with each other, but in striking contrast with Models 1–3. When including variables Renter and/or Subsidy, the correlation between energy poverty on the one hand, and HCDD and urbanization on the other becomes consistently negative for all three energy poverty indicators. Also, while the absolute values of the HCDD coefficients remain below 1, those of the Urbanization coefficients become larger than 1 and of comparable magnitude as those for Renter and Subsidy. Taking Model 5 as an illustration, this fact can be interpreted as follows: given a household that lives in a rented dwelling and receives a subsidy, their likelihood of incurring energy poverty is drastically reduced if they live in an urban area (a reduction of about 70 %, as indicated by the corresponding odds ratios of around 0.3). This result is in line with the trends observed in Fig. 3, bottom right panel, which highlights the negative correlation between urbanization and energy poverty for renters. The strong dependency of energy poverty on urbanization only emerges when one “slices” the households dataset along the renter/owner dimension. The sign reversal for the HCDD coefficients does not offer an immediate intuitive explanation – in principle one would always expect a positive correlation between extreme climate and energy poverty. We could perhaps conjecture that in areas with harsher climate more attention is typically paid to building quality, which would

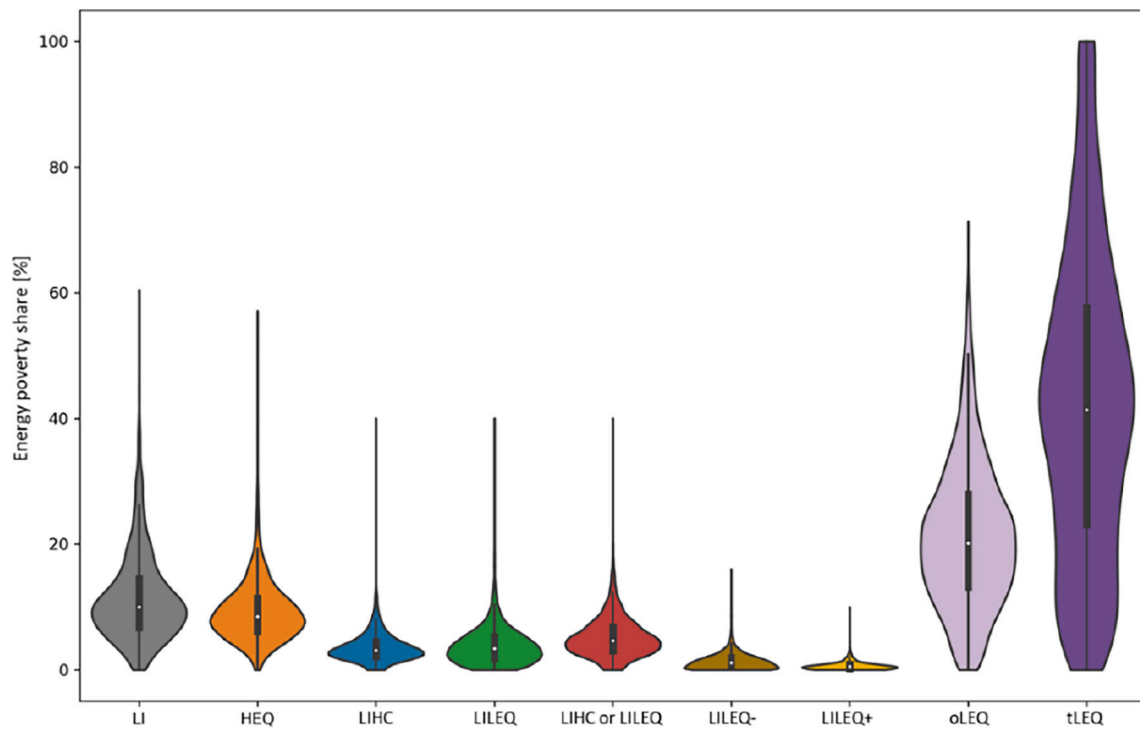


Fig. 5. Violin plot of distribution of energy poverty incidence levels across districts. The rotated kernel-density plot is standardized at 1.

Table 7
Potential drivers of energy poverty – logistic regressions results.

Independent variables				Dependent variables								
	Variable name	Type	Explanation	LIHC			LILEQ			LIHC or LILEQ		
				coefficient	error	odds ratio	coefficient	error	odds ratio	coefficient	error	odds ratio
Model 1	HCDD	Binary	A household is classified as HCDD if its heating or cooling degree days are above the national-level 75th percentile	0.17	2.70 %	1.18	0.40	1.20 %	1.48	0.24	1.60 %	1.27
Model 2	Urbanization	Binary	A household is classified as urban if its degree of urbanization is 1 or 2	0.14	3.00 %	1.15	−0.21	2.20 %	0.81	0.05	7.00 %	1.05
Model 3	HCDD	Binary		0.13	3.70 %	1.14	0.54	0.90 %	1.71	0.24	1.60 %	1.28
	Urbanization	Binary		0.10	4.50 %	1.10	−0.42	1.20 %	0.66	−0.02	15.30 %	0.98
Model 4	HCDD	Binary		−0.58	1.00 %	0.56	−0.22	2.80 %	0.8	−0.55	0.90 %	0.58
	Urbanization	Binary		−0.97	0.70 %	0.38	−1.31	0.50 %	0.27	−1.14	0.50 %	0.32
	Renter	Binary	Whether or not a household live in a rented dwelling	1.81	0.40 %	6.1	1.72	0.40 %	5.58	1.93	0.30 %	6.92
Model 5	HCDD	Binary		−0.66	0.90 %	0.52	−0.29	2.10 %	0.75	−0.63	0.80 %	0.53
	Urbanization	Binary		−1.08	0.60 %	0.34	−1.38	0.50 %	0.25	−1.26	0.50 %	0.28
	Renter	Binary		1.43	0.50 %	4.19	1.48	0.50 %	4.38	1.61	0.40 %	5.01
	Subsidy	Binary	Whether or not the household receives a subsidy	1.47	0.70 %	4.34	1.09	0.90 %	2.98	1.42	0.60 %	4.13

be consistent with the sign reversal in Models 4 and 5, and the fact that the HCDD coefficient is – in absolute value – much lower for LILEQ than for the other two indicators.

6. Sensitivity analysis of increase in energy prices

It is not possible to precisely calculate how quickly energy poverty

will rise at the current high gas prices: the price trend in international energy markets is inherently uncertain, households are faced with higher bills to varying degrees and periods due to the different energy contracts they have, and households will react differently to the price increase by adjusting their heating and cooking behavior. While making predictions is thus out of the question, one can still get an idea of the effect of high gas prices on energy poverty through a sensitivity analysis.

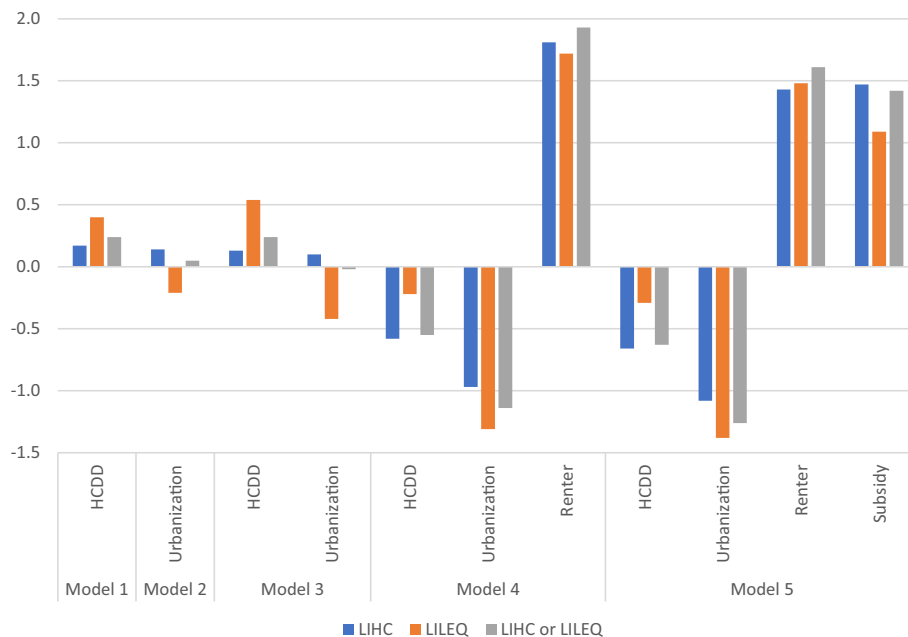


Fig. 6. Logistic regression coefficients for the various models.

For this purpose we estimate a new tariff of 45 ¢cents/m³ for gas and 11 ¢cents/kWh for electricity. This corresponds to an increase of about 30 % compared to the delivery rate in 2019 and 60 % compared to 2020 (because prices were relatively low then). Given the fixed supply and transport rates plus various taxes, this means a 20 % increase in the total yearly energy bill compared to 2020 for a household with average energy consumption (1500 m³ gas and 3500 kWh electricity). In the sensitivity analysis, we apply this price increase as an external shock, and recalculate our set of energy poverty indicators, keeping the thresholds constant and ignoring any behavioral changes. This set-up stems from the fact that LIHC and LILEK are relative energy poverty indicators, based on median thresholds for 'high energy costs' and 'low energy quality'. Despite the rudimentary nature of this sensitivity analysis, the results lead to two important insights.

First, the national energy poverty share increases by 1.7–2.1 percentage points, depending on the indicator (see Fig. 1). This corresponds to approximately an additional 130–170 thousand households crossing the energy poverty threshold. This result is very close to that obtain in a similar sensitivity analysis in PBL (2018). Despite the large uncertainty margins in these estimates, they provide some evidence that a relatively mild gas price increase may lead to a significant exacerbation of energy poverty, from roughly 550,000 to about 700,000 households. Given the actual gas price increase currently seen in the Dutch market in the aftermath of the Ukraine war there is serious reason to believe that energy poverty levels will rapidly increase.

The second insight is that the strongest increase in energy poverty takes place in a series of municipalities spread throughout the country, rather than mainly in the Northeast, as shown in Fig. 7. In addition to the Randstad, we also see a relatively strong growth in energy poverty in many medium-sized cities such as Arnhem, Nijmegen, Emmeloord, Maastricht, Den Helder, Tilburg, Zaanstad and Deventer. Underlying data show that in each of these cities the problem is again mainly concentrated in a limited number of districts.

7. Conclusions and discussion

We presented the first multifacetednation-wide spatial analysis of energy poverty in the Netherlands. Our energy poverty framework provides the analytical foundations for a national energy poverty monitor in the Netherlands, which is currently being developed by the

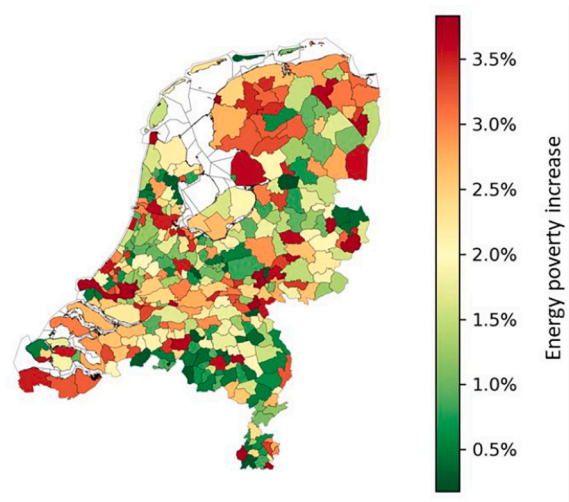


Fig. 7. Expected increase (in percentage points) of the share of energy-poor households* after energy price shock at municipality level. * Energy poverty is measured as LIHC or LILEK.

Dutch national statistics institute (CBS, Statistics Netherlands) at the request of the Dutch Ministry of Economic Affairs and Climate Policy. Monitoring the dynamics of energy poverty is important for ensuring that policy targets are effective and reaching those most in need. This also implies that the presented analysis marks a turning point in thinking about energy poverty in the Netherlands. Until recently, and in contrast to most other countries in North-West Europe, the Netherlands has neglected the concept of energy poverty in its national policy. Consequently, energy poverty has never been monitored at national level and the problem of an excessive energy bill has always been treated as an issue related to income poverty and income policy.

Against this background, in this study we introduced and operationalized a new framework for analyzing energy poverty in the Netherlands. We define energy poverty not only in terms of energy costs relative to income, but also in terms of the energetic quality of homes and at the extent to which people can join the energy transition by

making their homes more energy efficient. For each of these dimensions, we develop indicators based on microdata at the household level for the year 2019, provided by Statistics Netherlands. This has resulted in a dataset comprising >6.1 million households (78 % of total), spread over all 355 municipalities and 3018 districts (97 % of total) in the Netherlands. Based on these data, we answer three key questions: How many households in the Netherlands are energy-poor? Who are these people? And where do they live?

We argue that the traditionally widely used energy quote is not suitable to identify energy-poor households, but is informative to better characterize households that are identified as energy-poor on the basis of other indicators. In addition, we argue that the concept of energy poverty should be reserved for low-income households, and that, in view of policy practice, the energy poverty problem can best be defined by mapping households with a low income that either face high energy costs, or live in a house with a low energetic quality. Based on these methodological choices, our research shows that energy poverty in the Netherlands is on the one hand a serious problem, but on the other hand currently still remains a relatively manageable problem: we estimate that before the energy price hikes of 2021–2022 about 550,000 Dutch households (about 7 % of the total) have a low income and either high energy costs or a house with a low energetic quality. These households spend 13–20 % of their income on energy costs, against 5 % for the average Dutch household. Within this group of energy-poor households, approximately 250,000 low-income households have both a home with low energy quality and high energy costs. There are an estimated 140,000 households with hidden energy poverty; these are people who, due to financial problems, consume significantly less energy than similar households in similar dwellings do on average.

An assessment of the spatial distribution of energy poverty in the Netherlands revealed large geographical differences in energy poverty levels. Energy poverty appears to be spatially much more concentrated than income poverty. Compared to income poverty, the number of districts (and neighborhoods) with high energy poverty shares is currently limited. This makes targeted policy per municipality or region easier. However, unlike income poverty, energy poverty is not primarily an urban problem. On the contrary: energy poverty in the Netherlands is relatively common in underprivileged and non-urban areas, especially if we measure energy poverty in terms of low income in combination with a less energetic house.

Our research also shows that, although the number of households that suffer from high energy costs is still relatively limited at the moment, this number can potentially increase significantly under the influence of high energy prices and the growing need to make homes more energy efficient in the context of the energy transition. More specifically, we show that, spread over many Dutch municipalities, there are approximately 3.8 million households (48 %) with a home of relatively low energy quality that cannot make their home more energy efficient on their own: this group consists of tenants who depend on the landlord in this respect, and home-owners with insufficient financial capital. A large proportion of them currently have no problem paying their energy bills. But if the gas price continues to rise, some of the households in this group may incur an energy affordability problem. Even in absence of payment problems, these households have to deal with rising energy costs, a persistent lack of comfort and sometimes even health complaints related to low housing quality (e.g. moisture and mold). By using targeted policy to make more homes more energy efficient, we can prevent these problems and achieve the opposite: fewer payment issues, better homes for a larger share of the population, and therefore fewer health problems, plus an acceleration of the energy transition.

In our view, the observation that almost half of all households in the Netherlands cannot participate in the energy transition in the built environment on their own, underlines how important it is not to narrow down the idea of an inclusive energy transition to solving an affordability problem for low-income households. The situation of the large

group of households that cannot choose for themselves to join the energy transition evidently requires a different approach than the currently dominant Dutch energy transition policy framework for the built environment, which is primarily aimed at alleviating payment problems or offering financial incentives to make dwellings of home-owners more energy efficient. The underlying assumption of this approach is that individual home-owners in principle are able to organize and largely finance their home renovation, but our research suggests that this is only true for about half of the households in the Netherlands. For the other half, different policies are needed. For a large proportion of the tenants in this group, effective policies should instead take the form of performance agreements (including insulation standards) with social housing associations and landlords in the private rental sector. For the owners in this group, access to purpose-specific credit and objective information on how to improve home insulation should be made available.

In addition, inspiration for effective policy making in this context can be found around the well-known energy efficiency paradox: the phenomenon that a considerable (time) gap exists between the availability of proven and economically viable technological options to save energy – such as home insulation – and the actual adoption and use of these technological options in practice [21]. The explanations for this apparent contradiction are well known: it is a story of investment barriers such as uncertainty about future prices or policies combined with the irreversibility of investments made, learning effects, split incentives (e.g. between tenant and landlord), vested interests, and technological complementarity – i.e. the fact that one technological option must complement other (existing) technological options (for example, a heat network infrastructure should be complemented with the appropriate technical installation in the house). Breaking down these investment barriers requires more than a set of correct price incentives, let alone a focus on costs compensation or income policy (see, for example, [14,19,22,29]).

Present-day extraordinary high energy prices obviously deepen the long-standing problem of energy poverty. A sensitivity analysis on our data shows that at the gas price levels of end 2021, the national energy poverty rate, depending on the chosen indicator, increases by 1.7–2.1 percentage points. This corresponds to approximately 130–170 thousand households crossing the energy poverty threshold. By investing in making more homes more energy efficient now, starting with the homes with the lowest energy quality, we can prevent energy poverty from rising among low-income households. This form of leveling housing costs of course also accelerates the energy transition by reducing gas consumption.

Finally, the analysis presented here calls for further research on at least two points. First, in addition to quantitative data analyses it is important to invest in monitoring the living experience of energy-poor people, drawing on qualitative data on people's everyday lives to document the effects of reduced access to energy services [27]. This kind of research most frequently takes the form of individual or household-interviews in which people are asked open questions about their experience of energy poverty. Starting from the observation that energy poverty numbers reflect the situation of real households, living experience data offer insights into the coping strategies that people develop when facing reduced access to energy services, and into how people deal with intersecting challenges (e.g. energy poverty combined with low-income and health complaints). Results of this type of research can enable policy-makers and practitioners to better understand the (un)intended consequences of energy policies and their interaction with social and housing policies. This approach has been pioneered by the Scottish government in (energy) poverty assessment and monitoring (Ipsos MORI Scotland, 2020, Scottish Poverty and Inequality Research Unit, 2018) and is currently used by community-based organizations working on energy poverty in Spain (Aliança contra la Pobresa Energètica, 2021) and in the UK (APLE collective, 2021). This approach offers particular value in countries like the Netherlands, where energy poverty research is in many respects still in its infancy, which is due to

the fact that energy poverty has only very recently been accepted as an independent concept by policymakers. Quantitative data analyses like the one presented in this article are necessary but not sufficient: they certainly pave the way by providing insight into the extent and location of the energy poverty problem, but they also raise new questions that only living experience research can answer – for example, what drives the observed substantial differences in energy poverty incidence across space (in similar neighborhoods) and across households (with similar characteristics).

Second, we intend to deepen the current analysis with a spatial analysis of a so-called energy poverty gap, defined as the reduction in energy costs needed for a household to no longer be classified as energy-poor). The analysis presented here defines energy poverty only in terms of incidence, and does not yet provide insight into the depth of energy poverty. Hence, with the current framework, the question of the impact

of rising energy prices on energy poverty can only be analyzed in a rudimentary way in the form of a sensitivity analysis (see Section 5), but does not provide insight into the extent to which energy poverty is deepening among existing energy-poor households.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Appendix A. Calculation of the energy poverty correction factor

Given a total of N_0 households in the Netherlands and an energy poverty share before correction of s_{EP}' , we get that the uncorrected number of energy poor households is $N_{EP}' = N_0 s_{EP}'$. Let's call r the share of households that were not included in the database, and consider that the value for s_{EP}' has been obtained from a reduced number of households: $N_0' = N_0 (1 - r)$. The actual number of energy-poor households is thus:

$$N_{EP} = N_0 (1 - r) s_{EP}' + N_0 r s_{EP}^r.$$

The first term represents the total number of energy-poor households in the database. The second term is an estimate of the number of energy-poor households that are not included in the database, expressed in terms of s_{EP}^r , the share of energy-poor households among the group of excluded households. We want to write N_{EP} as:

$$N_{EP} = N_0 (s_{EP}' + c_{EP}),$$

where c_{EP} is our desired correction factor. Equating the two expressions for N_{EP} and solving for c_{EP} yields:

$$c_{EP} = r (s_{EP}^r - s_{EP}').$$

For a rough estimation of the correction factor we plug in the following values:

$$r = \frac{\text{excluded households}}{\text{total households}} = \frac{1.7 \text{ mil}}{8.0 \text{ mil}} = 22\%,$$

$$s_{EP}^r = 10\%,$$

$$s_{EP}' = 4\%.$$

The last two values are, respectively, an assumption – based on the fact that many households in the excluded group have relatively low incomes and are thus likely to incur a relatively high energy poverty share – and a representative value for one of our main indicators – namely the LIHC (see Table 1). With these values we obtain a correction factor $c_{EP} = 1.3\%$.

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